RESEARCH

Inside IISE Journals

This month, we highlight two articles that will appear in the November 2023 issue of *IISE Transactions* (Volume 55, No. 11). The first article asks: Can one distribute a network of virtual sensors to monitor the dynamics in the data space? Through virtual sensing, it is to place imaginary sensors at different locations in signaling trajectories to monitor the evolving dynamics and transform raw data into useful information. The authors introduced a self-organizing approach for optimizing the placement and distribution of virtual sensors in a multidimensional data space. They tested the idea in the case of multichannel electrocardiogram (ECG) signal monitoring and found that the virtual sensors effectively delineate the variations of inherent patterns. The second article assesses the impact of technology choices between traditional assembly lines and flexible assembly layouts. The examination is motivated by the increased flexibility and efficiency requirements faced by the automotive industry, as a result of high product diversity and dynamic demands. The authors found that flexible assembly layouts outperform traditional assembly lines, leading to up to 30% higher worker utilization and output levels, and that flexible assembly layouts are especially beneficial during the ramp-up of vehicles with alternative drivetrain technologies (like those in electric cars).

Virtual sensing networks help find Neo in the Matrix

Today, everyone is becoming a digital native. Every industry is facing the disruption of digital technology. The rapid pace of technological evolution drives data explosion at an unprecedented scale. These data are often not stationary, but rather dynamically changing over time.

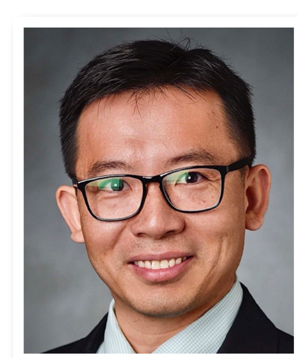
In the field of industrial analytics, there is an urgent need to harness the data for myriad purposes such as machine condition monitoring, process control and operations management. However, raw data needs to be processed for the extraction of useful information. The "usefulness" is reflected by the sensitivity to capture operational dynamics or physical activity. No doubt, it has been seen that conventional statistical process control (SPC) methods fail to handle the new generation of industrial data in the raw form.

In the movie "The Matrix," you may note that watchdogs are widespread in cyberspace to monitor the evolving dynamics of the character Neo. Now, a new hypothesis arises: Can we distribute a network of virtual sensors to monitor the dynamics in the data space?

This hypothesis is investigated in the paper, "Virtual Sensing Network for Statistical Process Monitoring" by doctoral student Alexander Krall, professor Daniel Finke and professor Hui Yang from the Pennsylvania State University.

Daniel Finke

Alexander Krall



Hui Yang

Traditionally, physical sensing refers to the use of "real" sensors in the real world. Virtual sensing entails the use of "virtual" sensors to process and transform raw data into useful information. The notion of virtual sensing is rather broad because the scope of data transformation is large.

This paper presents a new concept to build a virtual sensor network in the data space to monitor the changes of operational dynamics of the system. In this regard, virtual sensors can be treated as imaginary sensors (or cyber watchdogs) that sense the changing dynamics in the data.

Specifically, this paper introduces a "self-organizing" approach to optimize the placement and distribution of virtual sensors in the multidimensional data space. Each sensor competes with the others to form a network that covers and partitions the data space. As a result, a collection of virtual sensors can be converted into a network structure by treating sensors as nodes and data variations as the weights of edges. Statistical process monitoring of networking behaviors reveals individual and interactive characteristics in the underlying operations.

The team presented a case study leveraging the virtual sensing network to monitor the variations of cardiac conditions in multichannel electrocardiogram (ECG) signals. When the human heart is beating near periodically, cardiac ailments are reflected as deviations in the multichannel ECG signal waveforms. A network of virtual sensors is distributed to serve as cyber watchdogs of changing dynamics in cardiac operations.

This paper demonstrated that virtual sensors effectively delineate the variations of inherent patterns in the data space, which can be well connected with minute changes in cardiac conditions. The proposed virtual sensing network shows promise as a new SPC methodology for monitoring the dynamic stream of multidimensional data collected from complex systems.

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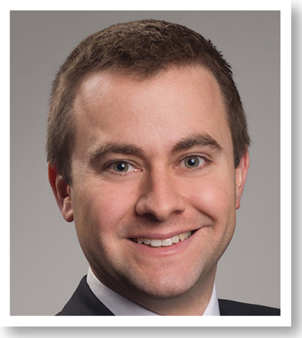
Driving efficiency and adaptability: The power of flexible assembly layouts in automotive manufacturing

Imagine a world where automotive manufacturing becomes smarter, more efficient and highly adaptable. The captivating research paper, "Flexible Assembly Layouts in Smart Manufacturing: An Impact Assessment for the Automotive Industry," by doctoral student Andreas Hottenrott, professor Maximilian Schiffer and professor Martin Grunow from the School of Management at the Technical University of Munich explores flexible assembly layouts and their transformative impact on the automotive industry. Automotive manufacturers must adapt to changing market demands and emerging technologies like electric drive trains. Due to the high product diversity and dynamic demand, traditional assembly lines suffer from inefficiencies and increased costs.



Andreas Hottenrott

Martin Grunow

Maximilian Schiffer

The authors propose flexible assembly layouts, also known as matrix production systems, to address this challenge. Here, automated guided vehicles transport bodyworks on individual routes between assembly stations. The authors assess the impact of the technology choice decision between traditional assembly lines and flexible assembly layouts, as well as the implications of different flexibility levers and configurations in flexible assembly layouts. Hereby, the authors use advanced optimization methodology to determine the practical benefits of flexible assembly layouts in automotive manufacturing.

The results of their quantitative analysis are remarkable. Flexible assembly layouts outperform traditional assembly lines, leading up to 30% higher worker utilization and output levels. Substantial cost savings and a crucial competitive advantage result. Flexible assembly layouts are especially beneficial during the ramp-up of vehicles with alternative drivetrain technologies, such as the current transition to electric vehicles, because they allow manufacturers to adapt to changing product mixes without compromising on efficiency.

In addition, the authors emphasize the importance of exploiting different flexibility levers in flexible assembly layouts to keep the work-in-progress low, streamlining operations and driving investment savings. In summary, the paper provides valuable insights into the potential of flexible assembly layouts in automotive manufacturing and has significant practical implications for automotive manufacturers.

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This month, we highlight two articles from *The Engineering Economist* (Volume 68, No. 3). In the first, the authors present a mixed risk-return optimization framework to mitigate tail risk exposure in the context of investing in the S&P 500 index. Their framework is founded on the construction of hypothetical portfolios comprising rolling put options with varying strikes. The objective is to achieve optimized tail risk hedging strategies with respect to different portfolio risk measures, safeguarding the portfolio value against rapid market downturns. The second article addresses the common trading approach of constructing portfolios based on cross-sectional ranking of asset returns. The authors propose a stochastic mean-risk optimization model that integrates time-varying risk aversion to safeguard against momentum crashes.

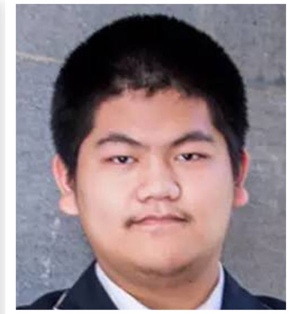
Optimizing tail risk hedging for assets in the S&P 500

Investors are increasingly facing significant challenges due to extreme market events that result in rapid and substantial losses in asset values. Extreme market events are usually outcomes considered to be at the tail of the distribution of market outcomes. These occurrences underscore the importance of tail risk exposure and the necessity to hedge against it.

One popular approach for hedging tail risk of financial assets is to purchase put options on the assets. Buying a put option on an asset gives the purchaser the right to sell the asset at some future time but at a price determined at the time of option purchase. This price is called the strike price. If an asset price drops below the strike in the future, the owner of the put option can sell the asset at the (higher) strike price and avoid much of the loss in asset value. However, it is a challenge to determine how many and what kinds of put options should be purchased as these instruments cost money and the resulting cost can erode the returns from assets.

This research in the paper, "Optimization-based Tail Risk Hedging of the S&P 500 Index," by professor Roy H. Kwon of the University of Toronto and data scientist Yuehuan He presents a novel mixed risk-return optimization framework that achieves strategically selecting long put option positions to mitigate tail risk exposure in the context of investing in the S&P 500 index. This framework is founded on the construction of hypothetical portfolios comprising rolling put options with varying strikes. The objective is to

Roy H. Kwon



Yuehuan He

achieve optimized tail risk hedging strategies with respect to different portfolio risk measures: variance and sample Conditional Value-at-Risk (CVaR).

The proposed methodology is tested using historical out-of-sample data of the S&P 500 index and put options of different strike prices. The results demonstrate that the optimized tail risk hedged portfolio effectively safeguards the portfolio value against rapid market downturns while maintaining satisfactory returns over extended timeframes, despite the cost of the purchased put options. Notably, the proposed framework outperforms both the unhedged S&P 500 index and traditional static tail risk hedged portfolios.

These static portfolios, popular strategies in practice, employ only put options with a fixed level of strikes, the market values of which suffer significantly from either the high cost of long-term holding of puts with higher strikes, or the insufficient protection provided by lower strikes. The research challenges the notion of high-cost tail risk hedging, presenting a cost-effective and robust framework for investors to mitigate extreme market tail risks.

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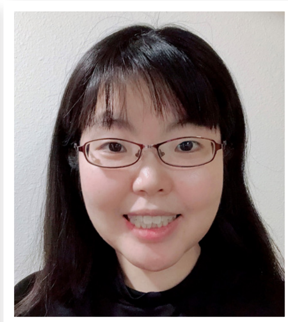
How can analytics help prevent a popular financial trading strategy from crashing?

Momentum in finance refers to the phenomenon where trends in asset returns persist in the short term. Investors leverage this momentum effect to create trading rules. The cross-sectional momentum strategy, which constructs portfolios based on cross-sectional ranking of asset returns, stands as the most common momentum trading approach. However, despite its exceptional performance documented across multiple periods and various asset classes, this strategy occasionally crashes by producing drastically negative returns.

In their paper, "Avoiding Momentum Crashes using Stochastic Mean-CVaR Optimization with Time-Varying Risk Aversion," Ph.D. graduate Xiaoshi Guo and professor Sarah M. Ryan from Iowa State University propose a stochastic mean-risk optimization model that integrates time-varying risk aversion. Their approach safeguards

Sarah M. Ryan



Xiaoshi Guo

against momentum crashes via three key methods:

1. The downside risk metric, conditional value at risk (CvaR), is deployed to regulate the anticipated investment loss under extreme scenarios.
2. The tail probability used for calculating CVaR and its weight in the optimization model's objective function are automatically and dynamically adjusted according to market conditions.
3. A hybrid moment-matching algorithm generates scenarios that effectively capture the statistical characteristics of uncertain returns from the momentum portfolio, with hyperparameters tuned according to an assessment of scenario reliability with respect to past observations.

Through extensive backtesting spanning from January 1926 to December 2020 while encompassing a broad range of equities, the authors find that portfolios rebalanced according to their model not only yield superior returns but also mitigate investment risk when compared to a cross-sectional momentum heuristic. More importantly, the cumulative returns exhibit no substantial declines during the simulation period, indicating the successful avoidance of momentum crashes.

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