Applications of System Dynamics - Jay W. Forrester

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SUMMARY

Professor Jay Forester's lecture focuses on the evolution and application of System Dynamics over the past 30 years, emphasizing its relevance in understanding complex social and economic systems. He discusses the challenges of data collection, the limitations of traditional economic forecasting, and the importance of modeling to uncover underlying dynamics in both corporate and urban environments.

- *Forester highlights his early work on simple models of social systems and transitions to discussing complex models in System Dynamics.*
- *He reflects on the historical context of high-speed computing and its applications, including military and industrial processes.*
- *The lecture addresses the difficulties in data collection from resistant populations and the skepticism surrounding economic forecasting models.*
- *Forester shares insights from his work with corporations, particularly the Digital Equipment Corporation, focusing on high-tech growth dynamics.*
- *He discusses the Urban Dynamics model, which analyzes the interplay between urban development, housing, and employment trends.*
- *The concept of "attractiveness" in cities is introduced, suggesting that urban issues often stem from population pressures rather than a lack of resources.*
- *Forester emphasizes the need for high-leverage policies to address systemic issues and critiques low-leverage policies that fail to create meaningful change.*
- *He concludes with a vision for integrating technology and social sciences to better address complex societal challenges through System Dynamics modeling.*

let me welcome everybody here to the second of this year's Killian award uh lectures uh recognizing the professional achievements Professor Jay Forester of the SL School of Management I'm glad to see many familiar faces here most of you many of you I know were at the uh first lecture last week but um I think even more people are here today so the word must be spreading it this man has some interesting things to say um it occurred to me that some of you

might want to do a little reading to follow up some of the U uh points made in these lectures and U uh last week particularly Professor Forester mentioned something about the background of computer technology at MIT and his role in the Whirlwind project and other events in the 1940s and 50s and I've since come across the first book that I listed here by Will dies and lingren uh which is an excellent history of electrical engineering computer science

at MIT a very handsome book uh well Illustrated with most of one chapter he devoted to Professor forester's work uh on the Whirlwind project I noticed in reading it that in addition to his work as a technologist he was um writing and speaking to the country at large as early as 1948 about both the uh the problems and the potentials of high-speed computers and um in a 1948 U talk mentioned um among possible applications we might mention the

control of industrial processes uh military Gunnery and Fire Control and the centralized control of air traffic I guess we still have a ways to go on the last one but we're we're getting there um I've also listed Professor forester's uh books published by the MIT press for those of you who um um might want to read further in the um material that he's talking about um today and last week and um if we have a third

meeting there'd be a short quiz based on these readings um last week Professor Forester spoke about um uh his early work on um uh simple models of Social and Behavioral Systems and um how they operate and with many interesting anecdotal examples uh this week he's going to speak more about complex models and applications of System Dynamics to help set the stage I might just say a couple of words about the difficult context that uh I think surrounds

Professor forester's um more recent work a context that seen from as one outside the field but first we those of us who have tried to do work at all related are aware of the increasing difficulty of collecting data from a resistant population that doesn't like to part with it I can give you one good story to illustrate that the daughter of a friend of mine was a census enumerator in Boston during the 1980 census and had

been alerted to the fact that um people are more or more reluctant to speak to census takers and give out information and and uh as she made her rounds in the South End she uh rang one doorbell and a very hostile woman came to the door and said who are you and what do you want he said well I'm Franny wood and I work for the Census Bureau what's that woman snapped and Franny said well we're part

of the federal government and we're trying to find out how many people live in the United States the woman said well listen Deary you've come to the wrong house because I don't know [Laughter] it uh does suggest some possible new ways of establishing a factual base of things by doing it through an opinion poll um I think the other uh difficult part of the uh the context for large-

scale modeling uh is that there's been so much disappointment with economic forecasting models uh many economists particularly Consulting economists have built models of that reports a forecast shortterm and longterm what's happening to the American economy and um so many of those forecasts have been disastrous particularly recently that all sorts of stories go around about people who try to use these models mean one concerns to um management Executives who um came to the Cambridge area for a special

Advanced Training Program having been badly burned by uh forecasts that turned out not to be true and while they were here they visited the famous Mount Orbin Cemetery which is a Scenic spot in itself but also Al the final resting place for many academic luminaries of this area I came across a tombstone that said um here lies a

great Economist and an accurate forecaster one of them turned to the other and said Gee I didn't know they were putting them to in

a [Laughter] grave since Professor Forester approaches this not as an economist but as a computer technologist and a person who works in industrial Dynamics um uh he is inred by that particular problem I give you Professor [Applause] Forester thank

you thank you Professor freden last time we had an opportunity to uh to discuss the background the philosophy of the field of System Dynamics and this afternoon I would like to bring the discussion more up to date you will recall that we talked about the 30 years of background from 1930 to about 19 UH

60 today I'd like to start with another 30 years but a more recent 30 years 30 years that I have been especially associated with the field of System Dynamics I can't possibly cover the entire field and everything that has been done so here I am calling attention to those things that I have been most directly connected with uh myself and several uh rather interesting points I think to make about them you will recall in discussing the 30 years uh in uh

computers and feedback control that we did say that there had been a hundred years of Prior thought leading up uh to that uh implementation at MIT uh beginning around 1930 well there's been 100 Years of Prior thought about the possibility of coming to a better understanding of social systems I'm indebted to my daughter for calling my attention to some passages from uh Leo tolstoy's uh War and Peace in which he

discusses the problems of historians and especially takes to task their tendency to look at events and people rather than the underlying currents that led to historical change and he says in one set of passages absolute continuity of motion is not comprehensible to the human mind laws of motion of any kind become comprehensible to man only when he examines arbitrary selected elements of that motion but at the same time a

large proportion of human error comes from the arbitrary division of continuous motion into discontinuous elements a modern branch of mathematics con forms to the chief condition of motion absolute continuity and thereby corrects the inevitable error which the human mind cannot avoid when it deals with separate elements of motion instead of examining continuous motion only by taking infantes small units for observation the differential of history

that is the individual Tendencies of men and attaining to the art of integrating them that is finding the sum of those infantes smals can we hope to arrive at the laws of history and he has other passages bearing on this uh same uh theme he was seeking the laws of history and that's what we are talking about the laws of social systems today a computer simulation model is a theory or if you like a law of behavior of the system

that it represents if it generates realistic behavior for the right reasons it is is a law in the same sense that the

laws of physics except that one is operating in a domain where there are a larger number of feedback loops where Randomness and noise have a greater impact on the behavior of the system and all of those uh somewhat more difficult characteristics have to be taken into account if we look at this diagram starting here and working around the

outside you see a chronology of what has gone on here at MIT in the last uh three decades or so we spoke last time about the instability of a production distribution system and I mentioned how that came out of some discussions with people at General Electric then I had the Good Fortune to have Robert sprag the founder of sprag electric come to my office one day he had followed our work in computers uh he

had adopted the practice of keeping in close contact with people in New branches of Technology he would often provide them small quantities of the new components they wanted at almost no cost other people would be offering uh specially designed small lot pulse Transformers for $1,000 a piece and sprag would say well we'll sell them to you for $20 a piece and out of this of course he kept in touch with the latest

things in technology and was in a position to learn about it ahead of other people and to build an electronics business well against that background after I had come to the Sloan school he came to my office one day and he said I don't know what you're doing here but whatever it is we would like to be a part and out of that came our first actual in the company industrial Dynamics modeling exercise uh dealing with the

interactions between the company and a market and some of the instabilities that can occur through the process of customers ordering ahead as the delivery delay gets longer as the delivery delay gets longer they order further ahead that increases the apparent number of orders in the uh system and can create an avalanche of essentially fictitious orders orders that once the suppliers have caught up are uh a tremendous uh lead to a tremendous over Supply in the

market my uh next uh and even yet the most major corporate modeling uh that I've been directly associated with was to guide my own position on the board of directors of the digital Equipment Corporation having to do with the growth of high-tech companies I'll come back to some of the aspects of that uh then as one keeps uh a certain flexibility and an open mind about where your career is going and uh a

willingness to change directions when new and interesting things come up I had the Good Fortune to encounter John Collins who had been mayor of auson for eight years he came to MIT as a visiting professor of urb urban Affairs and out of contacts with him we moved the whole field of System Dynamics away from the corporations for the first time and into larger social systems looking at the growth and stagnation of cities that

study branched and led to two different activities one to which I'm indebted to Carol Wilson for bringing me in contact with an organization called the uh Club of Rome which moved our interest out into the larger environmental population pollution and Industrial Development scene looking at the interactions of the environment with the growth of technology and population and the growth

of uh pollution Edward pastel president of the Technical University of Hanover was largely responsible for raising the money from the Volkswagen Foundation that led to the limits to growth uh study here two books uh the world Dynamics book the limits to growth book probably had the greatest impact on public debate of any thing coming out of the social sciences at least for any comparable amount of

effort the limits to growth book is available now in some 30 languages sold around 3 to four million copies uh it has been a subject of fairly intense debate with strong sides taken uh about it it came in at the end of the the concern about the environment that had been building up in any case through the 1960s it kind of put a Capstone on that gave it a focus and probably triggered

the backlash against the environmental movement which has run through the Reagan Administration and is essentially exemplified by James Watt and his uh view of the environment and I think that's a necessary part of the given take over a new set of ideas and now you can see the undercurrent beginning of a concern about environmental Affairs again coming into the ascendancy the other Branch out of urban

Dynamics uh led into the present work in applying System Dynamics to the behavior of the national uh economy most of our staff many people have been working on that no room here to try to put in their names and then moving into well there's been a thread through all of this the necessary computer software Jack Pew of Hugh Roberts and his whole series of Dynamo compilers which have had a very major influence on development of the

field more recently Barry Richmond at Dartmouth and high performance systems with his Stella software that I will give you some examples of and what I see as the most recent and newest work in System Dynamics the turn to computerized management case studies with uh three members of our present staff John Sturman Peter sheni Alan Graham and our PhD students all uh very much

involved my first comprehensive look at corporate modeling was as I said in connection with my being on the board of the digital Equipment Corporation and the question in that kind of a situation is what lies behind high technology growth what are the kinds of forces and one has to decide what is his task how is he going to go about it and the task undertaken was to try to explain the

very major differences between the growth scenarios that one could see in companies in the high-tech field there were those that were launched grew a while and failed for one reason or another very large number that grow briefly and then move into a state of stagnation those that have a continuing growth Trend with repeated major crises and a few very rare cases of sustained

high growth with uh nothing in the way of severe crisis the question is how and why and the objective of a corporate model is not to study especially the one particular company or situation but rather to to uh study the family to which that one belongs to obtain a generic model that tells you why the differences between the performances of the different examples in the uh field

and those examples cannot be explained by differences in products because sometimes even the best products are coming out of the most troubled companies it has to be and and those differences exist between companies existing in the same industry competitors of each other and in the same environment and so it must be something to do with the company not something to do with the external World in order to approach this kind of

problem and this goes back to a question that was asked at the end of the period last time what perspective should one follow What viewpoint what degree of aggregation and one can be too close to the situation I would say a production manager a sales manager or even the company president is too close to the corporation to be the right perspective from which to view the company and therefore too close to be the perspective from

which to build a model such a person tends to see the inside of the company tends to feel that he has no control over the outside environment and tends to see himself as reactive on the other hand if one moves to essentially The Other Extreme the public stockholder or perhaps the traditional economics one is so far away from the company that one does not see what is going on inside what are the real information sources what are the

policies being followed my nomination for the right perspective for this kind of model would be one of the outstanding investment bankers a person who does not care whether the product is 14 in wide or 18 or whether it's red or blue but he's interested in a consistent set of policies that go with the particular proposition he's interested in the integrity and the leadership of the people founding the company I'm reminded

of a story that appeared in the press a few years ago uh retail retelling the history of the melon Fortunes in Pittsburgh and telling about one of the melons coming out into the Hall one day and seeing a man that he had met with a few months before recognized him by name knew who he was uh they had agreed to finance his new company visited with him about how well things were going and then in parting

said and oh by the way what business are you in one of the less important questions uh the nature of the man uh his Viewpoint the consistency of his policies the history of his past successes far more important than what he happened to be doing at that uh moment and to understand that uh perspective which is not a perspective on a particular product but a perspective on the character and

essentially the policies that lead to the Dynamics of the organization would be the focus of such a study the model that developed I see David pcker in the audience he was a research assistant for me at the time and actually helped work through uh all of this uh was a model of about 60 levels or Integrations a 60th order system had in it about 250 variables it's still

a simple model compared to the reality of such a situation but far more comprehensive than we can manage in our mental models trying to tie together what goes on in a company you might as an interesting exercise sit down and just try to make a list of 250 variables in a growth company uh in other words it's not a uh it's not a simple model even though it is simplified from real life when we had developed this model

turned out that fully 90% of the variables in it are what are would ordinarily be called intangible variables which are not ordinarily measured variables like integrity and uh courage and uh leadership ability and the ability to project one's goals onto uh and organization the model had in it a pressure system that connected one parts of the system one to another pressure for greater production pressure

for greater marketing pressure for reducing the overload on people Financial pressures and these were generated in various parts of the system and used elsewhere as part of the mechanism for tying things together and then some explicit attention given to the nature of information channels I think there's a tendency to believe that information is information and it doesn't vary uh in its character but it

varies tremendously and here are some of the different concepts that have been used in modeling to represent what goes on within information channels one is persuasiveness is the information in fact influential here you come very close to what is called by many people the hardness or the softness of information the hardness is the degree to which it can be measured inventories very hard data you

can imagine that they could be measured you think they are being measured they appear on the profit they appear on the balance sheet to seven or nine decimal places they look very very accurate they're likely to be wrong in the first place but uh you nevertheless feel that there's a high persuasiveness to this uh information and contrast that with the much more important information but the much less persuasive information of what do we think that the

customers think about the quality of our product a very slippery uh sort of uh information Channel delays oh I might say that all of these terms seem to have a pajora of uh implication and I do not intend that because you may want information to be more or l persuasive you may want it to be more or less of any of these things I'm just saying that there are these different characteristics delay is fairly obvious there is a delay in the transmission of

information but in particular and most important there is the delay in the comprehension or the acceptance of information a person can be faced with information contrary to what he now believes and he may sit there for 10 years still still sort of discounting that information there are some very long psychological delays before new propositions are accepted Distortion Distortion means selective

differentiation of different frequencies or periodicities in the data one intentionally introduces Distortion when you average sales Data before you use it for planning production you would not want to change your production or down 100% every day as the incoming orders vary that much you average it over a month or more and adjust the production accordingly so you intentionally distort bias

is the orderly offset or the continuing offset between what the data is saying and what we believe all these are most pronounced in the channels that come from the Market back to a company take the matter of bias we would all like to think that we are doing a good job you can go into many companies and find that they have a philosophy about satisfying

the customer it's not possible to satisfy more than 90% of the customers there will be 10% that will buy our products that shouldn't buy them that will use them improperly there's bound to be 10% that aren't satisfied now the stage is set for a situation where when letters come in that are highly critical of the company and of the product they say oh well that's from one of the 10% and those go in the waste basket and then the

favorable letters come in a few of them a small number of them and they are from our valued customers and of course we know that satisfied people don't generally write letters so there must be a lot more of them than we actually get and those go on the bulletin board and reinforce reinforce our feeling that we're doing a wonderful job whether we are or not error is just the simple mistakes transposing two numbers and copying them

down probably more effort goes into preventing error than is devoted to any of the other five on that list and yet by All Odds it is the least important next month that transposition will be corrected anyway and dynamically error makes very little difference it's a Randomness on top of the randomness that permeates our systems anyway tremendous amount of effort to prevent error and for the most part misplaced cross talk is an interesting kind of defect in

information channels it's a telephone term I don't know of a word anywhere else that quite carries the meaning uh you're talking on the telephone and you hear somebody else's conversation occasionally uh tremendous amount of cross talk in corporate and Market channels for example suppose I have bought some piece of Machinery that I use in my office and it's squeaks and the paint is peeling off and it drips oil on the carpet I have decided I'm not going to

buy another one from that company so the salesman comes around to try to sell me one now do I tell him the problems not if I'm sensible I don't tell him these problems because I'm then on his Turf he will tell me when I say the oil drips that uh the oil seals have been redesigned and they don't drip anymore and I can't protect myself against that and I've decided not to buy and so I don't move

into that trap I tell him the price is too high That's My Prerogative and that's my value judgment and I tell him the price is too high and he goes back with that message but suppose I don't I tell him the troubles I want to help out the company so I tell him all the story and what's really wrong what does he do he's had the experience of going back and complaining about the designs and had

his ears pinned back because his job is to sell it not to design it so he goes home and says the price is too high but suppose he doesn't suppose he goes back and carries the message correctly to management what do they do they lower the price because they don't know how to fix the other things quickly and they aren't sure they'll get them fixed and so they lower the price everywhere along this channel the true story is transposed

into a different message we find this time after time in information channels you have to be very alert to it that model the corporate growth one high-tech one I did at that time it was my practice in the second term of System Dynamics to Simply teach whatever I was doing and whatever I was interested in at the time that model I began at the

beginning of a spring term and so the term consisted of every lecture describing what equations I had written up to that time and why I thought they represented what goes on in such a corporation halfway through the term the model had been fully developed when it was first put on the computer it uh essentially immediately exhibited one of those standard modes of behavior growth Trend with repeat did major

crises at that point I turned it over to the students to see how they to ask them to alter the policies and produce a better behaved system one that they would rather work for or run now they've been through six weeks of discussion of all the equations they had all the equations they could put on the computer they could get uh computer output of every variable and what was happening if they wanted to they had had at least

aund times maybe a thousand times more information about that system in the laboratory than anyone in a real company would have about the company and they were now free to alter policies and improve the behavior and they worked on it for the next six weeks it was before time sharing computers you had to take your uh uh problem over to the computer center and get it back the next day so each group could uh uh do

about two of these a week uh there were 12 students uh they were in teams of three uh four groups they could try about eight policy changes a week they did this for six weeks about 50 different policy changes they were able to try in that period of time I have never in all of my experience seen such a frustrated group of people no one had found anything that substantially affected the behavior

it still had a growth Trend it still had repeated major crises it was clear it was all hooked up there were little differences things would happen but nothing that substantially altered the behavior this it turns out it's the same experience that many managers around Route 128 were having you saw the students in the laboratory doing exactly the same things that the managers around Route 128 were doing and it wasn't working either place except around Route 128 it was always

blamed on the interest rates or the competitors or the uh customers or something outside of the company here in the laboratory you had to admit that somehow or other you hadn't come to grips with anything that mattered and in fact you were dealing with a set of self-defeating policies in which the multiple feedback loops in the system were able to compensate for policy changes and I don't mean policy changes of a few percent by the end of 6 weeks

these two students were making factors of two and five differences in the parameters in the system without finding anything that markedly affected the behavior I was working on it too at the same time and I should have done better of course having designed it and uh having thought it through but I had gone into this without any understanding or expectation myself that it was going to be a recalcitrant system this whole idea of uh low leverage policies really began

to emerge in that particular uh exercise but I found uh that there were policies having to do with pricing and aggressive of expansion that made a tremendous difference and we talked a little bit about those last time in the context of a uh of a simpler model the urban work at least my part of it took a turn into larger social

systems in the late 1960s John Collins who had been mayor of Boston spent his career in Boston politics came to MIT and by chance took an office next to mine and it was out of discussions with a newcomer that I began to feel out of his discussion of the urban crisis you may recall some of you that the main headlines of our great social problems in the late 60s were the urban crisis

the urban problems still exist but they've been pushed off by even more serious crisis pushed off the front pages by more serious crisis the urban crisis of high Unemployment uh economic backwardness uh housing problems all of these were the social condition of our older cities in the late 60s I talked to Collins about this and began

to get a feeling that I'd come to recognize in corporations it all seems to make sense people have a good rationale for what they're doing Point by point it seems to be appropriate and yet in some way it doesn't hang together and so I said to him wouldn't it be interesting if we would combine the background that we've had in the corporation with the knowledge of people like yourself and cities and see if we could come to any

better understanding now a lot of people you make that offer too and they say well it' be interesting to do that but I'm too busy right now well I suppose Collins wasn't too busy but anyway uh he wasn't the kind to uh to drop an idea I said we would have to have a group of people who knew cities not from reading about them not from the library but from really experiencing cities their problems watching what went on knowing

the internal politics and the pro difficulties and so he me more about the kind of people and how much would we how many much time would we need I said we'd need a half a week half a we'd need a half a day per week for nobody knows how long we would have to talk and meet and see if we could make some sense out of it and he quizzed me on the kind and his immediate response was they will be here

Wednesday afternoon and Colin's position in Boston at that time was such that he could call up almost anybody in business or politics and say I want all your Wednesday afternoons for a year and get them and so he produced the the group and it was out of maybe four months of discussions that uh what came to be known as the urban Dynamics model emerged I'm not going to go into much detail but it's a model of nine

principal variables newly constructed medium age deteriorating industrial buildings new premium housing aging into worker housing additional worker housing being built all of it aging into lowquality uh housing such as you now see in Roxbury and Harlem those were premium houses at one time in many of those areas but they have declined over

the years and then three categories of people the managerial professional skilled labor and the underemployed the real essence of this model is that you build new structures until the land is initially filled given the technology and the number of Stories being built and so forth till the land is filled and then the structures begin to age and as

the industrial structures age and move off to the right the employment per square foot goes down and and as

housing ages and moves to the right the occupancy per square foot goes up and so you have the stage set for a switch over in the relationship of people to jobs I will show you some effects of that in a

moment we said last time that rates of flow depend on the different system levels in this particular particular model each of these rates of flow probably depends on every one of the levels and uh here is an example of the channels that run from the system levels to one of those rates the movement of underemployed people into the city there are a large number of

non-linear table functions in the model I will show you only one that I've already uh referred to the effect on land occupancy the effect of land occupancy on construction if there's essentially no City here yet there is some attractiveness but not much not many people are going to move into a place where there is nothing but as the land becomes more and more occupied it becomes more and more attractive as a center of activity so the so-called

construction multiplier the influence on construction from occupancy goes up until the best land is used up and it's harder and harder to find the right place for the right thing and naturally at 100% occupancy you can't build anything else you have to clear something out you have to back down from this in order to have room most cities run out here I think around the 80% level more or less and that's where the urban Dynamics model itself runs

somewhere out in here once it is reached equilibrium the behavior of this system is is uh rather interesting you can start with an empty piece of land and the model will build a city here is a curve for skilled labor over a period of 250 years skilled labor peing declining sum moving into equilibrium and I've given you two ratios out of the model the ratio of

underemployed to jobs if underemployed is low compared to jobs the unit access Unity ratio being here it means there is good Economic Opportunity you can come and get work the underemployed with respect to ratio to housing is high large number of people compared to the housing there is a housing shortage throughout this entire period of growth and then as you reach the peak as you reach the point where land is filled for the first time a quick switch

over in which the Aging of the Industrial and urban and uh housing structures leads to a situation in which there is excess housing and a shortage of jobs and you move then into a small number of un underemployed relative to the housing and a high number of unemployed relative to the jobs a description essentially of the urban stagnation situation that

existed we looked at several National policies and we found that all of the US national policies lay somewhere between neutral and highly detrimental from the standpoint of either the city as an institution or from the Viewpoint of the unemployed low income residents either one job training program can increase unemployment in the city I discovered this one weekend in the model I put in a job training program in the model one week weend at

home a perfect job training program it simply took people out of the unskilled uh underemployed area and put them into skilled labor gave them all the cultural and all the educational background of being skilled labor and furthermore didn't Levy any cost on the city the absolutely perfect job training program and I was rather surprised to find that unemployment went up in the city I brought this back the next week to our Urban consultants and said now

what do you think of the model if I put in a job training program I have more unemployment and they sat there in dead silence for about a minute and then one of them said oh said Detroit has the best job training program in the country and the most rapidly Rising rate of unemployment and then you looked at what was going on in the model and perfectly plausible you were creating skilled labor beyond what was needed you were

creating an over supply of skilled labor relative to what was there this generated a spill off a flow back into the underemployed a Fallout from that uh group also because you were supplying the skilled labor it wasn't necessary for industry to reach into the unskilled pool and do its own training so you about half of what you did was lost by the system backing off and not doing for itself what you were doing for it and

the other thing was that such programs have high visibility and it drew people from other places it was said that the Huff area of Cleveland almost emptied out in that period and went to Detroit because of the visibility of the job training program and the presumed opportunities that it would present now if you were in the late 60s and suggested that lowcost housing was not a good idea I think it's come to be rather much more widely accepted now

than it was maybe not wholly but at that time it was a very emotional subject and uh one of the faculty members at our fine institution here came up to me after the book came out I looked right straight at me and he said I do not care whether you're right or wrong the results are unacceptable uh others who probably felt the same way but it a little more tenably they say it doesn't make any

difference whether you're right or wrong those ideas will never be accepted by elected officials or residents of the inner city it turns out those were the two groups we could count on for support if they got close enough to what was being said to understand it now that's a very large if get close enough to understand it our experience was that it took about four hours three or four hours almost oneon-one to cross the boundary from emotional

rejection to understanding what was being said and uh my first exposure to this is still the most memorable shortly after the urban Dynamics book came out we were putting on one of the periodic Urban Executives programs at the management school that were done every uh six months or so for a period of time and I was asked to present the urban Dynamics message and

model and viewpoint on a Monday afternoon and a Wednesday morning for this program that was running for a month I have never had a lecture any time any place on any subject go as badly as that Monday afternoon in the audience was a man named Jean cander these this was a group from uh of urban Executives a man from New York City and the department head in Lindsay's

government in New York BL from Harlem in intelligent articulate not buying a thing I was saying and carrying the whole group with him he said this is just another way to trample on the rights of the poor people and it's immoral he said you're not dealing with the black versus white problem if you don't deal with a black versus white problem you not dealing with the urban problem when I said the diff the trouble in Roxbury and Harlem is too much

housing not too little he says I come from Harlem and there's certainly not too much housing in Harlem and that's a sample of the afternoon Tuesday evening there was a dinner for the group neither John Collins nor I were able to go we weren't trying to avoid them but uh we couldn't be there but several of our students went and after dinner one of them called up called me up at home to report what was fairly obvious and that was that the

group was very hostile H with encouragement I started Wednesday morning about an hour in the Wednesday morning you could tell that Jean kender's questions or comments were changing character they were beginning to be questions to elicit information two hours into the morning he said we can't let this subject drop at the end of this morning we've got to have another session I heard him the first time but I don't think I let him know that I heard him I wanted to see

what would happen I went on and a few minutes later he repeated it and I said well I would be happy to meet with them I don't see any place in the schedule but if you can arrange a time and place I'll be happy to meet with you I wasn't trying to put him off but that's usually the end of that kind of exchange but it wasn't he went to the management of the program and got another

session then he made an appointment to come to my office and what do you suppose he wanted he said would I come down to New York and discuss the urban problem with them among his colleagues his peer group on his Turf he sat there just as relaxed as if he hadn't been on that last to that last Monday session at all he says you know it's not a race problem in New York at all it's an

economic problem he gave me a report out of his briefcase that didn't get to the New York Times for another uh nine months outlining the amount of empty housing in every burrow of New York and the rate of Abandonment the support for the idea that there was simply more housing than the economy of the area was capable of maintaining and supporting that's what we meant by too much housing two years later a journalist came to me

and wanted to know what had happened in the aftermath of urban Dynamics by that time it had been a book debated in the ptas and the League of Women Voters over the uh country and I said well you know I'm not the one to ask why don't you go and uh talk to some others and I suggested that he talk to Jean cender well he did he went to calendar interviewed for his article and then called me up afterward the journalist

did and said the calendar had told him that they don't don't just have a solution to the urban problem up there at MIT they have the only solution two years later back home that conversion that change was still with him and

I've have seen it on two or three other occasions with people out of that particular kind of setting more and more negative more and more emotional and if you're watching closely you can see when

it happens it just looks like they've been hit suddenly everything that they have known fits into a new pattern into a new kind of structure uh it's really quite a remarkable sort of uh uh transformation but there's no solution yet to how you get very many people to go through that uh process there's no Mass Production Way That We yet know about that will

really do it out of this came the idea of an attractiveness principle for cities attractiveness being all those things about cities that have anything to do with you're liking them or not liking them the school system the crime rate uh the pollution uh everything and if you sum all of these up in some way the assertion is that all cities are

equally attractive to any particular class of person if one is more attractive than the other there will be movement toward that City and essentially every dimension of attractiveness is depressed by Rising Urban population the larger cities have a higher cost per capita uh to operate them uh the crowding and all of its consequences reduce the attractiveness and so there is a balancing process that essentially makes equal attractiveness

everywhere and yet we Fe we find cities all the time trying to improve the attractiveness of the city trying to improve something that is a weakness and it never seems to work because it simply readjust population pulls them in it would be much better if one would address the urban Problem by saying what are we willing to make worse because if you make something worse other things will get better that you have this balancing and you uh if just imagine the perfect City

everything about it is the best you could ever imagine what happens it is flooded uh unless you can in fact keep them out I mean some place like West Berlin uh very attractive City but it's got certain things about it that make you not want to live there in the way of the political environment and so to even hold a population all the physical aspects of the city have to be above average and you look around the the

world you'll see I think that you can you can trace that idea of attractiveness into uh different uh uh different context for the better part of uh for a decade or so we've been applying System Dynamics toward a better understanding of economic behavior this grew out of urban Dynamics I was giving a paper on Urban Dynamics at a joint native us conference on cities held of all places

in Indianapolis and uh out of the audience William deedle who has recently retired as president of the Rockefeller Brothers fund came up and said they were thinking of doing something more than supporting the Boy Scouts like they'd been doing and he'd like to come up and talk about what we were doing and what they might uh what we might have in common out of that uh came a very large block of money to support the first four years or so of

applying System Dynamics to uh economic behavior since that time the sponsorship has been Diversified to 30 or 40 uh sponsors in the private sector it's always been private sector money uh almost no governmental money except from Canada uh the approach here is to understand Behavior going back to Professor fren's

comments not really for forecasting but to understand behavior and to understand how that behavior could be altered by changing the policies and structure of the system that is the primary objective we entered it believing that the what we had discovered in corporations would Prevail namely if you build up a model from the internal fine structure of decision making that you ought to find that it generates the Behavior Uh seen in economies well we succeeded I think

Beyond expectations or beyond our hopes find that we have a model economic model that generates the major modes of behavior seen in National economies the short-term business cycle of 3 to 10 years between Peaks economic longwave that I will come back to money inflation inflation due to Rising money supply there are other dynamics of price change that go along with these uh uh Dynamic modes and growth growth from po po ation

and growth from uh technological change the uh work that I suppose has caught people's attention uh most uh uh most especially has been the work that we've done on the economic long wave economic longwave is a great rise and fall of economic activity of some 45 5 to 60 years uh

between Peaks the low points in those Peaks have been the major depressions now what I'm telling you here is a personal opinion opinion of the group that we're in an opinion shared by many people around the world who believe in the economic long wave but there are many who don't I would say in American academic economics there's very little acceptance of the idea of there even being an economic longwave so

I give you that warning and we'll proceed to give you uh my views on the situation uh the controversy the reason why there's been essentially no belief in this phenomenon is there's been no theory for how it could occur and with no theory for how it could occur there is a tendency to look upon any episode like a major economic downturn as in the 30s as being an accident a happens attributable to some non-economic external event to a mistake by the

Federal Reserve or one thing or another we got into it entirely unexpectedly we got into it by having assembled some structures of consumer goods sector and a capital sector and finding that they interacted with each other to produce a huge rise and fall of activity with Peaks some several decades apart now when you get an unexpected Behavior out of such a

model your best uh guidance is to assume you've made a blunder uh that there's something about it that is entirely unsatisfactory but as I may have said last time as the model gets better there's a rising chance that it is telling you something about real life I'm reminded of Richard Foster who did a System Dynamics model of diabetes the way the body controls insulin and glucose in various aspects of diabetes and he found in his computer model some

kind of patient behavior in response to some sort of test that had never been reported in the medical literature and that raises a question about the model he took it back to the doctors at the jlin clinic this was a master's degree thesis in electrical engineering that he was doing with a professor in biology and his research with the leading doctors at the josin clinic on diabetes in Boston he went back to the doctors at the clinic and said now how should we

interpret this here and he showed them the behavior and what had happened they thought about it and they said well you know we had a patient like that once but we always thought it was a mistake in the measurements you see something unusual very easy to dismiss in the complexity of real life and uh a doctor who in fact catches those Clues and eventually ident identifies something gets some new disease named after him somebody syndrome you know uh because he finally

by happen stance saw what was going on well here is the chance to find a new medical uh disease sometimes even in a computer model our interpretation of the longwave literature goes this way it's a very controversial literature uh first of all there's the large block of people that don't believe there is any such thing then among those that do believe there are many camps who believe

in different causes different Unity unilateral uh unit causes it's caused by this or it's caused by that and very few see it as a systems behavior in which many things interlock uh the literature reminds one of the story of the blind four Blind Men and the Elephant each one looking at this phenomenon from a different Viewpoint and drawing totally inconsistent opinions about what the

real animal the elephant is is it a snake is it a tree is it a wall depending on what part you touch what we found in the National model is that all of these different interpretations had some element of truth if you could see how they were all tied together and interacting with one another uh this is also known as the krf cycle named after Nikolai krf who did his work in Russia in the 1920s and he came early on to really

quite a perceptive insight into the essence of what was happening uh he said essentially that it was the process of building Capital plant and the financial markets that allowed the financial Capital to build and to overbuild uh those uh the capital plant and the peing the crescendo of of rise in the economic longwave such as we have experienced the 1960s and 1970s and on into part of the

80s is a building and an overbuilding of capital plant worldwide we're now at a situation where there's excess capacity given the prices and the debt and the other things that surround it excess capacity in most Industries and those are now putting downward pressure on prices beginning to raise questions about the ability to pay back the uh debt here is a computer run uh from the model just to give you a

glimpse of uh of what it looks like the black curve is uh employment over a period of 80 years somewhat more than uh one cycle uh inflation the green nominal interest rate Bank interest and the red real interest real interest you know is the bank interest minus inflation it is the

interest rate that tells you whether you want to buy Capital assets if you have high inflation at any given interest rate then you buy the capital asset like Farmland you sell it at the end of the year it's worth more and so that reduces uh the interest and for American Farmland the real interest St went negative in the 1970s there was a scramble to buy farmland farmland was driven up because this was the protection against inflation everybody

wanted to buy it the price went up because everybody wanted to buy it it wor no relationship to its uh productive capacity uh Farmland was selling at a level where the interest on the investment was as much as five times the earning capacity of the land land with no development potential whatsoever uh and of course at some point up here people say ooh I wonder if this is real and a few people back off and as soon as they

stopped bidding up the price there's no reason for it to be up there at all the only reason it was going up was because it was going up now you're sitting up here with an entirely untenable price and prices in the speculative bubbles always go down faster than they came up uh there seems to be a progression through the economy Farmland is the first one to be overpriced and then hit and probably the equities Market as we

saw the beginning last October of a downturn uh the equities markets being one of the last in the sequence of assets that get overpriced and then hit a period of uh of deflation here the real interest rate prior to the peak can actually go negative great incentive to purchase Capital plan physical plant factories Farmland everything else and

then right after the peak that real interest rate Rises precipitously now this is ordinarily blamed as it's happening now High real interest rates blamed on the Federal Reserve or the Reagan Administration the Press says unprecedentedly High real interest rates that's not true at all real interest rates went to probably 12 14% in 1931 uh so that uh you have really a situation where this comes up out of the private sector of the economy in the National model you can change Federal

Reserve policies by big amounts and you do not change the fact that you get this precipitous rise in real interest rate right after the peak you can change it in detail but it's fundamental to the internal dynamics of the way banking business households interact with one another some people say we wouldn't have another major downturn another major depression because we would have learned

from the past one but what did we learn there's still no General agreement as to why the 1930s occurred and if there's no agreement as to why they occurred then what is the lesson from them and how do you know that one isn't going to uh repeat I think in these very complicated situations the only hope it's not a hope that's been fully accepted by any means but the only hope is eventually to move down this road of

dynamic modeling that ties the micr structure of the economy to the macro Behavior or the same thing for corporations begin to understand what is happening why and then see if there are leverage High leverage policies that you want to use uh that would alter uh behavior and make it more desirable uh there is however a free room to debate as to whether you want to eliminate the Great Depression because they serve some very useful purposes of cleaning up uh people's acts

and weeding out the inefficient corporations and opening a window of opportunity for new technological change are a lot of things that would uh some people would consider undesirable if you actually got rid of the major depression so we could have an interesting social debate another time on that out of all of this come some general insights about the characteristics of these complex

systems they have a great tendency great ability to transfer problems between sectors if you solve a problem one place in the system it reoccurs in a different form somewhere else suppose the uh city is being troubled by congested highways leading in so we build a lot of throughways next thing you find is that people build houses at the end of those ways and now you don't have any room in town to park the cars so you build

parking garages and now lots of people can come in so you need bigger Office Buildings and now more people live at the end of the uh Highway and drive into town and now you're back to the highway congestion just keep moving from one set of problems to another always trying to alleviate a problem always raising the total population trying to focus in that place rather than deciding what the long-term character of the city ought to be and how are you going to control it

what are you going to make undesirable enough that in fact you can maintain the kind of stability that might be desirable tradeoffs between the present and the future the idea that a policy that is advantageous in the short run is disadvantageous in the long run and vice versa and almost always true an idea that comes down to us from Antiquity uh from uh fables the ancient Greek fables aso's

fables the grasshopper and the Ants essentially the story uh play and make Merry in the summertime like the grasshopper and freeze in the winter work hard and store up food and survive like the uh ant that idea runs through a great deal of our literature our religions but modern society has for the most part I think adopted the feeling that they have escaped from those great truths that is not correct you find throughout models of systems uh

that uh the uh tradeoff between the present and the future is always occurring I just suggest you take any personal thing you do and say if you maximize the short run is there or is there not a detriment in the long run borrowing in your credit cards live it up this month you have to pay the bills next month and so it goes with almost everything that one uh does

transfer the burden to the intervenor all of our systems have the characteristic that if you come in and do something from the outside for the system you take the pressure off so the system stops doing that for itself and uh this is where the role of the intervenor has on the whole been an unhappy one doesn't uh do anything but run up the total tax costs for the government to come in and try to solve some of these social problems because

the local parts of the social system then give that job to the intervenor and use their own resources for something else very few High leverage policies combine that with the resistance to most policy changes if one is addressing a group of corporate Executives and you ask them this question have you ever had the experience of a major corporate difficulty and you have

adopted a policy to alleviate that problem and 5 years later the problem is still with you and fully three quarters will hold up their hands because we spend in all of our social systems a tremendous amount of energy debating what to do about policies that are essentially very low leverage and have almost no effect regardless of what you

do I would go so far as to nominate uh tax policy which is always the focus in Washington as one of those low leverage policies if you shift the tax burden from one group to another from individuals to corporations or from here to there given enough time prices wages money flows will shift prices and wages will shift the money flows so that it goes to where the taxes are extracted

we've had uh uh we have had progressive income tax for years partly Justified on the assumption that it would equalize the economic status of different parts of the population I think it certainly has not done that because uh it doesn't have the leverage to make that kind of uh of social change tremendous amounts of political energy go in to the debating of issues that make very little difference and not much realization that there are a few High

leverage policies and not much time devoted to finding them uh this is an interesting field if you like controversy makes life interesting the uh debates about most of these books have been uh intense probably the most widespread

most intense grew out of the limits to growth book uh highly polarizing certain segments of the society strongly for it uh others strongly against limits the growth sold 400,000 copies in the first summer alone in the Dutch language and I asked a man from Holland once why was also estimated that the urban

that the world Dynamics book my world Dynamics book that preceded limits to growth was sent out to a dozen or so members of the club of Rome in draft form manuscript form for their comments and it was estimated that 50,000 copies of that manuscript escaped into Holland before the publication of the book why I asked a man from Holland that once he says well if you'll just rank the countries of the world in the order of

GMP per acre we're at the top of the list and we closer to all those problems than anybody else problems of industrialization pollution uh population uh density but one shouldn't be surprised at this kind of controversy because even in technology one has controversies over new ideas it took us seven years after we had demonstrated that magnetic core memory would work before industry would believe

it and then it took us the next seven years to convince them they' not all thought of it first this matter of Living Dangerously means that you need to walk on the the edge of the unknown it's a little like walking on the edge of a cliff you need to practice it it's something you learn how to do you have to calibrate yourself to know how close to the edge you can go without

falling off any new and important work means controversy if it's new and simply authenticates what's being done that's interesting but it's not going to change the state of the world and therefore hardly is worthwhile if it's new and differs with what's been accepted then it's going to run into uh controversy one might say that the

value of a new idea can be measured by the

degree of acceptance of the Viewpoint that's going to be overturn or by the or measured by the stature of those to be proven incorrect one has to venture out into that territory one needs to work and one has the opportunity here of working in the area of messy and poorly understood problems they're no more difficult to make progress in I think they're even easier to make progress in than the

well-known problems and areas because they haven't been attacked there is more opportunity there is more pred dirt to be uncovered and usually a very small amount of dynamic analysis yields major new insights one of our PhD graduates who went to the Department of energy told me in a visit once he was absolutely appalled at how much power and leverage a second or third order model could have over the thinking in the department of energy so there

just isn't any Dynamic thinking and very simple models can have tremendous impact the academic culture perhaps leads to many PhD students in junior faculty in into taking the small safe steps that I think is unfortunate I try to challenge PhD students to answer the question how will the world be different if you succeed and if there's no answer to that look

for some other topic because there are these opportunities all around us turning now to the Future For a Moment the idea of computerized case studies management case studies one area close to my interests in corporate management education uh World there is now an opportunity of bringing together some threads that have been developing throughout this Century

combining two threads of background the Harvard Business School launched around 1910 management education using descriptive case studies essentially look at the situation from all angles see what's going on what policies are people following what are the problems how do they seem to be related and talk about it in a comprehensive and even-handed way and try to come to an understanding of what's going on very powerful source of information it

falters on the step where having put all this together you are then faced with that 20th to 30th order uh dynamic system that you can't solve in your head and so very often the case study leads someone down the wrong Avenue when it comes to what you do about it but it's very powerful in mining information out of the mental models about the relationships between people and what are they doing from 1950 on at MIT Carnegie and the other places

various aspects of mathematical analysis were brought to bear on managerial functions largely in functions and not to a great extent in the overall dynamics of how the parts of a business the business and the market interact with each other to some extent but not I would say very extensively the future going down this road I think is to combine the power the information sources of the mental models with the

computer simulation models that can give it a give those that mental information a context and show the dynamic implications of the interactions that are being discussed let me illustrate that with one example what we call the People Express case the uh but first i'm going to show it to you in the context of very

Richmond's Stella modeling software the Stella modeling Stella software runs on the Macintosh computer and allows you to build on the screen even as you talk about the situation build a model of the relationships you're discussing these little Wells over here along the left side have the icons such as you see out here which you click on one and locate

it where you want it and connect them together and as you do this in the background the structure of the equation is set up and you open another window and it prompts you as to what things you must properly connect up and say something uh about uh this is a little link out of training people which we will see a more elaborate version of in a moment where you hire people they become trainees after a certain training

delay they become uh uh experienced people there's a lot of misunderstanding about what goes on in those chains down here is a hand which you use with the m to push these things around and get them where you uh where you uh want them a little more elaborate version of the same idea the inexperienced and the experienced people drawn out of the People Express case which was originally

developed by John Sturman being pushed forward now by Peter sangi and our uh PhD uh uh students into uh some of the new ways of presenting it uh with computers and working toward the idea of how you really use it in education but here once these hiring of new inexperienced customer service managers as they were called in the People Express Airline uh they become more experienced people and then you recognize that the

inexperienced ones aren't fully productive compared to the experienced ones and furthermore the ratio of the two is very important you flood the system with inexperienced people and it actually requires experienced ones to train them so you could possibly even reduce the total production productivity of your customer service people the ones handling tickets and baggage and arrangements and uh uh looking after the uh Airlines

customers people Express Airline was a very interesting story at one time it was the most rapidly growing corporation that the US I think has ever had at least it got up to anywhere near the same size it was uh discussed in the press as the great new phenomenon Don Burr who was president was in great demand to make speeches to management schools and to uh managerial forums about his policies that were leading to this great success Don B policies were well known

they were discussed in the business press the Harvard Business School wrote up a case about them uh Burr was very outspoken about his policies for how you build a great Corporation and the policies that were discussed I think were the correct Pol the True policies that were actually followed and John Sturman built a model based on this publicly available information about how people Express was being run the model

itself uh in reduced overview form uh is there I will just point out that there are seven of these rectangles in it therefore a seventh order system not very complicated but it has some extremely interesting characteristics you take the well-known published policies and you get a behavior from them that look like this very rapid growth the passenger

capacity represented by new airplanes Rising like this but faltering on this matter of service donur started out to build an airline that had the lowest price and the best service it was going to be the outstanding pleasure to ride on people Express he underpriced at a factor of two under other companies and of course didn't have the revenue used to give that high quality service and then we

talked about a rooting goals last time starting out with the idea that this is going to be your life's great experience in Airlines and then as they failed to bring the service capacity up to the passenger capacity service declined the reputation went down and Don bur is quoted toward the end of his tenure as having said it's good for people to be under stress profits went up like this and then down

like that because the load factor in other words percentage of Planes full ran from essentially 100% off to a level that could not uh be run profitably at the fairs that they were uh that they were charging another very promising and interesting thread is the apparent the beginning the experimental beginning of this field

encroaching into high schools or being experimented with in high schools Brattleboro Vermont has a group of teachers uh who are uh have for several years now uh been uh working in this area Peter bner who is in the uh audience has been very much a part of that he's from Brattleboro if you are interested in firsthand information he could tell you about it after the uh meeting the

educational testing service that runs these college admissions uh tests have some people that are following it and are interested and I mentioned last time at the beginning that I came into this field under the tutelage of Gordon Brown now Gordon Brown has moved around to the other end of the field and he is acting as the messenger and uh uh to carry System Dynamics into the Tucson Arizona high schools uh a framework for organizing

information the students already possess an extensive mental database about what goes on in families and school systems and towns they would like to see that more organized it becomes more effective information if they can organize it and put it together one's talking here about a dynamic framework into which to put what the person already knows at whatever point in the life he happens to be uh personal computers of course make this and the

Stella software make this practical now uh in high schools Nancy uh Roberts uh more or less launched this with her PhD thesis in education a number of years ago doing experimental teaching of system Dynam ICS at the fifth and sixth grade levels the focus has been more on uh high schools recently now you might wonder why complicated high order Dynamic systems can be dealt with at the fifth and sixth grade levels in high school I've had some of our colleagues here

argue you can't do it until they're in graduate school the reason is that we focus on systems in the context of Integrations not in the context of differential equations or differentiation and this I think is very fundamental differentiation I suggest to you is a figment of the mathematician's imagination it's been very hard to explain to students and the reason that it's hard to explain is it doesn't

exist I defy you to find anywhere in nature where nature differentiates nature only integrates nature only accumulates there are no processes of differentiation in the natural or social world and you see this immediately when someone tries to solve differential equations going back to vanever Bush's differential analyzer it wasn't a differential analyzer it was built out of six integrators if you want to put differential equations on a digital computer you always reshape them into

Integrations this is important it's not just a uh a side issue because focusing on real life through differential equations and differentiation has an Insidious effect on many students it causes them to get an ambiguous or even a reversed sense of causality they do not see what is actually happening in the system or what the direction of causality is I've had students argue that there is no difference

between saying that the water out of the faucet is filling the glass as against saying the Rising water is forcing in the glass is forcing the water to flow now I gave you a diagram before where there is a control system and the rising water controls the flow rate but if you just look at a steady flow rate you don't properly look at it as something where it is the rising water that causes the flow it is the flow I suggest that

causes the rising water unless you get that direction of causality firmly in mind and so firmly that you can see it in all sorts of physical world and social World situations then then there is a great deal of opportunity for getting things backward and to go back to the fifth grade in the high school any child who can fill a water glass or steal toys from a playmate knows what accumulation or integration

is it comes absolutely naturally and you don't ever have to suggest that it's difficult and it never seems difficult and they can move right into uh Macintosh Stella simulation there are videotapes of high schools where the students are just riveted to what is going on and intense discussions among them as to what is happening because they're completely involved in the Dynamics of the processes they're looking

at going back to my opening comments about TL sto's Vision I think we should look forward to a bridge between the two cultures between technology and the humanities between technology and the liberal arts there is a foundation underlying all of these fields the ability to combine the technical the social the demographic

scientific psychological managerial economic and political into systems models to combine them when and as necessary so that one can see how they interact with each other I see this as really the great Frontier of the next several uh decades a frontier that is just opening up but will address many of the major issues uh that modern societies are

faced with [Applause]