Operation everything

It stocks your grocery store, schedules your favorite team's games, and helps plan your vacation. A primer on the most influential academic discipline you've never heard of.

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TO THE CONSTERNATION of his colleagues, Mark Eisner once told a reporter that his discipline "is probably the most important field nobody's ever heard of." Indeed, it's not one that's likely to come up at dinner parties.

> "I've been explaining for 40 years what operations research is," says Eisner, who is associate director of the school of operations research and industrial engineering at Cornell University. He defines O.R. as "the effective use of scarce resources under dynamic and uncertain conditions."

That may sound arcane, but it's pretty much the problem of living -- and certainly the central problem of economic life. O.R. isn't economics, however, though most economists have some O.R. training. It's applied mathematics. Since its origins in World War II to its recent resurgence fueled by the explosion in raw computing power, O.R. has developed analytical models of the tradeoffs and uncertainties involved in problems ranging from inventory management to police deployment, from scheduling sports leagues to determining how many people to call for jury duty.

Taking the kids to Disney World this summer? Operations research will be your invisible companion, scheduling the crews and aircraft, pricing the plane tickets and hotel rooms, even helping to design capacities on the theme park rides. If you use Orbitz to book your flights, an O.R. engine sifts among millions of options to find the cheapest fares. If you get directions to the hotel from MapQuest, another O.R. engine spits out the most direct route. If you ship souvenirs home, O.R. tells UPS which truck to put the packages on, exactly where on the truck the packages should go to make them fastest to load and unload, and what route the driver should follow to make his deliveries most efficiently.

At the park, O.R. can even let you skip the lines for the most popular rides. For Epcot's new Mission Space ride, for instance, you can join a "virtual queue" using the FastPass system introduced in 1999. A computer issues a pass that tells you when to claim your spot at the front of the line. But it doesn't just tell you to come back after an arbitrary length of time, say, an hour and 15 minutes. Rather, to calculate a return time for each guest in the face of constantly shifting waiting times, the virtual queue's software takes into account how many people are standing in the real line, how many are already in the virtual queue, and how many of each group the park wants to admit each time the ride opens up.

"That's the O.R. piece," says Irv Lustig, manager of technical services for ILOG Direct, a software and O.R. consulting company headquartered in Gentilly, France, and Mountain View, Calif. He visited the parks in February to see how Disney uses O.R. and woo the company as an ILOG client.

After decades in which the field's progress was mostly theoretical, computers have finally gotten powerful enough to collect the data and deliver the problem-solving solutions that O.R. has been promising since the heady days of the New Frontier. Beginning in the 1980s, when American Airlines demonstrated that airlines could save billions of dollars using O.R. techniques to design their schedules, O.R. has become an increasingly important, though largely invisible, contributor to rising productivity.

"What we talked about when I was a young graduate student are still the things that we talk about now, except then we could only talk about them," says Jack Muckstadt, a Cornell professor who entered the field in the early 1960s. "Now we can actually do them."

Indeed, when Irv Lustig got his doctorate in operations research from Stanford in 1987, his thesis was controversial. Although it had the obligatory theorems and proofs, it also included computational work that some members of Stanford's O.R. department (now its department of management science and engineering) thought too lowbrow.

By contrast, he says, today O.R. students who want to just do theory have a hard time. "Everybody wants to know, `What does it mean on a computer?'" says Lustig, whose work has included creating the National Football League's schedule. "That's a big culture change."

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O.R. started as a way of bringing scientific thinking to the complex problems of warfare: How do you find enemy submarines? How many bombers do you need to make sure a critical target is destroyed? When, where, and with how many troops and what equipment should you make an amphibious landing?

In World War II, scientists from a wide range of fields attacked military problems with a potent combination of empiricism and mathematical models. When airplanes came back riddled with holes from enemy attacks, for instance, the intuitive response was to reinforce the armor where the holes were. But, noted the scientists, those were the planes that made it back. They didn't need more armor where they were hit. The real challenge was to figure out the places that had been hit in the planes that went down.

"It was a lively, informal, paradoxical exchange of ideas between amateur and professional war makers and it produced some brilliant successes," wrote James R. Newman in "The World of Mathematics," published in 1956, which cited O.R.'s role in simplifying supply lines, providing a quantitative basis for weapons evaluation, and so on.

But O.R. didn't live up to its postwar hype, its implicit promise to "solve everything." Militarily, it could attack certain tactical problems but, as the Vietnam War illustrated, O.R. wasn't the right tool for addressing strategic issues of where, or why, to fight. Even for mundane business questions, like how to design sales routes or what inventories to hold, O.R. specialists often lacked the data and computing power to turn their models into practical results. By the 1970s, the Vietnam War had made O.R.'s military applications and Pentagon funding suspect in universities, and businesses were gradually disbanding their O.R. groups.

For decades, the academic discipline retreated to theory. Scholars built their reputations on mathematical proofs, largely abandoning empiricism or real-world problem solving. Some O.R. veterans blame the pure-math imperialism common to many theory-based fields for this retreat.

"Some time in the 1970s or 1980s, O.R. was in a sense hijacked by mathematicians who insisted on imposing their view of rigorous mathematics onto the field. This placed much less emphasis on modeling and empirical work," says Richard C. Larson, a professor of civil and environmental engineering and engineering systems at MIT and for 15 years the codirector of the institute's Operations Research Center, which recently celebrated its 50th anniversary. "In some OR journals today, the only empirical data are, `Date of submission' and `date of acceptance.'"

Other O.R. scholars argue that theory was the only way to advance the field in a world of scarce data. "A paper would start, `Here is an interesting problem. If I had all these data, this is what I could have done.' So the problem was challenging, but the focus was on theory, because the data to support it did not exist," says David Simchi-Levi, a professor of engineering systems at MIT.

But in the 1990s, the data became available. Now corporate information technology systems collect unprecedented amounts of data -- on costs, sales, and inventories, in itemized detail and real time. Wal-Mart and Procter & Gamble, for instance, know exactly how many 200-ounce bottles of liquid Tide Free have sold in which stores today. That information in turn determines how many new bottles are shipped from which warehouse tomorrow.

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Simchi-Levi exemplifies the new generation of O.R. scholar-practitioners. He entered the discipline as a theoretical mathematician "focusing on algorithms and the theory behind different logistics problems," but was drawn into applications in 1992 when the New York City school district called, looking for help with its bus schedules.

Intrigued by the enormous potential of applying O.R. techniques to logistics problems, in 1995 he and his wife Edith, a software developer, started a Chicago-based company called Logic Tools to apply O.R. techniques to supply-chain problems. Tweaking such mundane but strategically critical decisions as where to site plants, when to restock, and so on, can provide enormous productivity boosts.

In his work, says Simchi-Levi, mathematical theory and business applications complement each other. "When I go to a company, or when we develop a new product," he says, "I am familiar with the state of the art in terms of engines and algorithms. For instance, the inventory positioning technology is very, very recent, even in academia."

As ubiquitous as it is invisible, O.R. is a crucial ingredient in the productivity surge often credited to information technology. "The real driver of the productivity resurgence that we've had since 1995 has been the way the technology has allowed changes in business processes and the reorganization of work," says Erik Brynjolfsson, an MIT economist. "For every dollar of [information technology] there are 9 to 10 dollars of organizational change, human capital, and other investments."

O.R. is only part of that story, since companies often have to make major organizational changes to reap its benefits. But without O.R. problem-solving, many management innovations couldn't take place.

"Having data doesn't give you productivity. Having better decisions gives you productivity. So if O.R. is all about the science of making better decisions, then this is clearly an area in which we'd like to claim preeminence," says Michael Trick, a professor at the Tepper School of Business at Carnegie-Mellon and the former president of the professional society INFORMS, the Institute for Operations Research and the Management Sciences.

Trick's consulting projects include designing each year's Atlantic Coast Conference men's and women's basketball schedules. Arranging 16 games among the nine men's teams may sound easy, but it requires systematically sorting through hundreds of millions of possible combinations looking for the best way to satisfy dozens of conflicting goals.

"You don't want to play too many consecutive home games. You don't want to play too many consecutive away games. You have to make sure that every team has the same number of weekend home games," explains Trick. "There are various games that have to be played -- Duke-North Carolina is always played on the same day. And then the TV networks, who are paying for all this, have strong views on how they would like games to line up, so they can create a successful TV schedule. You don't want to have all the good games on the same weekend. You want to spread them out, so that every weekend there's a hot ACC game. All those things go into play."

Thomas L. Magnanti, the dean of engineering at MIT and previously the codirector of the institute's Operations Research Center, is optimistic about the field's future. Until recently, most O.R. scholars worked either in business schools, where the field is usually called management science, or in departments of O.R. or industrial engineering. Now, he says, departments like mechanical engineering and electrical engineering are hiring O.R. specialists.

Magnanti calls O.R. "a liberal education in a technological world." Just as a classical education once prepared students for a wide range of endeavors, from theology and science to diplomacy and warfare, he argues, so the habits and tools of O.R. are widely applicable to contemporary problems.

"You can do finance today, manufacturing tomorrow, telecommunications the day after. You can move from field to field and make contributions that have impact on all those fields," says Magnanti. "We do health care. We do criminal justice. You name it, we do it."

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