Shmuel Oren Interview by Ramteen Sioshansi, October 23, 2017, Houston, TX

From Optimization to Dynamic Pricing

RAMTEEN SIOSHANSI: I'm Ramteen Sioshansi. And I have the privilege of speaking to Shmuel Oren today.

It's actually a unique privilege for me, because-- hopefully you remember, Shmuel-- you're my academic father in a way. You were kind enough to serve as my PhD supervisor some number of years ago. So it's for me a unique opportunity to get to talk to you a little bit more about how you got into everything that you do now, and all your experiences with students, and all of that.

So just to start with, maybe if you'd like to tell us a little bit about yourself and, your academic position, things of that sort.

SHMUEL OREN: OK. So I got to what I'm doing now through essentially a random walk following my interest and my passion over the years. I got my undergraduate degree in Israel at The Technion as a mechanical engineer. And I was in an ROTC kind of program, so I did it before my military service there.

And then I served for four years in the Israeli army, spending most of my time in designing conversion kits for tanks, building tanks. My service overlapped the '67 war. So some of the tanks that I built were participating in the war.

We captured a lot of Russian tanks, T-55, so I became an expert on Russian tanks. And we turned them around and converted them.

So when I finished my military service, I was a little fed up of mechanical engineering and was more interested in pursuing more theoretical work. And I got a master's degree also at The Technion working on viscoelasticity.

And then I got interested in systems. I kept getting more interested in the math rather than the physical activities. So I applied to several universities. I got accepted to Stanford to do my PhD in a department called Engineering Economic Systems.

And to some extent, getting there was by mistake, because I was interested in numerically-controlled machines and systems engineering in general, but more closer to mechanical engineering. But when I got to Stanford, I found out that there were a bunch of professors that were trying to apply the principles of systems analysis to social problems and economics.

So I started to take courses in economics, I started to learn more. At the beginning I thought this is not really what I'm interested. But then I realized that what I was really interested became more and more in optimization.

So I started to work with David Luenberger at that time. He was working on a second book on non-linear programming, and I was helping him with that, and got interested in quasi-Newton algorithms, which was a hot topic, and ended up doing my thesis in this area.

I didn't spend much time in my PhD program. I actually got at Stanford in '69 and I got both a master's and a PhD in the department in two years.

But I definitely became more interested in decision analysis, systems. And at that time, one of the professors in the department, Dick Smallwood, started a new group at Xerox Research Center at Palo Alto Research Center that was in the Xerox lab that they built there. So he asked me if I wanted to join.

And at the same time, I was asked to teach some courses in the department. So I ended up spending the next eight years being a part-time faculty and then also working at Xerox labs, which was not too far away.

One of the big issues at the Xerox PARC were trying to introduce decision analysis into technology development. The big topic there was the office of the future. And we were trying to figure out how to introduce new product and analyze product development.

So we had a small group there at Xerox called the analysis research group. Mike Rothkopf later joined the group. And so we had about five people there in the group, and were trying to figure out how to help Xerox in improving their decision-making process.

In '75, '74, Xerox had a technology for laser printers and they were trying to decide whether to actually launch a product. At that time, IBM came out with their inkjet printer, so it wasn't clear whether a laser printer, which is based on cut sheet, is going to make it in a market that everything was fanfold.

So we got involved into doing market research, big market research study, and developing a forecast model. But it wasn't a statistical model forecast, because there was no data within-- there was no looking backwards. But we were developing a forecasting model based on extrapolating some of the market research results that we got and trying to project sales into the future.

That ended up being a very successful project. Xerox ended up launching their product. And at the time, I think that they kept that model running-- the model was written in APL-- I wrote APL code for a year. They used it for 12 years, and the thing was right on the nose in terms of forecasting. That project, we submitted it to the Edelman prize competition and it was a runner up-- I think it was third place-- in 1980.

And then I kept working there. At Xerox I was trying to make myself useful to the corporation. And Xerox became interested in broadband communication, so we started to look at how to do market research and how to look at evolution of a new area that there were no customers-- so how do you do market research?

And so at that time, Mike Rothkopf suggested that we hire Bob Wilson from Stanford as a consultant. And that probably had the most profound effect on my career and my future interests, because Bob Wilson introduced us to the whole area of non-linear pricing, mechanism design.

This is about the same area where the seminal work on non-linear pricing and mechanism design was done. Some people got the Nobel Prize for that work. And we ended up trying to apply some of these ideas developed looking at pricing strategy. So I got involved in economics, and learned a lot about pricing policies, and wrote some of the papers that ended up in marketing science at that time.

And in particular, we were working on models that tried to look at critical mass and how do you promote the evolution-- breaking critical mass. So the idea was that here you have a product-- like if you think about products like a fax-- that the value of using the product changes-- goes up-- with the more people that use it. So if you are the only one that have a fax machine, it's not worth much. But if you have 1,000 people that have fax, now you can communicate with each other, so it's worth more. So your willingness to pay for that product changes the more people are buying it.

So this creates a critical mass phenomenon. And the question is, first of all, what kind of pricing strategy you're going to use to try to make that happen, to actually break to reach the level that people are willing to pay for what they get.

And so we had several papers developing models where the demand for the individual customer is a function of the total sales-- and looking at dynamic pricing. So that's how I got into this whole pricing area, which, as you know, I've been involved for many years, and looking at different product differentiation, and how to create a product line, and how to price it in a way that will try to capture as much of the benefit and as much of the customers.

So this went a long way from the work that I was doing in optimization, which I worked on for maybe the first eight years and kept busy doing convergence analysis and numerical testing of algorithms.

Early Life Through Graduate School

RAMTEEN SIOSHANSI: So can you remind me where you grew up and what your childhood was like, Shmuel?

SHMUEL OREN: OK. So I was actually born in Romania in 1944. And I'm being told that I spent the first three months of my life being taken into shelters while the American airplanes were bombarding Bucharest on their way to the oil fields in Ploiesti.

And then in 1950 my family went to Israel. And so I grew up-- at that time, this was two years after the establishment of Israel. I grew up in some small village in Israel and went to school there. Before he came to Israel, he was a small merchant, was selling stuff in a small store. But under the communist regime, that was no longer a livelihood. So he worked all his life there, became a construction worker.

We moved to Haifa, and I decided that I want to go to high school. I probably was the only kid in my elementary school that went to high school. And this was a school where five hours a day you work in the shop and you learn the trade, and then another five hours you get academic school. That was a school that was affiliated with The Technion. And it was a model that they decided that they're going to take kids from high school and turn them into technicians.

So by the time I finished high school, I was actually a certified mechanic. I took classes in welding and machine shop. And I even went for an internship to Denmark, and worked at a factory, and was working on lathes and machines. And that's how I got interested in mechanical engineering. I ended up getting good grades in math and physics, so I was told that I can try to go to The Technion.

Because that school was affiliated with The Technion, they had a special route that you can just take entrance exam in math and physics and get in without going through the baccalaureate problem. So I ended up at The Technion.

When I did my master's started to read papers and decided, oh, I like to do that. So I went to the American embassy and started to look over all the catalogs-- the universities-- and applied to different. And I got admitted to Case Western, to University of Utah, and to Stanford. And I decided Stanford looked the most attractive, even though it wasn't very popular. This was during the time that Silicon Valley was evolving.

But, nobody in my family really had college degrees. When I got my diploma and I sent it back to my parents, they saw Doctor of Philosophy and they say, I thought you were an engineer, you became a philosopher? So I used to send my parents some publications so that they can show around their neighbors to know what their elusive son is doing in the United States.

RAMTEEN SIOSHANSI: Right, right. So obviously, they were upset that you were leaving Israel for the United States. But how did they feel about you going to college in the first place and then continuing as a graduate student?

SHMUEL OREN: My father was very encouraging. Even though he didn't have any education, he appreciated the value of education. My mother was less-- she was looking at the things she was giving up to help me out.

The alternative before I went to high school-- the clear alternative is to go to become-- after finishing elementary school to become an apprentice at some shop and to learn a trade, starting by sweeping the floor and then learning a trade. So going to high school was a big thing. And then by the time I finished high school I controlled my own fate. I knew what I was doing.

But the thing that made it all possible is the fact that I had good enough grades and I got into an ROTC program where essentially they defer my military service until I got my degrees and during the summers we would go for military training. So by the time I finished Technion I was a lieutenant in the Israeli army and I was in this ordinance corps.

Israel at that point didn't have the capability to cast tanks, so they were buying the old bodies from World War II that were in junkyards in Europe and then were excavating everything from the inside and putting new electronics, new cannons. And so my job was to basically fit in modern equipment into the body of the tank, and to modify as necessary, and then to make the drawings. I spent four years doing that. That was an interesting experience.

RAMTEEN SIOSHANSI: And so when you were applying to graduate schools in the United States, did you apply to mechanical engineering programs or were they more systems engineering you applied to?

SHMUEL OREN: No, I think one place that I applied to was in mechanics, because as I said, I did a master's thesis on viscoelastic stress analysis. Actually, it was a big thesis, could have been a PhD here. And so I applied to one place.

But I took a course in control and I got excited by control theory. And so I wanted to learn systems. And as I say, I was interested in numerically-controlled machines, using numerical algorithms and computers to control machines.

RAMTEEN SIOSHANSI: And so going back to when you arrived at Stanford, was that a real culture shock for you? Because your background up until that point had really been in technical engineering fields. And being in a more-- as you said-- social or human systems environment, was that--

SHMUEL OREN: Well, the first semester, it was a real adjustment. I was thinking, oh, what did I get myself into? And then tried to take some of the courses from Dave Luenberger. And he was starting to talk about optimization in Banach spaces, so I felt totally lost.

So I ended up essentially spending the first year re-taking all the math that I ever learned in the math department, learning numerical analysis, and functional analysis, and linear algebra, and all that. And then it all became easy. But it was a culture shock, initially. I wasn't ready for that. And the engineering training that I had wasn't quite adequate for what was essentially an OR program, much more mathematical. But then it worked out.

RAMTEEN SIOSHANSI: Right. And so your interest in optimization, and non-linear algorithms in particular, was that really inspired by interacting with David, or how did that interest grow?

SHMUEL OREN: Yeah, basically he was working on his book and was working on a chapter in the book on quasi-Newton methods. So he asked me to look at some of the literature and I got interested in that and came up with some ideas that he encouraged me to pursue. And before I knew, I had a thesis done.

In fact, he was heading for Washington. He ended up working in the Nixon administration. And so he was going away for a whole year, and I was trying to pass my qualifying-- my thesis defense. And I didn't have anything written, so I used his draft chapter for the book, which was based on my ideas. And I use that as the material to give to my readers. And so I ended up having him as an advisor.

Then the same year Dimitri Bertsekas came to Stanford. And he was my second reader. And then my third reader was George Forsythe, who passed away actually two weeks after he signed my thesis. But he was a very prominent numerical analyst.

So I was at that point working on convergence of algorithms, numerical analysis. So this is before I got deeper into economics.

Market Analysis and Related Topics

RAMTEEN SIOSHANSI: And so when you started getting into market analysis, pricing, non-linear pricing, was that more voluntary on your part or was your interest still at that point mostly in algorithms?

SHMUEL OREN: I think that the interaction, as I said, with Bob Wilson, we started to look at different things that we can help Xerox in their decision-making. At that point, they were trying to launch a company called X10, which the idea was in every town to have a satellite station and then to have small dishes on different buildings. So you would have a signal coming from satellite and people will be able to communicate between buildings-- so Xerox machine to Xerox machine via that satellite dish. And they were envisioning a very limited market that would essentially rely on a subscription model.

And we were trying to do a market research to see how much market potential there is. And as we were trying to look at it, we decided that it's one of those critical mass phenomena that the question-- it's chicken and egg. You have to create the pricing strategy to induce people to join, and the more people join the more valuable the product becomes. And that's how I got interested in the whole economics of market externalities, essentially.

RAMTEEN SIOSHANSI: And how much did the science actually exist at that time for doing the type of market analysis you were doing where you didn't have a history or a customer base to look at and these network externalities?

SHMUEL OREN: A lot of the technology was based on you design a concept test. In other words, you create hypothetical products and then you show them to customers or to focus groups. And then you collect data-- customer response-- and try to forecast, to make statistical prediction, extrapolate from the sample that you collected.

The innovation that we brought in there with our market analysis model was, first of all, to somehow characterize product in terms of attributes and try to get people to give us values of different features and create a value function. And then we're using a logit model to predict probabilities of choice, which turned out that that was quite an innovation.

I left Xerox in 1980. One of our interns who got a PhD also at Stanford, and he was a medical doctor, was actually hired in the same department that I was teaching part-time.

And he decided to create this new group and had some major grants. He did some work on screening for cancer. He ended up getting the Lancaster prize. His name was David Eddy.

So he asked me if I wanted to join him at Stanford and to work together and try to use this approach to try to work on, for example, fault detection. He had this model that worked for cancer detection. He said this should apply to fault detection in nuclear plants and things like that.

So I got excited about this whole opportunity, left Xerox, joined Stanford full-time on the soft money position. And I was teaching part-time and supervising students now-- medical students. Got involved into various aspects of clinical decision analysis, developed some models for clinical trials and how do you extrapolate the results in them.

And actually, Mike Rothkopf, who was working with me at Xerox, also came for a year to the same group. And we're working together at Stanford. He came on a fellowship sabbatical from Xerox. And so I was there for a couple of years.

Energy Research

About the same time, that's where I met Hung Po Chao, one of my friends from EPRI. And he joined EPRI, was developing a program to look at energy and innovative ideas. So I got involved.

So Bob Wilson and I wrote this proposal. And we essentially proposed something that goes under the name demand response how to offer to people differential service of electricity, to allow people to subscribe to lower reliability-- electricity that can be interrupted occasionally-- in exchange for price discounts. And EPRI bought it and gave us a big grant, so we started to work on energy. That was how I entered into the energy area.

RAMTEEN SIOSHANSI: And so was that really some of the first work on looking at incentivizing demand response in the electricity industry?

SHMUEL OREN: It was close. Actually, the work on demand response was started by Schweppe, and Caramanis, and Tabors. They wrote a paper in the '80s-- in 1980-- on the homeostatic control of appliances, the idea of how to use pricing mechanisms in order to modulate people's consumption of electricity. And so they developed some of these concepts of spot pricing of electricity.

And so we got into that area. It was fairly early in the game. There was some work on load-duration curve, on peak load pricing-- that was the initial how to price electricity to try to mitigate some of the peak loads by giving people incentives to curtail their consumption during high prices. And so there was a literature on peak-load pricing. But we came in and started to develop this whole concept with Bob Wilson on priority service and efficient rationing.

So the idea was how to offer people a menu of service reliability or probabilities of cutting them off if there is a situation that calls for that and have designed a pricing manual that will allow them to reflect their own choices, their own preferences. Now it's becoming back into the forefront, but we were working on that in the '80s.

So at that time, this was right after the embargo, the energy crisis, so there were a lot of initiatives of how to try to save energy, energy efficiency. And the public utility commission were giving a lot of incentive to utilities to introduce various approaches to save electricity.

So the idea was that if suddenly there is a shortage-- there is a hot day and everybody turns their air conditioner-- then some of the people that are heating up their pools or they're using their pool pumps would be able to get off the grid. And the way to do that was they had this device they will give us an early notice that within half an hour you are going to get only half of the kilowatts that you are getting to your home. And for every kilowatt that you were willing to subject to this curtailment, they were willing to pay you $5 a month or something like that. So about 10,000 households in Los Angeles were signed up for that.

And so what we were trying to do, we're trying to introduce an economic model to try to understand what would be the right pricing of this kind of a service, not only with two levels but perhaps with multiple levels, and what would be the economic benefit, and try to promote this whole idea. So out of that came some very seminal papers in very top rate economic journals on priority service and efficient rationing.

And this is actually now coming back, because now with smart meters and all of the new technology, the technology now is ripe for that kind of an approach. So I've been restarting a little bit, dusting off some of the old ideas. And I've been working on it recently. But this was how we got into the electricity area.

RAMTEEN SIOSHANSI: And did you find that-- back then in the 1980s, was the industry, were customers receptive to these ideas, or?

SHMUEL OREN: Well, the customer, obviously they responded to some of that. The thing is that by the end-- 1988-- turns out there was a recession, so suddenly there was an abundance of electricity. So this interest of the industry in trying to convince customers to sign up for interruption faded away, the money for that faded away. So a lot of these ideas died off. The technology wasn't quite at the level that it would have become commercial at this large scale. So this whole demand response idea died off.

But then in the mid-'90s-- suddenly there was new interest in deregulating the whole electricity industry. So that became a big topic. And I got involved. Bill Hogan became involved in that and he started to promote an idea of Schweppe.

Schweppe wasn't alive by that time, but Bill Hogan was championing the idea of locational marginal prices, the idea of having a system operator that is going to dispatch electricity, and they're going to manage congestion by having prices that are going to change based on supply and demand every five minutes and going to change by location. So that became a very topical subject.

And so again, Bob Wilson, and Hung Po Chao, and then myself became-- actually, my friend Steve Smith was still involved in that point. We created a little consulting company, and EPRI was basically funding a lot of our work in this area. And that's how I got into that.

Now, I should say that in '82-- I forgot to mention that I was at Stanford. But then there was an opening at Berkeley. And I thought it was the perfect opening for me. They were looking for somebody with expertise in optimization and in economics. Essentially, it was the position that was previously occupied by Shephard. He retired, so there was this opening. They were looking for somebody that does economics and production.

And so I applied for that position. That was the only position I applied for. And they invited me, and I gave a couple of talks. And they made me an offer I couldn't refuse, so I crossed the Bay and went to Berkeley.

The Broad Foundation of Optimization

RAMTEEN SIOSHANSI: Very fortuitous timing. So I'm just curious-- these three or four different areas that you worked in after finishing your PhD, obviously there was a lot of domain expertise that didn't carry over. But in terms of the sort of fundamental tools that you were using, was there a lot of commonality or did you have to reinvent your toolkit each time you moved to a different application area?

SHMUEL OREN: No, it was all based on optimization. The whole structuring of electricity, for example, was all driven by optimizing the dispatch, optimizing the way resources are being used. And so the core knowledge-- the core theory-- was always based on optimization. It's just that I got more interested in application rather than in developing algorithm and analyzing theoretical convergence. Now we started to look more at big optimization, large-scale optimization models, and how to implement some of the concepts, some of the results through market mechanisms.

So the new thing was the fact that market mechanism became a distributed optimization paradigm, that you can calculate the ideal solution under perfect information. But then the way to implement it is to use auctions and to use various market mechanisms.

And so I got more into auctions, and auction design, and mechanism design-- the whole theory of mechanism design-- and incentives. They became the core knowledge. But again, it all lays on a broad foundation that comes from optimization.

Electricity Market Restructuring

RAMTEEN SIOSHANSI: And so you brought up, obviously, being involved in electricity market restructuring. Well, first of all, what is your view on how market restructuring has evolved over the past 20 years? Because obviously most of the market concepts we have in place today are not the same as what was originally proposed 20 years ago.

SHMUEL OREN: Well, there were some false starts. And we're trying to learn.

For example, Bill Hogan, he was pushing the idea of nodal pricing, where if you have a network with thousands of nodes you're going to have a different price at every location. There were some of us, including myself, that thought, oh, that's too complicated. We can do zonal pricing,

we can create some major hubs and simplify the model. But this was driven by the fact that we thought the model is too complicated and optimization is going to be too complex.

Now as it turns out, optimization technology has evolved very rapidly. And so in a way, that concept became the novel pricing idea caught-- partly due to the persuasive powers of Bill Hogan, but partly because it was the right solution, it became the law of the land.

California was a little outlier in this way. They started with a market that was a little bifurcated. The idea was let's have a forward market, a day ahead market, that ignores some of the physical constraints of the network and has some of the trading that they had occur with simpler rules. And then the real-time market, the closer to real time, we'll have a system operator that is going to make everything right. This is similar to the model that currently prevails in Europe.

And that turned out to be the wrong way to go. California, we ended up with an energy crisis because different errors in the way that this restructuring took place. One of them was the bifurcation of the market, which created gaming opportunities.

Enron was notorious for exploiting some of those discrepancies, loopholes in design, where they were taking advantage that the day ahead market was ignoring physical constraints. So they were scheduling transactions that physically couldn't be executed and then counter-trading with the system operator to essentially relieve congestion that they created in the network. So they were manipulating the system.

And one of the most notorious games was the "dec" game, the decremental game, where they were scheduling transactions from north to south, three times the capacity of the transmission lines. And then they were selling back-- essentially, backing off the transaction. And the system operator had to pay them to do that, and they were making a fortune on this kind of strategy.

So that strategy now is actually legal because now there is no difference-- both markets recognize all the constraints, so it's appropriate to allow people to do some scheduled transactions in the day ahead, and then if they have differing forecasts what's going to happen to real time. But then there's no gaming opportunity anymore.

Now it's called virtual trading. You allow people without generation assets to buy or sell electricity in the day ahead and close their position in real time. So this is a good strategy that adds liquidity to the market, but it requires that you don't have different sets of rules in the two settlements.

But it took a lot of developing some domain understanding to understand how those things work. Nobody really understood exactly the technique. So I got interested in the whole gaming and the game theory that underlined these kinds of strategies.

And in that time I became a consultant to the Texas Public Utility Commission, helping them in 2001 to design their market. At the time, I was trying to tell them or inform them about all the mistakes that were made in California. They didn't buy them initially, so eventually they learned

by experience that indeed those strategies that I was predicting were executed and people were trying to game the market, so they changed it.

I kept being a consultant to the Texas Public Utility Commission until 2009. And by that time, they gradually moved and updated their market design and they bought into the most advanced design, like PJM has. And the same, California had a major reform after the energy crisis, and I did some consulting with them. I worked with the Public Utility Commission in California.

So there was a lot of market design that people had to understand. So over the 20 years, we basically learned what can happen and how the market should design. There is a whole body of knowledge now. But now we're moving into a new area with the renewables, so these insights are becoming obsolete and we have to move to reform the market again to deal with the introduction of renewables.

The thing is, this wasn't the standard operations research type project. I had to develop some domain expertise over the 15 years, first of all, to gain credibility with electrical engineers. I am very active in IEEE with the electrical engineering community. So anybody that thinks that operations research, you can jump into an area and we are so smart, we're going to offer you a solution, learn very quickly that that's not the case. There is a lot of domain knowledge that has to be acquired.

RAMTEEN SIOSHANSI: Yeah. So it's an interesting observation that it took us about 20 years to develop markets for the state of the electricity system 20 years ago, and now we're probably going to have to go through it again. But I'm curious-- do you think that that, having to go through-- in some sense-- a little bit of trial and error to get to where we are today was the inevitable way to develop these markets?

SHMUEL OREN: Yeah. I'm doing quite a bit of consulting now with helping the Israeli power authority, which is looking at reforming their market. I work in Colombia, the country of Colombia.

And people don't like to learn from other people's mistakes. They like to make the mistakes, to learn from their own. You cannot come to people and say I told you so. You see what's happening and what can happen, and that's basically what I've been doing in industry for a long time, trying to learn from experience and teach.

Everybody thinks that it won't happen there. So we're seeing that process of learning by making mistakes happening everywhere. So I tend to believe that there was no-- really-- either way. The Europeans are still struggling with their market design, and they keep coming up with new ideas, and they don't want to bite the bullet and change. We think that the American system now is the best, but not everybody thinks so.

Current and Future Electricity Markets

RAMTEEN SIOSHANSI: Right. And so thinking back over the past 20 years-- there was a lot of debate about, as you said, you know nodal versus zonal pricing, self versus centralized unit

commitment, PoolCo versus spot market, so on and so forth-- if you look at the market designs that are in use in the United States-- and obviously there are differences, but to a large extent there's a similar structure-- do they seem to you to be a good design, again, for the system of 10 or 20 years ago? Obviously, we have to go through further reform as systems are evolving in the future.

SHMUEL OREN: Yeah, I think that in the United States-- we developed a design that is probably best for a system with centralized resources and with the more traditional generation of resources that we have. We used to have quite a bit of nuclear power plants, coal plants, and so on.

So the idea of central dispatch and doing it through a big optimization algorithm, I think we pretty much perfected that. We also learned that markets need some sort of monitoring, that you need to have market monitors that are going to prevent to monitor and prevent market abuse. So I think that we did the best we can.

What's happening now, even though it's not necessarily going to lead to a more efficient system, we see a trend of democratization of the grid-- if I may call it-- that on one hand we have all these renewables and we have this proliferation of distributed resources that are taking over. And they create major challenges for the system operator.

And it's not quite clear that doing it-- the distributed resources-- is the best way to go. But at this point, it seems like that's what people want. A lot of the drive comes from trying to fight greenhouse gases and trying to combat global warming. So there is a big move toward using a lot of solar and wind power.

And to a large extent, the regulators have been promoting a lot of subsidies to try to promote that. We don't seem to have the political will to impose a carbon tax that is going to level the playing field and is going to enable us to operate the resources efficiently while trying to penalize carbon and drive the system toward decarbonization.

I use the analogy that democracies are not efficient. So in a way, we have to deal with the costs of anarchy and to tolerate that kind of move, because customer choice wants to do that. So we have to accept what people want to do and try to redesign the system. So the challenge is soft landing-- redesign and modify the system by introducing new rules or a mechanism that will allow the distributed resources.

So for an example, what we are seeing now in the United States, proliferation of aggregators that are going to be the entities that are going to consolidate and put together bundles of distributed resources. And they are going to act as an agent and offer them into those wholesale markets. So that's one approach to deal with that.

But this is ongoing. We're looking now at different ways. A lot of my research currently looks at different ways to mobilize flexibility that is built into the system. So when we're doing the unit commitment, how much can we use demand response and what kind of demand response

mechanisms can we use to make the system more flexible and tolerate some of the uncertainty introduced by the wind and the solar.

And so we're trying to look at how using the transmission infrastructure and operating it in a more flexible manner. We find out that if you are going to disconnect a line, that actually can improve the overall flow in the network because of the way Kirchhoff's laws work.

Now we have a lot of computer capability, so let's see if you put a binary variable on every transmission line-- and while you're dispatching the generators, you're also going to decide which lines redesign or readjust the topology, we call it topology control-- how that can improve the system.

Or if instead of running the lines with fixed constraints, thermal limits, can we run the lines recognizing that we are dealing with thermodynamics here so the line can run hot for a limited duration as long as you give it some time to cool off. That increases the computational burden of trying to optimize the dispatch of the system. But now we have supercomputers. My students are working with Lawrence Livermore where they get access to a 5,000-core supercomputer and there's an algorithm that can cope with that.

So this is the direction where we're going to try to substitute computation to make the infrastructure more agile. And that seems to be a trend. And that all a way to respond to the renewables.

RAMTEEN SIOSHANSI: One comment that you made, and I'm curious-- do you ever fear or worry that all of these policy mandates and things that are driving investment in the electricity sector can in a backhanded way undo the legacy of market restructuring? So in the case of California, if you have the Public Utility Commission essentially saying that this, this, and that needs to be built, do you ever worry that all the work that you and others have done in the past 20 years will slowly be eroded?

SHMUEL OREN: No. I think that what we're seeing is that over 20 years we've seen a tremendous evolution of certain technologies that are making some of these decisions.

So for example, this smart metering and the various demand response technologies we can try, for example, to manipulate, to adjust the air conditioners. Storage is a big thing now, so we're going to have new batteries-- that's a game-changer. So a lot of things that were necessary in the past can be now done in the future. Electric cars create new challenges. So we have to now try to create rules or the way to operate the system to accommodate electric cars.

On the other hand, we have much better computers so we can do more computation. For operations researchers, there are challenges now. They can develop algorithms and they can solve problems that you couldn't solve 15 years ago.

So I think that we have to recognize that as the technology changes, what we do-- people are now talking about the big things are big data, machine learning. A lot of the decisions now can take advantage of these new approaches. So it's a constant adjustment that we have to keep up.

And the methodology, and the rules, and the economic paradigms are interacting and to acknowledge the changes in the technologies. And I think that the markets will change if you can mobilize some of these new ideas and new technologies.

Career Retrospective

RAMTEEN SIOSHANSI: And so when you look over all these different areas that you've worked in over the course of your academic career-- optimization, algorithms, at Xerox, health care applications, the electricity industry-- was there one that in particular really captured your attention and interest?

SHMUEL OREN: Well, I remember talking to Dantzig when he was in his 90s and asking what's your most important work, and it was always what he did last week. So I think that there is always this element that things that I'm doing now is what I find the most exciting.

But as I said, to some extent I always viewed my career-- first of all, the reason that I went back to academia, and I always tell this to my students, is that when you go to academia, you're basically committing yourself to being a student for the rest of your life. And that's the privilege that we have as an academic, to be able to continuously learn, continuously adopt. A lot of my interests are sometimes motivated by what my students are teaching me rather than what I teach them. So this is what I find the most exciting part of my career.

And the fact that a lot of my OR, my methodological interest, has always been driven by applications, by solving problems, and to that extent has been a random walk. Mike Rothkopf introduced me to a lot of the auction theory and Bob Wilson to a lot of the economics.

That's why it's so important to lay a very big foundation of math and tools, because that gives you the flexibility when you get down your career. You know, because I pushed you to take a lot of courses that maybe you didn't like to. So I think that that's the important-- follow your nose and get interested in whatever is the most recent problem.

And if you look at other people in the profession, homeland security is now a big thing. I never got interested, but if you look at Ed Kaplan and Larry Wein, they suddenly became interested in homeland security. They couldn't predict that 30 years ago.

So I think that that's the key in our profession. That's the way operations research evolved, the people that came from different backgrounds in physics and biological sciences got interested in logistics during the war. And that's how operations research became what it is. So I think we keep following that, that the problems are evolving and the people chasing the problems. And as part of that, they're developing new tools, and new usage of computers, and so on.

RAMTEEN SIOSHANSI: So as a final question, yourself having been in this situation, if a young mechanical engineer stumbled upon systems engineering or operations research, what would you say to him or her as the selling points of this field compared to ME?

SHMUEL OREN: Yeah, I'd say go for it. As I said, I was pretty depressed the first time I got to Stanford and realized, oh, these guys are not doing numerical machines that I thought.

So anyway, I think that if I was maybe more interested in lab work and grinding and continuing to develop tanks or so on, I would have stayed there. So the basic drive toward systems is something that was my interest. I don't think that necessarily every mechanical engineer has to become an OR guy. But, yeah, if you see something that interests you, I think that you have to follow it.

RAMTEEN SIOSHANSI: All right. Well, I just want to say again thank you. It's been a privilege and an honor for me to get to do this. So I appreciate it.

SHMUEL OREN: My pleasure. Thank you.