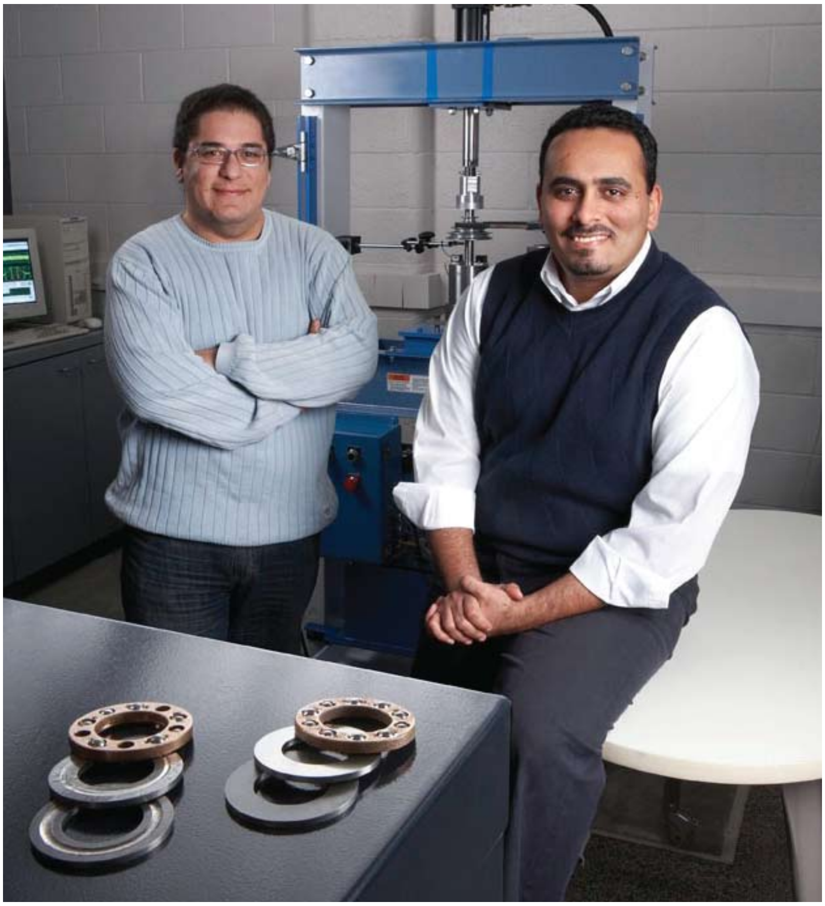
Research

EXECUTIVE SUMMARIES : EDITED BY CANDACE YANO AND JOSEPH HARTMAN

As manufacturing processes become more complicated, firms are discovering that using real-time data in more sophisticated ways and developing better statistical process control techniques for multivariate data can have significant payoffs. This month, we highlight two articles that address these issues. The articles appear in the July 2008 issue of IIE Transactions (*Volume 40, No. 7*).



Doctoral student Alaa Elwany and assistant professor Nagi Gebraeel of the Stewart School of Industrial and Systems Engineering at Georgia Tech developed statistical models that help maximize the life of spare parts through tracking data.

Sensor data eases inventory decisions

Today, U.S. industry spends more than $200 billion on reliability and plant maintenance. As companies increasingly embrace lean and just-in-time paradigms, preventive maintenance has become critical. Work-in-process inventory levels are too low to buffer against unexpected machine failures. Advancements in electronic and information technology now allow real-time monitoring of equipment conditions that can be used in making better decisions not only about maintenance, but also about other maintenance-related issues, such as spare parts inventories and equipment replacement.

Many failure mechanisms can be traced to an underlying degradation process that causes weakness and eventually leads to failure. It is in these situations that real-time sensor data are most useful because there may be advance signals of failure, but we need to understand the link between sensor data and the degradation process. We also need to recognize that there is randomness inherent in these degradation processes, so data being collected from specific equipment may not be representative of the population of similar equipment.

In "Sensor-Driven Prognostic Models for Equipment Replacement and Spare Parts Inventory," doctoral student Alaa Elwany and assistant professor Nagi Gebraeel of the Stewart School of Industrial and Systems Engineering at the Georgia Institute of Technology develop a methodology that overcomes these challenges. The core components of this approach include methods for estimating and updating the statistical distributions of residual lifetimes (time to failure) from the data and a method to adjust spare parts and equipment replacement decisions as equipment is monitored.

In a case study that involved vibration-based degradation signals acquired from rotating machinery, the authors compared the performance of their sensor-driven methodology with traditional replacement and inventory decision models. The proposed technique reduced the total failure and stock-out costs by approximately 55 percent. Rockwell Collins is considering the prognostic framework proposed by the authors for prognostics of electronics, and the U.S. military's Joint Strike Fighter program is considering it for the prognostics of avionic systems.

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Improving multivariate SPC

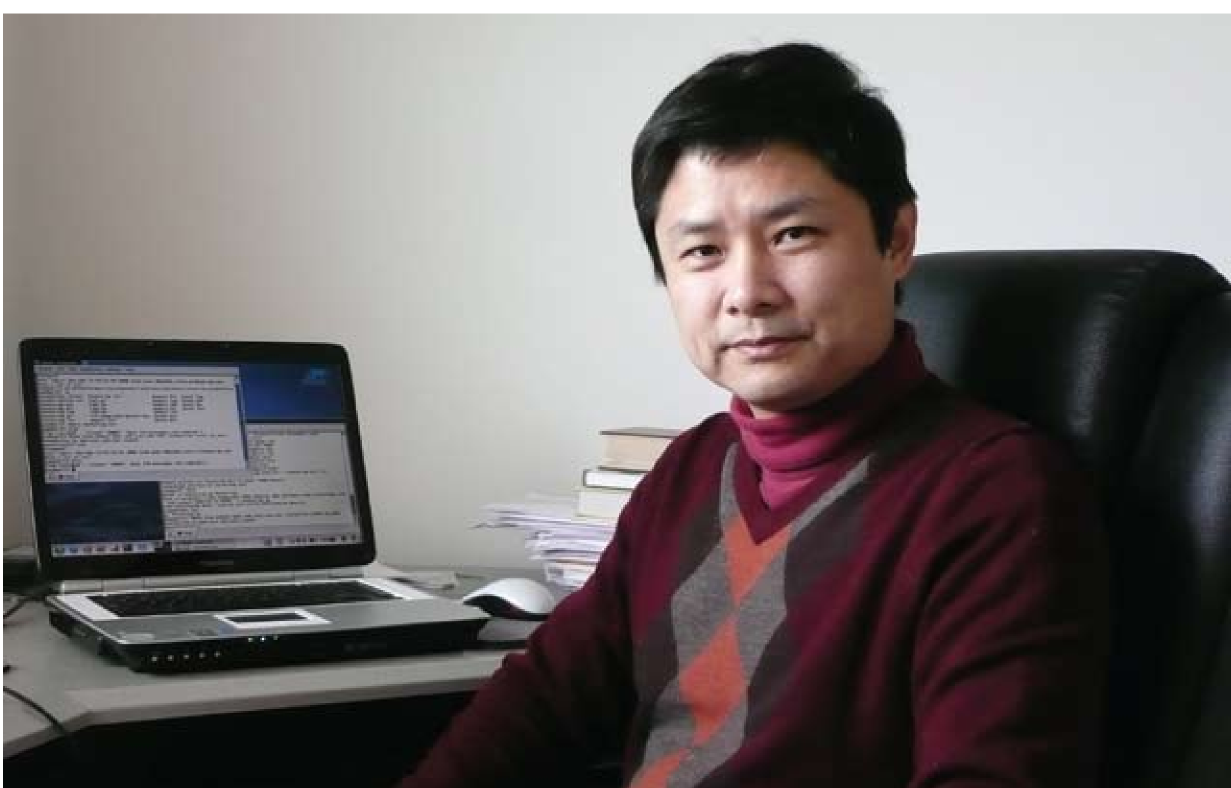
As products become increasingly more complex, manufacturing firms need to simultaneously monitor several product characteristics during the production process. Such problems arise in all industries, but are most salient in process industries involving pharmaceuticals, petroleum, chemicals, paper and other similar products. In these industries, chemical concentrations, processing temperature and viscosity of the product might be among the characteristics being measured.

Nearly all multivariate statistical process control procedures rely heavily upon the assumption that the variables to be measured have a multivariate normal distribution, which usually is not true in practical settings. As an example, when some components of the data are categorical or discrete, they cannot be modeled accurately by a normal distribution. A longstanding research challenge has been to find an effective way to design statistical process control charts for multivariate situations with non-normal distributions.

Is it possible to transform a non-normal multivariate dataset into a normal multivariate dataset and then apply conventional multivariate statistical process control charts to the transformed data? This question remains unanswered, but professor Peihua Qiu of the University of Minnesota has developed an approach that takes an important step toward a practical solution to the problem.

In "Distribution-Free Multivariate Process Control Based on Log-Linear Modeling," Qiu first suggests converting all data to categorical data — essentially putting data into "buckets" rather than retaining their exact original values. Then a log-linear modeling approach, widely used in dealing with categorical data, can be used to obtain an estimate of the multivariate distribution. Qiu then goes on to design a statistical process control chart for this situation.

The process of categorizing data leads



Peihua Qiu, professor in the School of Statistics of the University of Minnesota, performs numerical studies that lead to categorizing data for manufacturing settings.

to some loss of information but numerical studies in the paper show that the proposed chart works well in a variety of different cases. Currently, Qiu and his students are trying to improve the efficiency of the proposed control chart by studying its behavior as the number of categories changes and by using ordinal (rank) information in the categories.

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The most recent issue of The Engineering Economist *(Vol. 53, No. 1) focuses on a risk — through the use of real options, fuzzy analysis, probabilistic cash flow analysis or uncertainty in gas prices. Below are summaries of two articles from that issue. The first examines how to price options in light of incomplete markets, while the second looks at a survey of probabilistic cash flow analysis.*

Options in incomplete markets

Real options analysis strives to include the value of options — the ability of management to alter (and improve) an investment over time, often referred to as managerial flexibility — into the value of a project beyond traditional net present value means. For example, uncertainties in the price of gold define the risk in a mine investment. However, the risk and return of the investment can be modeled using gold mining stocks and riskless bonds, defining the option value (and increasing the perceived worth) of the investment.

However, not all risks in real investments can be captured through a tracking portfolio. For example, modeling the transition of a drug through the FDA approval process cannot be replicated with a portfolio due to the technical risks inherent in the investment. This situation defines an incomplete market and prevents the use of traditional methods for pricing the option.

In "Real Option Pricing and Bounds in Incomplete Markets," the value of an option to defer a capital investment decision in a dynamically incomplete market is derived by specifying the investor's risk preference. The bounds on this value are then tightened and compared to previous approaches. The result is a method that can price options in incomplete markets, and thus capture non-systematic risk associated with real investment decisions.

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Feasible investments

The deterministic analysis of investments is well-studied. However, it is well-known that investments are defined by uncertainty. "Probabilistic Discounted Cash Flow Analysis and Capital Budgeting and Investment — A Survey" examines the history of modeling and solving investment problems dealing with uncertainty.

The review includes modeling probabilistic cash flows, time horizons, discount rates and cash flow timing. It characterizes these analyses according to the method of analysis, including present worth, internal rate of return and cost-benefit analysis. The authors note, unfortunately, that the majority of this research is based on lone (single) investments, and there is a need to consider uncertainty in portfolios of investments.

In addition to the review of the literature, which grows from the 1960s to today, the authors present a unifying theory of "feasibility." The feasibility of an investment can be defined by the probability that its net present value is positive, the probability that its internal rate of return is greater than some value, the probability its payback period is less than some specified horizon or the probability the benefit-cost ratio is greater than one. As these measures of risk are related, so are these measures of feasibility, allowing for commonality in comparing measures of risk for an investment. As noted by the authors, this may be a unifying concept worth pursuing further.

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