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This is a lightly edited transcript of the first half of the Fireside chat with Professor Jay Wright Forrester (JWF) held on July 24, 2013 at the 31st system dynamics conference in Cambridge, MA. Interviewer is Khalid Saeed (KS). Bob Eberlein facilitated the conversation.

KS: Jay, system dynamics changed my life. I now disagree with everybody around me on everything. It is clearly a disruptive science. Our models seek counter-intuitive insights that can often be controversial. Was there something in its design or beginnings that led to its deceptive nature?

JWF: Disruptive results are part of the landscape. They come with system dynamics. They're fundamental to a good system dynamics study. They depend on the nature of real life systems, on the nature of people and on the fundamental nature of system dynamics.

If you look at real systems, we believe that the behavior of a system is caused and created by its internal structure and its internal policy. Unlike many people, we do not believe that troubles in a system come from heaven, or random events. But rather that they are caused by the system itself. System dynamics looks at the nature of that system. A good system dynamics study will, in an apparently simple model, show how and why the real system is causing any troubles that you might be encountering. So time after time, we've gone into real life systems and found that people know exactly what they're doing. They have policies that they deeply believe in. And when you put those policies into a simulation model, you find that the model generates the trouble that they are in.

In other words, it is the policies that they are proudly following and that they think will solve the problem at hand, which are causing the difficulty. Now when that comes to light, and you show that in fact escaping the troubles in the system calls for reversing some of the cherished policies they don't like to be told that what they've been doing is causing the problems that they have been lamenting. They don't want to be told they have to reverse those policies. And this is the nature of people. So we have the nature of people, the real life system and system dynamic revealing the nature of that real life system that leads to disruption. The disruption is the upset that the participant has as a result of the study.

In corporations, you don't see much in the way of aggressive responses to the idea of disruption. They just ignore it. But in a social world, people can become very overwrought by suggesting that their policies are just the cause of a problem. When Urban Dynamics[1] came out, it produced a lot of controversy. But one full professor of social science at MIT walked up to me, and he said, I don't care whether your book is right or wrong. It is unacceptable. So much for academic objectivity! There is a big gap in our research work, and the activities that system dynamics have engaged in. How do you bridge the gap? How do you get people to accept that they've been doing the wrong thing? How do you get them to see it and act on it? It's fairly easy to get people to see that the policies need to be reversed. But it's a totally different matter to get them to do it.

I worked with one manufacturing company for quite some time. They were losing market share. They had lost market share steadily and it turned out that they were losing market share because the entire company was deadly afraid of having excess inventory. It manifested itself when there was a prospect of a recession in the offing. And they would cut back production. Their loss of market share was always in the recessions. Because they cut back their production further than the market would have cut back the purchases.

We had this model. I never met anybody in the company that differed with the model. They accepted the idea that they had to reverse those policies. But there was a problem: The policies had been the basis of three generations of top management making public speeches about their reasons for their success. That's three generations of top management, all alive, all in town, all stockholders, and all on the board of directors. How does a recent graduate of the Harvard Business School come dare to reverse those policies in the interest of doing better with the company? I think it was a gesture of goodwill to me that they decided that in a forthcoming

[1] Forrester, JW. 1969. *Urban Dynamics*. MIT Press, Cambridge, MA

recession that was on the horizon they would only cut back half as much as they had planned. They manufactured heavy equipment -- engines, in fact -- and they would allocate some tens of millions of dollars to put those engines in the warehouse during the recession so that they could sell them when the market picked up.

Well, as the saying went in the company, every time an engine was scheduled for the warehouse, some damn fool went and sold it. They never got an engine in the warehouse. And the president, after the recession, said that it had netted a $10 million profit after taxes they otherwise would not have made. But in the next recession, they could not bring themselves to do it again. That's the power of tradition, the power of the circumstances around them.[2]

KS: Talking of tradition, Jay, there is a tradition in academics about building on existing wisdom, existing literature. There existed a plethora of literature on every subject you have addressed in your models. Why did you not build on it, and started from scratch?

In general the literature does not deal with dynamics. It does not deal with how the pieces are related to each other. It's more likely to be statistics of past behavior, which don't tell you much about dynamics. You could spend a whole career reading the literature, and get nowhere. It's my experience that you start with the knowledge of people in the field. The overwhelming knowledge about real systems lies in people's heads. Maybe a tenth of that, or a ten thousandth of that is to be found in the written literature, which again has a vastly more informative story than the statistics. And when you get down to the statistics, you are perhaps at a millionth of a millionth of the total picture. It's a very small basis to start working from.

For example, Urban Dynamics arose because of John Collins, who had been a mayor of Boston for eight years, grown up in Boston democratic politics, and he had polio in that epidemic about mid '50s. He walked with two iron canes. He had to have an office in a building that had automobile access to the elevator level. My building was only one at that time that qualified. The professor in the next office was on leave. Through a series of happenstances, Collins ended up in the office next to me. So I talked to him about his background with cities, which was at a time when the urban crisis was the headline news in the newspapers. Cities had riots. They had fires. The big news was the problems in the cities. I talked to him about this. He didn't have quite his full quota of those problems. But he discussed what they were doing in cities to help alleviate the situation.

I began to get a feeling I had come to recognize in the corporate world. Everything he said seemed to make sense on the surface. Yet he doubted that it would hang together underneath the surface. I suggested to him, we might combine my background and his, and see if we could shed any light on it. So he said, OK, how do we start? And I said, well, we're not going to find out what we want in our Urban Studies department. We're not going to find out what we want in the Urban Studies library. We're going to have to have may be six or eight people who have been battling these problems, working with some, struggling with some, for years. And we should get them together for a long discussion every Wednesday afternoon for we do not know how many weeks. Collins was a man of action. He said they would be here Wednesday afternoon. Collins'

[2] Such real life experiences led to the famous book Industrial Dynamics. See:
Forrester, JW. 1961. *Industrial Dynamics*. MIT Press, Cambridge, MA.

position in Boston was that he could ask almost any businessman or politician for their Wednesday afternoons forever. And so our meeting began.

The Urban Dynamics study was the first and only one I've ever gone into where I had no idea what we would do, no idea whether we could succeed, no idea whether there was going to be a system there that made sense. Every other situation-- corporate, economic-- I had known, we could do it and approximately how to go about it. So, for six or eight weeks, these conversations went on-- wandering, contradictory, apparently going nowhere. And I was spending something like three hours a week between them trying to figure out whether anything had been said that would be a useful model. I would make some suggestions, look at them, and say those won't go anywhere, and discard them. Until one Sunday morning, by some sort of intuition or happenstance, I sketched the block diagram that opens the Urban Dynamics book. The nine stocks: three ages of corporate business building, three ages of housing, and three kinds of people. And you could see immediately what was going to happen.

As the business structures aged, they had lower and lower occupancy, fewer and fewer people per square foot as the buildings became less and less satisfactory. On the other hand, as high priced premium housing decayed, the occupancy went up, up per square foot. And that's basically what the model shows.

When you have the stocks down, I prefer to model by identifying the stocks that I want to work with. I did not start with causal loop diagrams or some of the things that are very popular. Start with the stocks. And remember, we're talking about endogenous systems. The system is internally causing its problems. Nine stocks, that's going to do it. Everything else is fairly straightforward. It pulls in (to) or pulls out (of stocks), for a reason. And so you control it from the available stocks. It turns out that almost every flow had some input from almost every stock in that model.

The model showed how there would be a 100-year growth stage where businesses are being created in the space of the city, and they are attracting people. So you have a100 years of stability, in the sense that you also had jobs always ahead of occupancy. That the opportunity for jobs always was high, and the availability of housing was low. The equilibrium was being established by jobs pulling in, and housing keeping people out. Then, as the land filled up, this totally reversed in 50 or so years. Now the housing is in excess. The jobs are low. And you have people being pulled in by the housing, and kept out by the economic distress. None of that would have come out of the literature. One of the things that annoyed economists more than anything else about World Dynamics is that it does cite two sources-- one, the World Almanac, and the other, the Encyclopedia Britannica. They should have settled for those.

KS: For creating your models, you did a great job to use experiential information, whereas the tradition in academics is using literature. In your opinion, is that tradition of using literature help or hindrance to innovation?

Well, I saw a quote here very recently from Kenneth Boulding - a well known but controversial economist who said there are only two classes of people that don't understand economic growth; one of them was economists. You know, they really don't recognize the power of exponential growth. It doesn't look like much, until you get to some point. You can double a population every 30 years for hundreds of years in population and never notice the change. The last 30 years

become overwhelming. That is not really seen by most people, (although) it can be seen by1st or 2nd graders. [3]

We are developing a foundation for kindergarten through 12th grade education based on system dynamics. It's much easier to teach system dynamics in grades one through eight than it is any time later, because they have a lot less to unlearn. All the fundamental ideas can be grasped in the first few years. There have been people who quite successfully explained to kindergarteners the importance of stocks and flows. The water in the bathtub is a stock. The flows are obvious. Your reputation is a stock. The good and bad things you do are the flows. And they can go through their environment and find the stocks and the flows. By fifth and sixth grade they can be doing computer simulation models that, for the most part, are now being taught in graduate school.

KS: Let me jump to another subject. You have talked about long wave way back in the 1980s. Do you think long wave exists in the US economy? Where do we currently stand on it?

Well, I very much believe that the long wave does exist. It explains the Great Depression of the '30s. But there has not been any economic literature, any accepted general discussion or description of what caused the Great Depression. For the most part, people see it as just a bad business cycle downturn. It's an entirely different phenomenon. A business cycle is largely the rise and fall of consumer inventories. Long wave goes back into capital sectors. And it's largely a rise and fall in the capital sectors.

You saw it here not too long ago; housing was expanded and expanded and expanded to a point where the debt that supported the expansion was intolerable. The housing was beyond what the occupants could, in fact, afford. And then you have a crash where people stop buying. And the capital producing sectors almost go out of business.

We're now, I believe, on a long wave brought downturns. Every time there's a little upturn, the newspapers talk about how now the recession is ending. Well, first of all, it's not a recession. It's something entirely different. A little while later, they say right now, well, maybe the recession isn't going to recover. Maybe it'll even turn back down. What we're seeing is the business cycle, which still is alive, operating along the bottom of the economic long wave.[4]

The economic long waves are a great deal more than just a rise and fall of activity. They change the very nature of what's going on. The downturns are time stores for the major technological changes. In the '30s we went from railroads before the '30s to airplanes afterward. We went form

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[3] The reference here is clearly to World Dynamics. See:

Forrester, JW. 1971. *World Dynamics*. Wright Allen Press, Cambridge, MA.

[4] Long Wave is an important discovery in the findings of the National modeling project. It remains unpublished. Some information available in:

Graham A K. 1984. Introduction to the System Dynamics National Model Structure. *System Dynamics Group Memorandum #D-3573*. MIT, Cambridge, MA.

Sterman, J D. 1985. The economic long wave: theory and evidence. *System Dynamics Group Memorandum #* D-3712-1. MIT, Cambridge, MA.

radio to television. We went from people living in cities near where they worked to the automobile and the suburbs.

And it's unclear now what this next kind of major change is going to be. It's going to take 10 or 20 years to find out. And so we're going to be moving along, feeling things out, giving up cherished past technologies to be replaced with others.

There is a very interesting one-person simulation model to show a piece-- just one of four or so dynamic mechanisms of the long wave - the so-called self-ordering in capital sector. If you take all the capital sectors in their entirety, if they are going to expand their capital plant, they have to expand it with their own production. And that's the basis for a little model I want to describe. Everything is going on the computer screen in front of you. Some orders are coming in from the lower right corner. They go into an order backlog to be supplied capital equipment from the capital sector that you are running. Every month you decide whether you need more capital plant or less. No labor, no prices. You make capital plant with capital plant. That's all there is to the technology.

If you want to expand the capital plant, you must order more. But it has to come from you. So your orders go into the same order backlogs that other people's do. And as you get your share of the output, you can expand your capital plant. Essentially everyone will run this (system) in such a way that they have huge fluctuations of the capital sector with peaks 40, 50, 60 years apart. You're seeing a piece of the long wave there.

I watched it one day with two people cooperating on what to do. One was one of our Sloan School economists. And the other was a recently retired manufacturing vice president of PRW. They had the results of everybody else-- huge fluctuations 40, 50 years between peaks. The economist was absolutely sure he had been tricked some way because that couldn't happen. I turned to the retired manufacturing vice president. I said do you see any reality here? And he said I have relived my whole life. The economists are not in touch with the real world.

KS: On that same subject, Jay, you mentioned that when we recover from this bottoming out, there would appear many new technologies. Will one of these be a complete change in economics? Do you think that a revolution will ever happen in the field of economics, which, I sense from your conversation is very sophisticated but not extremely useful?

Well, there are several things going on in economics. And I think generally your question and general talk applies to what is referred to as the mainstream economics. This is what would be taught at MIT, Columbia, and Chicago, and Stanford, and the main, big, well known universities. But there's a lot going on besides that. There are doctoral students in many places that are rebelling against mainstream economics, strong movement in France, strong movement in some of the other lesser universities in this country. But the mainstream economists have a tremendously strong self-contained paradigm. You do not change paradigms easily or quickly.

For example, it was only in 1950, 50 years ago that the Catholic Church finally admitted that Galileo had been right - a few hundred years to change that paradigm. I do not think for a moment that we're going to convert mainstream economists, maybe a few, but probably not. First of all, they have excelled in the profession. And if they were to go to system dynamics, this is another profession. It will take them as long to learn as it took them to learn their own business.

System dynamics is at least as complicated as medicine or engineering. If you want to come to the top of the list of skills, you have three, four, five years of study. And they're not about to do it. So I think what we'll see in that future is not the conversion of mainstream economists, but their replacement. They will be replaced. They will be gradually overwhelmed. And you will all have to outlive them.

KS: Jay, what do you think you'll be known for in about 20 years?

JWF: That's much too short a time. I would rather talk about what would be remembered for 50 or 80 years from now. Because the whole future, the possibilities of system dynamics are so huge that it's going to take a very long time for the main part of it to take shape.

Just for example, one thing that we should look forward to is a replacement of differential equations in the engineering and the social sciences. Differential equations have been the fundamental way of dealing with dynamics. It is terribly misleading. It causes a great deal of harm. And the reasons for this, mathematicians have had some difficulty defining a derivative. And there is a reason. There is no such thing. Nowhere in engineering, science, cultural theories, nowhere in the real world is a derivative taken. Nature only integrates. Nature only accumulates. And as soon as you approach it from that point, any child who can fill a water glass or take toys away from a playmate knows what accumulation is. So they can move into complex systems, and never discover that they're difficult.

I had two doctoral students from our department of electrical engineering and computer science. They'd had all of the math and all the theory about all the state physics. They came over. And they built a system dynamics model of one or two levels about what was going on in the electron cloud at the contact point of a transistor. They said it was the first time they had ever understood what was happening. The differential equations had completely obscured the reality of what was going on. I have had MIT students argue aggressively with me that the water flows out of the faucet because the water in the glass is rising. That's what the differential equation says. It causes a reverse sense of causality in many students. It totally obscures the dynamics in most for the others.

So I would like to be known for having thrown out differential equations in all fields. This is not going to be over the next 50 years. And, I would like to be known for having completely replaced economics, and that's not going to be in 25 years either. There are a few others, but that's enough for now.