Lab Studying Science Behind Traffic Patterns

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LOS ALAMOS, N.M.—Atop a remote mountain rising from the desert floor, scientists who once wrestled with the fundamental nature of matter and the limits of artificial intelligence are now trying to unravel an even more daunting mystery:

Why is traffic so damn bad?

Los Alamos National Laboratory, better known as the birthplace of the atom bomb and home of the world's fastest supercomputer, has turned the covert tools of the Cold War to the hot-under-the-collar war waged by commuters.

Nuclear physicists who once spoke of "weapons platforms" now talk of "road rage." Computer models designed to perfect tactics for tank battles are being retrofitted to forecast highway congestion. And supercomputers developed to test warheads could simulate the travel behavior of every person between Washington and Boston.

The research in New Mexico is the latest chapter in the romance between traffic and physics, a relationship that has lured some of the century's sharpest minds to apply natural laws to the flow of cars along a highway. Physical Review Letters, a premier scientific journal, averages one article on the topic each month.

These scholars, moreover, are employing their theories where rubber meets the road: suggesting concrete solutions, from ramp metering lights for ironing out highway traffic to simulations that can forecast the benefits of specific road improvements.

Through the eyes of a scientist, motorists trapped in a seemingly inexplicable Capital Beltway backup are actually prisoners of rules that are obscure from behind the steering wheel. The patterns can be analyzed and, perhaps before long, even accurately predicted.

Yet despite some tantalizing progress, reaching a full understanding of traffic jams has been slow going. Scientists said they are closer to comprehending the birth of the universe than the daily tie-ups along Interstate 66.

"Physics offers a wide variety of methods for understanding traffic.
But there are still a lot of open problems," said German physicist Kai Nagel, a key figure in the Los Alamos project.

Hani S. Mahmassani, a University of Texas professor and perhaps the leading American expert in traffic flow theory, put it this way: "All of a sudden to go from free flow to stop-and-go, this remains one of the mysteries of our time."

Traffic Chaos Theories

Some scholars have compared the traffic stream to a fluid, focusing on the waves that ripple through it as cars brake or accelerate in succession.

Others have tried to explain it in terms of what is known as chaos theory. They suggest that at certain moments, when a highway is becoming crowded, the flow of cars is so unstable that a major tie-up can arise from something as minor as a single driver riding the brakes a split second too long.

One approach likens sudden slowdowns to phase changes, which happen in nature, for instance, when steam turns to water or water to ice.

In light traffic, motorists drive as they like. As the road grows crowded, drivers suddenly find themselves being carried along in the traffic stream, moving at a common speed and often unable to change lanes. This intermediate phase, called "synchronized" flow, is much like liquid. When traffic goes through a second transition into stop-and-go, cars are like water particles crystallized into ice.

But although a motorist may be akin to a water particle, a driver trapped at the Woodrow Wilson Bridge during rush hour is no run-of-the-mill molecule. People adjust their routes based on yesterday's backups or today's traffic forecasts. Molecules, moreover, exist to collide into each other. For motorists, that's not so wise.

So although physicists often are drawn to traffic because they recognize similarities with their traditional work, it is the human element that makes it so intoxicating.

Chris L. Barrett, the scientist who convinced Los Alamos that traffic was a matter of grave national security and now heads its transportation project, said: "Traffic is particles with motive. I think it's cool as hell."

The Father of Road Physics

The paternity of traffic science is widely attributed to Robert Herman, known as the father of the Big Bang because he accurately predicted the microwave echoes of the creation of the universe long before they were detected.

When Herman initially considered shifting his gaze from the early cosmos to traffic, his colleagues counseled against it, saying it was too complex.
Undaunted, he joined General Motors Research Labs outside Detroit in 1956. Adequate scientific equipment was scarce, so Herman and his colleagues followed each other home from work to observe their own driving behavior.

By the early 1960s, Herman hooked up with Ilya Prigogine, whose Nobel Prize-winning theories had earned him the nickname the "poet of thermodynamics." They began to examine traffic as a collective flow.

Where daily commuters see only frustration, late charges at day-care and excuses for the boss, Prigogine spies a basic organizing principle of the universe. He has likened traffic to "the magnificently coordinated flight of a large flow of birds or the remarkable darting collective motion of a school of fish."

In the last 10 years, a new wave of physicists emerged in Germany, home to the leading think tank at DaimlerChrysler and a ready-made laboratory called the autobahn.

These scholars included the likes of Boris S. Kerner, who found that the change from free to synchronized flow can happen almost spontaneously -- much faster than scientists previously thought. Often, it happens near on-ramps, when a sudden burst in the number of cars entering the road can cause traffic to jell into a single, moving whole. This sluggish condition will spread up and down the road, persisting perhaps several hours, long after the ramp has cleared.

In Duisberg, Germany, physicist Michael Schreckenberg made a name for himself as the "Jam Professor" in part through his real-life experiments. He and about 15 colleagues bundle into a phalanx of five vehicles, set out on the nearby roads and intentionally create bottlenecks. "It is quite interesting to see how people react," he said.

Nagel, one of Schreckenberg's main collaborators, was a mere graduate student when he started making his mark. Now 33, Nagel looks the part of a German intellectual: A curtain of blond bangs dangle above narrow, oblong black eyeglasses; a green turtleneck peeks above the collar of a gray sport jacket. Even before he finished his doctorate in physics, he had refined a process for running simulations faster than ever before and then began using it to model weather patterns.

But Barrett, at Los Alamos, had other plans in store for him. Barrett needed someone who could design simulations fast enough to be practical. Nagel became the bridge that crossed the Atlantic.

Studying for a Solution

Holed up atop their desert mesa, where the biggest backup is two dozen cars idling at a red light on the serpentine, cliff-side road and rush hour lasts only half an hour, Barrett's band of physicists, chemists, mathematicians and computer theorists aims to revolutionize traffic forecasting and planning.

They tapped the lab's Cold War experience in supercomputing and
war-fighting models. Expertise in simulating military logistics and tank battles became the basis for traffic modeling: "Rip off the turrets and you have cars," quipped one researcher. Studies of wind currents during so-called nuclear winter laid the groundwork for forecasts of auto emissions.

After Barrett joined the top-secret Los Alamos weapons lab in 1988, he did something he can't talk about. That reticence is out of character for so fast-talking a character, whose roller-coaster soliloquies cascade from idea to idea, physics to biology to moral philosophy and back, who shuttles as easily between discussions of neural networks and bus networks as between neckties and bolo ties.

Lately, he's had his ear tuned to traffic.

"Traffic is like music," Barrett said with childlike exuberance. "Traffic constructs itself like a singer sings. It's the same song. But everyday, the song is a little bit different."

To capture the countless decisions that individual travelers make in shaping a metropolitan area's traffic patterns, Barrett's team is creating a vast, mirror world in cyberspace of every motorist and transit rider, every traffic light, turn lane and bus stop.

They do this by simulating a region's population, mining census data and other statistics to create a mirror people with the same ages, incomes, jobs, children.

This virtual population is turned out onto the cyber roads, trains and buses of a region modeled right down to the duration of red lights and the frequency of buses. The individuals can adjust their travel habits if the trips take too long, switching to different streets or from car to bus -- or even finding a new dentist.

The artificial network, still under development, could potentially gauge the precise benefits of widening a highway, erecting a bridge or building a subway line. It could measure the effects of changes in car-pool restrictions or cheaper bus fares or even new technology, such as electric cars. It could forecast the traffic impact of proposed subdivisions and the graying of a region's population.

The current locale being modeled is Portland, Ore. Washington could be next.

When President Clinton toured Los Alamos last year, he was so impressed by the traffic model -- and so depressed by this region's gridlock -- that he suggested while returning on Air Force One that the capital area be modeled. Since then, federal and regional officials have been briefed but no decision has been made. The program is designed to run on computers available to local planners and the cost would be about $13 million.

In Germany, Inroads

The theoretical breakthroughs in Germany have their own practical potential. Kerner's findings about ramp traffic can be used to
program metering lights to feed vehicles onto the highway in a slow and regular fashion. This understanding also could smooth out traffic by calibrating speed limits to different traffic conditions.

DaimlerChrysler also is developing guidance and navigation systems for Mercedes that could tap traffic information from a computer network of road sensors that would improve the driving of individual cars, ironing out disruptions that can cause a sudden slowdown.

In the fall, Schreckenberg plans to launch a project to provide one-hour traffic forecasts in the Rhine-Ruhr region, comparable to the Los Angeles area, by combining data from sensors in the road with computer simulation.

This could prove the most significant advance in traffic forecasting during the last 40 years of commuting and computing. But it pales next to what Los Alamos envisions down the road.

William "Buck" Thompson, a deputy director at Los Alamos and a physicist and nuclear engineer by training, predicts planners will soon want to construct a model of every traveler, every car and every street in the megalopolis sprawling between Washington and Boston. That would require the might of Blue Mountain.

Locked behind heavy blue security doors in the heart of America's most sensitive weapons lab, Blue Mountain is the pinnacle of computing, actually 6,200 processors in 550 blue and gray computer cabinets, each rising six feet high and arrayed in 14 rows like a bountiful metallic cornfield.

It is a supercomputer so fast it can process in one second the entire contents of the Library of Congress, albeit it a simple task compared to simulating rush hour.

"At some point," Thompson said, "we could be able to model the entire United States with a machine like this."

Traffic Patterns

Scientists have identified "phase changes" in traffic, similar to the sudden transitions that occur when steam turns to water or water to ice. Understanding the timing and dynamics of phase changes in traffic, like those in nature, poses a challenge for physicists. But this could hold the key to easing the frustration of commuters, including those traveling along the Outer Loop of the Capital Beltway near the Persimmon Tree Road overpass in Montgomery County on a typical Tuesday morning.

Phase 1

When traffic is light, motorists drive much as they like, moving at the speed they want and changing lanes easily. Motorists are comparable to steam particles with great freedom of movement.

Phase 2
As the road becomes crowded, motorists suddenly lose much of their freedom and are forced to drive as part of the overall traffic stream, moving at the speed of the general flow and often unable to change lanes. This phase, similar to water, has been called "synchronized" flow.

Phase 3

In heavy congestion, traffic is stop-and-go. Like water freezing into ice, the motorists are stuck in place.

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