Monday, 10:30AM

MA01

Sala Consiglio, Politecnico di Milano

Data Modelling, Monitoring and Decision Making for Smart Manufacturing

Contributed Session

1 Big data methods for in-situ monitoring of additive manufacturing processes

Marco Grasso[1], Matteo Bugatti[1], Bianca Maria Colosimo[1]

[1]Politecnico di Milano

The industrial applications of Additive Manufacturing (AM) have been rapidly expanding across various fields, driven by continuous technological advancements. In all relevant industrial sectors, the production of mission-critical and high value-added parts is prompting ongoing research efforts toward achieving novel zero-defect capabilities. Consequently, the quality, stability, and repeatability of AM processes are among the most critical issues, necessitating increased research efforts in this domain. This talk presents an overview of statistical learning and machine learning solutions for in-situ monitoring and inspection in AM. Furthermore, the key role of in-situ monitoring and control techniques is highlighted, emphasizing their importance in facilitating the twin (green and digital) transition.

2 Statistical Methods in Industry 4.0

Christian Capezza[1], Fabio Centofanti[1], Antonio Lepore[1], Biagio Palumbo[1]

[1]Department of Industrial Engineering, Università degli Studi di Napoli Federico II, Naples, Italy

Statistical and machine learning techniques have emerged as powerful tools in Industry 4.0 to benefit from the increasing availability of sensors and data and enable informed decision-making and process optimization. This presentation will provide an overview of several industrial applications in high-dimensional settings developed by the Statistics for Engineering Research (SFERe) group (www.sfere.unina.it), affiliated with the Department of Industrial Engineering at the University of Naples FEDERICO II. In these applications, the definition and use of novel statistical methods have served as a competitive advantage for naval, automotive, and rail companies. The open-source software packages that implement these methods will also be mentioned to highlight their accessibility and potential applicability in different industrial contexts.

The research activity of A. Lepore, C. Capezza and F. Centofanti were carried out within the MICS (Made in Italy – Circular and Sustainable) Extended Partnership and received funding from the European Union Next-GenerationEU (PIANO NAZIONALE DI RIPRESA E RESILIENZA (PNRR) – MISSIONE 4 COMPONENTE 2, INVESTIMENTO 1.3 – D.D. 1551.11-10-2022, PE00000004).

The research activity of B. Palumbo was carried out within the MOST - Sustainable Mobility National Research Center and received funding from the European Union Next-GenerationEU (PIANO NAZIONALE DI RIPRESA E RESILIENZA (PNRR) – MISSIONE 4 COMPONENTE 2, INVESTIMENTO 1.4 – D.D. 1033.17-06-2022, CN00000023). This work reflects only the authors' views and opinions, neither the European Union nor the European Commission can be considered responsible for them.

Monday, 11:30AM

MA02

Sala Consiglio, Politecnico di Milano

Quality and Reliability Improvement in Advanced Manufacturing

Invited Session

1 Novel Bayesian optimization algorithms for robust engineering design with computer experiments

Han Mei[1]

[1]College of Economics and Management, Nanjing University of Aeronautics and Astronautics, Nanjing, Jiangsu, China

Manufacturing and environmental variations are commonly encountered to deteriorate product quality in aerospace design activities. To make such aerospace systems less sensitive to such variations, robust engineering design methods, such as robust parameter design, are effective in selecting high-quality product design by considering input variations. With rapid developments in computers, simulation models have been commonly used in engineering design, and Bayesian optimization is popular in optimizing time-consuming computer simulations. In this talk, we shall discuss developing efficient Bayesian optimization algorithms to actively learn a contour for integrated responses, better minimize the expected quality loss in robust parameter design with a general loss function and with parallel computing techniques, and more efficiently solve the multi-objective stochastic optimization problem in engineering design. Novel acquisition functions for determining the follow-up design points are proposed. Fast calculation formulas for the proposed acquisition functions are further developed to speed up optimization. Numerical examples and case studies in robust airfoil design are also presented to demonstrate the advantages of the proposed Bayesian optimization algorithms.

2 In-Situ Quality Process Monitoring in additive Manufacturing

Yuanyuan Gao[1], Ruiyu Xu[2], Jianguo Wu[2]
[1]Astronautics, Nanjing, China,
[2]Peking University, Beijing, China

The quality control technology in metal additive manufacturing (AM) significantly promotes the high-quality development of AM. However, due to the complexity of AM which builds products layer-by-layer, there are still numerous quality issues. In this work, a sparse Gaussian process-based anomaly detection method was proposed for online monitoring and anomaly detection in metal additive manufacturing. This study designed an anomaly detection algorithm based on monitoring the melt pool temperature to achieve early warning of abnormal states during the manufacturing process. Specifically, the method includes two stages. In the first stage, a quadratic regression and sparse Gaussian process mixture model was used to model the melt pool temperature under normal conditions. By decoupling the effects of power and spatiotemporal variables on melt pool temperature using the mixture model, the temperature variations were captured accurately. In the second stage, anomaly detection was performed based on the deviation degree of the cumulative residual mean, and the CUSUM method was used for quality monitoring and anomaly detection. Ultimately, the proposed method achieved excellent performance with high detection rate, low false alarm rate, and low latency rate.

3 Reinforcement Learning for Process Control in High-Temperature Superconductor Manufacturing

Qianmei Feng [1,2], Shenglin Peng [1], Ying Lin [1,2], Siwei Chen [2,3,4,5], Mahesh Paidpilli [2,3,4], Chirag Goel [2,3], Eduard Galstyan [2,3,4], Venkat Selvamanickam [2,3,4]
[1] Department of Industrial Engineering, University of Houston, Houston, TX, USA,
[2] Advanced Manufacturing Institute, University of Houston, Houston, TX, USA,
[3] Department of Mechanical Engineering, University of Houston, Houston, TX, USA,
[4] Texas Center for Superconductivity, Houston, TX, USA,
[5] Princeton Plasma Physics Laboratory, Princeton, NJ, USA

With high efficiency and low energy loss, high-temperature superconductors (HTS) have demonstrated their profound applications in various fields, such as medical imaging, transportation, accelerators, microwave devices, and power systems. The high-field applications of HTS tapes have raised the demand for producing cost-effective tapes with long lengths in superconductor manufacturing. However, achieving the uniform and enhanced performance of a long HTS tape is challenging due to the unstable growth conditions in the manufacturing process. Although it is confirmed that the process parameters during the advanced metal organic chemical vapor deposition (A-MOCVD) process influence the uniformity of the produced HTS tapes, the high dimensional process parameter signals and their complicated interactions make it difficult to develop an effective control policy. In this research, we propose a dynamic measure for the uniformity of HTS tapes to provide instant feedback for our control policy. Then we model the manufacturing of HTS tapes as a Markov decision process (MDP) with continuous state and action spaces to assess the instant reward in real time in our feedback control model. As our MDP involves continuous and high-dimensional state and action spaces, a neural fitted Q-iteration (NFQ) algorithm is adopted to solve the MDP with Artificial Neural Network (ANN) function approximation. Based on our case studies on real A-MOCVD dataset, the obtained control policy increases the average uniformity of tapes and performs especially well on sample HTS tapes with a low uniformity.

Tuesday, 9:00AM

KEYNOTE

Room A, Villa Parravicini Revel
Keynote Speaker
Plenary Session

Smarter Decisions for a Better World with OR, AI, and INFORMS

Julie Swann[1]
[1]**North Carolina State University - INFORMS**

INFORMS helps academics and practitioners who drive Smarter Decisions for a Better World using operations research, management science, analytics, and artificial intelligence. Dr. Swann will give examples of how these methods can contribute to solving complex, critical problems across a variety of domains, from healthcare to manufacturing, supply chains, and beyond. Dr. Swann will draw upon her own experiences as well as innovations of AI and OR from practice. Dr. Swann will also outline some of the current initiatives of INFORMS, many of which have the potential to connect with the QSR area.

Tuesday, 10:20AM

KEYNOTE

Room A, Villa Parravicini Revel
Keynote Speaker
Plenary Session

Stochastic maintenance for a large fleet of structures

Alain Bensoussan[1]
[1]**University of Texas at Dallas**

The traditional way of maintenance for equipment or structures consists in periodically assessing their level of degradation and taking decision to repair the observed damage if any. Of course, if there is a failure arriving any time, a procedure is decided on the spot. This is analogous to what is done for the health of human beings. The terminology of health of structures is also used accordingly. Since the development of Big Data and the possibility of equipping structures with measurement instruments providing information in real time about their degradation, the traditional maintenance approach has appeared far from being optimal. Big Data offers also the possibility of building knowledge models for the degradation, which are quite generally probabilistic. The availability of these models also calls for new approaches of maintenance. The maintenance decision is better characterized as a maintenance policy or rule or feedback, since it depends on the information which is available, in this context, in real time. Markov Decision Processes turn out to be a much better approach than the traditional one.

Tuesday, 11:30AM

BEST PAPER AWARD

Room A, Villa Parravicini Revel
ICQSR Best Paper Competition

1 MFRL-BI: Design of a Model-free Reinforcement Learning Process Control Scheme by Using Bayesian Inference

Yanrong Li[1], **Juan Du**[2], **Wei Jiang**[1], **Fugee Tsung**[2]
[1]**Shanghai Jiao Tong University**
[2]**The Hong Kong University of Science and Technology/Guangzhou**

Design of process control scheme is critical for quality assurance to reduce variations in manufacturing systems. Taking semiconductor manufacturing as an example, extensive literature focuses on control optimization based on certain process models (usually linear models), which are obtained by experiments before a manufacturing process starts. However, in real applications, pre-defined models may not be accurate, especially for a complex manufacturing system. To tackle model inaccuracy, we propose a model-free reinforcement learning (MFRL) approach to conduct experiments and optimize control simultaneously according to real-time data. Specifically, we design a novel MFRL control scheme by updating the distribution of disturbances using Bayesian inference to reduce their large variations during manufacturing processes. As a result, the proposed MFRL controller is demonstrated to perform well in a nonlinear chemical mechanical planarization (CMP) process when the process model is unknown.
Theoretical properties are guaranteed and numerical studies also demonstrate the efficiency of our methodology.

2 Distribution-Free Online Change Detection for Low-Rank Images

Tingnan Gong[1], **Seong-Hee Kim**[1], **Yao Xie**[1]
[1]**Georgia Tech**

We present a distribution-free CUSUM procedure designed for online change detection in a time series of low-rank images, particularly when the change causes a mean shift. We represent images as matrix data and allow for temporal dependence, in addition to inherent spatial dependence, before and after the change. The marginal distributions are assumed to be general, not limited to any specific parametric distribution. We propose new monitoring statistics that utilize the low-rank structure of the in-control mean matrix. Additionally, we study the proper- ties of the proposed detection procedure, assessing whether the monitoring statistics effectively capture a mean shift. The effectiveness of our procedure is demonstrated through real data experiments.

3 CODA: Temporal Domain Generalization via Concept Drift Simulator

Chia-Yuan Chang[1], Yu-Neng Chuang[2], Zhimeng Jiang[1], Kwei-Herng Lai[2], Anxiao Jiang[1], Na Zou[3]
[1]Texas A&M University
[2]Rice University
[3]University of Houston

Machine learning models in real-world applications often suffer performance issues due to data distribution shifts. Temporal domain generalization aims to adapt models to the "concept drift," maintaining future performance. Existing works based on model-centric training strategies may entail extensive interaction between data and model to appropriately train the model for distribution shifts. To this end, we aim to nip the problem in the bud by generating future domain data for model training and naturally bypassing the cumbersome interaction between data and model. We propose the COncept Drift simulAtor (CODA) framework incorporating a predicted feature correlation matrix to simulate future data for model training. Specifically, the feature correlations matrix serves as a delegation to represent data characteristics at each time point and the trigger for future data generation. Experimental results demonstrate that using CODA-generated data as training input effectively achieves temporal domain generalization across different model architectures with great transferability.

4 Exploring Drug Candidates: All ε-Best Arms Identification in Linear Bandits

Zhekai Li[1], Tianyi Ma[2], Cheng Hua[1], Ruihao Zhu[3]
[1]Shanghai Jiao Tong University
[2]University of Michigan – Shanghai Jiao Tong University Joint Institute
[3]Cornell SC Johnson College of Business

Motivated by the needs to successfully identify multiple candidates that can dramatically enhance outcomes in complex and high-stakes tasks such as drug discovery, we propose a nearly optimal adaptive allocation policy to identify all **ε**-best arms. Specifically, we introduce LinFACTE, an algorithm designed to optimize the identification of all **ε**-best arms in linear bandits. To the best of our knowledge, we provide the first information-theoretic lower bound on the complexity of this problem. Additionally, we demonstrate that our algorithm achieves instance optimality, matching this lower bound up to a logarithmic term. Numerical results demonstrate the practical advantages of LinFACTE compared to baseline methods, highlighting its ability to accelerate early-stage drug development.

Tuesday, 3:00PM

TB01

Room A, Villa Parravicini Revel
ENBIS Session
Invited Session

1 Transfer Learning in Industrial applications

Mathilde Mougeout[1]
[1]ENSIIE & ENS Paris-Saclay

In recent years, significant progress has been made in the implementation of decision support systems based on machine learning methods by exploiting very large databases and the use of learning algorithms.
In many research or production environments, the available databases are rarely as large, and the question arises as to whether it makes sense to use machine learning methods in this context.
This talk will introduce transfer learning, which uses knowledge from related applications to implement efficient models with an economy of data.
Several achievements will be presented that successfully use these learning approaches to design machine learning for industrial small data regimes and to develop powerful decision support tools even in cases where the initial data volume is limited.

2 Predictive Ratio Cusum (PRC): A Bayesian Approach in Online Change Point Detection of Short Runs

Konstantinos Bourazas[1], Frederic Sobas[2], Panagiotis Tsiamyrtzis[3,4]
[1]Dept. of Economics, Athens University of Economics and Business, Greece
[2]Multisite Hemostasis Laboratory, Hospices Civils de Lyon, France
[3]Department of Mechanical Engineering, Politecnico di Milano, Italy
[4]Dept. of Statistics, Athens University of Economics and Business, Greece

The online quality monitoring of a process with low volume data is a very challenging task and the attention is most often placed in detecting when some of the underline (unknown) process parameter(s) experience a persistent shift. Self-starting methods, both in the frequentist and the Bayesian domain aim to offer a solution. Adopting the latter perspective, we propose a general closed-form Bayesian scheme, whose application in regular practice is straightforward. The testing procedure is build on a memory-based control chart that relies on the cumulative ratios of sequentially updated predictive distributions. The derivation of control chart's decision-making threshold, based on false alarm tolerance, along with closed form conjugate analysis, accompany the testing. The theoretic framework can

accommodate any likelihood from the regular exponential family, while the appropriate prior setting allows the use of different sources of information, when available. An extensive simulation study evaluates the performance against competitors and examines the robustness to different prior settings and model type misspecifications, while continuous and discrete real datasets, illustrate its implementation.

3 A Novel Multivariate Functional EWMA Control Chart for Profile Monitoring

Christian Capezza[1]
[1]**University of Naples Federico II, Department of Industrial Engineering**

In modern industrial settings, product quality measures often involve complex data or profiles, leading to the necessity for advancements in traditional statistical process monitoring (SPM). This work presents a novel control chart that extends the EWMA scheme to the multivariate functional data setting. The performance of the proposed control chart is extensively tested through Monte Carlo simulations and shows its superiority over competing SPM methods. The practical application is demonstrated through a case study in the SPM of a resistance spot welding (RSW) process in automobile manufacturing. This case involves monitoring the vector of dynamic resistance curves that is collected on each car body in white and is acknowledged to provide a full informative signature of the spot weld quality.

The research activity of A. Lepore, C. Capezza and F. Centofanti were carried out within the MICS (Made in Italy – Circular and Sustainable) Extended Partnership and received funding from the European Union Next-GenerationEU (PIANO NAZIONALE DI RIPRESA E RESILIENZA (PNRR) – MISSIONE 4 COMPONENTE 2, INVESTIMENTO 1.3 – D.D. 1551.11-10-2022, PE00000004).
The research activity of B. Palumbo was carried out within the MOST - Sustainable Mobility National Research Center and received funding from the European Union Next-GenerationEU (PIANO NAZIONALE DI RIPRESA E RESILIENZA (PNRR) – MISSIONE 4 COMPONENTE 2, INVESTIMENTO 1.4 – D.D. 1033.17-06-2022, CN00000023). This work reflects only the authors' views and opinions, neither the European Union nor the European Commission can be considered responsible for them.

Tuesday, 4:30PM

TC01

Room A, Villa Parravicini Revel

Design and analysis of expensive computer experiments

Invited Session

1 Simulation model calibration with dynamic stratification

Bingjie Liu[1], **Pranav Jain**[2], **Sara Shashaani**[2], **Eunshin Byon**[1]
[1]**University of Michigan, Ann Arbor, MI, USA,**
[2]**North Carolina State University, Raleigh, NC, USA**

Calibrating simulation models that take large quantities of data as input is a challenging simulation optimization problem. We propose integrating stratification with stochastic optimization for improving the efficiency in calibration process. Stratification can exploit local dependence in the simulation inputs and outputs. We devise a new procedure for data-driven calibration problems that involve a large dataset to calibrate models within a fixed overall simulation budget. We find that dynamical adjustment of stratification structure accelerates optimization and reduces run-to-run variability in generated solutions. Our case study for calibrating a wind power simulation model, widely used in the wind industry, using the proposed stratified adaptive sampling, shows better-calibrated parameters under a limited budget.

2 ESPs: a new cost-efficient sampler for expensive posterior distributions

Benedetta Bruni[1], **Flora Shi**[2], **Yi (Irene) Ji**[1], **Simon Mak**[1]
[1]**Duke University, Durham, NC, USA**
[2]**Massachusetts Institute of Technology, Cambridge, MA, USA**

Bayesian inverse problem to model complex physical systems require the evaluation of forward simulation models, which can be prohibitively expensive in terms of CPU hours. Therefore it is important to design "cost-efficient" samplers, to achieve a satisfactory representation of the desired posterior under a fixed computational budget. Most of current sampling algorithms (e.g., Hamiltonian Monte Carlo methods) are "sample-efficient", meaning they provide a good representation of the posterior given limited samples, but are highly cost inefficient, as they require at least one evaluation of the forward model per sample. We present a new sampler, cost-Efficient Stein Points (ESPs). ESPs is an extension of the recent Stein points from Chen et al. (2018, ICML), which achieves sample-efficiency by sequential minimization of the kernel Stein discrepancy with respect to the posterior of interest. The key novelty of ESPs is the use of carefully-constructed Gaussian process surrogate models of the kernel Stein discrepancy, for cost-efficient sequential minimization via Bayesian optimization based on Expected Improvement. We demonstrate the cost-efficiency of ESPs in comparison to state-of-the-art posterior sampling algorithms, via a suite of numerical experiments and a calibration application.

3 On the testing of statistical software

Ryan Lekivetz[1]
[1]**SAS Institute, Cary, NC, USA**

Testing statistical software is an extremely difficult task. What is more, for many statistical packages, the developer and test engineer are one and the same, may not have formal training in software testing techniques, and may have limited time for testing. This makes it imperative that the adopted testing

approach is both efficient and effective and, at the same time, it should be based on principles that are readily understood by the developer. As it turns out, the construction of test cases can be thought of as a designed experiment (DOE). This article provides a comprehensive treatment of DOE principles applied to testing statistical software and includes other considerations that may be less familiar to those developing and testing statistical packages.

4 Experimental design for expensive path planning simulators via integer programming

Yen-Chun Liu[1], Simon Mak[1]
[1]Duke University, Durham, NC, USA

Path planning -- the exploration of feasible paths for navigation -- plays an integral role in broad modern applications, including robotics, surgical planning and assembly planning. For such applications, the feasibility of a selected path is often evaluated via sophisticated virtual simulation models. This introduces two critical challenges: each simulation run can be computationally costly, and the parameter space for path planning is typically quite high-dimensional. A careful design of such simulation experiments is thus critical for timely decision-making. We propose here a novel design approach for path planning experiments, which leverages an underlying Gaussian process surrogate model for response surface exploration. The key novelty of our approach is the use of integer programming (IP) formulations, algorithms and theory for design construction of simulation runs. We present first an IP-based approach for efficient initial design construction with an arbitrary run size n. We then outline a flexible IP-based framework for sequential design of subsequent runs, targeting either active learning or black-box optimization of the response surface. Finally, we demonstrate the effectiveness of our design framework over the state-of-the-art, in a suite of path planning numerical experiments and an application to rover trajectory optimization.

Tuesday, 4:30PM

TC02

Room B, Villa Parravicini Revel
Data analytics and AI in critical industry
Contributed session

1 Sequential Sponsored-Products and Off-Amazon Advertising Optimization for Etailers

Houmin Yan, Gary Feng, Yina Ning, Yangyang Xie
City University of Hong Kong, Deparment of Management Sciences, Hong Kong

The Sponsored-Products (SP) advertisement is a popular way for promoting products on Amazon. Etailers can choose and pay for specific keywords to secure ad placements for their products. These keywords are the ones that shoppers are likely to search for when looking for products on Amazon. To improve the efficiency of SP ads, etailers who have a large catalog of products often create ad groups for products with similar attributes. An ad group consists of a set of products and a set of keywords, and all the products in the ad group share the same keywords set. Etailers may also choose to link to external websites for advertising their products and attracting consumers, which is called off-Amazon (OA) ads. This study focuses on the sequential SP and OA ads optimization problem for etailers. Practically, many etailers set sales targets for products as manufacturing and logistics are planned ahead of time. Hence, we consider that the objective of the etailer is to minimize the expected long-run average cost associated with advertising and the cumulative deviation between the sales target and actual sales. When the mean of the sales number per unit time (i.e., sales rate) for each product is known, we characterize the optimal sequential Sponsored-Products and off-Amazon advertising policy (abbreviated as SSPOA policy) for products in an ad group, which is of a threshold type. However, in reality, etailers may not know the exact mean of sales rates, and therefore the SSPOA problem becomes a controlled Markovian multi-armed bandit problem with an exploration–exploitation trade-off. We devise a Thompson sampling-based SSPOA algorithm to balance exploration and exploitation adaptively via sampling and updating processes. Moreover, we prove that the regret bound of the proposed algorithm is ˜O(p,T), where T is the number of time periods. We also conduct numerical experiments to compare our proposed algorithm with upper confidence bound and greedy algorithms, which shows that the standard deviations of the algorithms are similar when T is large and the average regret per unit time of our proposed algorithm is smaller than existing algorithms.

2 Enhancing Manufacturing Design with Active Learning and Constrained Bayesian Optimization

Xiaoning Jin, Guoyan Li
Northeastern University, Mechanical and Industrial Engineering, MA, USA

This study addresses the complex challenge of identifying process parameters for optimal manufacturing outcomes in advanced manufacturing, in which nonlinear and costly process-to-quality relationships prevail. We introduce a novel experimental design framework that energizes the optimization of process parameters and feasibility constraint learning with minimal human intervention. Our approach is grounded in two primary methodologies: (1) active multi-criteria sample for constraint estimation and (2) Bayesian optimization-based sample for optimal parameter identification. This integration facilitates the efficient discovery of globally optimal parameter settings and out-performs multiple benchmark models in constraint estimation accuracy. The framework's efficacy is demonstrated through application on both synthetic datasets and a real-world case study involving the synthesis of 2D materials, demonstrating

its potential to enhance manufacturing efficiency and quality in complex manufacturing processes significantly.

3 Center to Stream Health in Place (C2SHIP): Big Data and Opportunities for Collaborations

Shu-Fen Wung, Janet Roveda
University of Arizona, Tucson, AZ, USA

C2SHIP is a National Science Foundation-funded Industry University Cooperative Research Centers (IUCRC) Consortium. The mission of this six-university C2SHIP Center is to engage academic and industrial partners in joint efforts that develop healthcare technologies for in-place care and accelerate innovation through multi-specialty collaborations. Our research areas include: 1) Design wearable sensors/manufacturing for quality in-place care, 2) Data Mining: machine learning models to extract clinically meaningful information to promote in-place care, 3) Cyber Security/Feedback: Methods to securely stream data from multiple sensors/devices and visualize results back to users using multi-modal interfaces to promote in-place care. Our broader impacts are on educating the next-generation clinical and engineering innovators and the societal impact of in-place technologies on the lives of individuals and families.

Tuesday, 5:30PM

TD01

Room A, Villa Parravicini Revel

Advanced Analytics with Human in the Loop

Invited Session

1 The skill-fit model: utilizing skills to advance machine learning based job recommendation systems

Alon Atzil[1], Hila Chalutz-Ben Gal[1]
[1]Bar-Ilan University

The growing practice of utilizing Machine Learning based Job recommendation systems (JRS) has become a major component in talent management. However, recent disruptions in the labor force (e.g. flexible work, freelancing, gig work) result in the need to adopt a Skill-Fit Model. For this purpose, we present an analysis of the ML based JRS literature and propose a synthesized approach to analyze and model skills. Our results indicate that some JRS features may benefit from the Skill-Fit Model thus may be adopted by ML-enabled JRS in order to achieve improved performance. This study contributes to the understanding and systematically developing skills – based JRS to support the new world of work.

2 A Two-Phase Classification & Optimization Model with Limited Human Resource Allocation

Danit Shifman Abukasis[1], Chen Ben-Mayor[1], Itay Margolin[2], Gonen Singer[1]
[1]Bar-Ilan University, Faculty of Engineering, Ramat Gan, 52900, Israel
[2]Intuit Inc.

Efficiently allocating limited resources in classification tasks is crucial in many real-world applications such as fraud detection where there is a limited number of transactions that can be analyzed in a day, allocating tests for disease diagnosis, and making hiring decisions when positions are limited. We propose a two-phase methodology consisting of machine learning and optimization models to address this challenge. In the first phase, our framework uses a machine learning model to predict the likelihood of successful outcomes for potential classifications. The second phase leverages these predictions in an optimization model designed to minimize misclassification costs while considering resource constraints. This study addresses two types of constraints: target-based constraints that limit the total number of classifications per class, and feature-based constraints that impose classification limitations for a specific feature value (such as gender based limitations). Through an experimental study, we demonstrate the effectiveness of our model in significantly enhancing allocation efficiency compared to conventional methods.

3 Design for Human Explainability - Using DOE for an Efficient XAI

Aviv Notovich[1], David Steinberg[2], Irad Ben-Gal[1]
[1]Industrial Engineering Department, Tel Aviv University
[2]Statistics Department, Tel Aviv University

In recent years with the development of complex AI models, the field of Explainable AI (XAI) has experienced rapid growth. A popular method to determine feature importance in Explainable AI (XAI) is the SHAP Value. Despite its many benefits, SHAP also suffers from major drawbacks, including high computational complexity, limited ability to analyze high-order feature interactions, and complex feedback between the XAI model and the user. In this work, we propose a new Design for Explainability (DFX) methodology rooted in the statistical Design of Experiments, a well-known methodology that provides information about factorial effects in input-output models. For a given trained Machine Learning (ML) model; a feature training set; and a list of potential features interactions, DFX generates a DOE plan to measure the importance or the effect of features, while estimating selected interactions among the features, with a lower computational cost than SHAP. DFX applies four steps: i) building a DOE plan; ii) computing the response over the DOE design matrix; iii) adding relevant potential interactions of interest to the analysis; and iv) fitting a linear regression model whose coefficients give the features' effects. Unlike SHAP, estimating interactions does not require retraining the ML model, thus does not entail a computation cost which is quadratic in the total number of features and interactions. Application of DFX to 10 real-world datasets finds that DFX

and SHAP are equivalent in approximately 80% of the cases in identifying the top 10% of the most important features, while on average, DFX reduces, by a factor of 100, the number of evaluations required by comparison to SHAP.

Tuesday, 5:30PM

TD02

Room B, Villa Parravicini Revel

Data Science for Quality and Reliability Improvement Invited Session

1 Image Degradation-Based Stochastic Process and Condition Monitoring for Manufacturing Process

Munwon Lim, Suk Joo Bae
Hanyang University, Seoul, South Korea

As the advance of sensing technology, data-driven condition-based maintenance (CBM) has been developed to automate production process control within the engineering sector. CBM typically focuses on diagnosing production statuses by utilizing real-time data from sensors. In this presentation, we propose an image-based degradation modeling and change-point detection approach using a spatio-temporal process. This method enables us to articulate deteriorating patterns in image observations by considering spatial and temporal relationships. Simultaneously, we estimate change-points to distinguish degradation under normal and abnormal production statuses. To enhance the precision of parameter estimation, we employ the Markov chain Monte Carlo (MCMC) sampling method. Through the application to real industrial image streams, our proposed monitoring scheme efficiently provides a bi-phase representation, delivering valuable insights into the manufacturing process.

2 Deep Latent Factor Model for Spatio-Temporal Forecasting

Wonmo Koo[1], Eun-Yeol Ma[1], Heeyoung Kim[1]
[1]Korea Advanced Institute of Science and Technology (KAIST), Daejeon, Republic of Korea

In environmental monitoring systems, enhancing the accuracy of predicting future responses at unmeasured as well as measured locations (i.e., spatio-temporal forecasting) is essential because it can improve the quality of forecasting services without increasing costs. However, making accurate predictions at unmeasured locations is especially challenging in the absence of historical data. Latent factor models have been studied as a prevalent approach for spatio-temporal forecasting, and they commonly achieve this by modeling temporal dependence using latent factors and considering spatial dependence using a spatial prior on factor loadings. However, they may fail to capture complex spatio-temporal dependence, and their forecast accuracy may be limited due to the assumption that latent factors follow a classical linear time series model, such as a vector autoregressive model. In this paper, we propose a deep latent factor model for spatio-temporal forecasting that can model complex spatio-temporal dependence more flexibly by leveraging the high expressive power of a deep neural network. Specifically, the latent factors are modeled using a recurrent neural network, and the factor loadings are modeled using a distance-based Gaussian process. We derive a stochastic variational inference algorithm for scalable inference, and validate the proposed model using simulated and real data examples.

3 Domain-Knowledge-Informed Functional Outlier Detection for Line Quality Control Systems

Sungil Kim[1]
[1]UNIST, Ulsan, South Korea

Detecting defective products at quality inspection stations is crucial. Consequently, modern production systems collect diverse sensor data during inspections to monitor the condition of products. However, a significant challenge in the pursuit of zero-defect manufacturing emerges with the presence of latent defects. These defects are not discoverable during the quality inspection phase and become apparent in the early stages of customer use. As a result, detecting such defects solely based on collected data becomes almost impossible. In this study, we introduce a novel functional outlier detection method that leverages domain knowledge to identify defective products, especially those with latent defects. The proposed method presents a systematic framework for integrating domain knowledge into the recently developed functional outlier detection method known as sequential transformations (Dai et al., 2020). To validate our proposed method's effectiveness, we evaluated its performance using simulated data and real sensor data from refrigerator inspection lanes.

Wednesday, 8:00AM

KEYNOTE

Room A, Villa Parravicini Revel
Keynote Speaker
Plenary Session

Analytics for Decarbonization

Hui Szu Ng[1]
[1]**National University of Singapore**

As the consequences of global warming become increasingly evident, there's a growing urgency to transition towards a sustainable, low-carbon future. Decarbonization, which involves reducing the carbon footprint across various industry sectors, is a critical step towards achieving this goal. In this talk, we will look at the role data science and analytics has played in facilitating decarbonization and the research work ongoing at the Department of Industrial System Engineering and Management @National University of Singapore, to develop tools and analytics to understand the trends and pathways to decarbonization. An in-depth focus on international shipping's commitment and actions will also be provided.

Wednesday, 11:30AM

KEYNOTE

Room A, Villa Parravicini Revel
Keynote Speaker
Plenary Session

Data Science and Wind Energy

Yu Ding[1]
[1]**Georgia Tech**

Wind energy is one of the fastest-growing clean energy sources. Despite the significant growth in the past two decades, wind energy missed some intermediate goals set forth earlier. One critical element needed for accelerating wind energy growth is to significantly reduce its operational cost and further boost its market competitiveness. In his book, Data Science for Wind Energy, the speaker demonstrated how statistical and machine learning methods can help address research needs in wind energy applications. The speaker will discuss some of the challenges encountered in wind applications and present use cases in which statistical and machine learning models and solutions make sensible impacts.

Wednesday, 1:30PM

WA01

Room A, Villa Parravicini Revel

System Reliability Modeling and Inference
Invited Session

1 A causal perspective on importance measures

Zitong Lu[1], **Min Xie**[1]
[1]**Department of Systems Engineering, City University of Hong Kong**

The importance measures serve a pivotal function in system reliability and find extensive applications across diverse domains. Given the increasing complexity of modern systems, several types of importance measures have been investigated, e.g. Birnbaum importance measure, Barlow-Proschan importance measure, and criticality-importance. However, those traditional methods are predicated upon correlation, lacking a definitive causal elucidation, particularly in scenarios where components may affect each other. This paper endeavors to offer an exploration of the importance measures through a novel causal perspective. We propose Causal Importance Measure (CIM), a novel framework designed to introduce causality into importance measures and address the interdependence among components. Within this framework, those traditional importance measures, despite their diverse formulations and intended utilities, can be construed as specialized forms of CIM under certain conditions. A numerical example is used to illustrate the proposed approach.

2 Software Reliability Modelling and Analysis Constrained by the Shape of the MVF

Kangan Chen[1], **Jian Liu**[2], **Qingpei Hu**[3]
[1]**School of Mathematics Science, University of Chinese Academy of Sciences,**
[2]**Department of Systems and Industrial Engineering, University of Arizona**
[3]**Academy of Mathematics and Systems Science, Chinese Academy of Sciences**

While parametric Software Reliability Growth Models (SRGMs) serve as a cornerstone in software reliability assessment, their reliance on known fault-detection time distributions often presents a significant limitation in practical software testing. In this study, we develop a novel shape-restricted spline estimator for quantifying software reliability. Comparing with parametric SRGMs, the proposed estimator not only shares a key characteristic with parametric SRGMs, a feature largely underexplored in existing literature, but also obviates the need for specifying fault-detection time distributions. More importantly, it effectively utilizes the critical shape information of the mean value function (MVF) of fault-detection process, a detail seldom considered in prior work. Furthermore, we investigate the predictive performance of the proposed methods by employing the so-called one-step look-ahead prediction method. In numerical experiment, we show that spline estimators under restriction demonstrates competitive performance compared to parametric and certain non-parametric models.

3 Subsampling Strategies for Heavily Censored Big Lifetime Data

Yixiao Ruan[1], Qingpei Hu[1], Dan Yu[1]
[1]Academy of Mathematics and Systems Science, Chinese Academy of Sciences, School of Mathematics Science, University of Chinese Academy of Sciences

As the era of big data is approaching, computational capability often falls short when confronted with massive data, posing a common challenge in establishing a statistical model or statistical inference method dealing with big data. While subsampling techniques have been extensively developed to downsize the data volume, there is a notable gap in addressing the unique challenge of handling extensive reliability data, in which a common situation is that a large proportion of data is censored. In this article, we propose an efficient subsampling method for reliability analysis in the presence of censoring data, intending to estimate the parameters of lifetime distribution. Moreover, we design a novel subsampling method for subsampling from severely censored data, i.e., only a tiny proportion of data is complete. The subsampling-based estimators are given, and their asymptotic properties are derived. The optimal subsampling probabilities are derived through the L-optimality criterion, which minimizes the trace of the product of the asymptotic covariance matrix and a constant matrix. Efficient algorithms are proposed to implement the proposed subsampling methods to address the challenge that optimal subsampling strategy depends on unknown parameter estimation from full data. Numerical studies and a real-world hard drive dataset case are employed to demonstrate the superior performance of the proposed methods.

Wednesday, 1:30PM

WA02

Room B, Villa Parravicini Revel

System Reliability & Resilience Modeling and Maintenance

Invited Session

1 Reliability engineering for hybrid renewable energy systems: Challenges and research opportunities

Reem Nasser[1], Dariusz Mazurkiewicz[2], Yiliu Liu[1]
[1]Norwegian University of Science and Technology, Trondheim, Norway,
[2]Lublin University of Technology, Lublin, Poland

This paper explores the hybridization of renewable energy systems through the lens of reliability engineering, focusing on the integration of binary energy resources with advanced energy storage technologies, such as pumped hydro-storage, battery storage, and hydrogen storage. The research systematically reviews the configuration and potential of hybrid systems that combine wind, solar, wave, and hydropower resources, addressing both their capabilities and limitations. It also discusses the dynamic interactions between different energy sources and storage systems, highlighting how these bring challenges system reliability and availability. Moreover, the review categorizes the proactive, active, and reactive methods that have potentials to bolster system reliability and resilience. It recommends specific capabilities that should be integrated into the renewable energy power system framework to mitigate the impacts of natural and manmade hazards, thereby enhancing overall system robustness.

2 Dynamic resource matching in manufacturing using deep reinforcement learning

Saunak Panda[1], Yisha Xiang[1]
[1]University of Houston, Houston, the United States

Matching plays an important role in the logical allocation of resources across a wide range of industries. The benefits of matching have been increasingly recognized in manufacturing industries. In particular, capacity sharing has received much attention recently. In this paper, we consider the problem of dynamically matching demand-capacity types of manufacturing resources. We formulate the multi-period, many-to-many manufacturing resource-matching problem as a sequential decision process. The formulated manufacturing resource-matching problem involves large state and action spaces, and it is not practical to accurately model the joint distribution of various types of demands. To address the curse of dimensionality and the difficulty of explicitly modeling the transition dynamics, we use a model-free deep reinforcement learning approach to find optimal matching policies. In our computational study, including small- and large-scale experiments, the proposed algorithm consistently outperformed traditional deep RL algorithms, yielding higher rewards and demonstrating greater efficiency in time and episodes.

3 Microgrid expansion planning with resilience and environmental benefits under single and multiple structures

Jian Zhou[1], Xiaoting Nie[1]
[1]Nanjing University of Science and Technology, Nanjing, China

As electricity demand quickly grows, power system expansion planning is important to meet the increasing electrical load of different customers. The Paris Agreement's goal of achieving net-zero carbon emissions from power generation also urgently requires the energy transformation of power systems. Microgrid integrates different dispatchable and non-dispatchable distributed energy resources (DERs) as well as energy storage systems. It not only helps to relieve the tension of power supply, but also promotes the application of renewable energy. In this study, microgrids work as backup power systems when the main power grid fails. A long-term microgrid expansion planning framework with power resilience and greenhouse gas (GHG) emission reduction

constraints is proposed. Value of lost load (VOLL) is applied to quantify customer losses during , and GHG emissions from different DERs are considered in the resilience constraints and environmental constraints. A 20-year microgrid expansion planning case study is conducted using real-world weather and electrical load data. Deep reinforcement learning (DRL) algorithm is used to solve this large-scale system planning problem. Experimental results show that optimal microgrid expansion planning can improve power supply resilience and significantly increase the utilization of renewable energy with limited investment cost. The proposed framework is also extended to the case of multiple microgrids. The results show that multiple microgrids with interconnected structures remarkably contribute to the stability of power supply and the application of renewable energy.

Wednesday, 2:30PM

WB01

Room A, Villa Parravicini Revel

Quality Monitoring in I4.0 and additive manufacturing

Contributed Session

1 Online Defect Detection in Extrusion-Based Bioprinting Using In-Situ Thermal Imaging

Egon Prioglio[1]

[1]**Politecnico di Milano**

In-situ monitoring is crucial in facilitating the industrial expansion of extrusion additive manufacturing by enabling the early detection of defects in a non-destructive manner and at a low cost. In this study, a technique for evaluating the geometric accuracy of extrusion additive manufacturing is presented using a thermal imaging camera as a sensor to monitor the extrusion-based bioprinting process in situ. The geometry of the extruded material is segmented during deposition, and the diameter of the segmented shape is calculated in real-time along the trajectory of the extruder. The implementation of statistical process control demonstrates that this method can detect extrusion defects online.

2 Infer and Control Effects of Lurking Variables for 3D Printing Quality

Qiang Huang[1]

[1]**University of Southern California**

In physical experiments, the system or process response can be affected by three categories of variables: experimental variables or factors to be investigated, observable variables assumed to be fixed, and lurking variables that are unknown or unmeasurable. The lurking variables have been assumed to be constant and independent of other variables without verification. This talk presents a rigorous formulation to infer and control the effects of lurking variables through an effect equivalence approach. Hypothesis testing can be conducted to test the possible violation of the assumption. Application in 3D printing accuracy control is demonstrated.

3 Faults in PCBs using Advanced Deep Learning Techniques for Handling Data Imbalance

Marzieh Hashemzadeh Saadat, Farnoosh Concordia

Institute for Information System Engineering, Concordia University, Montreal, CANADA

In the era of Industry 4.0, the demand for high-quality Printed Circuit Boards (PCBs) continues to rise, necessitating advanced fault detection methods to ensure product quality and reliability. Accurate anomaly detection in PCB circuit board production lines is crucial for maintaining product quality and reducing manufacturing costs. Analyzing the large amount of data collected during inspection and production processes presents a complex challenge, especially when dealing with various data modalities and the presence of imbalanced data. This complexity significantly complicates the diagnostic process. In this paper, we present a novel approach utilizing machine learning algorithms and deep neural networks tailored explicitly for imbalanced data in for fault diagnosis of PCBSs. Leveraging the inherent advantages of these algorithms, particularly in handling skewed class distributions, we demonstrate their effectiveness in enhancing anomaly detection accuracy. Our experiments on real-world production data reveal promising results, highlighting the potential of machine learning techniques in improving failure detection in the PCB manufacturing industry.

Wednesday, 2:30PM

WB02

Room B, Villa Parravicini Revel

Methods for anomaly detection, prognosis and transfer learning

Contributed Session

1 An Adaptive Sampling Strategy for Real-time Anomaly Detection with Unmanned Sensing Vehicles

Ana Maria Estrada Gomez[1], **Yue Jiang**[1]

[1]**Purdue University**

Unmanned sensing vehicles (USVs) have been widely used for real-time anomaly detection in various applications, including environmental monitoring, precision agriculture, and military surveillance. The USVs collecting data can only provide partial information about the space being monitored. Thus, it is critical to decide where to deploy the USVs at each point in

time to maximize the change detection capability, while minimizing deployment costs. This paper proposes an adaptive sampling strategy for real-time anomaly detection with USVs. First, a novel spatio-temporal sequential tensor decomposition algorithm is developed to decompose the high-dimensional data collected by the USVs into three components, a spatial component, a temporal component, and a sparse component, that captures the locations suspicious of change. The spatial and temporal components are used for one-step prediction to guide the adaptive sampling strategy. The strategy is designed to maximize the detection power and control the deployment costs. The main idea is to balance exploration and exploitation by designing a sampling distribution function to decide where to collect data at each acquisition time. The movement of the USVs is controlled by using Voronoi tessellations on the sampling distribution function. The performance of the proposed framework is demonstrated through simulations and case studies.

2 Multi-modal data fusion for prognosis after mild traumatic brain injury

Jing Li[1], Catherin Chong[1]
[1]Georgia Tech, H. Milton Stewart School of Industrial and Systems Engineering

After mild traumatic brain injury, some patients will develop persistent headaches while others may resolve on their own. Currently, there is no effective approach to generate an accurate prognosis to assist clinicians in deciding what type of intervention is appropriate for each patient. In this study, we collected multi-modal datasets such as clinical questionnaires, imaging, headache diary, and mobile app-based speech. We developed statistical machine learning methods to fuse the multi-modal datasets for predicting headache persistence.

3 A novel solution for Transfer Learning in 3D Bioprinting

Filippo Bracco[1], Kamran Paynabar[2], Bianca Maria Colosimo[1]
[1]Department of Mechanical Engineering, Politecnico di Milano
[2]Georgia Tech, H. Milton Stewart School of Industrial and Systems Engineering

Bioprinting represents a promising group of technologies with significant applications. However, current technologies and biomaterials struggle to replicate the complexity found in biological tissues. A multitude of factors—both controllable and uncontrollable, such as material formulation, process parameters, and various biological, physical, and chemical influences—and their intricate interplay present challenges to advancing this technology towards achieving its full potential. Progress in this area hinges on enhancing the sophistication of predictive and control models, efficiently managing the size and cost of experimental data, and incorporating existing knowledge into new models.
This work introduces a novel Transfer Learning (TL) method designed for robust and resource-efficient optimization of bioprinting processes by merging established knowledge with new experimental conditions. TL encompasses a set of Machine Learning strategies focused on transferring knowledge across distinct, yet similar, domains. We present a case study applying TL to extrusion-based bioprinting, where knowledge from an existing printability response surface model (the source) is applied to a new model (the target) under conditions of limited experimental data availability. We assess the accuracy of the transferred model by comparing its prediction error with that of a reference regression model, which is developed from scratch following conventional practices. Further, we investigate the method's performance and limitations by altering the number of experimental target points. This method demonstrates the feasibility of knowledge transfer in bioprinting as a catalyst for more sophisticated applications across diverse printing conditions, materials, and technologies.

Wednesday, 4:00PM

WC01

Room A, Villa Parravicini Revel

Manufacturing & Field Reliability Improvement Using Degradation & Failure-Time Data

Invited Session

1 Nonlinear Quantile Regression for Accelerated Destructive Degradation Data

Suk Joo Bae[1], Moowon Lim[1]
[1]Hanyang University, Seoul, Korea

Traditional regression approaches to accelerated destructive degradation test (ADDT) data have modeled the mean curve as representative. However, maximum likelihood estimates (MLEs) of the mean model are likely to be biased when the data are non-Gaussian or highly skewed. In this presentation, we introduce a nonlinear quantile regression (QR) approach for estimating quantile curves of ADDT data. We propose an iterative QR algorithm that uses the generalized expectation-maximization (GEM) framework to estimate the parameters of the nonlinear QR ADDT model, based on the asymmetric Laplace distribution to accommodate non-Gaussian and skewed errors. We propose a new prediction method of the quantile of the failure-time distribution in the normal use condition. Confidence intervals for the quantiles of the failure-time distribution are constructed using the parametric bootstrap method. The proposed model is illustrated using two industrial applications and compared with the existing model. Using various simulation studies, we validate the performance of the proposed model and demonstrate its robustness to assumed error distributions.

2 An On Line Approach For Joint Optimization Of Data Driven Predictive Maintenance and Production Planning

Xiaoyan Zhu[1], Hanchao Wang[1], Tao Yuan[2]
[1]School of Economics and Management, University of Chinese Academy of Sciences, Beijing, China
[2]Department of Industrial and Systems Engineering, Ohio University, Athens, Ohio, United States

Our aim is to establish a data-driven intelligent optimization approach which solves the real-time joint O&M decision-making problem under uncertain demand. The widespread adoption of smart and intelligent devices and techniques generate vast amount of monitoring data, which help make decisions for a smart manufacturing. Smart manufacturing can be defined as making information as well as manufacturing procedures available as and when required, such that it is possible to make decisions regarding the course of any critical business operation. Both maintenance scheduling and production planning are core factors for a smart manufacturing system. Extensive literature has focused on the joint optimization for maintenance and production planning, but few of them make full use of monitoring data.

3 Early Anomaly Detection in Automotive Warranty Data through Bias Correction and Sequential Testing

Seongjoon Kim[1], Sina Park1, Hyojung Kim[1]
[1]Chosun University, Gwangju, Republic of Korea

Estimating reliability from automotive warranty data is crucial for validating targets and identifying issues. However, two-dimensional warranty policies (e.g., 3 years or 60,000 km) lead to censored and truncated data, reducing estimation accuracy. This study proposes an iterative reliability assessment method using bias correction to minimize errors caused by data incompleteness. Second- and third-order bias correction techniques (BC2, BC3) are applied to reduce parameter estimation bias, and a sequential testing method evaluates if corrected estimates meet predefined targets. Numerical experiments and application cases confirm the method's higher accuracy compared to existing analysis methods. By combining bias correction and iterative decision making, we hope this study can contribute to field reliability assessment and early detection of abnormalities based on warranty data.

Wednesday, 4:00PM

WC02

Room B, Villa Parravicini Revel
Statistical Process Control and Quality Engineering
Invited Session

1 From Features to Benefits: A Data-Driven Approach for the Economic Design of Adaptive Quality Control

Zhaoguang Xu[1], Stefan Minner[2]
[1]Dalian University of Technology
[2]Technical University of Munich

Control charts are crucial for maintaining product quality in manufacturing. Their parameter design directly impacts quality control costs. Traditional control charts typically employ static chart parameters, which are not optimal for minimizing cost. In contrast, adaptive control charts tend to outperform static charts from an economic perspective. Existing economic designs of adaptive control charts often overly assume specific quality distributions, have a restricted choice of parameter combinations, and rely too heavily on historical samples. Such limitations hinder companies from accurately determining the most economical control chart parameters for quality control. Leveraging extensive industrial big data, we propose a data-driven, mixed-integer linear programming model for the economic design of adaptive control charts. This approach enables the optimal design of control limits without the need for preconceived assumptions about quality output distributions or extensive historical sample collection. Control limits within the chart are dynamically designed as a function of features to minimize expected quality control costs. Considering the trade-off between false alarms and undetected error costs, we develop a benchmark model incorporating big data feature information to set control limits. Then, we construct a simulation environment to evaluate the model using novel performance measures. Our findings demonstrate the economic value of adaptive control limits strategies incorporating feature data for companies compared to traditional practice-relevant benchmarks. Additionally, we expanded the model to incorporate an endogenous sample size framework, discovering that our data-driven method facilitates sampling with smaller sizes, yet continues to maintain lower control costs effectively. We undertook a case study using real-world data from a casting company and revealed that employing our approach culminates in a 24.6% reduction in costs relative to the company's existing quality control protocols. Our approach enables manufacturers to make strategic decisions about quality control by operationalizing the available big data, thereby proving advantageous for companies in terms of reducing quality control costs.

2 Fourier Methods for Statistical Monitoring of Queues

Russell R. Barton[1]
[1]The Pennsylvania State University

SPC methods for queueing or number-in-system (NIS) data have a special complexity. There have been two common approaches. First, there are SPC methods that identify the steady-state probability distribution for NIS, but this approach requires independent observations, so they must be spaced far apart in time to avoid autocorrelation. Second, there are

methods based on a Markov chain characterization of NIS at each instant that an entity finishes service. Such methods apply likelihood calculations for observed transitions in NIS count from one departure to the next. Previous methods for statistical monitoring of queues have been based on static NIS data at instants of departures and perhaps arrivals. This talk presents a new SPC method based on dynamic characterization of changes in NIS over time: NIS trajectories. The NIS mean value is not part of our monitored statistic. The method uses a weighted sum of Fourier Magnitudes (waFm) statistic presented in prior work. In the SPC context the computation of the waFm statistic must be modified to deal with relatively short signal segments, analogous to subgroups in traditional SPC. Its performance is illustrated for several examples.

3 A Robust Statistical Process Monitoring Framework for Multivariate Functional Quality Characteristics

Antonio Lepore, Christian Capezza, Fabio Centofanti, Biagio Palumbo
Università degli Studi di Napoli Federico II

In classical statistical process monitoring (SPM) applications the Phase I sample is assumed to come from an in-control process, which is however not always valid, especially when the monitoring characteristic for each item/case is a vector of profiles, i.e., a multivariate functional quality characteristic. As is known, control charts are very sensitive to outlying observations in Phase I, which can inflate control interval width and reduce power to detect process changes in Phase II. In the multivariate functional data setting, this issue is exacerbated by the curse of dimensionality and calls for monitoring frameworks that are robust to the presence of outliers.

Traditional multivariate robust estimators assume only a so-called \textit{casewise} contamination model for the data, which consists of a mixture of two distributions, one representing the majority of cases that are free of contamination, and another describing the minority of the cases assumed as generated by an unspecified outlier distribution. However, when the dimensionality of the data is high, the fraction of perfectly observed cases can be very small, and outliers may occur more realistically in one or a few components and are called \textit{componentwise} outliers. Our research introduces a novel monitoring framework for multivariate functional quality characteristics, named robust multivariate functional control chart (RoMFCC), that is robust to the influence of both functional casewise and componentwise outliers. The RoMFCC framework contains four main elements: a functional filter to detect functional componentwise outliers, a robust imputation of missing components in multivariate functional data, a robust dimension reduction that deals with functional casewise outliers, and a procedure for prospective process monitoring. The performance of the proposed framework is assessed through a wide Monte Carlo simulation also in comparison to competing monitoring schemes that already appeared in the literature before. The practical applicability of the RoMFCC is demonstrated through a real case study in the SPM of a resistance spot welding process in automotive body-in-white manufacturing. The RoMFCC is implemented in the R package funcharts, openly available on CRAN.

The research activity of A. Lepore, C. Capezza and F. Centofanti were carried out within the MICS (Made in Italy – Circular and Sustainable) Extended Partnership and received funding from the European Union Next-GenerationEU (PIANO NAZIONALE DI RIPRESA E RESILIENZA (PNRR) – MISSIONE 4 COMPONENTE 2, INVESTIMENTO 1.3 – D.D. 1551.11-10-2022, PE00000004).

The research activity of B. Palumbo was carried out within the MOST - Sustainable Mobility National Research Center and received funding from the European Union Next-GenerationEU (PIANO NAZIONALE DI RIPRESA E RESILIENZA (PNRR) – MISSIONE 4 COMPONENTE 2, INVESTIMENTO 1.4 – D.D. 1033.17-06-2022, CN00000023). This work reflects only the authors' views and opinions, neither the European Union nor the European Commission can be considered responsible for them.

4 Anomaly Detection in Profile Monitoring through Functional Conformal Prediction

Simone Vantini[1], Teresa Bortolotti[1], Bianca Maria Colosimo[2]
[1]MOX, Department of Mathematics, Politecnico di Milano
[2]Department of Mechanical Engineering, Politecnico di Milano

We propose a novel methodology for detecting anomalies in the monitoring of profiles in industrial processes (e.g., electromagnetic, thermal, or vibrational spectra). Our approach is grounded in functional data analysis (i.e., by modeling profiles as functions) and integrates conformal prediction and copula-based methods to detect unusual patterns. Theoretically, we guarantee the control of the probability of having one or more false positives (i.e. type I errors) along the domain. This control is achieved through the utilization of simultaneous functional conformal prediction bands which have been recently proposed in the literature. Our method enables concurrent control of false positive probability across the profile domain, even with limited sample sizes which are common for instance in 3D printing applications. Additionally, it identifies the localization of potential anomalies throughout the domain. Furthermore, to enhance interpretability and to increase the power of the proposed procedure, we extend the methodology by employing copulas to simultaneously monitor functions and their higher-order derivatives. An extensive simulation study showcases the potential of the proposed approach and proves the effectiveness of functional conformal prediction and the copula adjustment in detecting anomalies while controlling the probability of false positive. We finally illustrate the applicability of our methodology across various industrial applications.

Thursday, 8:00AM

ThA01

Room A, Villa Parravicini Revel

Advances in high-dimensional data analysis

Contributed Session

1 Multi-agent Sequential Decision Making for Optimal Design

Raed Al Kontar[1]

[1]University of Michigan

This presentation introduces a general purpose methodological framework for collaboration, wherein multiple entities (human, machines and digital twins) join forces to expedite and enhance the optimal design process. The framework particularly excels in delivering personalized solutions, especially in cases of heterogeneity, and is federated by nature, thereby preserving privacy and intellectual merit.

2 Ordinal Discriminative Dimensionality Reduction for Functional Profiles of Biosensor Signals

Giulia Patanè[1], Federica Nicolussi[1], Alexander Krauth[2], Gunther Gaugliz[2], Bianca Maria Colosimo[3], Luca Dede'[1], Alessandra Menafoglio[1]

[1]MOX, Department of Mathematics, Politecnico di Milano

[2]University of Tuebingen,

[3]Department of Mechanical Engineering, Politecnico di Milano

Optical biosensors, leveraging biological elements such as DNA and antibodies, prove to be efficient analytical instruments. Despite their effectiveness, the analysis of sensor signals, particularly within extensive datasets like reflectometric imaging sensors, poses challenges in terms of time consumption and memory usage. This communication introduces the application of a reflectometric imaging sensor to monitor the progression of antibody-antigen reactions through video images of the biosensor surface. Examining temporal changes in light intensity yields valuable insights into the reaction progression. However, the demand for an automated detector for biological process reactions necessitates the reduction of data dimensionality from the sensor, which is presented as functional profiles derived from video signals. A detailed workflow is presented, encompassing tasks such as addressing light disturbances, condensing video data, and reducing the dimensionality of the acquired functional data. Departing from conventional methods like Functional Principal Component Analysis (FPCA), we present functional-ordinal Canonical Correlation Analysis, a novel method enabling the optimization of the correlation between the high-dimensional predictor and the outcome. The conclusion emphasizes the synergy of preprocessing and CCA (Canonical Correlation Analysis) in effectively discriminating among different reagent concentration levels, facilitating the projection of the video signal into a 2-dimensional space. This innovative approach significantly bolsters our capability to discern virus vitality in biomanufacturing processes.

3 Robust Multivariate Singular Spectrum Analysis by RODESSA

Fabio Centofanti[1], Mia Hubert[2], Biagio Palumbo[1], Peter J. Rousseeuw[2]

[1]University of Naples Federico II, Department of Industrial Engineering

[2]Section of Statistics and Data Science, Department of Mathematics, KU Leuven, Belgium

Multivariate Singular Spectrum Analysis (MSSA) is a highly regarded technique for analyzing complex multivariate time series data applicable across various sectors including finance, healthcare, ecology, and engineering. Its effectiveness is compromised due to a lack of robustness to outliers, as it depends on singular value decomposition, which is notably vulnerable to anomalous data, potentially leading to skewed outcomes and inaccurate interpretations. In this work, we propose a robust MSSA variant called RObust Diagonalwise Estimation of SSA (RODESSA), which demonstrates resilience against both cellwise and casewise outliers. This method innovatively replaces the traditional decomposition phase with a robust low-rank estimation tailored to the unique structure of the trajectory matrix. A swift and efficient algorithm is presented, proven to reduce the objective function with each iteration. Additionally, we introduce a novel visualization tool, the enhanced time series plot, designed to identify and illustrate various outlier types. The effectiveness of RODESSA is validated through comprehensive Monte Carlo simulation, and its real-world applicability is showcased through temperature analysis in passenger railway vehicles. Acknowledgements: The research activity of F. Centofanti was carried out within the MICS (Made in Italy – Circular and Sustainable) Extended Partnership and received funding from the European Union Next-GenerationEU (PIANO NAZIONALE DI RIPRESA E RESILIENZA (PNRR) – MISSIONE 4 COMPONENTE 2, INVESTIMENTO 1.3 – D.D. 1551.11-10-2022, PE00000004). The research activity of B. Palumbo was carried out within the MOST - Sustainable Mobility National Research Center and received funding from the European Union Next-GenerationEU (PIANO NAZIONALE DI RIPRESA E RESILIENZA (PNRR) – MISSIONE 4 COMPONENTE 2, INVESTIMENTO 1.4 – D.D. 1033.17-06-2022, CN00000023). This work reflects only the authors' views and opinions, neither the European Union nor the European Commission can be considered responsible for them.

Thursday, 8:00AM

ThA02

Room B, Villa Parravicini Revel

Application of generative AI and LLM in quality engineering

Invited Session

1 Large-Language-Models (LLMs) for Time Series Analysis

Ziyue Li[1]

[1]**Department of Information Systems, University of Cologne, Germany**

This talk explores the application of large language models (LLMs) to the domain of time series analysis, leveraging their advanced capabilities for a variety of predictive tasks. We investigate the use of LLMs for time series prediction and spatiotemporal prediction, highlighting their effectiveness in capturing complex temporal and spatial dependencies. Furthermore, we delve into time series classification, demonstrating the models' proficiency in distinguishing patterns and anomalies within sequential data. A novel contribution of our work is the integration of time series and text dual modality, where we show how LLMs can simultaneously process and relate temporal data with textual information, enhancing the overall predictive accuracy and interpretability. Our comprehensive experiments reveal that LLMs, when applied to time series analysis, significantly outperform traditional methods, providing a robust framework for future research and practical implementations in this field.

2 Hierarchical Multi-label Classification for Fine-level Event Extraction from Aviation Accident Reports

Xinyu Zhao[1], **Hao Yan**[1], **Yongming Liu**[1]

[1]**Arizona State University, Tempe, USA**

A large volume of accident reports is recorded in the aviation domain, which greatly values improving aviation safety. To better use those reports, we need to understand the most important events or impact factors according to the accident reports. However, the increasing number of accident reports requires large efforts from domain experts to label those reports. In order to make the labeling process more efficient, many researchers have started developing algorithms to identify the underlying events from accident reports automatically. This article argues that we can identify the events more accurately by leveraging the event taxonomy. More specifically, we consider the problem a hierarchical classification task where we first identify the coarse-level information and then predict the fine-level information. We achieve this hierarchical classification process by incorporating a novel hierarchical attention module into BERT. To further utilize the information from event taxonomy, we regularize the proposed model according to the relationship and distribution among labels. The effectiveness of our framework is evaluated with the data collected by National Transportation Safety Board (NTSB). It has been shown that fine-level prediction accuracy is highly improved, and the regularization term can be beneficial to the rare event identification problem.

3 Multi-Agent Causal Discovery Using Large Language Models

Chen Zhang[1]

[1]**Department of Industrial Engineering, Tsinghua University, Beijing, China**

Large Language Models (LLMs) have demonstrated significant potential in causal discovery tasks by utilizing their vast expert knowledge from extensive text corpora. However, the multi-agent capabilities of LLMs in causal discovery remain underexplored. This paper introduces a general framework to investigate this potential. The first is the Agents-only model, which relies exclusively on reasoning and discussions among LLM agents to conduct causal discovery. The second is the Coding agents model, which leverages the agents' ability to plan, write, and execute code, utilizing advanced statistical libraries for causal discovery. The third is the Hybrid model, which integrates both the Agents-only model and Coding agents model approaches, combining the statistical analysis and reasoning skills of multiple agents. Our proposed framework shows promising results by effectively utilizing LLMs' expert knowledge, reasoning capabilities, multi-agent cooperation, and statistical causal methods. By exploring the multi-agent potential of LLMs, we aim to establish a foundation for further research in utilizing LLMs multi-agent for solving causal-related problems.

Thursday, 9:00AM

ThB01

Room A, Villa Parravicini Revel

QSR Flash talks

1 Data-driven Condition Monitoring Framework for Heat Exchanger Slagging in Coal-fired Power Plants

Seonggwan Son[1], **Hyeongju Yu**[2], **Seongjoon Kim**[1]

[1]**Chosun University, Gwangju, Republic of Korea**

[2]**Korea Midland Power (KOMIPO), Boryeong, Republic of Korea**

In this study, we present a data-driven framework designed for the condition monitoring of heat exchangers in coal-fired power plants, specifically addressing the challenge of slagging — a critical efficiency-reducing factor caused by ash accumulation. In the literature, conventional slagging assessment methods require a deep understanding of boiler combustion physics and design, limiting their applicability to different boiler types and requiring complex model adjustments. The proposed framework avoids the need for such domain knowledge by using multiple machine learning models, thereby increasing the applicability without requiring customization for different boiler types. We propose a feature extraction technique to measure slagging severity and

an online monitoring algorithm to provide operators with real-time insights for optimal boiler operation. The proposed framework has been validated at two power plant sites in South Korea, effectively capturing the slagging status and supporting the stable boiler operation.

2 Battery Consumption Prediction Model for Micro Electric Vehicles: A Real-World Prediction Approach

Ingyu Choi[1], Seongjoon Kim[1]
[1]Chosun University, Gwangju, Republic of Korea

As Micro Electric Vehicles (MEVs) gain popularity for urban transportation, managing their limited battery capacity becomes critical. This study presents a predictive model for MEV battery consumption based on extensive driving data to improve usage efficiency and planning. Our two-step approach combines a detailed consumption model with a novel driving profile extractor, simplifying to a single-input model for practical application. Validated with real-world data, the proposed model reliably predicts driving range and vehicle availability, providing a valuable tool for optimizing MEV operations.

3 Early Detection of Field Reliability Issues Using Hazard Rate Models on Warranty Data

Yuri Kim[1], Inkyu Choi[1], Seongjoon Kim[1]
[1]Chosun University, Gwangju, Republic of Korea.

This study presents a method for monitoring and early detection of reliability problems in the marketplace using random effects hazard rate models developed for the dynamic nature of continuous product sales and warranty claims. Conventional models often struggle to capture the real-time characteristic of the market because they tend to focus on static data sets. The proposed method aims to improve early detection capabilities by using the random effects hazard rate model and performing multiple hypothesis testing on monthly sales and warranty data. Through numerical analysis and application to real-world data, we demonstrate the accuracy and timeliness of the proposed method in identifying reliability problems.

4 Reliability Modeling and Maintenance Optimization of Performance-Based Balanced Systems

Tianzi Tian[1], Jun Yang[1], Changzhen Zhang[1]
[1]Beihang University, Beijing, China

Performance-based balanced systems (PBSs) are widely used as critical equipment in many fields, so their reliability assessment has become a hot topic. Taking the battery pack PBS as an example, the balance means the performance differences between components are within an acceptable range, where the common bus is used to redistribute the performance for rebalancing, and the redistribution is affected by the transmission loss and transmission capacity limit. To reflect the above characteristics, a reliability evaluation method is proposed for PBSs with common bus performance sharing (PBSs-CBPS) considering balance degree threshold, transmission loss, and transmission capacity limit. Firstly, a continuous-time discrete-state Markov model is built to address the complex transition behaviors of components. Next, to further consider the effects of balance degree threshold and transmission loss, the rebalancing process is formulated as a nonlinear programming problem to obtain components' performance after rebalancing, and the system reliability model is established. Then, the universal generation function (UGF) method combined with nonlinear programming is proposed to calculate system reliability, and Paper-Cut UGF Algorithm (PCUGF) is proposed to improve computational efficiency. Finally, an analytical example and a numerical example of 6S1P lithium-ion battery packs are given to show the effectiveness of the proposed method.

5 Quality evaluation for wind turbine design by an uncertain HoQ

Wanwan Zhang[1]
[1]Norwegian University of Science and Technology, Trondheim, Norway

A horizontal axis wind turbine was designed from scratch and tested in a semirealistic scenario. Different methods to design and build a blade as well as a generator are described. The aim of the project is reaching the maximum efficiency with the predefined conditions under computational experiments. With the given constraints for the project, the blade is designed using the Blade Element Momentum (BEM) method and the chosen NACA prole, while the type of generator selected is a single-phase generator with four poles. After building the generator and blade separately, the two components were installed and tested together in the wind tunnel. Finally, the results from the wind tunnel are evaluated. The designed blade achieves an efficiency of calculated of 42% and the generator transforms energy with an efficiency of 67 %. The construction of the wind turbine is considered a success.

6 Application of Lean Principles in the Pakistani Cattle Feed Industry

Arsalan Fayyaz[1], ChenGuang Liu[1], Yan Xu[1], Ammara Farooq[1], Wei Xin[2], Fahad Khan[1]
[1]School of Management, Northwestern Polytechnical University, Xi'an 710072, China
[2]Cancer specialist in Shaanxi Provincial Hospital, Xi'an, Shaanxi, China

The need for sustainable food production systems cannot be overstated, with an expected 59–98% growth in food demand and a predicted 9.8 billion people globally by 2050. This research focuses on the significance of cattle farming, which supplies beef, veal, and milk to the $178.2 billion market. Cattle farming is a significant linkage in the food supply chain. Due to their limited purchasing capacity, especially in developing countries, small-scale farmers encounter difficulties even with the development of specialist cattle feed

items. Minimizing the costs associated with producing cattle feed could close this gap and help farmers and producers produce more efficiently. Initially, we used time and motion studies to calculate the productivity per station, and then we opted for a product-oriented approach; we chose a product size that was in high order and designed pallets on which sacks could fit easily, and those pallets were easy to put in containers via forklift. This study aims to lower the price difference between XYZ Feeds, Pakistan's biggest producer of cow feed, and traditional alternatives. XYZ feeds industry knows that applying "lean" manufacturing concepts to their current production operations can help their industry find and remove inefficiencies involved in their daily operations. As per preliminary assessments, critical non-value-added activities, notably in material mobility, are found in the cattle-feed industry. This study tries to enhance on-floor machine productivity by optimising personnel use and utilising lean manufacturing principles effectively. Moreover, the suggested pattern changes will improve transportation productivity by 45% daily, lowering carbon emissions. In addition, by focusing on covered areas for inventory management, this study tries to manage raw materials and finished goods effectively while reducing labour, rework, extra movement, and risks involved in the entire lead time. Integrating lean principles into the cattle-feed industry covers a research gap. It promises sustainable, cost-effective, and efficient food production practises vital for meeting the demands of a growing global population.

Thursday, 10:20AM

ThC01

Room A, Villa Parravicini Revel
History and frontiers in Quality Engineering
Contributed Session

1 A Brief History of AI Impacting Statistical Process Monitoring Research and Future Directions

Shing I Chang[1], Parviz Ghafariasl Ganjinehketab[1]
[1]Kansas State University, Manhattan, Kansas, USA

It has been long overdue to revamp the existing statistical process control (SPC) or statistical process monitoring (SPM) approaches in manufacturing or service industries since Water Shewhart first proposed the use of control charts in 1924. The techniques applied to SPM applications are mostly statistically oriented in the last 100 years. The recent advances in Artificial Intelligence (AI) have reinvigorated the opportunities of adopting AI for SPC or SPM research and applications. This talk first reviews a brief history of AI methods such as neural networks for SPC applications started in 1990s. Then a literature review will shed light on the AI/ML influenced SPC applications from 2000-2019. In this regard, machine learning (ML) is considered a branch of AI. Then, AI/ML/SPM works in the last five years will be reviewed and discussed in an attempt for spotting the trend. Finally, the direction of future AI impacting SPM will be articulated for the next five years.

2 FCOM: A Federated Collaborative Online Monitoring Framework via Representation Learning

Tanapol Kosolwattana[1], Huazheng Wang[2], Raed Al Kontar[3], Ying Lin[1]
[1]University of Houston, Houston, TX, USA
[2]Oregon State University, Corvallis, OR, USA
[3]University of Michigan, Ann Arbor, MI, USA

Monitoring a large population of dynamic processes with limited monitoring resources poses a significant challenge across various industrial sectors due to 1) the inherent disparity between the limited monitoring resources available and the large population of processes to be monitored and 2) the unpredictable and heterogeneous dynamics inherent in the progression of these processes. Online learning approaches, commonly referred to as bandit methods, have demonstrated notable potential to solve this problem by dynamically allocating limited resources, effectively balancing the exploitation of processes yielding high rewards, and the exploration of uncertain processes. However, most online learning algorithms are designed under 1) a centralized setting that requires data sharing across processes to obtain an accurate prediction or 2) a homogeneity assumption that estimates a single global model from the decentralized data. To overcome these limitations and facilitate online learning in a heterogeneous population under a decentralized setting, we propose a federated collaborative online monitoring method. Our approach captures the latent representative models inherent in the population through representation learning and designs a novel federated collaborative UCB algorithm to estimate the representative models from sequentially observed decentralized data. This allows an informed strategy for monitoring resource allocation. The efficiency of our method is illustrated through theoretical analysis, simulation studies, and decentralized cognitive degradation monitoring in Alzheimer's disease.

3 Multi-physics Guided Generative Diffusion Models with Manufacturing Applications

Naichen Shi[1], Hao Yan[2], Raed Al Kontar[1]
[1]University of Michigan, Ann Arbor, MI, USA
[2]Arizona State University, Tempe, USA

Generative AIs are revolutionizing multiple fields of science and engineering. Denoising diffusion models are the core of several prevailing image and video generation AIs. Despite the impressive performance, a caveat of the diffusion model is the lack of understanding of the physical world. As a result, the predictions from video diffusion models lack long-term time consistency, even for state-of-the-art models like SORA. In this work, we propose a simple yet effective method to integrate physical knowledge into the diffusion model.

Specifically, when the underlying physics of the dynamic system is characterized by partial differential equations (PDEs), we leverage approximate solutions of the PDEs to inform the diffusion process. This approach marries the strong data pattern representation power of diffusion models with domain-specific physics knowledge, presenting a data-driven method for realistic physics simulation. In practice, our method can generate high-fidelity thermal video frames from laser-based metal powder deposition additive manufacturing processes.

Thursday, 10:20AM

ThC02

Room B, Villa Parravicini Revel

AI and Analytics for Condition Monitoring and Maintenance

Contributed Session

1 Managing predictive maintenance and production planning for a smart manufacturing system

Hanchao Wang[1], Xiaoyan Zhu[1], Tao Yuan[2]
[1]University of Chinese Academy of Sciences, Beijing, China
[2]Ohio University, USA

The new scientific and technological revolution is emerging around the world. Rapidly developing intelligent sensing technology makes it possible to obtain degradation data on equipment in a smart manufacturing system, and big data technology makes it possible to obtain demand information from market promptly. Consequently, it is possible to make decisions as and when required regarding the course of any critical operation in smart manufacturing. For a smart manufacturing system, assets maintenance and production operations are two critical decisions and are closely related. To minimize the total maintenance and operation cost, including corrective and preventive maintenance costs, costs due to asset failure and production downtime, inventory holding cost, lost sales cost, and so on, of a production system, it is necessary to consider joint optimization of maintenance strategy and production planning with uncertain demand in a continuous manner. Aiming at solving this problem for an infinite time horizon, an online approach of predictive maintenance and production planning (PdM&PP) is established, making full use of monitoring degradation data and market demand information simultaneously. The proposed approach is based on a rolling horizon schema, which decomposes the optimization problem in a large scale of a dimension into a series of tractable finite-period subproblems with the same model structure. The approach also adopts a novel data-driven RUL prediction method and a mixed integer linear programming optimization. Over a rolling horizon, the PDM&PP approach predicts the remaining useful lifetimes of assets and forecasts the product demands, next uses these pieces of information in the joint optimization model to simultaneously determine the maintenance actions and production plan, then implements the maintenance and production decisions to the production system at the time required, and finally updates the system production state and collects the latest monitoring data. The approach is validated on the public dataset C-MAPSS. The performance of the proposed PDM&PP approach is compared with an approach that separates maintenance decision-making without considering production demand and making production decisions without considering availability of maintenance. A series of Monta Carlo simulation experiments are conducted, and effectiveness and robustness of the proposed approach are verified.

2 Optimal Abort Policy for Mission-Critical Systems under Imperfect Condition Monitoring

Qiuzhuang Sun[1], Jiawen Hu[2], Zhi-Sheng Ye[3]
[1]The University of Sydney, Australia
[2]UESTC, China
[3]National University of Singapore, Singapore

While most on-demand mission-critical systems are engineered to be reliable to support critical tasks, occasional failures may still occur during missions. To increase system survivability, a common practice is to abort the mission before an imminent failure. We consider optimal mission abort for a system whose deterioration follows a general three-state (normal, defective, failed) semi-Markov chain. The failure is assumed self-revealed, while the healthy and defective states have to be predicted from imperfect condition monitoring data. Due to the non-Markovian process dynamics, optimal mission abort for this partially observable system is an intractable stopping problem. For a tractable solution, we introduce a novel tool of Erlang mixtures to approximate non-exponential sojourn times in the semi-Markov chain. This allows us to approximate the original process by a surrogate continuous-time Markov chain whose optimal control policy can be solved through a partially observable Markov decision process (POMDP). We show that the POMDP optimal policies converge almost surely to the optimal abort decision rules when the Erlang rate parameter diverges. This implies that the expected cost by adopting the POMDP solution converges to the optimal expected cost. Next, we provide comprehensive structural results on the optimal policy of the surrogate POMDP. Based on the results, we develop a modified point-based value iteration algorithm to numerically solve the surrogate POMDP. We further consider mission abort in a multi-task setting where a system executes several tasks consecutively before a thorough inspection. Through a case study on an unmanned aerial vehicle, we demonstrate the capability of real-time implementation of our model, even when the condition-monitoring signals are generated with high frequency.

3 Efficient Asymptotics for Condition-Based Replacement Thresholds

Poulad Moradi Shahmansouri[1]

[1]University of Luxembourg

Condition-based maintenance aims to proactively plan actions to prevent equipment failure while considering economic implications. In this study, we address the problem of a component experiencing independent and identically distributed incremental degradation, wherein failure occurs upon surpassing a threshold of accumulated degradation. Our approach involves inspecting the component at regular intervals and deciding whether replacement is necessary. Although this problem has been extensively studied, computing optimal replacement policies necessitates dynamic programming, presenting challenges in implementation and tractability. To address these issues, we conduct an asymptotic analysis of optimal replacement thresholds and cost rates, leading to the development of an efficient replacement heuristic with an asymptotic performance guarantee. Our extensive numerical experiments show that the average optimality gap of our heuristic replacement policy is at most 0.01% when the incremental degradation follows a discrete distribution and 0.52% when the distribution is continuous. Notably, the heuristic outperforms the exact algorithm in terms of computational time by over 1000 times. Furthermore, we are extending our analysis to situations where the parameters of the incremental degradation distribution are unknown, necessitating a learning approach.