NSF grants $1.2 million to cope with complexities in manufacturing systems

by Brian Fitzgerald

In response to the recent explosive growth in computer power — and consequently, new access to enormous amounts of information that can speed up manufacturing processes — the National Science Foundation (NSF) has awarded $1.2 million to an interdisciplinary research team that includes three faculty members of ENG's manufacturing engineering department and one from the Center for Computational Science.

Their mission: to propose solutions to computational challenges in industry that are fundamentally new and enormously complex. "Our research will focus primarily on the planning and control of manufacturing production," says Michael Caramanis, professor of manufacturing engineering and the grant's principal investigator.

However, the ramifications of the grant are expected to transcend disciplinary boundaries. The NSF's Knowledge and

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BU's Knowledge and Distributed Intelligence team uses a "Lego car factory" in a manufacturing engineering laboratory to teach undergraduates about the stochastic dynamic nature of manufacturing systems. From left, Francis Alexander, assistant research professor at BU's Center for Computational Science, Manufacturing Engineering Professor Michael Caramanis, along with Yannis Paschalidis and Christos Cassandras, assistant professor and professor, respectively, in ENG's manufacturing engineering department. Photo by Kalman Zabarsky

Engineering Grant

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Distributed Intelligence (KDI) initiative seeks to unify experimentally and theoretically derived concepts related to learning and intelligent systems and use them in a wide variety of fields in the physical, engineering, and social sciences.

The BU team was one of 40 successful teams out of 850 KDI competitors. The other members of the BU team are Christos Cassandras and Yannis Paschalidis, professor and assistant professor, respectively, in ENG's manufacturing engineering department, and Francis Alexander, an assistant research professor at BU's Center for Computational Science. The grant is not only interdisciplinary, but intercollegiate: the research team also consists of Dimitri Bertsekas and John Tsitsiklis, professors at MIT's department of electrical engineering and computational science, and Yannis Ioannides, a professor in Tufts University's economics department.

Caramanis, an expert in the design and control of manufacturing systems, points out that industry has become much more complex since Henry Ford's 20-horsepower Model T was first driven out of his Detroit factory in 1908. Obviously, technological advances enabled manufacturers to build stronger car engines. But there are other major differences.

"Manufacturing today necessitates decision-making in large stochastic systems," he says. Caramanis explains that stochastic systems involve random variables. "In a manufacturing system, the complexity arises from the fact that lots of decisions have to be made in multiple time scales, ranging from building new plants and ordering new machinery — which involves time scales that are extremely large — all the way down to daily and hourly production decisions."

The manufacturing enterprise consists of multiple, but highly interconnected, hierarchical layers. "Typically, in the old days, when Henry Ford built his first Model T line, manufacturing production was specialized and made in big volumes," says Caramanis. "However, after World War II, consumer tastes changed, and there was a need to produce not only a much larger variety of products, but also to produce them in a short period of time, and to track demand closely in order to avoid maintaining huge inventories."

Today, many data-intensive problems in a factory that produces a plethora of products must be solved in real time. "Cellular manufacturing technology, which was essentially introduced by the Japanese in the 1960s and adopted by American industry, calls for creating smaller factories, or cells, within the factory, each one of which is responsible for producing a group of similar products," says Caramanis. "For example, in an automobile factory, one cell makes engine blocks, another makes rotating parts, another makes doors."

To call such a system complex is understating it. "There are monthly decisions, such as reorganizing the allocation of machines among those cells, which behave like focused factories within the factory," he says. "Each focused factory also has to make weekly decisions: how much to produce during this time period. They also make decisions on an hourly and minute-by-minute basis. They must even make decisions on a second-by-second basis, such as how to guide the machine, and how to control pressure and temperature in a chemical process."

What happens when decisions aren't made quickly enough? "Obsolescence," answers Caramanis. "Think of personal computers. The model that you buy now may be supplanted by a new model two or three months from now. Manufacturers that are slow in producing will be left with lots of outdated, semifinished products in the pipeline. Obsolescence will drive up costs."

These crucial decisions are characterized by dynamics, or change. "The time scale of these dynamics is incredibly varied," says Caramanis. "In addition, there is considerable uncertainty involved: machines breaking, demands changing unpredictably, absent workers, changes in the economy, and so forth. If you are a manufacturer and want to do something about uncertainty, you can either rely on a costly worst-case analysis, or be much more flexible in your decisions and rely on smart computational approaches capable of more accurate predictions and efficient decision support."

Effective management of complex systems depends on the ability to make on-the-fly analyses of data to control situations as they happen. KDI, according to the NSF prospectus, "aims to foster distributed intelligence as a foundation for advancing all areas of science and engineering research and education, and to spin off important new results and technologies with positive benefit to society at large."

At present, economists, neuroscientists, sociologists, and philosophers of science — with the help of mathematicians and computer scientists — study these systems, but separately. "Collaboration," states the NSF, "may reveal important similarities in how these disparate systems produce knowledge from their distributed intelligence, and hence insights into improving system performance."

"Our team," concludes Caramanis, "has identified three areas, in addition to manufacturing, where our work is likely to have an impact: modern computer networks, such as the Internet, economics, and computational physics. Our hope is that this activity will allow cross-fertilization between seemingly diverse areas."