NSFC-RGC 2025

http://nsfc-rgc2025.com/

Frontiers of Digital twin in Intelligent Manufacturing and Smart cities

CONFERENCE HANDBOOK

25 – 28 April 2025

Lee Shau Kee Lecture Centre, HKU, Hong Kong, China

The conference was supported by a grant from the Joint Research Scheme sponsored by the Research Grants Council of the Hong Kong Special Administrative Region, China and the National Natural Science Foundation of China (Reference No. N_HKU7130/24)

Welcome Message from the Conference Chairs

Welcome to the International Conference on Frontiers of Digital Twin in Intelligent Manufacturing and Smart Cities (NSFC-RGC 2025), hosted by the esteemed academic institutions of the National Natural Science Foundation of China (NSFC) and the Research Grants Council (RGC) of Hong Kong. This landmark event will be held from 25 April 2025 to 28 April 2025, in Hong Kong, offering a dynamic platform to advance research and collaboration in sustainable development, resilient technologies, and cutting-edge innovations for the future.

This conference has seen an exceptional level of engagement, with submissions from authors representing countries around the world, a testament to the global appeal and relevance of this event. After a rigorous peer-review process, we are proud to feature an impressive selection of high-quality research, showcasing diverse topics. Attendees will have the opportunity to engage with distinguished speakers, including keynote addresses, editor forum, and panel discussions led by world-renowned scientists and industry leaders.

The NSFC-RGC 2025 conference theme reflects the urgent need to address the application and exploration of digital twin in intelligent manufacturing and smart cities through interdisciplinary research and collaboration. With the rapid development of the global scientific and technological level, this event serves as a critical forum for exploring transformative ideas and strategies that drive progress across academia, industry, and society.

Participants can look forward to an intellectually stimulating program that includes keynote speeches from leading experts, technical sessions showcasing groundbreaking research, interactive panels, and networking opportunities. This conference not only fosters the exchange of ideas but also builds bridges between disciplines, creating fertile ground for collaboration.

We are thrilled to welcome you to NSFC-RGC 2025. Your contributions and participation make this conference a success, and we look forward to an engaging and inspiring event that advances the frontiers of knowledge in this critical field.

Prof. Ray Y. Zhong
Conference Chair
The University of Hong Kong
Hong Kong, China

Prof. Qinglin Qi
Conference Chair
Beihang University
Beijing, China

The conference was supported by a grant from the Joint Research Scheme sponsored by the Research Grants Council of the Hong Kong Special Administrative Region, China and the National Natural Science Foundation of China (Reference No. N_HKU7130/24)

Conference Co-Chairs

From Hong Kong

Prof. Yu Yantao

Assistant Professor, Department of Civil and Environmental Engineering, The Hong Kong University of Science and Technology

Prof. Yi Wen

Assistant Professor, Department of Building and Real Estate, The Hong Kong Polytechnic University

Prof. Lu Guoyang

Assistant Professor, Department of Architecture and Civil Engineering, City University of Hong Kong

Prof. Xue Fan

Associate Head (Research) and Associate Professor, Department of Real Estate and Construction, The University of Hong Kong

Prof. Zheng Pai

Associate Professor, Department of Industrial and Systems Engineering, The Hong Kong Polytechnic University

Prof. Gao Siyang

Associate Professor, Department of Systems Engineering, City University of Hong Kong

Prof. Long Zhuoyu Daniel

Associate Professor, Department of Systems Engineering and Engineering Management, The Chinese University of Hong Kong

Prof. Weng Yiwei

Assistant Professor, Department of Building and Real Estate, The Hong Kong Polytechnic University

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From Mainland

Prof. Tao Fei

Professor, International Research Institute for Multidisciplinary Science, Beihang University

Prof. Chen Ke

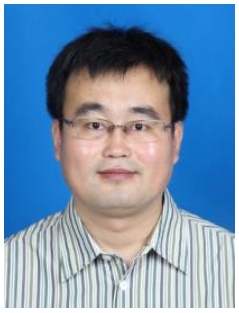
Associate Professor, School of Civil and Hydraulic Engineering, Huazhong University of Science and Technology

Prof. Hu Tianliang

Professor, School of Mechanical Engineering, Shandong University

Prof. Bao Jinsong

Professor, College of Mechanical Engineering, Donghua University



Prof. Wang Junqiang

Professor, Institute of System Integrated and Engineering Management, Northwestern Polytechnical University

Prof. Liu Qiang

Professor,School of Electromechanical Engineering, Guangdong University of Technology

Prof. Liu Jianhua

Professor, School of Mechanical Engineering, Beijing University of Technology

Prof. Qin Wei

Associate Professor, Department of Industrial Engineering and Management, Shanghai Jiaotong University

Prof. Zhou Guanghui

Professor, School of Mechanical Engineering, Xi'an Jiaotong University

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Local Organizing Team Members

Prof. Cheng Yao, HKU Hong Kong, China

Prof. Kuo Yong-Hong, HKU Hong Kong, China

Prof. Li Jiayang, HKU Hong Kong, China

Prof. Xu Yang, HKU Hong Kong, China

Prof. Zhang Fangni, HKU Hong Kong, China

Dr. Besklubova Svetlana, HKU Hong Kong, China

Dr. Kang Kai, HKU Hong Kong, China

Dr. Huzaifa Raza, HKU Hong Kong, China

Dr. Pan Yanghua, HKU Hong Kong, China

Dr. Ma Lin, HKU Hong Kong, China

Ms. Dai Yaqi, HKU Hong Kong, China

Mr. Yu Chenglin, HKU Hong Kong, China

Mr. Ding Haoran, HKU Hong Kong, China

Mr. Su Shuaiming, HKU Hong Kong, China

Ms. Yin Li, HKU Hong Kong, China

Mr. Zhao Shuxuan, HKU Hong Kong, China

Mr. Zhu Zhengxu, HKU Hong Kong, China

Mr. Guo Xinyue, HKU Hong Kong, China

Mr. Li Yi, HKU Hong Kong, China

Ms. Ng Chung Lam, HKU Hong Kong, China

Mr. Chen Wei, HKU Hong Kong, China

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Conference Venue

Grand Hall HKU

Google Map

Please scan the QR code for the detailed location information of Lee Shau Kee Lecture Center/ Grand Hall

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Conference Sponsors/Partners

Hosted by

香 港 大 學
THE UNIVERSITY OF HONG KONG

THE HONG KONG POLYTECHNIC UNIVERSITY
香港理工大學

香港科技大學
THE HONG KONG UNIVERSITY OF SCIENCE AND TECHNOLOGY

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The Chinese University of Hong Kong

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香港城市大學
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University Grants Committee

NSFC
National Natural Science Foundation of China

Mainland/Hong Kong Collaborators

Supported by

CMES
中国机械工程学会

Key Information

Conference Registration

URL: http://nsfc-rgc2025.com/registration

Registration Category	Early Bird Rate (if paid by April 09, 2025)	Normal Rate (after April 09, 2025)
General Registration Fee	4500 HKD	4800 HKD
Student Registration Fee	3000 HKD	3500 HKD
Additional Conference Banquet Ticket	1000 HKD	1500 HKD
HKU DASE MSc Student	50 HKD	50 HKD

Catering

• **Welcome reception** - Lee Shau Kee Lecture Centre
• **Coffee break** –Lee Shau Kee Lecture Centre
• **Lunch** – Lee Shau Kee Lecture Centre (The lunch box will be provided)
• **Gala Dinner** – Hotel Alexandra, North Point (Bus service will be provided from HKU to the dinner venue)

WiFi Access

If you are a visitor to HKU and wish to use the WiFi network, you can use your device to navigate to Settings; then WiFi; and select the Wi-Fi.HK via HKU.

Presentation Format

- Each presentation should be a maximum of 15 minutes, followed by 5 minutes Q&As.
- There are no specific templates for the PPT file. However, presenters must ensure their texts and images are readable and understandable.
- Presenters must come and provide their PPT file to the room's volunteer at least 15 minutes before the event. The presenter's responsible for checking the PPT file and USB port, as we won't let presenters connect their laptops to the HKU system due to internet security protocol.

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Accommodation Recommendations for Conference Attendees

We are pleased to recommend the following hotels near the University of Hong Kong for your convenience, offering a range of comfort and amenities to suit various preferences. To make a reservation, please click the hotel name, which will take you to their official booking page. We recommend early booking due to high demand during the conference period.

JEN Hong Kong by Shangri-La

Address: 508 Queen's Road West, Western District, Hong Kong

Price Range: HK$ 1100–2300 per night

Proximity to HKU: ★★★★★

One-Eight-One Hotel & Serviced Residences

Address: 181 Connaught Road West, Sai Wan, Hong Kong

Price Range: HK$ 1700–2500 per night

Proximity to HKU: ★★★★☆

Courtyard by Marriott Hong Kong (Sai Ying Pun)

Address: 167 Connaught Road West, Sai Ying Pun, Hong Kong

Price Range: HK$ 1200–2000 per night

Proximity to HKU: ★★★★☆

Eco Tree Hotel

Address:156-160 Des Voeux Road West, Sai Ying Pun, Hong Kong

Price Range: HK$ 900–1800 per night per night

Proximity to HKU: ★★★★☆

Keynote Speeches

Prof. Xiangsheng Chen (Chinese Academy of Engineering, 中國工程院院士)

陈湘生，中国工程院院士，俄罗斯工程院外籍院士，深圳市高层次人才国家级领军人才，享受国务院政府特殊津贴专家。深圳大学教授，博士生导师，土木与交通工程学院院长，未来地下城市研究院院长，滨海城市韧性基础设施教育部重点实验室主任，矿山深井建设技术国家工程研究中心主任；兼任深圳市地铁集团有限公司技术委员会主任、煤炭科学研究总院北京建井研究院院长。长期从事地下工程控制地层变形技术的研发工作。建立了人工冻土物理力学基本体系；构建了深井冻结壁和冻结管变形极限双控的时空设计理论体系和公式，解决了防控冻结管断裂淹水难题；研制了首套离心机土壤冻-融循环模拟装置并提出了抑制冻-融的实用技术；研发了水平冻结技术，为地下工程中防控突水涌砂提供了金钥匙。创建了地铁隧道下穿建筑物的“掘-测-智-控”群泵注浆矫正建筑物的控制变形技术；带领研发了跨地铁运营隧道的地下空间施工“加固-跳挖-反压-隔离-精测”的控制地层变形组合技术，将运营隧道规范控制限值降到 3 米以内，释放了地铁安保区原来无法利用的大量土地资源。获国家科技进步奖 3 次。出版专著 8 部、国内外正式刊出论文 90 余篇。

Prof. Anthony G.O. Yeh (Chinese Academy of Sciences, 中國科學院院士)

Professor Anthony G.O. Yeh is a Member of the Chinese Academy of Sciences and the Hong Kong Academy of Sciences, Chair Professor in Urban Planning and GIS at the University of Hong Kong. He has been Director of GIS Research Centre, Dean of Graduate School of the University of Hong Kong. He is also a Fellow of TWAS (The World Academy of Sciences), Academy of Social Sciences in the UK, Hong Kong Institute of Planners (HKIP), Royal Town Planning Institute (RTPI), Planning Institute of Australia (FPIA), Royal Institution of Chartered Surveyors (RICS) and Chartered Institute of Logistics and Transport (CILT). One of his research areas is the applications of geographic information systems (GIS) as planning support system in smart city and urban development and planning. He has been President of Asia GIS Association, Founding Secretary-General of the Asian Planning Schools Association and Asia GIS Association, Founding President of the Hong Kong GIS Association, Chairman of the Hong Kong Geographical Association, Vice-President of the Commonwealth Association of Planners, Vice-President of the Hong Kong Institute of Planners, and Chairman of the Geographic Information Science Commission of the International Geographic Union (IGU).

Speech Title: Self-Learning Digital Twin for Smart Cities

Abstract

Digital twin provides a continuous real time exchange of data, analysis, and feedback between the physical space (the city) and the cyberspace (the digital model). A reliable and accurate short-term traffic forecasting system is crucial for the successful deployment of any intelligent transportation system. A lot of forecasting models have been developed in recent years but none of them could consistently outperform the others. In real-world applications, traffic forecasting accuracy can be affected by a lot of factors. The impacts of long-term changes to traffic patterns to short-term traffic forecasting are profound and this can easily make an existing forecasting system to be outdated. It is very important for forecasting systems to detect long-term changes in traffic patterns and make updates accordingly. Digital twin offers an opportunity to implement the automatic self-learning system in transport modelling for enhancing the adaptability of traffic forecasting model in improving traffic forecasting.

Prof. Lihui Wang (KTH, Canadian Academy of Engineering)

Professor Lihui Wang is a Chair in Sustainable Manufacturing and the Director of Centre of Excellence in Production Research (XPRES) at KTH Royal Institute of Technology, Sweden. His research interests are primarily focused on condition monitoring, human-robot collaboration, brain robotics, cyber-physical production systems, and predictive maintenance. Professor Wang is actively engaged in various professional activities. He is the Editor-in-Chief of Robotics and Computer-Integrated Manufacturing, International Journal of Manufacturing Research, and Journal of Manufacturing Systems. He has published 11 books and authored in excess of 750 scientific publications. Professor Wang is a Fellow of Canadian Academy of Engineering, AET, CIRP, SME and ASME; the President (2020-2021) of North American Manufacturing Research Institution, and the Chairman (2018-2020) of Swedish Production Academy. He was elected one of the 20 Most Influential Professors in Smart Manufacturing in 2020 and a Gold Medal recipient in 2024, both from Society of Manufacturing Engineers.

Speech Title: Condition Monitoring for Predictive Maintenance

Abstract:

Reliable product services depend on the timely acquisition, distribution, monitoring, analytics and utilisation of usage information from the products across spatial boundaries. These activities can improve accuracy and reliability in utilising the products, and help in maintenance scheduling to bring the products back to normal service conditions. As an emerging tool, digital twin (often combined with big data analytics) provides new opportunities to achieve this objective. This presentation will first present the current status and the latest advancement of relevant technologies in general, and digital twin in particular. In order to understand such new technologies and their future potential, definitions and characteristics among them will be explained. This talk will then project their future growth enabled by digital twin. Research and applications will also be outlined to highlight the latest advancement in the field. While digital twin shows great promise in the future, challenges towards Internet-of-Everything in the areas of future trends remain to be identified in this talk.

Prof. Zhiliang Gao (Member of RAE)

高志亮，教授，长安大学智慧油气田研究院荣誉院长、首席专家，数字与数据科学研究中心主任，广东财经大学数字经济学院特聘教授。 长期从事数字与数据科学、中国数字油田与跨境数字贸易研究，是国内数字与数据研究的知名专家，先后出版发行了十多部数字油气田研究和数字与数据科学专著， 拥有 20 多项发明及其他专利，其中数能转换定律在 2024 年 4 月获得日内瓦发明展金奖等，2022 年 4 月当选俄罗斯工程院外籍院士，同西安贵隆数字化工程科技有限责任公司建有外籍院士工作站。

题目：数字与数据科学的数能转换定律研究与探讨

摘要

数字与数据来源于物质、事物，又还原于物质、事物，形成了数字理论与数据原理，构成了数字与数据的科学，成为无尽的前沿。自数字与数据科学诞生以来其伴随着人类社会的进步与科学技术的发展，成就过无数的科学技术与无数个科学家，并创建了数字与数据的新文明。在今天，数能转换定律以数字生产力与数据生产要素作为最强新质生产力，转换成新的社会能量与经济动能在推动着数字化时代与数据社会的进步，数字与数据科学在以城市、土地、矿产、制造业数据空间与可信价值数据中完成价值生产与价值增值，将具有良好的表现。报告给出了数字与数据科学模型、数能转换定律模型与跨境数字贸易中城镇土地空间及可信价值数据模型进行探讨。

数字改变世界，数据成就未来。

Prof. George Q. Huang

Professor George Q. Huang joined Department of Industrial and Systems Engineering at The Hong Kong Polytechnic University as Chair Professor of Smart Manufacturing and Director of PolyU Research Institute of Advanced Manufacturing (RIAM). George graduated from Southeast University (China) with BEng and Cardiff University (UK) with PhD degrees respectively. George has been working on smart manufacturing ever since his PhD study and continued and expanded into smart logistics and smart construction with substantial research grants from governments and industries. He published extensively in the related fields and his works have been widely cited with the research community. He served as senior / department / area / regional / associate editors and on editorial boards of more than a dozen of reputable journals. George is Chartered Engineer (CEng), Fellow of IEEE, ASME, IISE, IET, CILT and HKIE.

Title of Keynote: Three Laws of Digitization for Industry 4.0 Cyber-Physical Systems

Abstract

To automate or to digitize, this is no longer a question for industrial transformation. While automation is situational, digitization is imperative to develop Industry 4.0 smart manufacturing cyber-physical systems. Both strategies share the same aim at creating values, critical masses and interoperability. But they lead to differing cost and impacts when operational settings vary. If industrial operations are repetitive and the repetition is substantial with prevailing certainty, then automation is an appropriate strategy for most cost-effective industrial transformation. However, significant proportion of industrial operations are still human-centric and cannot be fully automated. Digitization is often associated with so-called “Three High Problems”, namely high cost, high risk and high technical threshold. This talk presents three laws for tackling the Three High Problems. The Three Laws are (i) The First Law of Universal Value – The Value Law; (ii) The Second Law of Sharing Equilibrium – The Sharing Law; and (iii) The Third Law of Cyber-Physical Entanglement – The Entanglement / Coupling Law. The talk will outline the principles and properties of the three laws and demonstrate how they can be utilized for cost-effective digitization.

Prof. Fei Tao

陶飞，教育部长江学者特聘教授（2019），现任北航国际前沿交叉科学研究院院长、北航党委人才办副主任、国家智能制造专家委员会委员、“十四五”国家重点研发计划工业软件重点专项总体专家组专家。长期从事数字孪生与数字工程、智能制造与装备、制造工业软件等教研工作。第一作者出版专著 5 部，在 Nature 等期刊上发表 30 余篇 ESI 高被引论文，单篇引用 1000 次以上 9 篇，总被引用 4 万余次；连续六年入选科睿唯安全球高被引学者和 Elsevier 中国高被引学者（2019-2024）。第一完成人带领团队获国家科技进步二等奖 2 项、教育部自然科学一等奖、中国机械工业技术发明一等奖和科技进步一等奖、中国青年科技奖、北京市教学成果二等奖等。现任中国机械工程学会和中国图学学会理事、《Digital Engineering》国际期刊创刊主编、RCIM 副主编、CIRP 通信会员等。2023 年获科学探索奖、入选美国 SME 智能制造 Top 20 最具影响力学者（2021），创办《Digital Twin》国际期刊、国际论坛和国际会议。

题目：复杂装备生命周期数字孪生与数字工程理论及实践

摘要

在新环境、新趋势、新背景下，装备系统数字化、智能化、网络化、体系化转型需求迫切。报告在总结分析中国近 20 年数字化进程基础上，阐述数字工程 1.0 到 5.0 的演化进程。对实现数字工程的核心支撑，数字孪生的国内外研究应用现状进行分析，并探讨数字孪生成熟度和概念。从复杂装备全生命周期新需求出发，探讨复杂装备全生命周期数字工程的概念、理论框架、关键技术及应用场景，并介绍团队在空天装备、纺织装备、工业装备等高端复杂装备数字试验验证、智能制造、运维管控方面的理论研究与工程实践工作。

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Editors Forum

Prof. Lihui Wang (KTH, Canadian Academy of Engineering)

Chair Professor in Sustainable Manufacturing and the Director of Centre of Excellence in Production Research (XPRES) at KTH Royal Institute of Technology, Sweden.

Editor-in-Chief:

- Robotics and Computer-Integrated Manufacturing
- International Journal of Manufacturing Research
- Journal of Manufacturing Systems

Prof. Fei Tao (Beihang University)

Distinguished Professor of the Changjiang Scholars Program of the Ministry of Education (2019), National Leading Talents, Dean of the International Institute of Interdisciplinary and Frontiers at Beihang University.

Founding Editor-in-Chief:

- Digital Engineering
- Digital Twin

Prof. Hui Fu (Guangdong University of Technology)

Professor in School of Electromechanical Engineering, Consulting expert of Urban Logistics Planning Institute of China Transportation Education Research Association, Vice Chairman and Secretary General of Industrial Engineering Branch of Guangdong Mechanical Engineering Society, Director of the Journal Center of Guangdong University of Technology.

Editor-in-Chief:

- 《工业工程》

Prof. Dengsheng Wu (Shenzhen University)

Professor in College of Management, Distinguished Young Scholars of the NSFC, Director of the Management Science and Engineering Society, Supervisor of Chinese Society of Optimization, Overall Planning and Economical Mathematics.

Associate Editor:

- 《中国管理科学》
- Annals of Data Science

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Program Summary

Day 1: Friday, 25th of April, 2025 **Lee Shau Kee Lecture Centre and Lecture Rooms, LG Centennial Campus, HKU**	
16:00~19:00	Registration
18:00~20:00	Welcome Reception

Day 2: Saturday, 26th of April, 2025 **Lee Shau Kee Lecture Centre and Lecture Rooms, LG Centennial Campus, HKU**		
Time	Event	Host
08:50~09:30	Registration	
09:30~09:55	Opening Address	Prof. Ray Y. Zhong
09:55~10:00	Group Photo	
10:00~10:30	Keynote Speech 1 (Prof. Xiangsheng Chen)	Prof. Ray Y. Zhong
10:30~11:00	Keynote Speech 2 (Prof. Anthony G.O. Yeh)	Prof. Xiaowen Fu
11:00~11:30	Coffee Break	
11:30~12:00	Keynote Speech 3 (Prof. George G.Q. Huang)	Prof. Wei Pan
12:00~13:30	Lunch	
13:30~15:30	Parallel Sessions	
15:30~16:00	Coffee Break	
16:00~18:00	Parallel Sessions	

Day 3: Sunday, 27th of April, 2025 **Lee Shau Kee Lecture Centre and Lecture Rooms, LG Centennial Campus, HKU**		
Time	Event	Host
08:50~09:30	Registration	
09:30~10:00	Keynote Speech 4 (Prof. Zhiliang Gao)	Prof. Qinglin Qi
10:00~10:30	Keynote Speech 5 (Prof. Lihui Wang)	Prof. Yuanfa Dong
10:30~11:00	Keynote Speech 6 (Prof. Fei Tao)	Prof. Weihua Liu
11:00~11:30	Coffee Break	
11:30~12:30	Editor Forum	Prof. Yantao Yu
12:30~13:30	Lunch	
13:30~15:30	Parallel Sessions	
15:30~16:00	Coffee Break	
16:00~18:00	Parallel Sessions	
19:00~21:00	Gala Dinner	

Day 4: Monday, 28th of April, 2025	
10:00~12:00	Innowing and Lab visit at HKU Main Campus (Max 50)

Special Sessions

SS1：Key technologies of intelligent manufacturing systems driven by digital twins towards Industry 5.0

Goal: In the rapidly advancing realm of manufacturing, the complexities associated with system optimization have grown increasingly sophisticated. Digital twin modeling, powered by Large Language Models (LLMs), has emerged as a pivotal solution to tackle these intricacies. Moreover, digital twin plays a crucial role in enabling predictive maintenance of intelligent manufacturing systems to reduce downtime and enhance overall productivity. Furthermore, digital twins facilitate dynamic decision-making and optimization, allowing manufacturers to adapt swiftly to changing demands and conditions. Of particular note, the integration of digital twins with artificial intelligence and communication technologies has ushered in unprecedented innovation in manufacturing systems. Human-machine-environment symbiotic manufacturing, where humans, machines, and the environment work harmoniously can be realized with the insights provided by digital twins. Additionally, distributed manufacturing systems, leveraging digital twins, have revolutionized production processes by enabling seamless collaboration across diverse locations. To enhance coordination among various system components, digital twin-based multi-agent manufacturing systems are proposed to further optimize functionality, efficiency, and reliability. These advancements underscore the transformative impact of digital twin technologies in shaping the future of manufacturing. This session serves to gather researchers and practitioners around the world to explore the key technologies of intelligent manufacturing systems driven by digital twins towards Industry 5.0 to preview the next steps on the way.

Sub-topics:

- Digital twin modeling and optimization of manufacturing systems driven by Large Language Models.
- Predictive maintenance of intelligent manufacturing systems driven by digital twins.
- Dynamic decision-making and optimization of manufacturing systems driven by digital twins.
- Human-machine-environment symbiotic manufacturing systems driven by digital twins.
- Distributed manufacturing systems driven by digital twins.
- Digital twin-based multi-agent manufacturing systems.

Organizers:

Dunbing Tang, Professor, Nanjing University of Aeronautics and Astronautics, China. E-mail: d.tang@nuaa.edu.cn

Changchun Liu, Assistant Researcher, Nanjing University of Aeronautics and Astronautics, China. E-mail: liuchangchun@nuaa.edu.cn

Qingwei Nie, Lecturer, Yangzhou University, China. E-mail: d.nie@yzu.edu.cn

Tong Zhou, Lecturer, Nanjing Tech University, China. E-mail: t.zh@njtech.edu.cn

Yi Zhang, Associate Professor, Nanjing Institute of Technology, China. E-mail: y.zhang@njit.edu.cn

SS2：Digital Twin-driven Human-Robot Collaboration

Goal: Digital twin (DT) technology has rapidly evolved into a foundational tool for enabling intelligent systems across industries such as manufacturing, healthcare, and urban management. By creating real-time, virtual replicas of physical entities, digital twins provide advanced capabilities for monitoring, simulation, and prediction, which are critical for optimizing complex systems. Meanwhile, the field of human-robot collaboration (HRC) has seen significant advancements, with robots increasingly capable of working alongside humans in dynamic and unstructured environments. These robots, enhanced by artificial intelligence (AI), can now adapt to human intent, learn from interactions, and perform tasks that require a high degree of precision and flexibility.

The convergence of digital twin technology and human-robot collaboration is an interesting topic. Digital twins serve as a bridge between humans and robots by enabling real-time interaction, fostering better understanding of robot behavior, and optimizing collaborative tasks through simulation and analysis. For example, digital twins allow humans to guide robots in complex environments by visualizing and predicting their actions virtually, while robots equipped with digital twins can adapt to human feedback to improve performance. This synergy between digital twins and human-robot collaboration is unlocking unprecedented potential across domains, enabling smarter, safer, and more efficient systems.

Track topics and their description:

This special session aims to present the state-of-the-art, theories, technologies, tools, and applications to focus on the advancements and challenges of digital twin-driven human-robot collaboration systems. To contribute to these areas, this special session includes the following topics, but is not limited to

- Digital twin modeling and optimization for human-robot collaboration.
- Human-in-the-loop control and decision-making in digital twin-driven robotics.
- AR/VR-enabled interfaces for enhanced interaction with robots through digital twins.
- Symbiotic human-robot systems enabled by digital twin technology.
- Digital twin applications in collaborative robotics for manufacturing, healthcare, and urban management.
- Security in digital twin-driven human-robot collaboration.

Organizers:

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SS3：Digital Technology-enabled ESG Reporting and Assurance against Greenwashing

Introduction: Environmental, Social, and Governance (ESG) disclosure obligations for companies are rapidly increasing around the world. Investors are becoming increasingly aware of both company financial statements and ESG reports. In this sense, ESG reporting reflects management strength and engenders investor confidence in the long-term prospects of the company. However, there are several challenges along with the ESG reporting process: data authenticity in report preparation, data consistency in report writing, and data transparency in report publication.

The ESG agenda is moving forward together with increasing scrutiny on the quality of ESG information disclosed by businesses. Companies put in place necessary systems, processes, and controls to manage ESG data that not only facilitates performance monitoring, but also supports external assurance. Similarly, the primary challenge with respect to ESG assurance is the credibility and reliability of ESG data. Digital technologies have the potential to deal with the aforementioned challenges and therefore offer unprecedented opportunities for combating the ESG greenwashing behaviors. Furthermore, as the digital technologies continue to evolve, there is an increasing need for theoretical foundation, new methodologies and approaches, and empirical evidence to support the development and applications.

The aim of this special issue is to explore the transformative impact of digital technologies and attract top-quality research on the methodology development and applications of digital technologies, and novel data analytics in practice and research within the field of ESG reporting and assurance. Both theoretical and empirical work is welcome, and studies developing new methods for modelling, mechanism design, optimization, inference and prediction, empirical studies, and interdisciplinary research are encouraged.

List of topic areas:

- AI-empowered ESG data authenticity assessmen
- Artificial Intelligence Generated Content (AIGC) in ESG reporting
- Blockchain-enabled ESG data sharing
- Digital asset models for ESG data
- ESG data security
- ESG data trading mechanism design
- Federated learning for ESG assurance
- Impact of digital transformation on anti-greenwashing
- Incentive mechanism design for the use of digital technologies
- IoT-enabled ESG data collection
- Knowledge graph of ESG data
- Large Language Models (LLMs) for ESG assurance
- Smart ESG data analytics

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Program Details

	25/04/2025	26/04/2025	27/04/2025	28/04/2025
Time	Day 1 Registration	Day 2	Day 3	Day 4 Lab visit
8:50		Registration	Registration	
9:30		**Opening Address** (Prof. Max Shen, Prof. David Srolovitz, Prof. Liang Gao)	**Keynote Speech 4 (Prof. Zhiliang Gao)**	
9:55		Group Photo		
10:00		**Keynote Speech 1 (Prof. Xiangsheng Chen)**	**Keynote Speech 5 (Prof. Lihui Wang)**	Innowing and Lab Visit at HKU Main Campus (Max 50)
10:30		**Keynote Speech 2 (Prof. Anthony G.O. Yeh)**	**Keynote Speech 6 (Prof. Fei Tao)**	
11:00		Coffee Break	Coffee Break	
11:30		**Keynote Speech 3 (Prof. George G.Q. Huang)**	**Editors Forum (Prof. Lihui Wang, Prof. Fei Tao, Prof. Hui Fu, Prof. Dengsheng Wu)**	
12:00		Lunch		
12:30			Lunch	
13:30–15:10		Speech #1 – Speech #6; **SS1:** Key technologies of intelligent manufacturing systems driven by digital twins towards Industry 5.0; **SS3:** Digital Technology-enabled ESG Reporting and Assurance against Greenwashing; **RS1:** Digital twin-enabled systems and engineering management; **RS3:** Key technologies for intelligent manufacturing and smart cities; **RS4:** AI-Driven Optimization and Learning for Intelligent Systems	Speech #1 – Speech #6; **SS2:** Digital Twin-driven Human-Robot Collaboration; **RS5:** Decision making in cyber-physical systems; **RS6:** Digital ecosystems for smart cities; **RS8:** Data-driven analysis for intelligent systems engineering	
15:30		Coffee Break	Coffee Break	
16:00–17:40	Registration	Speech #7 – Speech #12; **SS1:** Key technologies of intelligent manufacturing systems driven by digital twins towards Industry 5.0; **SS3** Digital Technology-enabled ESG Reporting and Assurance against Greenwashing; **RS2:** Digital twin for smart cities; **RS3:** Key technologies for intelligent manufacturing and smart cities; **RS9:** Digital Twin-enabled Health monitoring and Fault diagnosis	Speech #7 – Speech #12; **SS2:** Digital Twin-driven Human-Robot Collaboration; **RS5:** Decision making in cyber-physical systems; **RS7:** Frontiers analysis for complex engineering systems; **RS8:** Data-driven analysis for intelligent systems engineering	
17:40	Welcome Reception			
18:00				
19:00			Gala Dinner	
20:00				
21:00				

The conference was supported by a grant from the Joint Research Scheme sponsored by the Research Grants Council of the Hong Kong Special Administrative Region, China and the National Natural Science Foundation of China (Reference No. N_HKU7130/24)

Paper Assignment by Session and Day

Day 2 – 26th April 2025 (Saturday)

Day 2: 13:30-15:30
Room: CPD-LG.07
Chair(s): Prof. Yi Zhang & Dr. Tong Zhou

Session SS1: Key technologies of intelligent manufacturing systems driven by digital twins towards Industry 5.0		
Paper ID	Authors	Paper Title
25	Changchun Liu, Dunbing Tang, Ye Ma	Large Language Model-Enhanced Embodied Intelligence For Digital Twin-Assisted Human-Robot Collaboration Assembly
98	Yi Zhang, Haihua Zhu, Dunbing Tang	A Sim2real Reinforcement Learning Scheduling Framework Based On Digital Twin Workshop Model
13	Tong Zhou, Yahui Lin, Dengfeng Zhang	Digital Twin-Based Job Shop Scheduling Considering Machine Predictive Maintenance and Random Job Insertions
23	Shulin Lan, Xingshan Yao, Yingchao Wang, Chen Yang	Deep Reinforcement Learning Based Secure Computation Task Offloading In Smart Manufacturing Systems
12	Zeao Li, Le Yao, Jiusun Zeng	Enhancing Industrial Soft Sensing Models For Unknown Conditions: A Retrieval-Augmented Generation Approach With Large Language Models
47	Xinxin Liang, Zuoxu Wang, Jihong Liu	A Self-Cognitive Product Design System With Large Language Model-Driven Fine-Grained Multi-Modal Feature Recognition

Day 2: 13:30-15:30
Room: CPD-LG.08
Chair(s): Dr. Yelin Fu & Dr. Mingxing Li

Session SS3: Digital Technology-enabled ESG Reporting and Assurance against Greenwashing		
Paper ID	Authors	Paper Title
1	Wei Chen, Yelin Fu, George Q. Huang, Ray.Y. Zhong	AI-Driven ESG Assurance Framework For Sustainable Manufacturing
101	Qiulin zhu, Man-Chung Yue, George Q. Huang, Yelin Fu	Advancing ESG Integration In Emerging Markets: A Six-Factor Model For China's A-Share Market

78	Weihua Liu, Jiahe Hou, Yang Cheng	The Potential of Smart Factory For Reducing Environmental Emissions: The Evidence From Chinese Listed Manufacturing Firms
108	Changhong Liu, Tuxian Ye, Xingxin Yang, Jianxiang Cheng, Dinghao Wang, Ray Y. Zhong, Tao Zou	Design and Experimental Analysis of Bag-Breaking Device for Bagged Garbage based on Drilling Mechanism and Digital Twin Technology
71	Muhammad Huzaifa Raza, Svetlana Besklubova, Ekaterina Kravchenko, Ray Y. Zhong	Evaluating Cost And Environmental Impact: A Comparative Analysis of 3D Printing And Traditional Construction
88	He Siyang	Assessing The Environmental Impact of Demolishing Prefabricated Elements Through Various Construction Waste Management Approaches

Day 2: 13:30-15:30
Room: CPD-LG.09
Chair(s): Dr. H.H. Cheung & Dr. Bingqing Tan

Session RS1: Digital twin-enabled systems and engineering management		
Paper ID	Authors	Paper Title
21	Zhengxu Zhu, Shuxuan Zhao, Ray Y. Zhong	Digital Twins Based Automated Modeling And Safety Simulation of Building Cracks
32	Li Yin, Ray Y. Zhong	An Integrated Smart Approach For Off-Site Construction Logistics Management
53	H.H. Cheung, P.J. Liu, L. K. Wen, Alvin P.L. Lai, W.Z. Li, Derek K.C. Tong	A Digital Twin Driven Intelligent Printing Management System
56	Kai Kang, Bing Qing Tan	Value of Digital Twin For Supply Chain Resilience Enhancement
83	Wang Jiaji	Integration of Geometry Physics Neural Operator Solver For Digital Twins of Engineering Structure
97	Yuqi Huang, Yonghong Kuo	Digital Twin Simulation Platform of Flexible Production Scheduling System

Day 2: 13:30-15:30
Room: CPD-LG.10
Chair(s): Dr. Wei Wu & Dr. Hao Zheng

Session RS3: Key technologies for intelligent manufacturing and smart cities		
Paper ID	Authors	Paper Title
15	Yuxuan Ji, Linya Liu,	Sorting System Software Design And Simulation Debugging

	Yong Wang, Xi Vincent Wang, Lihui Wang	
16	Huang Xiaofen , Liu Chi, Wang Yujuan	Construction of The Evaluation Index System For The Fit of Breast Prosthesis Bra Under Wearing Condition - A Study Based On The Delphi And Hierarchical Analysis Methods
17	Zhuomin Liang, Tongtong Xie, Zelong Yi, Yelin Fu	Explainable Agricultural Price Prediction With A News-Based Ambilstm Framework
19	Tongliu Wang, Chi Liu	Research On The Optimization Design Of The Structure Of Fitted Blouse For Mildly Hunchbacked Body
26	W. Wu, C.B. Li , X.F. Zhang, G.Q. Huang	Repass: A Methodology Of Real-Time Energy Consumption Prediction For Automotive Spray-Painting System Based On Multi-Source Data Fusion
38	A. Xiaobin Li, B.C. Bohang Chen, Chao Yin	Car Sales Production Prediction Based On CNN-BILSTM Model With Self-Attention Mechanism

Day 2: 13:30-15:30

Room: CPD-LG.17

Chair(s): Dr. Yishu Yang & Mr. Haoran Ding

Session RS4: AI-Driven Optimization and Learning for Intelligent Systems		
Paper ID	Authors	Paper Title
4	Xinzheng Xu, Zhicheng Huang , Lihong Qiao, Yongqiang Wan, Peilin Shao, Chao Chen	A Novel Approach For Mining Typical Machining Process Based On Representation Learning And Graph Clustering
8	Yi Li, Ray Y. Zhong	Multi-Agent Reinforcement Learning Based Spatial-Temporal Coordinated For Modular Integrated Construction Management
10	Haoran Ding, Ray Y. Zhong, George Q. Huang	Cyber-Physical System-Enabled Prototype System For Modular Prefabricated Construction
110	Tianyun Jin, Yuan Qu , Max Z.J. Shen	How large are too large? Deployment region analysis of dockless electronic bike-sharing systems
37	Yang Yishu, Ming Li, Chenglin Yu, Ray Y. Zhong	Digital Twin-Enabled Visibility And Traceability For Building Materials In On-Site Fit-Out Construction
49	A. Lu-Yao Zhang, B. Ying-Jie Zhu, C. Jia-Qi Hou	Research On Global Response Prediction Of Large-Span Steel Structure In Gymnasium By Digital Twin

Day 2: 16:00-18:00

Room: CPD-LG.07

Chair(s): Dr. Qingwei Nie & Dr. Changchun Liu

Session SS1: Key technologies of intelligent manufacturing systems driven by digital twins towards Industry 5.0		
Paper ID	Authors	Paper Title
54	Zimo Zhang, Juntao Li, Junyan Xiong, Dengcheng Tang, Daqiang Guo	Integrating Digital Twins And Large Language Models In Manufacturing: A Review And Conceptual Framework For Design-To-Manufacturing (D2M)
9	Zimo Zhang, Yichen Wang, Haokun Chen, Daqiang Guo	A Digital Twin Based Optimization Approach For Dynamic Configuration Of Production-Logistic System
40	Yi Luo, Xiujie Zhao	Condition-Based Maintenance Optimization In Dynamic Environment
60	Wang, Yuchen	Data-Driven Decision Support And Visualization For Warehouse Management Optimization
31	J. Man, R. Feng, Z. He	Data-Driven Remaining Useful Life Prediction And Predictive Maintenance Policy For Hard Failures
106	Shoeb Ahmed Memon, Steve Rowlinson, Adrian Bridge, Waled Shehata	Generative Artificial Intelligence (Genai) In Project Lifecycle: A Systematic Review

Day 2: 16:00-18:00

Room: CPD-LG.08

Chair(s): Prof. Yantan Yu & Dr. Kai Kang

Session SS3: Digital Technology-enabled ESG Reporting and Assurance against Greenwashing		
Paper ID	Authors	Paper Title
99	He Jing	Develop Simulation Model For An Integrated Environment Of Emergency Department And Inpatient Unit
58	Hai Shen, Yuhan Xie, Jiaobo Zhao, Yu Li, Xiaogang Zhao	Low-Carbon Supply Chain Decision-Making: The Role Of Carbon Labeling And Retailer-Driven Altruistic Preferences
48	Yirui Wang, Yantao Yu	IFC-Based Embodied Carbon Assessment For Tunnel Project
104	Mohammad Mehdi Keramati Feyz Abadi, Chao Liu, Yuchun Xu	Energy-Aware Manufacturing through Digital Twin and Reinforcement Learning-Based Control
109	Y.-J. WANG, Y. GAO, N. WANG	Recycled Express Packaging In Sustainable Logistics: Investigating Consumer Behavior

Day 2: 16:00-18:00

Room: CPD-LG.09

Chair(s): Dr. Svetlana Besklubova & Mr. Shuaiming Su

Session RS2: Digital twin for smart cities		
Paper ID	Authors	Paper Title
2	Xinyue Guo, Ray. Y. Zhong	Game-Theoretic Models for Cooperative Autonomous Driving: Supporting Digital Twin enabled Smart City Traffic Management
33	Shuaiming Su, Li Yin, Svetlana Besklubova, Jidong Song, Ray Y. Zhong	Digital Twin-Enabled Reverse Supply Chain For Building Demolition Waste Trading
79	E. Kravchenko, T. Minkina, M. Zhelnin	AI-Powered Prediction And Optimization Of Sustainable 3D-Printed Concrete
82	Yongbing Feng, Guohua Gao	Towards Urban Vertical Farming: Digital Twin-Enabled Generative Design For Multi-Layer Cultivation Systems With Solar Light
96	Zhenyu Liang, Weitao Che, Peter Kok-Yiu Wong, Boyu Wang, Jack C. P. Cheng	Digital Twins for Intelligent Management and Operation of the Low-Altitude Economy in Smart Cities
100	Zhixuan Wu, Hui Fu, Yu Cui, Hongpeng Li, Qi Hu, Lirong Huang	Operation Framework of Multi-Modal Low-Altitude Logistics System Based on Digital Twin

Day 2: 16:00-18:00

Room: CPD-LG.10

Chair(s): Prof. Yang Xu & Mr. Yi Li

Session RS3: Key technologies for intelligent manufacturing and smart cities		
Paper ID	Authors	Paper Title
46	Zhifeng Yang, Junning Zhang, Bin Zhou, Yuanfa Dong	Interactive Strategies For Driving Risk Warning Integrating The Coupling Effect Of Driving Style And Emotional State
107	Liang Guo, Yuantong Li, Xun Xu, Longkun Luo, Changcheng Wan	Virtual-Real Mapping Of Devices Based On Strong-Weak Digital Twins— A Case Study Of 3d Printer
64	Luo Yushan	A Novel Approach For Optimizing 3D-Printed Concrete Mix Design
66	Ruilin Su, Svetlana Besklubova, Muhammad Huzaifa Raza, Ray Y. Zhong	Big Data Analytics For Wip Inventories Management In The Context Of Industry 4.0
69	Qilei Zhou	Big Data Analytics For Impact Of Goods Type On Warehouse Operation For SMEs

81	Yang Xu	From Microscale To Macroscale: Novel And Intelligent Processes In Vat Photopolymerization

Day 2: 16:00-18:00

Room: CPD-LG.17

Chair(s): Dr. Maxiao Hou & Mr. Yuming Xu

Session RS9: Digital twin-enabled Health monitoring and Fault diagnosis		
Paper ID	Authors	Paper Title
5	Q.H. Chen, Y. Zhang, X. Dong, J.C. Cui, Y.K. Lu, P. Zheng, W. Liu	A Novel High-Accuracy Shape Sensing Method For Deformation Digital Twin Monitoring Of Thin-Walled Component
11	Le Yao, Jiaqi Shen, Zheren Zhu, Jiusun Zeng	Semi-Supervised Multi-Scale Graph Convolution Autoencoder Network for Industrial Fault Diagnosis
39	Ruixian Li, Jianguo Wu, Yongxiang Li	Periodnet: Noise-Robust Fault Diagnosis Method Under Varying Speed Conditions
52	Yang Fu, Deqiang He, Zhenzhen Jin, Jiachen Ma, Longyu Cui	SCADA Data Driven Lifelong Learning Digital Twin Model for Wind Turbine Intelligent Fault Diagnosis under Time-varying Running Conditions
86	Wen-Bin Wang, Hong-Wei Xu, Li-Lan Liu	Knowledge-Enhanced Large Model-Based Fault Diagnosis Method For Aircraft Assembly
105	Yuming Xu, Tao Peng, Ray Y. Zhong, Kendrik Lim	An Intelligent Fault Diagnosis Approach For Construction Machinery Based On Enhanced Knowledge Graph

The conference was supported by a grant from the Joint Research Scheme sponsored by the Research Grants Council of the Hong Kong Special Administrative Region, China and the National Natural Science Foundation of China (Reference No. N_HKU7130/24)

Day 3 – 27th April 2025 (Sunday)

Day 3: 13:30-15:30
Room: CPD-LG.07
Chair(s): Prof. Pai Zheng & Dr. Jiazhen Pang

Session SS2: Digital Twin-driven Human-Robot Collaboration		
Paper ID	Authors	Paper Title
92	Jiazhen Pang, Pai Zheng	A Mobile Spatial Augmented Reality Framework For Bare-Eye Information Access In Industrial Metaverse
73	H.H. Cheung, L.K. Wen, Derek. K.C. Tong, W.Z. Li, R.Y. Zhong	A Digital Twin-Enabled Human-Robot Collaboration Platform For Intelligent Manufacturing
3	Tong Liu, Song Du, Fei Teng, Yiwei Weng	Energy Consumption Modeling For A Robot Arm In 3D Concrete Printing
6	Song Du, Yiwei Weng	Autonomous Motion Planning For Mobile Robots In Dynamic And Uncertain Construction Environments
20	Jianwu Luo, Bodong Yang, Zuoxue Wang , Min Cheng, Xiaobin Li, Jiang Pei	Energy Consumption Prediction Of Industrial Robots Based On A Model-Based And Data-Driven Hybrid Method
30	Shuxuan Zhao, Chenglin Yu, Junjie Lei, Chaofan Lv, Yishuo Jiang, Ray Y. Zhong	Digital Twin-Enabled Anti-Collision System For Human-Robot Interactions In Smart Construction Sites

Day 3: 13:30-15:30
Room: CPD-LG.08
Chair(s): Prof. Zhiheng Zhao & Ms. Chung-Lam Ng

Session RS5: Decision making in cyber-physical systems		
Paper ID	Authors	Paper Title
7	Nan Jiang, Wei Zhang, Huixin Yang, Xiang Li	State Of Health Prediction Of Lithium-Ion Batteries Based On Random Quantization Data Augmentation And Federated Learning
14	Junlong Chen, Feng Wu, Chi Liu	A Cost-sensitive Deep Learning Approach Integrating Three-way Decision Theory for IC Chip Vision Inspection
22	Chung-Lam Ng, Ming Li, Ray Y. Zhong, George Q. Huang	Carbon Outlay For Modular Construction Logistics In Cyber-Physical Internet (Cpi)
24	Mingxing Li, Yiyan Xie, Ting Qu, Yishuo	Sync-State Driven Rescheduling for Multi-Resource Constrained Production-Logistics in Cyber-Physical

	Jiang, Ray Y. Zhong	Modular Integrated Construction
27	Jinpeng Li, Zhiheng zhao	Look-Around Reasoning-Enabled Resource Allocation In Production Logistics Within Industry 4.0
29	Xin Wang, Nian Yin, Zhinan Zhang	Intelligent Design And Optimization Of Ship Pipeline Layout

Day 3: 13:30-15:30

Room: CPD-LG.09

Chair(s): Dr. Muhammad Huzaifa Raza & Mr. Xinyue Guo

Session RS6: Digital ecosystems for smart cities		
Paper ID	Authors	Paper Title
28	Y. Zhu, S. Besklubova, and R. Zhong	Sustainable Concrete Recycling Practices with CO2 Sequestration from Power Station Flue Gases: A Case Study in Hong Kong
36	Zhao Xueyu, Yang Xiangchuan	A Hierarchical Optimization Model For Public Transit Connectivity Network Addressing Spatial Heterogeneity In Land Value Appreciation Around Metro Stations
61	Long Meining	Warehouse Allocation Strategies Based On Data Analytics For Enhanced Utilization
65	Keke Qian	Cost Examination And Life Cycle Assessment Of 3D Printed Buildings
68	Jiawei Liu, Yuhan Xie, Yu Li	A Robust Optimization Method For Hotel Room Reservation Considering Uncertain Customer Arrival Time And Its Application
94	Peter Kok-Yiu Leung, Shanjing (alexander) Zhou, Yawei Du, Weitao Che, Jack C.P. Cheng	Comparative Study Of VLM Variants For Urban Flooding Digital Twinning

Day 3: 13:30-15:30

Room: CPD-LG.17

Chair(s): Prof. Su Xiu Xu & Prof. Xiang T.R. Kong

Session RS8: Data-driven analysis for intelligent systems engineering		
Paper ID	Authors	Paper Title
34	A. Yifang Ding, B. Su Xiu Xu , C. Meng Cheng, D. Sini Guo, E. Jianghong Feng	A VCG-Like Auction With Platform Escrow For Metaverse Exchange
50	Minshan Xie, Yantao Yu	A Simulation-Based Muscle Fatigue Assessment Method For Construction Workers
59	Shi Jun	Dynamic Planning Approaches For Route Optimization In Cyber-Physical Internet

63	Fu Zilong	An Inventory Management System Based On Big Data Analytics For SMEs
67	Shi Chenling	Data-Driven Decision-Making For Space Optimization In SMEs' Warehouses
72	Xiang T.R. Kong, Xuemei Yang, Bing Qing Tan	Scaling Strategy Design Of Comprehensive Utilization Enterprises Considering Carbon Trading Through Evolutionary Game Theory

Day 3: 16:00-18:00

Room: CPD-LG.07

Chair(s): Dr. Shimin Liu & Dr. Ying Yu

Session SS2: Digital Twin-driven Human-Robot Collaboration		
Paper ID	Authors	Paper Title
45	M.X Hou, H.R. Cao	Digital Twin-Driven Force Control Framework For Robotic Milling
55	H.H. Cheung, W.Z. Li, L.K. Wen, Derek. K.C. Tong	An Intelligent Mobile Robot System For Intelligent Manufacturing
85	Ying Yu, Chenglin Yu, Chao Ma, Pei Zhao	Digital Twin-Inspired Efficiency Analysis Of Kiva Robotic Warehousing And Manual Picking Systems For Smart Logistics
95	Sichao Liu, Xi Vincent Wang, Lihui Wang	Vision-Language-Controlled Robotic Manipulation For Collaborative Assembly
102	Nuan Wen, Qiang Fu, Yi-Jia Wang, George Q. Huang	Digital Twin-Enabled Human-Machine-Environment System for Smart Agriculture
111	Zhongxu Hu	Large Language Model-Based Multi-Agent Scheduling Chain for Flexible Job Shop Scheduling Problem

Day 3: 16:00-18:00

Room: CPD-LG.08

Chair(s): Prof. Gangyan Xu & Ms. Li Yin

Session RS5: Decision making in cyber-physical systems		
Paper ID	Authors	Paper Title
35	Peng Zhao, Xiaocong Wang, Jiajian Li, Zihao Nie, Xinluo Wang,Yanjun Shi	A Collaborative Edge Computing Offloading Solution for Industrial Internet of Things Based on Location Prediction Mechanism
76	Sun Zhengshan	Data-Driven Warehouse Decision-Making System For Hong Kong SMEs
77	Xiufeng Li, Bo Li	Investment Strategies Of Iot Platforms On Smart Device Startups During Innovating New Products

90	Wei Juan, Suo Haoran, Chen Tingmin, Zhang Xuejing	Research On The Optimization Of Solar-Heat Pump Composite Heating System Based On Virtual Model
91	Xi Chen, Xun Wang, Gangyan Xu, Xuanyu Zhang, Wei Li	Hybrid Intelligence-Driven Wise Maintenance of Complex Equipment
93	Jun Xu, Handian Liu, Yusheng Wang, Shuaiyin Ma	Integrated Automated Guided Vehicles and Preventive Maintenance for Energy-efficient Flexible Job Shop Scheduling Based on An Improved NSGA-II

Day 3: 16:00-18:00

Room: CPD-LG.09

Chair(s): Prof. Jiewu Leng & Mr. Yizhi Zhen

Session RS7: Frontiers analysis for complex engineering systems		
Paper ID	Authors	Paper Title
41	Sangqi Zhao	Cost-Effective Decision-Making for Maintenance, Inventory Planning, and System Sizing in k-out-of-n Load-Sharing Systems with Self-Announcing Failures
42	Ge Li, Yian Wei	A Business Pattern Selection Framework For Parking Lot Operators Running Charging Piles
43	Jiewu Leng, Caiyu Xu, Xueguan Song, Qiang Liu, Xin Chen, Weiming Shen, Lihui Wang	High-Performance Manufacturing System: Connotation, Performance Metrics, Relationships, Enablers, Challenges and Directions
44	Yian Wei	State Transition Analysis In A Fleet Of Service Systems Under A Three-Dimensional Maintenance Policy
70	S. Besklubova, Y. Li, R.Y. Zhong, and I. Brilakis	Network Analysis Of Construction Falling Accidents Using Natural Language Processing
103	Yizhi Zhen, Jie Lin, Fangni Zhang	Integrating Unmanned Aerial Vehicles And Public Buses For Parcel Delivery In Urban Area

Day 3: 16:00-18:00

Room: CPD-LG. 17

Chair(s): Mr. Wei Chen & Mr. Zhengxu Zhu

Session RS8: Data-driven analysis for intelligent systems engineering		
Paper ID	Authors	Paper Title
74	Feng Xinjie	Assessment And Optimization Of Construction And Demolition Waste Management Based On Data-Driven In Hong Kong
75	Yan Kexin	Data-Driven Approaches To Synchronize Demand And Inventory Levels
80	Hao Luo,	Two- Echelon Location And Routing Problem In A Pharmaceutical

	Chen Ling	Logistics Enterprise
84	Bolin Chen	A Data-Driven Method For Predicting Abnormal Operating State Of Aircraft Assembly System
87	Qian Peng	A Routing Model For Construction And Demolition Waste Recycling In Hong Kong
89	Zhang Rui	Optimization Of Traffic Flow For Demolition Waste Collection And Transportation Based On Traffic Management System (TMS) In Hong Kong

The conference was supported by a grant from the Joint Research Scheme sponsored by the Research Grants Council of the Hong Kong Special Administrative Region, China and the National Natural Science Foundation of China (Reference No. N_HKU7130/24)

Abstracts of Accepted Papers

NSFC-RGC-001

Wei Chen (HKU), Yelin Fu (SZU), George Q. Huang (PolyU), Ray.Y. Zhong* (HKU).

AI-Driven ESG Assurance Framework for Sustainable Manufacturing.

Abstract. Nowadays, sustainable development has garnered significant attention from the manufacturing industry worldwide. Environmental, Social, and Governance (ESG), as an important framework for assessing a company's sustainability, is frequently used in business cooperation, procurement, and investment. However, the ESG reports and data provided by companies are often unverified, with incidents of greenwashing occurring from time to time. To address this challenge, this article proposes an AI-Driven ESG assurance framework for sustainable manufacturing. Firstly, at the data layer, we conduct authenticity analysis of ESG raw data from IoT devices and enterprise information systems using spatiotemporal analysis and federated learning methods. Secondly, at the knowledge layer, we use knowledge graph to model the data of each company, and employ deep learning techniques, including convolutional neural networks and graph neural networks, to analyse the data, constructing ESG features for each company, and performing data validation. At the model layer, we leverage data from the knowledge layer to train a large language model specifically designed for ESG report evaluation, with capabilities in analysing, auditing, and verifying ESG reports. Through model training, the system enables in-depth analysis of ESG report content, identifying data authenticity, compliance, and impact on sustainable development. This assists companies and investors in more effectively evaluating ESG performance. Finally, at the application layer, we develop a series of ESG fidelity-related applications for various stakeholders based on the technologies from the previous three layers. These applications include data visualization and tracking, intelligent report analysis, decision-making recommendations, and more. Additionally, in this paper, we discuss and analyse the benefits and potential challenges of this approach, along with an outlook on future research directions.

Keywords: ESG, Greenwash, Knowledge Graph, Deep Learning, Large Language Model.

NSFC-RGC-002.

Xinyue Guo (HKU), Ray.Y. Zhong* (HKU).

Game-Theoretic Models for Cooperative Autonomous Driving: Supporting Digital Twin enabled Smart City Traffic Management.

Abstract. With the rapid advancement of autonomous driving technology, cooperative driving has emerged as a crucial component that has garnered significant attention from both academia and industry. This paper explores the application of game theory in cooperative driving, focusing on the dynamic interactions between cooperative and non-cooperative vehicles, particularly in the context of sharing perception data and planning information. We propose a game-theoretic model aimed at enhancing the collaborative capabilities of multiple vehicles in complex traffic environments, particularly within the framework of smart city traffic control. In our model, cooperative vehicles share perception data and planning information, creating an interconnected network that enhances their understanding of the environment and provides a more comprehensive basis for decision-making. The integration of digital twin technology allows for real-time simulations and predictive modeling, further refining vehicle interactions within the smart city infrastructure. We first constructed a non-cooperative game model, employing Nash equilibrium as a solution method to analyze vehicle behavior in the absence of cooperation. When vehicles face significant decision-making changes, such as lane changes or other complex maneuvers, we transition to a Stackelberg equilibrium model to address the problem. In the Stackelberg game, the decision-making process between leaders and followers is explicitly modeled, effectively capturing the interdependencies of vehicles in a dynamic environment. For the cooperative game, we utilize optimization techniques to identify Pareto optimal solutions. By incorporating Control Barrier Functions (CBFs), we ensure that vehicles adhere to safe and stable control strategies during cooperative driving. The design of CBFs accounts for vehicle motion constraints and effectively mitigates potential collision risks, thus ensuring safety in collaborative maneuvers. To analyze the necessity and sufficiency of cooperation, we construct a payoff function model that quantifies the benefits and costs associated with cooperation. This model considers the differences in vehicle payoffs between cooperative and non-cooperative scenarios and examines the driving factors behind vehicle cooperation in various contexts. Through an in-depth analysis of the payoff function, we can identify the conditions under which vehicles are more inclined to adopt cooperative strategies, providing a theoretical foundation for the design of future cooperative driving systems.

Keywords: Game Theory; Cooperative Driving; Stackelberg Equilibrium; Control Barrier

Functions; Pareto Optimality.

NSFC-RGC-003.

Tong Liu (PolyU), Song Du (PolyU), Fei Teng (PolyU), Yiwei Weng* (PolyU).

Energy Consumption Modeling for a Robot ARM IN 3D Concrete Printing

Abstract. The construction sector is a major contributor to global CO2 emissions and energy consumption. 3D concrete printing (3DCP) provides sustainable solutions to tackle the environmental challenges. However, the long-time and continuous operation of robotic arm printers in 3DCP incur critical challenges in energy efficiency. To address these challenges, this study aims to develop an energy consumption (EC) model of a robotic arm in 3DCP. The proposed EC model has desirable agreement compared to the experimental result, achieving an accuracy 99.51%. The impact of the proposed EC model is evaluated by printing a pre-designed path with various positions. Results reveal that the EC reduction can achieve up to 53.72% with varying positions. The findings reveal that the proposed EC model has the potential to reduce the EC for energy efficiency in 3DCP.

Keywords: 3D Concrete Printing, Energy Consumption, Positions, Robots.

NSFC-RGC-004.

Xinzheng Xu, Zhicheng Huang* (BUAA), Lihong Qiao, Yongqiang Wan.

A Novel Approach for Mining Typical Machining Process based on Representation Learning and Graph Clustering

Abstract. The typical machining process (TMP) is a category of process knowledge in common use, which can be reused as a process template to assist in rapid design of machining processes for the component part. With the frequent use of CAPP systems in manufacturing enterprises, a large number of planed process documents have been produced and stored in the database, which is highly of value to be mined. It has become a research hotspot in the field of intelligent manufacturing systems how to accurately identify and extract one planed process that is the most suitable for one part family. The paper proposes an approach for mining TMPs based on representation learning and graph clustering. In this method, a machining process model is established based on graph with various entities and relationships among them. In order to capture the deep-level features of machining processes comprehensively for the following data analysis, a representation learning model is developed based on TransD, which maps entities and relationships to a low-dimensional vector space. Then, a similarity calculation model is constructed for machining processes in the form of graph, and graph clustering algorithm is developed using K-Means-based spectral clustering, which performs in the vector space. The machining process corresponding to the centroid of each cluster is regarded as TMP. Finally, an index V_{TP} is defined to quantify and evaluate the typicality of a TMP in view of the application of TMPs in CAPP systems. The proposed method is performed on the dataset obtained from planed process documents of shaft, gear, plate, and box parts, and comparisons are provided with several existing TMP mining methods. The results show that the proposed method achieves the V_{TP} value around 86%, which is higher than any other TMP mining methods, thus verifying its correctness and effectiveness.

Keywords: Knowledge Mining, Typical Machining Process, Representation Learning, Graph Clustering.

NSFC-RGC-005.

Q.H. Chen (DLUT), Y. Zhang* (DLUT), X. Dong (DLUT), J.C. Cui (DLUT), Y.K. Lu (DLUT), P. Zheng (PolyU), W. Liu (DLUT).

A Novel High-Accuracy Shape Sensing Method for Deformation Digital Twin Monitoring of Thin-Walled Component

Abstract. High-accuracy shape sensing of thin-walled components is critical for achieving deformation digital twin monitoring (DDTM), and thus, it is also key to ensuring compliant assembly in the production of aircraft, automobiles, and similar products. However, the uncertainty of material parameters and the inevitable measurement noise make high-accuracy shape sensing challenging. This paper proposes a novel high-accuracy shape sensing method to fill this gap. The method integrates the advantage of iFEM, which is independent of material properties, and establishes an online deformation fusion data-driven sensing model to achieve real-time correction of deformation calculation errors caused by measurement noise. Furthermore, an enhanced bilinear interpolation function extends this correction across the entire structure, enabling high-accuracy

shape sensing independent of accurate material parameters, even in the presence of strain measurement noise. Experimental results from shape sensing during the robot-assisted shape compensation assembly process of scaled wing panels demonstrate that the proposed method can accurately compute the deformation of thin-walled components, with a relative error not exceeding 12.80% and an average relative error of only 4.66%. Compared to traditional iFEM, the average relative error is reduced by 68.58%. This method provides a new and effective approach for DDTM.

Keywords: Deformation Digital Twin Monitoring, Shape Sensing, iFEM, Full-Field Correction.

NSFC-RGC-006.

Song Du (PolyU), Yiwei Weng* (PolyU).

Autonomous Motion Planning for Mobile Robots in Dynamic and Uncertain Construction Environments

Abstract. Autonomous motion planning for mobile robots is a promising solution to relieve construction workers from repetitive and physically demanding tasks, thereby enhancing both safety and productivity in construction. Many studies have developed various methods for environmental perception and localization, and path planning, forming the basis for autonomous and adaptive motion control of mobile robots to facilitate construction assistance. However, two challenges remain. First, the real-time dynamic nature of construction environments demands high data processing capabilities. Methods that rely on pre-built maps indeed face limitations in real-time responsiveness. Although multi-sensor fusion can provide more comprehensive environmental perception, managing large volumes of real-time data to achieve effective perception and dynamic responses remains a technical challenge. Secondly, there is a lack of motion control studies that integrate path planning with factors affecting construction outcomes. Many studies focus on finding the shortest or fastest paths rather than considering energy consumption, safety, or dynamic constraints comprehensively. Additionally, in construction environments, particularly in scenarios involving human-robot collaboration, flexible setting and timely updating of target positions is also a crucial factor. This study proposes a low-feature, multi-constraint motion planning method for efficient and energy-saving autonomous movement in construction settings. Specifically, employing multi-sensor fusion as input, a dynamic environment construction method based on a 2D grid is proposed, enabling real-time perception with low data processing. Safety, energy consumption, stability, and human-robot collaboration are considered as constraints in dynamic motion planning within the construction environment. Real-time experiments demonstrate that the proposed method reduces CPU usage by 19%, memory usage by 8%, and energy consumption by 9.5% compared to traditional methods using LIO-SAM mapping and RRT path planning. This study provides a novel perspective on safe and efficient motion planning for mobile robots in dynamic and uncertain construction environments with autonomous, real-time, and energy-efficient performance.

Keywords: Autonomous Motion Planning, Dynamic Construction Environment, Multi-Constraint Optimization, Human-Robot Collaboration, Low-Feature 2D Mapping.

NSFC-RGC-007.

Nan Jiang (SAU), Wei Zhang* (SAU), Huixin Yang (SAU), Xiang Li (XJTU).

State of Health Prediction of Lithium-ion Batteries Based on Random Quantization Data Augmentation and Federated Learning

Abstract. In recent years, global attention to environmental protection has increased. Replacing traditional fuel-powered vehicles with electric ones can reduce carbon emissions and enhance air quality. In this context, lithium-ion batteries, as efficient energy storage devices, are widely used in electric transportation and play a critical role in the adoption of clean energy. The state of health (SOH) prediction of lithium-ion batteries is essential for the reliable operation and health management of new energy vehicles, electric aircraft, and other transportation systems. Accurate prediction, however, requires a substantial amount of battery data to train models. Collecting sufficient data is challenging for individual users, and traditional centralized learning may cause privacy breaches, hindering the full utilization of data resources. To address these challenges, this paper proposes a framework for predicting the SOH of lithium-ion batteries using random quantization data augmentation and federated learning. First, random quantization data augmentation is used to expand individual users' datasets, thereby enhancing data diversity and improving prediction accuracy. Next, a federated learning framework is developed, with both local and global models utilizing convolutional neural networks (CNNs). This approach enables multiple users to collaboratively train a global model while ensuring privacy protection. Finally, the method is validated using two datasets, and the results demonstrate that the proposed approach achieves

high accuracy while maintaining privacy. This method offers a novel approach for the SOH prediction of lithium-ion batteries.

Keywords: Lithium-ion Battery, Random Quantization, Data Augmentation, Federated Learning, State of Health (SOH) Prediction.

NSFC-RGC-008.

Yi Li (HKU), Ray Y. Zhong* (HKU).

Multi-Agent Reinforcement Learning Based Spatial-Temporal Coordinated for Modular Integrated Construction Management

Abstract. Module Integrated Construction (MiC) is an advanced construction method whereby free-standing integrated modules are manufactured in an off-site prefabrication factory and then transported to site for on-site assembly. It effectively addresses the challenges associated with traditional construction, including chaotic site management, frequent safety incidents, significant environmental pollution, and high costs. However, the lack of effective coordination between production, transportation, and on-site installation processes in MiC undermines the anticipated advantages, leading to schedule conflicts, improper module handling, equipment downtime and potential safety risks. Therefore, spatial-temporal coordination across the MiC multiple processes plays a pivotal role in achieving seamless integration of lifecycle and effective management of heterogeneous entities. The multi-process interactions lead to combinatorial explosion of scheduling dimension, where errors in decision-making at one stage can trigger a chain reaction. Traditional heuristic algorithms struggle to effectively explore the entire solution space, which often become trapped in local optima. To address this, this paper proposes a novel multi-agent reinforcement learning (MARL) framework that integrates Long Short-Term Memory (LSTM) networks and multi-agent Proximal Policy Optimization (PPO) algorithms. Specifically, each MiC process is treated as an individual agent with scheduling tasks handled by an actor module, while all agents share a common critic and LSTM. A multi-head attention module is proposed to extract spatial features from the relevant observations, which are then fused with the previous temporal state and action encoded by LSTM. The actor uses this integrated information to make spatial-temporal coordination decisions. Experiments conducted on a MiC scheduling dataset collected through Internet of Things (IoT) devices demonstrate that the proposed method outperforms the state-of-the-art reinforcement learning methods in optimizing scheduling efficiency.

Keywords: Multi-Agent Reinforcement Learning; Spatial-Temporal Coordination; Modular Integrated Construction (MiC); Multi-Head Attention Mechanism; Long Short-Term Memory (LSTM).

NSFC-RGC-009.

Zimo Zhang* (HKUST-GZ), Yichen Wang (HKUST-GZ), Haokun Chen (HKUST-GZ), Daqiang Guo (HKUST-GZ).

A Digital Twin based Optimization Approach for Dynamic Configuration of Production-Logistic System

Abstract. The increasing customized demand requires a manufacturing system could quickly adapt its physical layout and corresponding production strategies to meet changes. The advancements of digital twin in Industry 4.0 provide a promising approach for dynamic optimizing a manufacturing system. This paper presents a digital twin-based approach that provides a virtual simulation environment for dynamic configuration of factory layouts and optimizing production-logistics strategies. The proposed approach is encapsulated in software, providing a robust solution for modelling and optimizing manufacturing systems by incorporating randomness and dynamic interactions between components. The software leverages Python's Mersenne Twister algorithm to model the stochastic nature of job interarrival times, job types, and service times, ensuring accurate and reliable system performance analysis. Its modular design allows for reconfiguration of production-logistics system layouts, by incorporating appropriate task allocation strategies, making it adaptable to diverse manufacturing environments with various randomness. Statistical analysis from the simulation tests within a manufacturing system with six workstations and one automated guided vehicle (AGV) demonstrate the software's effectiveness in optimal layout configuration and task allocation under various randomness. This work provides insights for designing and optimizing manufacturing systems through digital twin-based simulation and optimization.

Keywords: Digital Twin, Manufacturing System Optimization, Industry 4.0, Stochastic Simulation, Task Allocation Strategies.

NSFC-RGC-010.

Haoran Ding (HKU), Ray Y. Zhong (HKU), George Q. Huang* (PolyU).

Cyber-Physical System-enabled Prototype System for Modular Prefabricated Construction

Abstract. Modular Prefabricated Construction enhances efficiency by integrating off-site prefabrication and on-site assembly but faces challenges from fragmented workflows and uncertainties. This paper presents a Cyber-Physical System-enabled prototype system across four subsystems: off-site factories, prefabrication yards, on-site assembly, and prefabrication logistics. Physical models demonstrate improved synchronization and efficiency, validated through a hospital construction case study. The proposed system addresses coordination issues, optimizes resource utilization, and reduces delays, offering a scalable framework for smart and resilient construction practices.

Keywords: Modular Prefabricated Construction, Cyber-Physical Systems, Synchronization, Smart Construction, Real-Time Data Analytics.

NSFC-RGC-011.

Le Yao* (HZNU), Jiaqi Shen (HZNU), Zheren Zhu (HZNU), Jiusun Zeng (HZNU).

Semi-Supervised Multi-Scale Graph Convolution Autoencoder Network for Industrial Fault Diagnosis

Abstract. This paper presents a novel semi-supervised multi-scale graph convolution autoencoder network for industrial fault diagnosis, addressing the challenge of limited labeled data by leveraging both labeled and unlabeled data. The model comprises a multi-scale feature extraction network, a multi-scale graph structure learning module, and a mix graph convolution network. Two main models, MFP-GCAN and PMF-GCAN, are proposed, each with different optimization methods: frozen and cross optimization. The multi-scale feature extraction network captures inherent information from raw industrial data through multiple perspectives, using either a Multi-scale Feature Pyramid Network (FPN) or a Parallel Multi-scale Feature Network (PMN). The multi-scale graph structure learning module generates topological relationships for different scales, learning the most prominent inter-variable relationships. The mix graph convolution network mitigates over-smoothing issues in deep graph convolution networks by aggregating information from multiple layers. The models were evaluated on industrial process data, specifically the Revised Tennessee Eastman process, demonstrating superior performance in fault diagnosis compared to existing methods. The semi-supervised models effectively utilized unlabeled data to improve fault diagnosis accuracy. The results showed that the proposed models outperformed supervised learning approaches, particularly when the ratio of unlabeled data increased. Ablation experiments confirmed the importance of each component in the semi-supervised models, highlighting the significant role of the multi-scale feature extraction network and the mix graph convolution network in capturing dynamic relationships in industrial process data. The proposed semi-supervised multi-scale graph convolution autoencoder network models provide a robust solution for industrial fault diagnosis by integrating multi-scale features and graph structure relationships, making them valuable tools for industrial process monitoring and maintenance.

Keywords: Semi-supervised Learning, Multi-scale Feature Extraction, Graph Convolution Autoencoder, Industrial Fault Diagnosis, Graph Neural Networks.

NSFC-RGC-012.

Zeao Li (HZNU), Le Yao* (HZNU), Jiusun Zeng (HZNU).

Enhancing Industrial Soft Sensing Models for Unknown Conditions: A Retrieval-Augmented Generation Approach with Large Language Models

Abstract. In the context of industrial process soft sensing, predicting key process indicators under unknown conditions is a critical task. The integration of Retrieval-Augmented Generation (RAG) with large language models (LLMs) offers a novel approach to enhance the predictive capabilities of soft sensing models. This method leverages the power of LLMs to process and understand complex patterns in time series data, while RAG provides the means to access and incorporate external knowledge that is relevant to the current process state. To construct a soft sensing model for unknown process conditions, a time series knowledge base is first established. This knowledge base contains a curated set of representative sequences from historical process data, which are selected through techniques such as K-means clustering. When a prediction query is presented, Dynamic Time Warping (DTW) is employed to retrieve sequences from the knowledge base that exhibit similar patterns to the query sequence. These retrieved sequences, along with the original query, are then reformulated into a natural language prompt and fed into the LLM for prediction. The RAG-enhanced LLM is trained to align the sequence modality with the natural language modality, ensuring that the model can effectively process the combined input. The model's

performance is evaluated using metrics such as Symmetric Mean Absolute Percentage Error (SMAPE), Mean Absolute Scaled Error (MASE), and Overall Weighted Average (OWA). Experiments on diverse industrial datasets have shown that the integration of RAG with LLMs can significantly improve prediction accuracy. This approach not only enhances the model's ability to generalize to unseen conditions but also provides a more robust and reliable framework for predicting key process indicators in industrial settings. The combination of RAG and LLMs in soft sensing models represents a significant advancement in the field, offering a promising direction for future research in knowledge-enhanced sequential data management for industrial process control and optimization.

Keywords: Industrial Soft Sensing, Unknown Working Conditions, Retrieval-Augmented Generation (RAG), Large Language Models (LLMs), Zero-shot Learning.

NSFC-RGC-013.

Tong Zhou* (NJTECH), Yahui Lin, Dengfeng Zhang.

Digital Twin-based Job Shop Scheduling Considering Machine Predictive Maintenance and Random Job Insertions

Abstract. As manufacturing processes grow increasingly complex and uncertain because of factors like machine breakdowns and job insertions, the need for dynamic scheduling methods has become more urgent. Traditional job shop scheduling methods, due to their limited real-time response capabilities, are not suitable for handling highly dynamic and complex production environments. This study aims to address the dynamic flexible job-shop scheduling problem (DFJSP), considering machine predictive maintenance and the insertion of new jobs, to optimize total tardiness. A scheduling agent based on the double deep Q-network (DDQN) architecture is constructed. Based on Digital Twin, the agent continuously interacts with the scheduling environment, predicting potential future breakdowns to proactively select the optimal scheduling rules for each possible failure or new job insertion. The experiments, simulating DFJSP with a predictive maintenance (PdM) mechanism, verify the scheduling optimization effectiveness of the DDQN in scenarios involving machine failures and random job insertions. The results demonstrate that the DDQN architecture effectively addresses scheduling problems in dynamic environments, especially when a predictive maintenance mechanism is introduced. The production efficiency and stability of the scheduling system are further enhanced by forecasting and managing potential failures in advance through the digital twin-based virtual models.

Keywords: Dynamic Flexible Job-Shop Scheduling Problem, Deep Reinforcement Learning, Double Deep Q-Network, Predictive Maintenance, Digital Twin.

NSFC-RGC-014.

Junlong Chen (XJTU), Feng Wu* (XJTU), Chi Liu (XPU).

A Cost-sensitive Deep Learning Approach Integrating Three-way Decision Theory for IC Chip Vision Inspection

Abstract. In integrated circuit (IC) chip fabrication industry, defect inspection after packaging is a necessary step to ensure the final product quality. Due to the effect of high yield and small-batch, imbalanced class data is a common issue in IC chip defect inspection. In addition, misclassifications of real defects causing high recall cost also deserves concentration. However, existing machine learning-based approaches usually consider either data augmentation or cost-sensitive learning to solve the imbalanced data. In this paper, we proposed a novel IC chip inspection method called cost-sensitive residual convolutional neural network integrating three-way decision theory (CS-ResNet-TDT). To deal with the imbalanced data and consider the misclassification costs, we introduced a data augmentation method based generative adversarial network to increase defect samples, added a cost-sensitive adjustment layer to assign larger weigh to misclassification of defects, and adopted a three-way decision scheme to address the different misclassification costs. In order to obtain the best scheme to deal with imbalance and different misclassification costs, we conducted a series experiments to investigate the effect of single strategy and the combination of different strategies. Comparative experiments demonstrate that the proposed CS-ResNet-TDT achieves the highest F1-score, recall, and the lowest misclassification cost.

Keywords: Imbalanced Data; Residual Convolutional Neural Network; Cost-Sensitive Learning; Three-Way Decision Theory; IC Chip Defect Inspection.

NSFC-RGC-015.

Yuxuan Ji (ECJTU), Linya Liu (ECJTU), Yong Wang* (WUST), Xi Vincent Wang (WUST), Lihui Wang (WUST).

Sorting System Software Design and Simulation Debugging

Abstract. Material sorting refers to the process of sorting, sorting and sorting out the materials of different types and properties according to the specified requirements according to certain rules. In the field of modern logistics and production, material sorting is a vital link, which can improve work efficiency, reduce labor costs, reduce error rate, and can also achieve fast and accurate material processing. At present, it has been applied in many fields, such as logistics centers, warehouse operations, etc. Based on the in-depth exploration of the automatic and material sorting system mechanism, this paper adopts the integrated design concept for the specific sorting needs, comprehensively considers the characteristics of software and hardware, and implements mutual reinforcement and optimization, to build a material conveying and sorting system. The system takes PLC as the main control core, uses the combination of sensor technology, pneumatic device, and position control technology, and realizes the intelligent classification and counting of copper, iron, silver, and red, green, and blue material blocks through the trapezoidal diagram programming and design program.

Keywords: Programmable Controller (PLC); Sensor; Pneumatic Control; Material Sorting.

NSFC-RGC-016.

Xiaofen Huang (XPU), Chi Liu* (XPU).

Construction of Evaluation Index System of Mastectomy Bra fitness Under Wearing State

Abstract. To explore the main influencing factors of mastectomy bra fitness and construct a set of scientific and practical evaluation index system, Based on bra theory and ergonomics theory, combining the literature analysis method and system analysis method, we initially constructed the evaluation index framework, formed the expert consultation questionnaire, applied the Delphi method to optimize and establish the evaluation index system, and applied the improved hierarchical analysis method to establish the index weights. The evaluation index system of mastectomy bra fitness includes 4 first-level indexes of size and shape, activity demand, physiological demand and psychological demand, 6 second-level indexes of fit, stability, heat and moisture comfort, safety, aesthetic and pressure comfort, and 23 third-level indexes. A set of evaluation index system of mastectomy bra fitness is established, and relevant reflections are given to provide reference for related research.

Keywords: Mastectomy Bra, Fitness, Evaluation Indicator System, the Delphi Method, Hierarchical Analysis Method.

NSFC-RGC-017.

Zhuomin Liang (SZU), Tongtong Xie (SZU), Zelong Yi* (SZU), Yelin Fu (SZU).

Explainable Agricultural Price Prediction with a News-based AM-Bilstm Framework

Abstract. News-driven predictive modeling has gained significant attention in recent years; however, the influence of news-related factors (such as topics and sentiment) on price volatility remains poorly understood, thereby affecting the efficiency of agricultural supply chain members' news-based operational strategies. To address this issue, our study presents an advanced price prediction framework that integrates a Bi-directional Long Short-Term Memory (BiLSTM) model with an attention mechanism (AM) to improve forecast accuracy and interpretability. Using historical wheat prices and news corpus data from 2017 to 2023, we employ sentiment analysis and topic modeling to capture both market trends and contextual factors. Analysis of sentiment scores and topic features derived from news headlines reveals that positive sentiment is typically associated with factors such as agricultural growth and policy support, while negative sentiment is closely linked to issues such as crop problems and market uncertainty. Notably, industry brands, specific agricultural products, geographic location, and sustainability play a crucial role in price forecasting. This framework contributes to precision agriculture by guiding decision-making for farmers and supply chain participants, fostering sustainable production practices, and mitigating risks associated with volatile market conditions.

Keywords: News Extraction, Agricultural Supply Chain, Price Prediction, Natural Language Processing (NLP), Interpretability Analysis.

NSFC-RGC-019.

TONGLIU WANG (XPU), CHI LIU* (XPU).

Research on the Optimization Design of the Structure of Fitted Blouse for Mildly Hunchbacked Body

Abstract. The aim of this study was to optimize the structural design of fitted blouses for mild

hunchback bodies in order to improve the comfort and aesthetics of fitted blouses worn by women with mild hunchback conditions. By analyzing the structural features of fitted blouses and the characteristics of hunchback bodies, standard samples of fitted blouses were produced. The first subjective experiment was conducted using a five-point scale with female subjects who have mild hunchback conditions to identify the parts that needed modification, propose an optimized design, and produce a fitted blouse with an optimized structure. The same subjects then wore the structurally optimized fitted blouse, while controlling other variables of the experiment, and the same subjective experiment was conducted again. By comparing the results of the two subjective experiments, the degree of structural optimization of fitted blouses for mild hunchback bodies was summarized. Finally, the structural optimization design was completed, which effectively improved the wearing experience of fitted blouses for women with mild hunchback conditions and enhanced the market competitiveness of fitted blouses.

Keywords: Mildly Hunchbacked Body, Fitted Blouse, Structural Optimization Design, Wearing Comfort, Subjective Evaluation.

NSFC-RGC-020.

Jianwu Luo (CQU), Min Cheng (CQU), Rui Chen, Long Bai (CQU), Xiaohong Chen (CQU), Fuqiang Liu (CQU), Xiaobin Li (CQU), Pei Jiang* (CQU).

Energy Consumption Prediction of Industrial Robots Based on a Model-Based and Data-Driven Hybrid Method

Abstract. Industrial robots are characterized by high energy consumption and low energy efficiency, and their widespread application in manufacturing presents significant energy-saving potential. However, the complex energy consumption mechanisms of industrial robots constrain prediction accuracy. This study proposes a modelling approach that integrates both model-based and data-driven methods. The approach utilizes dynamic equations to model the joint torque of the robot, and a compensation model based on Deep Stacked Auto-encoders (DSAE) is employed to address parameter deviations and frictional forces in the dynamic model. To account for the time-lag effects of energy storage components in the circuit on energy consumption, a model combining one-dimensional Convolutional Neural Networks, Long Short-Term Memory networks, and Attention Mechanism (1DCNN-LSTM-AM) is introduced to enhance the energy consumption model, thereby improving prediction accuracy. Experiments conducted on a KUKA KR60-3 six-degree-of-freedom (DOF) robot demonstrate that the proposed method reduces the mean absolute percentage error of energy consumption predictions to less than 2.74%, significantly enhancing prediction accuracy.

Keywords: Industrial Robot; Energy Consumption Prediction; Model-based; Data-driven; Error Compensation.

NSFC-RGC-021.

Zhengxu Zhu (HKU), Shuxuan Zhao (HKU), Ray Y. Zhong * (HKU).

Digital Twins based Automated Modeling and Safety Simulation of Building Cracks

Abstract. During the process of building demolition, the existing damage to the building often brings insecurity to the construction. At present, research on automated assessment of building cracks is still in the stages of identification and mapping. An automated modeling process can optimize workflows and greatly improve the efficiency of security modeling. This study uses infrared imaging technology to identify cracks on building surfaces and inside walls, extracts crack information, and maps cracks to a finite element model through automatic mapping algorithms. Automated processes were designed and analyzed for three different crack modeling methods. The results indicate that the method is effective in the accuracy of crack mapping and can increase the efficiency of safety assessment through automated processes.

Keywords: Digital Twin, Cracked Structures, Automation, Finite Element Analysis.

NSFC-RGC-022.

Chung-lam Ng (HKU), Ming Li* (PolyU), Ray Y. Zhong (HKU), George Q. Huang (PolyU).

Carbon Outlay for Modular Construction Logistics in Cyber-Physical Internet (CPI)

Abstract. The efficiency benefit of modular construction (MC) has stimulated its rapid development in Hong Kong. This accordingly increases its supporting logistics service, to transit between factories and construction sites. The increased weight and volume of upgraded modules are taking more challenges for controlling carbon emissions and transportation affordability during shipment. The emerging cyber-physical internet (CPI) is a promising solution to operate on-demand

logistics services through CPI routers. While the routers depend on its built-in metrics to determine the transits of modules. To bridge this gap, this study aims to develop an equilibrium model for carbon outlay as a routing metric in CPI routers. The proposed metric is designed to synchronize carbon regulation and reduction among multiple MC logistics service providers. For matching with real-world situations, quota limits and quota allowances are incorporated in carbon outlay among multiple logistics companies. Meanwhile, the proposed carbon outlay is updated monthly regarding company performance in routers, ensuring a fair and flexible carbon allocation and trading in MC logistics. Finally, the proposed method is validated and examined through a simulation study in the Great Bay Area. The results indicated that the proposed carbon outlay is able to improve carbon regulations and reduction in MC logistics. This study advances the theoretical understanding of carbon regulations and provides guidelines for encouraging logistics companies to achieve carbon reduction.

Keywords: Cyber-Physical Internet; Carbon Emissions; Modular Construction Logistics.

NSFC-RGC-023.

Shulin Lan (UCAS), Xingshan Yao (BIT), Yingchao Wang (BIT), Chen Yang* (BIT).

Deep Reinforcement Learning based Secure Computation Task Offloading in Smart Manufacturing Systems

Abstract. Offloading computing tasks from manufacturing end devices to edge servers can significantly reduce response time. Most studies focus on offloading performance metrics such as latency and energy costs, neglecting the risks associated with network transmission and the potential for malicious edge servers to compromise sensitive data. These oversights raise significant security and privacy concerns. To address these issues, we propose a blockchain-based offloading framework designed to prevent malicious edge servers from participating in the offloading process. Meanwhile, we adopt multiple encryption algorithms with varying strengths to meet diverse security requirements. We further design a multiphase optimization approach based on the Deep Deterministic Policy Gradient (DDPG) algorithm, which selects task offloading proportions and encryption algorithms according to the different security requirements of tasks, eliminating the need for training multiple policy networks. Simulation results demonstrate that the DDPG algorithm outperforms the Deep Q-Network algorithm and that the iterative optimization algorithm can effectively meet diverse task requirements for offloading performance and security across varying numbers of edge servers.

Keywords: Task Offloading, Blockchain, Security and Privacy, Deep Reinforcement Learning.

NSFC-RGC-024.

Mingxing Li (JNU), Yiyan Xie (JNU), Ting Qu* (JNU), Yishuo Jiang (Cornell), Ray Y. Zhong (HKU).

Sync-State Driven Rescheduling for Multi-Resource Constrained Production-Logistics in Cyber-Physical Modular Integrated Construction

Abstract. In Modular Integrated Construction (MiC), the module manufacturing is a complex process that involves integrated management of production and logistics with multiple resources such as human labor, assembly stations, equipment, and materials. And its complexity is further amplified by the presence of multi-source uncertain events. It is defined as a novel Multi-Resource Constrained Production-Logistics Synchronization (MRC-PLSync) problem. This paper proposes a Sync-State driven rescheduling mechanism to address MRC-PLSync problem under uncertainty. Firstly, a stochastic programming model with Monte Carlo simulation is applied to handle uncertain processing time. Considering uncertain events such as machine breakdowns and urgent orders, the Sync-State is then defined to evaluate real-time system state from two-dimension and four-perspective: “Material supply-production sync” and “production-site delivery sync” dimensions with “Scheduled State-Current State-Future State-Ideal State” perspectives. Based on the real-time Sync-State monitoring and analytics, the mechanism is able to capture the most suitable timing for rescheduling to balance immediate needs with long-term goals in dynamic environments. A case study highlights the superiority of the proposed strategy in terms of synchronization quality, optimized resource allocation, and improved system stability. This study is among the first attempt to discuss coordinated production-logistics management in MiC manufacturing under multi-resource constraints in dynamic environments. It provides a new perspective on MiC management decision-making with real-time system state analytics, adding to the growing body of research on smart decisions for Industry 4.0 construction.

Keywords: Modular Integrated Construction, Manufacturing planning and control, Production-Logistics Synchronization, Uncertainty, Data-driven Decision.

NSFC-RGC-025.

Changchun Liu* (NUAA), Dunbing Tang (NUAA), Ye Ma (NUAA).

Large Language Model-enhanced Embodied Intelligence for Digital Twin-assisted Human-Robot Collaboration Assembly

Abstract. Over recent years, embodied intelligence has been found to be an effective approach to achieve human-like reasoning, perception and execution in human-robot collaborative (HRC) assembly scenarios. As the carrier of embodied intelligence, embodied agents are almost staying at an exploring stage. Due to the lack of enabling technologies with generalization abilities and out-of-touch with physical control, repetitive training of various functional models is required for dynamic HRC scenarios. As a result, embodied agents can hardly cope with complex and changing HRC environments effectively. To address this issue, an embodied intelligence architecture enhanced with Large Language Model (LLM) for digital twin-assisted HRC assembly is proposed in this study. With the powerful generalization capabilities of LLM, repetitive training of various reasoning perception models can be avoided, and flexible selection of cobot execution can be enabled. In more detail, the HRC task can be analysed and transformed into an assembly plan sequence in structured languages via LLM-enhanced embodied task reasoning, so that cobots can understand the corresponding assembly tasks both of its own and the operators. Based on task reasoning results, a digital twin-assisted interaction interface is designed to map the visible HRC assembly guidance, while supporting the seamless conversation with LLM. Several comparative experiments conducted in an actual HRC assembly scenario demonstrate that the proposed approach has competitive advantages in task reasoning and digital twin-assisted assembly.

Keywords: Human-Robot Collaborative Assembly, LLM-enhanced Embodied Intelligence, HRC Task Reasoning, Digital Twin, Assembly Guidance.

NSFC-RGC-026.

W. WU (PolyU), C.B. LI* (CQU), X.F. ZHANG (CQU), G.Q. Huang (PolyU).

REPASS: A Methodology of Real-Time Energy Consumption Prediction for Automotive Spray-Painting System Based on Multi-source Data Fusion

Abstract. The spray-painting system in automotive manufacturing characterizes a large amount of energy consumption at a time, thus exposing the process to potential overload risks. It becomes imperative to dynamically predict the energy consumption of spray-painting systems to facilitate preventive and security measures. However, the monitoring data derived from the spray-painting system exhibits high dimensionality and non-linearity, posing challenges to prediction accuracy. Therefore, this paper proposes a methodology framework of real-time energy consumption prediction for the automotive spray-painting system (REPASS). First, a hybrid feature extraction approach is designed to cope with multi-source data concerning device, process, production, and multiple energy sources for holistic energy management so as to enhance the overall energy efficiency. Specifically, maximal information coefficient (MIC) is introduced to scrutinize the correlation of influencing factors with energy consumptions, and then random forest (RF) is applied to rank the importance of these factors and identify primary contributors to energy consumption, thus reducing model complexity and elevating training efficiency. Second, a deep learning model CNN-BiLSTM-Attention (CBA) is proposed for the real-time energy consumption prediction, while the coati optimization algorithm (COA) is employed for network structure optimization. Finally, a real-world case study is implemented in an electric vehicle painting workshop, with a smart energy management system module developed, to verify the effectiveness and superiority of the proposed method based on real-time data. This methodology is expected to serve as a tool for practitioners to meet similar requirements and spark new ideas for future research.

Keywords: Energy-efficient Manufacturing, Energy Consumption Prediction, Data-driven Prediction, Automotive Spray-painting System, Deep Learning.

NSFC-RGC-027.

Jinpeng Li (PolyU), Zhiheng Zhao* (PolyU).

Look-Around Reasoning-Enabled Resource Allocation in Production Logistics within Industry 4.0

Abstract. Production logistics (PL) is characterized by significant complexity and unpredictability, primarily due to fluctuating resource demands and asynchronous operational workflows. Effective and resilient resource allocation is critical for optimizing production processes, particularly in achieving zero inventory targets within an uncertain environment. This paper presents a recommendation-driven approach to real-time resource allocation in PL. Initially, a resource spatial-temporal knowledge graph (RSTKG) is developed to model and analyze the relationships between

entities and historical allocation data. Subsequently, we introduce a novel look-around reasoning mechanism, which utilizes the temporal and spatial attributes of material buffers on the shop floor to evaluate the cost-effectiveness of requested resources in comparison to available ones, ultimately generating an optimized resource allocation plan. To validate the proposed approach, a case study is conducted within an air conditioning manufacturing company. The results demonstrate a punctuality rate exceeding 90%, thereby outperforming conventional resource allocation strategies.

Keywords: Production Logistics, Cyber-Physical System, Intelligent Manufacturing, Decision-Making, Industry 4.0.

NSFC-RGC-028.

Y. Zhu (HKU), S. Besklubova (HKU), R. Zhong (HKU).

Sustainable Concrete Recycling Practices with CO2 Sequestration from Power Station Flue Gases: A Case Study in Hong Kong

Abstract. The construction industry is one of the cannonading industries in the world today, with a huge impact on economic development. As an important component of the national economy and a significant contributor to economic growth, the construction industry has laid the material and technological foundation for the development of modern civilization. However, the construction industry has caused a serious impact on the environment due to the increase in construction and demolition waste. In Hong Kong, the local government has implemented relevant strategies to recycle construction and demolition waste. Although this measure has played a certain role, the generation of a large amount of waste concrete powder resulted in incomplete elimination of the serious impact to the environment. Waste concrete powder can return to the circular economy by replacing cement to reduce carbon emissions by carbonization. Through carbonization, recycled concrete aggregates and waste concrete powder can not only enhance their performance, but also effectively absorb carbon dioxide. However, this technology is currently not mature enough, especially in terms of finance. This paper took relevant data from Hong Kong as a case study, adopted mathematical models based on cost-benefit analysis and activity-based costing approach to analyze the cost of transporting, recovering, and storing carbon dioxide from power stations' flue gas, and evaluated the feasibility of using waste concrete for concrete mixtures. The research results indicate that compared with the traditional method, the proposed alternative approach significantly reduces environmental costs while improving economic efficiency, providing a good case study for the development and application of carbonization technology.

NSFC-RGC-029.

Xin Wang, Nian Yin, Zhinan Zhang* (SJTU).

Intelligent Design and Optimization of Ship pipeline Layout

Abstract. The ship pipeline system is crucial as the transmission pathway for water, oil and gas, of which the layout design directly affects system efficiency and safety. However, varying influencing factors including explicit and implicit knowledge are involved in the complex ship pipe routing design problem. Traditional algorithms are difficult to fully meet the requirements in terms of search efficiency and solution quality. This research proposes a systematic framework for pipe routing design, which includes a Dual-Strategy Enhanced Ant Colony Optimization (DEACO) algorithm and a physical characteristics-based neural network (PBNN) evaluation method. The DEACO is enhanced by both active and passive strategies, covering behaviour patterns of natural ant colonies and their response to the environment to enhance searching flexibility and efficiency. The PBNN method divides complex scenarios into smaller sub-scenarios and transform the subjective experience to quantifiable metrics by feature extraction. Through feature disturbance analysis, the method accurately identifies suboptimal regions and clarifies potential improvements. Case studies have shown that the proposed approach saves the computation time by 30.5% in the solution generation phase and improves the evaluation score by 9.85% with good robustness. This approach is of great significance for enhancing the efficiency and quality of pipeline layout design.

Keywords: Ship Pipeline, Pipe Routing, Neural Networks, Intelligent Evaluation, Design Auxiliary Methods.

NSFC-RGC-030.

Shuxuan Zhao (HKU), Chenglin Yu (HKU), Junjie Lei (HKU), Chaofan Lv (DHU), Yishuo Jiang (HKU), Ray Y. Zhong* (HKU).

Digital Twin-enabled Anti-Collision System for Human-Robot Interactions in Smart Construction Sites

Abstract. The construction industry is one of the most dangerous sectors in the world, with significantly higher fatality rates compared to other industries. Collisions with heavy construction machines are one of the major causes of worker injuries and fatalities in dynamic and uncertain construction sites. To improve the construction safety, this research proposes an anti-collision system for the human-robot interaction. A five-dimensional digital twin model is developed to construct digital construction sites and provide collision warnings within the virtual space. The physical layer designs multi-sensor fusion approach to respectively collect image data, depth data, and motion data, so as to achieve comprehensive perception of construction sites. The digital data layer designs multi-modal analysis methods to obtain on-site information such as category, position and motion status. The virtual entity layer integrates geometry model, physical model, behavior model, and rule model to achieve the synchronization between physical entities and digital entities. It also divides construction sites into dangerous zones, warning zones, and safe zones to perform collision warnings based on the status of construction robots and workers. The services layer provides services such as supervision, motion status monitoring, zone prediction, and data management for the DT system. The connections establish the information interconnection and synchronization between these layers. Case study is conducted to verify its performance in key points detection, visualization and collision warning. It is proven that the proposed method can achieve a prediction accuracy of over 96% for dangerous zones and over 95% for warning zones. The closed-loop optimization of "perception, analysis, decision-making, execution" for the human robot interaction in smart construction sites can be greatly achieved.

Keywords: Construction Safety; Human Robot Interaction; Collision Warning; Digital Twin.

NSFC-RGC-031.

J. Man* (BIT), R. Feng, Z. He (TJU).

Data-driven Remaining Useful Life Prediction and Predictive Maintenance Policy for Hard Failures

Abstract. With the development of digital twins, smart manufacturing, and online monitoring technology, real-time monitoring signals of subjects and systems are increasingly available. System degradation analysis, remaining useful life prediction, and predictive maintenance policy have attracted intensive attention. The system is commonly subject to multiple working conditions or environments, and the degradation signals are compounded with other factors or noises. As a consequence, the degradation process usually has stochastic behavior. In this study, we proposed to use the mixed-effects model and Wiener process to characterize the stochasticity of the degradation signal, and consider the degradation signals with the proportional hazard model for the hard failure events. Based on that, the corresponding remaining useful life (RUL) prediction method and the predictive maintenance policy with consistently updated RULs are explored. Simulation studies and case studies are conducted to evaluate the performance of RUL prediction and the maintenance policy.

Keywords: Degradation, Remaining Useful Life Prediction, Stochastic Process, Predictive Maintenance.

NSFC-RGC-032.

Li Yin (HKU), Ray Y. Zhong* (HKU).

An Integrated Smart Approach for Off-Site Construction Logistics Management

Abstract. Off-site construction logistics management faces challenges in coordinating supply chains, ensuring quality control, and integrating fragmented data across stakeholders. This study synthesizes three interconnected innovations to address these gaps. First, a comprehensive review of global practices, technologies, and regional barriers in off-site construction logistics (OSCL) is conducted. By analysing academic literature and industry trends, a smart BIM-centric framework for logistics management is proposed that integrates digital twins (DTs) to bridge lifecycle management gaps. It addresses regulatory misalignment and operational inefficiencies in regions such as North America, Asia-Pacific, and Europe, offering a logistics perspective approach for data interoperability from design to maintenance. Second, a cyber-physical internet (CPI)-based intelligent platform is developed for off-site construction supply chain management (OSC-SCM). The platform adopts a three-layered architecture: (1) A scalable layer connects off-site factories, logistics units, and on-site teams via industrial drivers (IDs) to establish real-time data flows; (2) A kernel service layer designs DT protocols with incentive mechanisms to synchronize stakeholder collaboration; (3) An application layer provides thirteen services spanning production planning, logistics tracking, and assembly coordination. A case study demonstrates a 20% reduction in project duration and cost savings of $3.5 million, validating the platform's efficiency in resource allocation and workflow automation. Third, an explainable super-resolution (SR) visual method targets post-transportation quality assurance facilitating assembly preparation by detecting micro-cracks in modular components. The method combines gradient-guided SR reconstruction to enhance low-

resolution images and a pixel-level selection module to suppress background noise, improving crack visibility. Experiments on real-world datasets confirm its effectiveness in accurately identifying micro-cracks, addressing a critical risk factor in logistics quality control. The proposed methodology offers a blueprint for resilient, transparent, and sustainable off-site construction logistics, with implications for global supply chain digitization.

Keywords: Off-site Construction; Logistics Management; CPI; BIM; Visual Detection.

NSFC-RGC-033.

Shuaiming Su (HKU), Li Yin (HKU), Svetlana Besklubova (HKU), Jidong Song, Ray Y. Zhong* (HKU).

Digital Twin-enabled Reverse Supply Chain for Building Demolition Waste Trading

Abstract. The escalating volume of building demolition waste has presented significant challenges to the ecological environment. In demolition waste management area, while scholars have addressed various perspectives, there remains a lack of focus on digital technology and collaborative cooperation mechanisms among stakeholders. Consequently, building waste management falls behind in terms of digitalization, and fails to meet the expectations of stakeholders. Based on this, this paper proposes a digital twin-based reverse supply chain (RSC) for building demolition waste (BDW) trading. A mathematical model is established to investigate the impact of various factors in the RSC on cost-benefit relationship of the demolition contractor, who serves as the origin of RSC. Lastly, implications are summarized to provide insights to practitioners involved in establishing a BDW RSC, forming a BDW trading market, and selecting appropriate demolition strategies.

Keywords: Digital Twin, Building Demolition, Reverse Supply Chain, Waste Trading, Cost-Benefit Analysis.

NSFC-RGC-034.

Yifang Ding (BIT), Suxiu Xu* (BIT), Meng Cheng (SZ PolyU), Sini Guo (BIT), Jianghong Feng (SCAU).

A VCG-like Auction with Platform Escrow for Metaverse Exchange

Abstract. In the metaverse market, the critical role of auction mechanisms aligns the interests of both suppliers and demanders of virtual assets. Each agent owns a virtual asset and wants another meta-item. In our setting, the traditional Vickrey-Clarke-Groves (VCG) auction runs at a deficit. To ensure an equilibrium for all parties, we introduce a novel mechanism that combines the VCG auction with scale control and platform escrow concepts, called SCE-VCG auction. To improve the platform's surplus, we use scale control to limit the number of winners and platform escrow to increase market demand. We prove that SCE-VCG auction is incentive compatible and individually rational. If multilateral matching achieves maximal social welfare, then the substitute condition does not hold (impossibility theorem). We also prove that the platform's surplus can be improved by scale control in some conditions. Our experimental results show that a mix of scale control and platform escrow schemes can further improve the platform's profit and successful trading ratio. The computational results indicate that truthful bidding is almost an optimal strategy for the platform, thus promoting a transparent and beneficial auction environment.

Keywords: Metaverse Exchange, Auction Design, Platform Escrow, Scale Control, Incentive Compatibility.

NSFC-RGC-035.

Peng Zhao (DUT), Xiaocong Wang (DUT), Jiajian Li (DUT), Zihao Nie (DUT), Xinluo Wang (DUT), Yanjun Shi* (DUT).

A Collaborative Edge Computing Offloading Solution for Industrial Internet of Things Based on Location Prediction Mechanism

Abstract. With the rapid advancement of Industrial Internet of Things (IIoT), the complexity and scale of IIoT devices are growing at an exponential rate. Traditional static offloading strategies struggle to meet the low-latency, low-energy consumption, and service fairness requirements in dynamic task demand, device mobility, and resource heterogeneity scenarios. To address these challenges, this paper proposes an IIoT-CEC offloading model. The model is based on a position prediction mechanism and is designed for complex dynamic computation offloading scenarios involving multiple servers and IIoT devices. The proposed model comprehensively considers the energy and delay requirements of different tasks while dynamically adjusting optimization

objectives. To mitigate the issue that IIoT devices may move beyond communication range during computation offloading, this paper introduces a position prediction mechanism based on the Extended Kalman Filter (EKF). This mechanism utilizes the predicted positions of IIoT devices along with target device or server position information to compute reliability values and optimize offloading targets. It effectively avoids delays in task result back-transmission and potential increases in system costs caused by device movement. Experimental results demonstrate that the proposed model significantly improves computation offloading efficiency and overall system performance.

Keywords: Industrial Internet of Things; Collaborative Edge Computing; Position Prediction; Deep Reinforcement Learning (DRL).

NSFC-RGC-036.

Xueyu Zhao* (HUE), Xiangchuan Yang.

A Hierarchical Optimization Model for Public Transit Connectivity Network Addressing Spatial Heterogeneity in Land Value Appreciation around Metro Stations

Abstract. In response to the problem of unbalanced bus connection efficiency caused by the spatial heterogeneity of land value appreciation around metro stations, this study proposes a hierarchical collaborative optimization framework. The research focuses on the collaborative planning of rail transit and surface buses. By constructing a bi-level programming model, the dynamic balance between the decision-maker's requirements and passengers' needs is achieved. The upper-level model, from the perspective of the bus company, coordinates three major objectives: minimizing operating costs, maximizing service coverage, and equalizing service quality. It optimizes the overall efficiency through dynamic route adjustment and resource allocation. The lower-level model, based on passengers' travel choice behaviour, integrates time utility, cost sensitivity, and spatial heterogeneity characteristics (such as walking preference in the core area and bus dependence in the marginal area), and uses the discrete choice theory to analyse the preference for connection modes. The model solves the Pareto optimal solution set through the NSGA-II algorithm, and validates the effectiveness of the model with a typical high-density urban area as a case study. The results show that this model can significantly improve the fairness of connection services and the efficiency of resource utilization, providing theoretical support and innovative planning methods for solving the "last mile" problem in urban transportation.

Keywords: Spatial Heterogeneity, Land Value Appreciation, Bi-level Programming Model, NSGA-II Algorithm.

NSFC-RGC-037.

Yishu Yang (PolyU), Ming Li (PolyU), Chenglin Yu (HKU), Ray Y Zhong* (HKU).

Digital Twin-enabled Visibility and Traceability for Building Materials in On-site Fit-out Construction

Abstract. Fit-out construction is crucial for the functionality of completed infrastructures. However, the absence of a robust data collection system hinders efficient project management, causing delays and extra costs. This paper introduces a digital twin-enabled platform that utilizes Internet of Things (IoT) and neural network technologies for real-time visibility and traceability of prefabricated materials. The effectiveness of the proposed platform has been validated through a real-life prefabricated construction project in Hong Kong. Leveraging the IoT-captured data, visual and event-driven process models are developed to simulate materials flow and workflow executions. Hierarchical finite state machines (HFSM) facilitate the management of prefabricated construction supply chain. Results show the platform's effectiveness in identifying abnormal event states and notifying stakeholders in real-time, thus supporting advanced project management practices. This platform improves information coordination among stakeholders, providing real-time visibility and traceability, and enabling hierarchical management at strategic, tactical, and operational levels throughout the prefabrication process.

Keywords: Digital Twin (DT), Complex Event Processing (CEP), Hierarchical Finite State Machine (HFSM), Prefabricated Construction Supply Chain.

NSFC-RGC-038.

Xiaobin Li* (CQU), B.C. Bohang Chen (CQU), Chao Yin (CQU).

Car Sales Production Prediction based on CNN-Bilstm Model with Self-attention Mechanism

Abstract. For automotive companies, developing effective methods for car sales prediction is crucial for inventory management and production planning. To overcome the shortcomings in current study of car sales production prediction, this paper proposes a hybrid model (CNN-

BiLSTM-SA) integrating Convolutional Neural Networks (CNN), Bidirectional Long Short-Term Memory (BiLSTM), and a self-attention mechanism. The model consists of five components: an input layer, CNN module, BiLSTM layer, self-attention layer, and output layer. The CNN extracts spatiotemporal features and enhances local information from input data, the BiLSTM captures long-term dependencies, and the self-attention mechanism identifies internal correlations. Compared to traditional machine learning method and deep learning models, the CNN-BiLSTM-SA model demonstrates superior performance in adapting to trends and predicting specific values in car sales data. This approach offers a novel solution for sales forecasting in the automotive industry.

Keywords: Convolutional Neural Network, Bidirectional Long Short-Term Memory, self-attention mechanism, Car sales production.

NSFC-RGC-039.

Ruixian Li (HKU), Jianguo Wu (PKU), Yongxiang Li* (SJTU).

PeriodNet: Noise-Robust Fault Diagnosis Method under Varying Speed Conditions

Abstract. Rolling bearings serve as vital elements in contemporary mechanical systems and are extensively utilized in a wide array of rotating machinery. Nevertheless, due to increasingly diverse operational demands, the conditions under which these bearings function have grown more complex, substantially raising the risk of failure. Moreover, the presence of pronounced background noise along with fluctuations in operating speeds further complicates the task of intelligent fault diagnosis, particularly for conventional methods that possess limited feature extraction capabilities. In response to these challenges, this study introduces a periodic convolutional neural network—dubbed PeriodNet—which functions as an intelligent, end-to-end framework for diagnosing bearing faults. The architecture of PeriodNet is established by integrating a periodic convolutional module (PeriodConv) prior to its backbone network. Developed on the foundation of the generalized short-time noise resist correlation (GeSTNRC) method, PeriodConv is adept at extracting features from noisy vibration signals gathered under varying speed conditions. By employing deep learning strategies, PeriodConv enhances the GeSTNRC approach, enabling its parameters to be optimized during the training phase. An open-source dataset, which encompasses data collected under variable speed conditions, is utilized to evaluate the effectiveness of the proposed method. Case studies indicate that PeriodNet exhibits robust generalizability and performs reliably under different speed conditions, while additional experiments incorporating noise interference further confirm its high resilience in noisy environments.

Keywords: Bearing Fault Diagnosis, Complex Operating Conditions, Deep Learning, Noise Resist Correlation, Periodic Convolutional Module.

NSFC-RGC-040.

Yi Luo* (HKU), Xiujie Zhao (TJU).

Condition-based Maintenance Optimization in Dynamic Environment

Abstract. This study addresses the challenge of optimizing maintenance strategies for systems with varying degradation characteristics in dynamic environment. A condition-based maintenance policy is proposed for repairable systems, where degradation process is modelled by a Wiener process, with its drift parameter influenced by time-varying environmental conditions. The environment is represented as a discrete-time Markov chain. The maintenance problem is formulated as a Markov decision process to minimize the expected cost over finite and infinite horizons. At scheduled inspection intervals, the system's degradation level and environmental state are observed, enabling decisions among corrective replacement, preventive replacement, or no maintenance action. Meanwhile, the backward dynamic programming algorithm and value iteration algorithm are employed to gain the optimal maintenance policies over the finite and the infinite planning horizons, respectively. Finally, the proposed model is further explained with concrete examples and a comprehensive sensitivity analysis. Numerical results clearly demonstrate notable variations in the optimal maintenance strategies in different periods and underscore the importance of taking proactive maintenance measures in harsh environmental conditions, even if the degradation level of the system is relatively low.

Keywords: Condition-based Maintenance, Stochastic Degradation, Dynamic Environment, Markov Decision Process.

NSFC-RGC-041.

Sangqi Zhao* (HKU).

Cost-Effective Decision-Making for Maintenance, Inventory Planning, and System Sizing in K-Out-

Of-N Load-Sharing Systems with Self-Announcing Failures

Abstract. The k-out-of-n configuration is commonly seen in engineered systems. During its operation, a k-out-of-n system fails due to component deterioration, requiring timely maintenance. When the components are non-repairable, the operator needs to make joint decisions regarding component replacement and spare part replenishment. This task becomes challenging when the system is subject to self-announcing failures and has load-sharing components with load-dependent deterioration rates. Moreover, due to the load-sharing nature, the system size has a significant impact on the overall cost rate, adding complexity to the decision-making process. In this paper, we propose a Semi-Markov Decision Process based reinforcement learning framework to design a joint sizing, maintenance, and inventory policy for such systems. First, we propose a scheme that determines state-specific actions regarding component replacement and spare part replenishment. Afterwards, the optimal system size is obtained. Next, we formulate the optimization problem based on an SMDP framework. Finally, we customize a Dueling Double Deep Q-Network algorithm to mitigate the issue of dimensionality explosion. The proposed policy yields a lower cost rate than existing threshold-based maintenance and inventory policies and guides the operator toward cost minimization.

Keywords: System Sizing, Maintenance and Inventory Planning, Self-Announcing Failures, Semi-Markov Decision Process, Deep Reinforcement Learning

NSFC-RGC-042.

Ge Li* (HKU), Yian Wei (HKU).

A Business Pattern Selection Framework for Parking Lot Operators Running Charging Piles

Abstract. With the rise of environmental awareness, electric vehicles are increasingly popular as a cleaner alternative to internal combustion engine vehicles, which increases the demand for charging and attracts many parking lot operators (PLOs) to invest in charging piles. When entering the charging pile market, PLOs can choose from different business patterns offered by charging pile operators (CPOs), which can be divided into two categories: PLO-owned and CPO-owned based on the ownership of operating rights of charging piles. Selecting the appropriate business pattern based on local demand characteristics and associated costs is very important for enhancing the economic benefits of PLOs. In addition, the failure of charging piles during operation is an important factor influencing the selection of patterns. Failure of a charging pile can lead to a reduction in service quality and revenue, and if a charging post fails during service, the ongoing service will be randomly switched to another idle and functional charging pile, a phenomenon we refer to as failure-induced demand switching (FDS). Considering this stochastic interaction between the failure of the charging pile and the customer, the optimal maintenance policy is proposed jointly with the number of charging piles to invest under different business patterns. The state transitions of the parking lot are modeled by a continuous-time Markov chain considering stochasticity of demand arrival and completion, failure of charging piles, and corresponding FDS, based on which the average profit rates of PLO are obtained under different business patterns. Finally, a joint decision on pattern selection, number of charging piles to invest, and maintenance policy is obtained for PLO to maximize the profit.

Keywords: EV charging infrastructure, Business pattern selection, Stochastic process, Maintenance policy.

NSFC-RGC-043.

Jiewu Leng (GDUT), Caiyu Xu (GDUT), Xueguan Song (GDUT), Qiang Liu* (GDUT), Xin Chen (GDUT), Weiming Shen (GDUT), Lihui Wang (GDUT).

High-Performance Manufacturing System: Connotation, Performance Metrics, Relationships, Enablers, Challenges and Directions

Abstract. In today's market, there is a growing appetite for personalized services and premium quality. This evolving landscape has driven manufacturers to prioritize the capabilities of their manufacturing systems, such as flexibility, reconfigurability, resilience, and reliability. This paper introduces a manufacturing system paradigm named High-Performance Manufacturing System (HPMS), which serves as a guide for the design, manufacturing, configuration, and operation to satisfy the demand for system performance. Drawing on this paradigm, the paper conducts an exhaustive examination of the performance metrics together with their interrelations. The paper's contributions are threefold. Firstly, it provides an in-depth review of the definitions and assessment methods for manufacturing performance metrics from a holistic perspective. Secondly, it analyzes the intricate relationships among multiple performance metrics. Lastly, the paper explores potential key enablers, challenges, and research directions in the lifecycle management of HPMSs. It is anticipated to help practitioners be clearer in balancing their goals in the lifecycle management of

their manufacturing systems, evolving into a value-oriented paradigm towards Industry 5.0.

Keywords: High-Performance Manufacturing System; Mass Individualization Paradigm; System Performance; Performance Evaluation; Industry 5.0.

NSFC-RGC-044.

Yian Wei (HKU).

State Transition Analysis in a Fleet of Service Systems under a Three-Dimensional Maintenance Policy

Abstract. Self-service systems, such as electric vehicle charging stations, are typically installed in fixed locations and may experience malfunctions whether idle or in use. When a unit fails during operation, the service process is disrupted, posing challenges in managing the overall system performance. The continuous arrival of customers combined with frequent system malfunctions creates a complex operational environment. To address these challenges, we examine the long-term service reliability of such fleets and propose a novel three-dimensional maintenance policy aimed at maximizing profitability over time. We develop a model based on a Markov regenerative process to capture the transitions between different system states. Eight state transition scenarios are quantitatively investigated. A detailed numerical case study based on a fleet of electric vehicle charging stations in Hong Kong is presented to demonstrate the practical applicability of our approach. Ultimately, the insights from this study are expected to help operators enhance both the reliability and profitability of their systems.

Keywords: Self-Service Systems, Long-Run Fleet Profit, Imperfect Maintenance.

NSFC-RGC-045.

M.X Hou (XJTU), H.R. Cao* (XJTU).

Digital Twin-driven Force Control Framework for Robotic Milling

Abstract. The in-situ machining mode of industrial robots is expected to improve the machining efficiency of large parts. Milling force is a critical index in robotic milling. The force control for robotic milling can improve the machining performance, protect the tool and the workpiece, and so on. This paper proposes a digital twin-driven force control framework based on acceleration and spindle speed for robotic milling. First, the milling force model parameters in the virtual space are updated by the milling force and the objective function. Where the milling force is identified by the acceleration in the physical space, i.e., an accelerometer is used instead of an expensive dynamometer. Next, the reference spindle speed corresponding to the peak milling force is obtained based on the milling force model. Then, a spindle speed control strategy is proposed based on the reference spindle speed and the machine model with time delay. The stability of the proposed controller is proved theoretically. Finally, a force control system is designed and applied to robotic milling. The effectiveness of the proposed force control method is verified by robotic milling experiments. The results show that the percentage error between the measured peak milling force in the physical space and the reference peak milling force in the virtual space is less than 5% after applying the proposed force control framework to robotic milling.

Keywords: Robotic Milling, Spindle Speed, Milling Force, Force Control.

NSFC-RGC-046.

Zhifeng Yang* (CTGU), Junning Zhang (CTGU), Bin Zhou (CTGU), Yuanfa Dong (CTGU).

Interactive Strategies for Driving Risk Warning Integrating the Coupling Effect of Driving Style and Emotional State

Abstract. As digital twin technology propels the intelligent manufacturing system into the Industry 5.0 era, its integration into intelligent driving systems heralds a new era for smart transportation and autonomous driving. In this context, ensuring driving safety has emerged as a critical challenge. This paper introduces an interactive risk warning strategy that considers the coupling effect of driving style and emotional state to enhance the safety of intelligent driving systems. Initially, a human-vehicle interaction simulation environment is established to collect real-time behavioral data and physiological signals from drivers. Next, the influence mechanisms of driving style and emotional state on driving behavior are analyzed, leading to the development of a human-factor-based driving risk field model to quantify risk levels. Finally, an adaptive, personalized interactive risk warning mechanism is designed, providing timely and effective warnings tailored to individual driver characteristics based on risk assessment outcomes. Experimental results demonstrate that the proposed warning strategy effectively delivers timely and relevant alerts that align with each driver's

unique profile.

Keywords: Digital Twin, Human-Vehicle Interaction, Risk Early-Warning Mechanism, Human Factor-induced Risk Field.

NSFC-RGC-047.

Xinxin Liang (BUAA), Zuoxu Wang* (BUAA), Jihong Liu (BUAA).

A Self-Cognitive Product Design System with Large Language Model-driven Fine-Grained Multi-Modal Feature Recognition

Abstract. Facing the promising tendency of human-artificial intelligence (AI) collaborative product design, fine- grained and multi-modal mechanical part recognition and semantic understanding have become a basic task for achieving a self-cognitive product design system. However, traditional semantic understanding approaches for mechanical parts can only handle single-modal data, which is either textual or image data, leaving the gaps of 1) insufficient mining on fine-grained part's functional/behavioral/structural information, and 2) ineffectiveness on multi-modal part information alignment, therefore restricting the intelligence level of the previous product design assistants. To mitigate these challenges, this paper proposes a fine-grained multi-modal reasoning approach for mechanical part semantic understanding. The proposed approach utilizes a pre-trained Convolutional Neural Network (CNN) for visual feature extraction, a large language model (LLM) called LLaMA3 for advanced textual analysis, and a Unified Feature Fusion Module (UFFM) to facilitate robust cross-modal interactions. A positive and negative sample generation mechanism is implemented to refine the model's ability to discern subtle variations in complex components. Experimental evaluations demonstrate a significant improvement in classification accuracy, providing a more precise and intelligent solution for the semantic understanding in complex product design systems.

Keywords: Multi-Modal Fusion, Semantic Recognition, Fine-Grained Reasoning, Complex Product Design Systems.

NSFC-RGC-048.

Yirui Wang (HKUST), Yantao Yu* (HKUST).

IFC-based Embodied Carbon Assessment for Tunnel Project

Abstract. The urgent need to reduce carbon emissions in tunnel construction necessitates efficient and accurate embodied carbon (EC) assessment methods. Traditional EC assessments rely on manual data collection and calculations, making them time-consuming and error-prone. While Building Information Modeling (BIM) has shown promise in streamlining EC assessment, its application in tunnel projects remains limited due to the lack of standardised data integration frameworks. To address this gap, this study proposes an Industry Foundation Classes (IFC)-based methodology for cradle-to-site EC assessment in tunnel construction. The approach includes (1) developing an integrated ontology to identify key data requirements, (2) enriching BIM models with essential EC parameters, and (3) implementing a calculation tool to extract and process data from the IFC model. The proposed method enhances multi-source data interoperability and enables efficient EC assessment in collaborative environments. These findings validate the effectiveness of the IFC-based approach in facilitating rapid and accurate EC assessment, supporting sustainable decision-making in tunnel construction.

Keywords: Building Information Modelling (BIM), Embodied Carbon Assessment, Tunnel, Industry Foundation Classes (IFC).

NSFC-RGC-049.

Lu-Yao Zhang (NCUT), Ying-Jie Zhu* (NCUT), Jia-Qi Hou (NCUT).

Research on Global Response Prediction of Large-span Steel Structure in Gymnasium by Digital Twin

Abstract. Aiming at the global response prediction of large-span steel structures in gymnasium under the influence of complex environmental factors, a global intelligent analysis and prediction method of structure performance based on digital twin technology is proposed in this paper. Parametric data was generated by ABAQUS parametric modeling technology, and the surrogate model was trained by graph neural network to learn the mapping relationship between input load (wind speed, wind pressure, wind direction, temperature) and output structural response. On this basis, the digital twin model of the steel structure of the gymnasium was constructed by using the monitoring data of limited measuring points, so as to deduce the global structural performance. Principal component analysis is used to fuse time series and spatial features, which can dynamically update the feature set to achieve real-time prediction of structural performance and automatic

warning based on safety standards and historical data thresholds. This method not only fully reflects the global response of the structure, but also significantly improves the accuracy and real-time of prediction and early warning, provides accurate decision support for the safety management of the steel structure of the stadium, reduces the risk of accidents, and provides a new idea and method for the intelligent monitoring and maintenance of large complex steel structures.

Keywords: Digital Twin, Large-Span Steel Structures, Structural Performance Global Response, Structural Performance Prediction and Early Warning.

NSFC-RGC-050.

Minshan Xie (HKUST), Yantao Yu* (HKUST).

A Simulation-based Muscle Fatigue Assessment Method for Construction Workers

Abstract. Muscle fatigue contributes to work-related musculoskeletal disorders (WMSDs) among construction workers due to prolonged exertion, repetitive motion, and awkward postures, assessing muscle fatigue state can effectively prevent WMSDs from developing early on. Traditional fatigue assessment methods often lack accuracy or feasibility for on-construction-site applications. This study proposes a non-invasive, simulation-based approach using an RGB camera and pressure insoles to estimate muscle activity and metabolic cost to aid muscle fatigue assessment via OpenSim. A validation experiment with surface electromyography (sEMG) on the erector spinae during a masonry task showed feasibility but revealed discrepancies in muscle activation patterns, highlighting areas for improvement. This method advances scalable, non-invasive fatigue assessment for construction safety and ergonomics.

Keywords: Muscle Fatigue Assessment, Musculoskeletal Simulation, Work-related Musculoskeletal Disorder (WMSD).

NSFC-RGC-052.

Yang Fu* (GXU), Deqiang He (GXU), Zhenzhen Jin (GXU), Jiachen Ma (GXU), Longyu Cui (GXU).

SCADA Data Driven Lifelong Learning Digital Twin Model for Wind Turbine Intelligent Fault Diagnosis under Time-varying Running Conditions

Abstract. SCADA data driven intelligent fault diagnosis (IFD) is the research hotspot in wind turbines. However, most of existing wind turbine IFD models are static models, which cannot track the fault evolution law dynamically under the time-varying running conditions, leading to the low generalization ability. To overcome the abovementioned shortcoming, this paper proposes a lifelong learning digital twin model (LLDT) for wind turbine IFD. Firstly, the fault features under time-varying running conditions are extracted from the SCADA data by spatio-temporal collaborative analysis. Then, a multi-scale spatio-temporal graph network is developed to construct the initial digital twin model of wind turbine IFD. Finally, a lifelong learning algorithm is proposed for the digital twin model to track the fault evolution law dynamically under the time-varying running conditions from the steaming SCADA data. The experiment validation results show that the proposed LLDT model can track the fault evolution law dynamically, and update itself online to improve its generalization capacity.

NSFC-RGC-053.

H.H. Cheung (HKU), P.J. Liu (HKU), L.K. Wen (HKU), Alvin P.L. Lai (LEO PAPER GROUP), W.Z. Li (HKU), Derek K.C. Tong (HKU).

A Digital Twin Driven Intelligent printing management system

Abstract. Advanced Industry 4.0 technologies enables, manufacturing enterprises to develop intelligent manufacturing systems for optimising production operations and quality. In line with the wave of intelligent manufacturing, repetitive tasks that were originally performed by human in factories, such as simple assembly tasks, are gradually being put into the hands of robots. However, in the intelligent manufacturing environment, though robots can replace humans for some low-level tasks, humans are still responsible for monitoring and decision-making. To facilitate the collaboration of human and robot in smart factory, it is important to establish a bi-directional information exchange flow connecting humans and robots. This paper presents a digital-twin enabled human-robot collaboration platform integrating innovative technologies, such as mixed reality, computer vision to connect humans and robots through a mixed reality-enabled digital twin platform, with the aim of enhancing intelligent manufacturing operations and providing a reference solution for the manufacturing industry in the context of Industry 4.0 and gaining some management insights based on the research. The proposed platform consists of a human-robot collaboration

product assembly system integrating computer vision to enable product assembly and a digital twin for the robotic-arm-enabled assembly system to exchange information between with the physical system for purposes, such as monitoring, decision making, and error handling. Finally, a 3D printed product assembly prototype is used to demonstrate the functionality and features of the platform.

Keywords: Digital Twin; Human-Robot Collaboration; Intelligent Manufacturing.

NSFC-RGC-054.

Zimo Zhang, Juntao Li, Junyan Xiong, Dengcheng Tang, Daqiang Guo* (HKUST-GZ).

Integrating Digital Twins and Large Language Models in Manufacturing: A Review and Conceptual Framework for Design-to-Manufacturing (D2M)

Abstract. The rapid growth of digital technologies and artificial intelligence has made digital twins (DTs) and large language models (LLMs) core tools in smart manufacturing. This paper presents a review of DT-LLM integration in manufacturing systems. The review examines key technologies, methods, and application of DT-LLM in the manufacturing industry. The analysis of the reviewed paper identifies promising research area that bridge customized and even personalized demands with flexible production systems. Inspired by this, a novel concept termed Design-to-Manufacturing (D2M) is introduced. Furthermore, a conceptual DT-LLM-enabled D2M framework is proposed to demonstrate how the integration of DT and LLM can revolutionize the traditional design-to-manufacturing process. This framework incorporates digital twin data, generative design, human-AI augmented decision-making, and flexible human-robot collaborative manufacturing system. This paper offers valuable insights into a new manufacturing paradigm designed to meet the rising demand for personalized products.

Keywords: Personalized Production, Smart Manufacturing, Digital Twin, Large Language Model, Design-to-Manufacturing.

NSFC-RGC-055.

H.H. Cheung, W.Z. Li* (HKU), I.K. Wen, Derek. K.C. Tong.

An Intelligent Mobile Robot System for Intelligent Manufacturing

Abstract. Robotic technology has been widely integrated into intelligent manufacturing and smart cities, owing to its advanced automation and flexibility. Currently, most mobile robot systems for intelligent manufacturing are only used to deliver specific items along fixed routes, lacking flexibility and intelligence to autonomously navigate for automatic item recognition, localisation, picking and delivery in a quick, accurate, and flexible way. Therefore, to alleviate the limitations of the existing mobile robot systems, this paper presents an intelligent mobile robot system with the integration of a 6-degree-of-freedom robotic arm, an 8-wheel omnidirectional mobile robot, the Robot Operating System (ROS), an RGB-D camera, 2D Barcode, LiDAR, Inertial Measurement Units (IMU), and odometry, which can autonomously navigate to a position and scan 2D barcodes tagged on items to identify and locate a specific item for picking and delivering. For the autonomous navigation function, multi-sensor fusion simultaneous localisation and mapping (SLAM) is implemented in the robot system to build the map of the workspace and real-time locate the robot; the ROS navigation stack is employed to achieve autonomous navigation and obstacle avoidance for the robot. For automatic identification and localisation of target item, a robotic arm mounted on the mobile base is combined with an RGB-D camera to perform an eye-in-hand manipulation system, which offers high-precision object recognition, localisation, and picking; such functions are achieved by integrating ArUco Marker, OpenCV, and Rapidly-exploring Random Tree Star Algorithms (RRT*). Furthermore, a dynamic 3D model for the robot is established that can be dynamically updated based on sensor data to accurately reflect the robot's current status. This enables remote monitoring and adjustment of the robot's real-time state through ROS visualisation tools (RViz) and network communication interfaces. Finally, tests with an intelligent manufacturing scenario are presented to validate the functions, accuracy, and stability of the intelligent mobile robot system.

Keywords: Intelligent Mobile Robot System, Autonomous Navigation, Automated Item Recognition, Localization, Picking and Delivery, ROS.

NSFC-RGC-056.

Kai kang (SZU), Bing Qing Tan* (SZTU).

Value of Digital Twin for Supply Chain Resilience Enhancement

Abstract. Modern supply chains are unstable and vulnerable to many high-profile crises in dynamic and turbulent markets. With diverse types of frequent disturbances, there is growing concern about

supply chain resilience (SCR). Digital twin (DT) exhibits its potential for coping with risks and building resilience in supply chains. In this paper, we formulate a stylized model to explore the impact of adopting DT on SCR. In the basic model, we consider a supply chain with a single manufacturer who decides whether to adopt DT to mitigate the negative impact of risks and a retailer selling the product to the consumer. We show that adopting DT is always preferable for the manufacturer and the retailer even if consumers have to pay more for the product. We then extend our model to examine the impact of power shift caused by the adoption of DT on the supply chain performance. We discover that the manufacturer leading the supply chain with adoption of DT is an optimal solution to the manufacturer and the retailer, even if the retailer is dominated by the manufacturer. Furthermore, we relax the assumption by considering the upfront investment and imperfect recovery of DT to make the model more practical. The findings present that the upfront investment and resilient ability of DT are critical factors that jointly affect the manufacturer's decision on the adoption of DT. Finally, several managerial implications are proven to set a good reference for improving SCR.

Keywords: Digital Twin (DT), Supply Chain Resilience (SCR), Supply Chain Management, Game Theory.

NSFC-RGC-058.

Hai Shen, Yuhan Xie, Jiaobo Zhao* (XISU), Yu Li, Xiaogang Zhao.

Low-Carbon Supply Chain Decision-Making: The Role of Carbon Labeling and Retailer-Driven Altruistic Preferences

Abstract. With the rise of carbon-labeled products and increasing global attention to environmental protection, low-carbon supply chains have become a focal point for businesses. This study addresses the impact of consumer preference for carbon-labeled products and retailers' altruistic preferences on the profits and utility of low-carbon supply chains. A Stackelberg game model comprising retailers and manufacturers is developed to analyze the mechanisms through which consumer preferences for carbon-labeled products and retailers' altruistic preferences influence supply chain decisions. Numerical simulations are then used to compare the decision outcomes. The results show that consumer preference for carbon-labeled products effectively promotes both retailers and manufacturers to enhance their low-carbon efforts, leading to an increase in overall supply chain profits. Retailers' altruistic preferences, within a reasonable range, can strengthen collaboration among supply chain members and improve overall efficiency. However, excessive altruism may lead to a decrease in the retailer's own profits. This study provides a verifiable methodological framework for profit (utility) analysis of large retailers under different scenarios.

Keywords: Carbon Labels; Low-Carbon Supply Chain; Altruistic Preferences; Optimal Decision-Making; Retailers.

NSFC-RGC-059.

Shi Jun (HKU).

Dynamic Planning Approaches for Route Optimization in Cyber-Physical Internet

Abstract. The logistics industry, as a critical driver of economic growth, faces numerous challenges related to efficiency, cost, and sustainability. With the advent of Industry 4.0, the need for seamless integration between physical and digital logistics systems has become more urgent, particularly in the context of cross-regional logistics operations. The Physical Internet (PI) introduced a framework for standardized connectivity within logistics, yet it falls short in addressing dynamic routing and real-time data synchronization, limiting its ability to meet modern logistics demands. Specifically, existing PI networks struggle to integrate real-time information effectively, resulting in suboptimal decision-making and inefficiencies. This research gap highlights the necessity for an enhanced framework capable of adapting to dynamic changes and optimizing routing in a more efficient manner. To overcome these limitations, the Cyber-Physical Internet (CPI) is proposed, adding an advanced cyber layer that facilitates real-time decision-making and intelligent logistics management. The field of logistics optimization, particularly for cross-regional operations, stands to benefit from this enhanced system. This study focuses on two primary research questions: (1) How can dynamic routing and real-time data integration be optimized within the CPI framework to enhance logistics efficiency and reduce transportation costs? (2) What routing protocols and optimization strategies are most effective in coordinating Autonomous Logistics Systems (ALS) within CPI networks for efficient cross-regional logistics operations? To address these questions, this research develops a comprehensive CPI-based route optimization model, focusing on real-time data integration and adaptive routing protocols for cross-regional logistics. The methodology combines theoretical analysis and numerical simulation, utilizing algorithms like A* and Ant Colony Optimization (ACO) to determine optimal routing strategies. The expected outcomes include a framework that enhances the integration of fragmented logistics networks and improves

the efficiency of cross-regional logistics operations. This study aims to make a modest yet significant contribution to the field of logistics optimization, demonstrating how real-time data-driven routing protocols can address the inherent limitations of existing logistics systems, enabling smarter, more adaptive, and sustainable logistics operations in the context of Industry 4.0.

Keywords: Cyber-Physical Internet (CPI); Dynamic Routing Optimization; Logistics Management.

NSFC-RGC-060.

Yuchen Wang (HKU).

Data-Driven Decision Support and Visualization for Warehouse Management Optimization

Abstract. As e-commerce continues to develop, the logistics industry, integral to e-commerce operations, is experiencing revolutionary transformations. Particularly in China, including Hong Kong, the logistics sector's complexity and scale are expanding. Amid intensifying market competition, Small and Medium Enterprises (SMEs) face mounting pressure for efficiency and cost control, presenting various challenges in warehouse operations. Warehouse management, a critical component of warehouse operations, significantly impacts service levels and logistics costs. Hence, optimizing warehouse management is crucial. This research focuses on Company A, a Hong Kong-based SME specializing in electronic commodity trading. The objective is to develop a data-driven decision support system that enhances warehouse efficiency and reduces operational risks through advanced analytics. By analyzing the records of Company A, this research identifies critical inefficiencies in supplier performance and warehouse workflows. The research aims to address three core challenges: detecting anomalies in time-sensitive logistics data, overcoming sparse behavioural patterns of suppliers, and balancing multi-dimensional performance metrics. A novel framework is proposed, integrating supplier classification, risk assessment, and real-time operational monitoring. Key innovations include a dynamic early-warning system that adapts to historical performance trends and a visual analytics platform for holistic supply chain oversight. The results demonstrate actionable insights into inventory optimization, supplier collaboration, and process standardization, achieving measurable cost reductions while maintaining service quality. This work contributes a replicable model for SMEs to transform fragmented operational data into strategic assets, bridging the gap between traditional logistics practices and modern data-driven decision-making. The proposed system not only addresses Company A's specific challenges but also offers scalable solutions for similar SMEs navigating complex supply chain environments.

Keywords: Warehouse Management Optimization, Data-Driven Decision Support, Supplier Behavior Clustering, Temporal Anomaly Detection.

NSFC-RGC-061.

Meining Long (HKU).

Warehouse Allocation Strategies based on Data Analytics for enhanced Utilization

Abstract. The rapid development of e-commerce has intensified competition in the logistics industry, making operational efficiency and cost-effectiveness key determinants of business competitiveness. Against this backdrop, warehouse management has become a critical but under-explored component, especially for small and medium-sized enterprises (SMEs). Current challenges include poor functional area layout, non-data-driven storage strategies, and inefficient resource allocation. This study aims to address the dual inefficiencies of misaligned functional zones and unscientific storage strategies in warehouses by developing a holistic optimization framework. Using Hong Kong's Electronic Trading Company A as the research target, this study aims to improve operational efficiency while reducing costs through systematic layout redesign and dynamic storage strategy development. The SLP-EIQ-ABC method is used to analyze the functional area and the number and frequency of goods in and out. Aiming at the characteristics of goods in Class A storage area, a multi-objective mathematical model is established with the minimization of picking work and the minimization of cargo space spacing of the same kind of goods as the objective function; for Class B storage area, a mathematical model is established with the minimization of picking operation time as the objective function. Design the parameters and solve the genetic algorithm to optimize the original functional area and cargo storage area. Apply Flexsim software to simulate and optimize, compare the optimization results, formulate a reasonable optimization plan, and improve the operational efficiency of the automated warehouse. These results suggest that, despite resource constraints, integrated layout-storage optimization can improve the efficiency of SME warehouses to a level comparable to that of large automated facilities. By addressing spatial planning at the macro level and inventory dynamics at the micro level, this study advances sustainable logistics practices while providing reference value for cost-sensitive SMEs.

Keywords: Warehouse Layout Optimization; SLP Method; Warehouse Storage Location; EIQ-ABC Method; Genetic Algorithm.

NSFC-RGC-063.

Zilong Fu (HKU).

An Inventory Management System based on Big Data Analytics for SMEs

Abstract. Against the backdrop of complex market environments and supply chain uncertainties, modern enterprises face enormous challenges in inventory management, including management difficulties, inaccurate demand forecasts, low space utilisation, inefficient resource allocation and stringent environmental regulations. In this study, we first categorise goods in the warehousing process (e.g., hazardous, perishable, and general goods), carry out cargo measurement and contamination risk assessment, and develop a preliminary allocation strategy. By analysing the characteristics of the goods, the space allocation is optimised, partition management is implemented, and the storage location is dynamically adjusted to improve the space utilisation rate. Correspondence between cargo types and storage requirements is established, and optimal space allocation is achieved through accurate measurement. Compared with the initial proposal, the research now emphasises advanced technologies such as artificial intelligence and big data. Machine learning algorithms have improved the accuracy of demand forecasting, leading to more rational inventory decisions. The integration of IoT technologies has enhanced real-time monitoring and improved management efficiency and reliability. The developed management system achieves standardisation, intelligence and refinement of warehouse management, improves the competitiveness of enterprises, promotes economic efficiency as well as environmental protection, and achieves the goal of sustainable development. More advanced mathematical models and efficient algorithms were designed to solve the optimisation problems. In-depth case studies demonstrate the practical value of warehouse configuration and management optimisation. The smart warehouse model greatly improves operational efficiency and market competitiveness, showing the potential for environmental protection and sustainable development. Future work will focus on further optimising the model, exploring applications in different industries and providing comprehensive inventory management solutions.

Keywords: Intelligent Warehousing, Spatial Optimization.

NSFC-RGC-064.

Yushan Luo (HKU).

A Novel Approach for Optimizing 3D-Printed Concrete Mix Design

Abstract. The realm of 3D-printed concrete has revolutionized the construction industry by offering unprecedented levels of efficiency, customization, and sustainability. However, the intricate relationship among diverse input parameters in concrete mix designs plays a pivotal role in determining the printability and ultimate properties of 3D-printed structures. The unique challenges posed by 3D printing, such as layer adhesion, extrusion consistency, and dimensional accuracy, exacerbate the necessity for meticulous optimization of mix components. Traditional research on concrete mix design typically employs the trial-and-error approach, which is both material-intensive and time-consuming. With the thriving advancements in machine learning technology, it has demonstrated remarkable prowess in data feature extraction and predictive accuracy. Given this backdrop, coupled with the intricate properties of concrete, this study endeavors to introduce an innovative methodology for optimizing concrete mix design through the integration of multi-objective optimization(MOO) techniques and machine learning(ML) algorithms. After identifying objectives and constraints, several data groups are collected and preprocessed from previous experiments. The heatmap has shown potential positive correlations among CS(Compressive Strength), FA (fly ash), GS (ground slag) and SP (superplasticizer), also among FS (Flexural Strength), FA and SP.This provides valuable insights and guidance for the further training process.ML techniques, including XGBoost, Support Vector Regression, and Artificial Neural Network, are then applied to capture the essential features influencing mechanical properties. The performance and prediction accuracy of these three techniques are subsequently compared, and the Pareto Front is extracted using the MOO method to provide an optimal mix design. To validate the effectiveness of this methodology, experimental verifications are conducted to compare the predicted outcomes with the actual test results. The findings highlight a significant improvement in optimizing 3D-printed concrete mix designs, resulting in remarkable advancements in both printability and mechanical properties.

Keywords: 3D Printing, Concrete Mix Design, Machine Learning, Multi-Objective Optimization.

NSFC-RGC-065.

Keke Qian (HKU).

Cost Examination and Life Cycle Assessment of 3D Printed Buildings

Abstract. With the increasing concern for sustainable development in the construction industry, 3D printed construction, as an emerging construction technology, has gradually gained attention due to its advantages of saving formwork, reducing labour costs, and lowering construction waste. However, there is still a lack of systematic quantitative research on its environmental impact and economic benefits compared to traditional cast-in-place concrete construction. In this study, the environmental impacts and economic costs of 3D-printed buildings are compared with those of traditional cast-in-place concrete buildings in the material acquisition and construction phases based on the Life Cycle Assessment (LCA) method using One Click LCA software. The concrete wall model was selected as the functional unit for the research object, and the performance of the two construction methods in terms of environmental indicators such as Global Warming Potential (GWP), Energy Consumption (PE), Acidification (AP), Eutrophication (EP), etc., were calculated and analysed in terms of their material costs and construction costs, respectively. Preliminary results show that 3D printed buildings consume less energy during the construction phase, reducing formwork and labour costs, but have higher carbon emissions than conventional construction due to the higher use of cement. In addition, the increased use of recycled aggregates can effectively reduce the environmental impact of 3D printed buildings, but material ratios need to be optimised to ensure structural performance. In terms of economics, the cost advantage of 3D printed buildings is more obvious in complex geometries, while in simple structures, the material costs may be higher than in conventional construction. This study provides a quantitative basis for the environmental and economic feasibility of 3D printed buildings, and proposes optimisation directions to reduce cement usage, optimise the printed structure, and improve the material economics, in order to promote the sustainable application of 3D printing technology in the construction industry.

Keywords: 3D Printed Buildings, Cast-in-place Concrete, Life Cycle Assessment (LCA).

NSFC-RGC-066.

Ruilin SU*, Svetlana Besklubova, Muhammad Huzaifa RAZA, Ray Y. Zhong (HKU).

Big Data Analytics for WIP Inventories Management in the context of Industry 4.0

Abstract. This study develops a practical framework to enhance Work-In-Process (WIP) inventory management in small and medium-sized electronics assembly companies by integrating Big Data Analytics (BDA) and Digital Twin (DT) technologies within the Industry 4.0 context. Focusing on mobile phone screen assembly workflows, the research addresses inefficiencies caused by material delays and fragmented visibility through a combination of warehouse logistics data and simulated production scenarios. The framework enables real-time data integration to identify bottlenecks and dynamically adjust inventory levels, while prioritizing cost-effective solutions compatible with existing systems. Key methods include modular design principles and incremental implementation strategies to ensure adaptability in resource-limited environments. Initial tests show improved WIP visibility and reduced accumulation in simulated scenarios, demonstrating the framework's potential to streamline production processes. Challenges such as interoperability and data security are addressed through phased deployment and localized data processing. By bridging theoretical Industry 4.0 concepts with practical needs, this study offers a scalable approach for manufacturers seeking to adopt data-driven operations without requiring advanced infrastructure. Future work will validate the framework through real-world case studies and extend its application to broader assembly contexts.

Keywords: Inventory Management, Digital Twin, Big Data Analytics.

NSFC-RGC-067.

Chenling Shi (HKU).

Data-Driven Decision-Making for Space Optimization in SMEs' Warehouses

Abstract. Small and medium-sized enterprises (SMEs) often face the problems of low space utilization and low order processing efficiency in warehouse management, especially in the case of large demand fluctuations. Therefore, this study takes an e-trading company in Hong Kong as an example, and proposes a data-driven warehouse space optimization scheme to improve the efficiency of warehouse management. In order to solve these problems systematically, a detailed research method is designed, which includes four core steps: data collection, optimization modeling, algorithm solving and simulation verification. First, the study identifies high-frequency SKUs and order characteristics through data collection and analysis, using historical order and inventory data, combined with RFID and IoT devices. Then, a multi-objective optimization model is constructed, which takes order processing time, path length and space utilization into consideration. The research results show that the application of data-driven decision support system can significantly improve the space utilization and order processing efficiency of SMEs' warehouses. The dynamic replenishment strategy improves inventory turnover, and the real-time monitoring of RFID enhances operational accuracy. This study provides a low-cost storage optimization scheme suitable

for small and medium-sized enterprises, provides practical guidance for enterprises to achieve efficient storage management, and lays a theoretical foundation for future research. In the future, real-time data analysis and dynamic optimization strategies can be further explored to enhance the adaptability and practicality of the scheme.

Keywords: Data-driven Decision-making, Warehouse Space Optimization, Intelligent Optimization Algorithms, Small and Medium-sized Enterprises.

NSFC-RGC-068.

Jiawei Liu, Yuhan Xie, Yu Li (XISU).

A Robust Optimization Method for Hotel Room Reservation Considering Uncertain Customer Arrival Time and Its Application

Abstract. The challenge of a hotel room manager is to decide accepting and rejecting reservation requests for the purpose of maximizing room utilization. This paper proposes robust optimization models to address the hotel room reservation management problem in the presence of uncertain arrivals, considering two types of uncertainty, namely, bounded uncertainty and symmetric uncertainty, as well as incorporating new parameters: uncertainty level, infeasibility tolerance and reliability level. Numerical illustration demonstrates that under the robust optimization framework, the expected revenue decreases as the uncertainty level increases, increases as the infeasibility tolerance and the reliability level increase.

Keywords: Hotel Room Reservations; Robust Optimization; Revenue Management; Uncertainty.

NSFC-RGC-069.

Qilei Zhou (HKU).

Big data Analytics for impact of goods type on warehouse operation for SMEs

Abstract. Over the past decade, with advances in machine learning and artificial intelligence technologies, data analytics tools have become smarter and more automated, allowing companies to predict demand more accurately, optimize inventory management, and improve labor productivity and warehouse space utilization. However, small and medium-sized enterprises (SMEs) face unique challenges in supply chain management due to resource and technology limitations, and different types of goods put forward different requirements and challenges for warehouse operations. Previous studies mainly focused on improving warehouse efficiency through various methods and models, but these studies largely ignored the internal level of enterprises. Therefore, this dissertation shifts its focus to SMEs equipped with IoT-based technologies, examining how different types of goods affect the use of warehouse operations through data from an electronic company in Hong Kong. This helps the company to identify the problems in the operation process, improve efficiency and reduce costs. In this dissertation, the data collected from the company will be cleaned first. Then the goods will be classified according to the volume and weight. Next, warehousing operation process of SMEs will be sorted out, and the data related to the warehousing operation process and commodities for analysis will be selected. Based on the correlation of data, the data of different forms of SMEs are summarized subsequently, and SPSS, Stata and other software tools are used to analyze the relationship between commodity categories and warehousing operations by cluster analysis, descriptive statistics, regression modeling and other methods. The main purpose of the research is to improve the efficiency of warehousing operations in SMEs, thereby enhancing the overall supply chain network. By achieving this, the study aims to help enterprises reduce costs and ultimately enhance their competitiveness.

Keywords: SMEs, Warehouse Operation, Big Data Analytics.

NSFC-RGC-070.

S. BESKLUBOVA* (HKU), Y. Li, R.Y. Zhong, I. Brilakis.

Network Analysis of Construction Falling Accidents Using Natural Language Processing

Abstract. As urban development accelerates, the need for construction projects has significantly increased. Despite this growth, the construction industry remains the most dangerous sector, with falls from heights being the leading cause of fatal accidents, ranking first among the "five major injuries". Construction safety demands strong attention, as understanding and analyzing the causes of accidents is crucial for reducing their frequency and enhancing overall safety levels. However, traditional accident analysis methods often rely on expert experience and limited data, which restricts a comprehensive and systematic understanding of the complex factors contributing to these incidents. This study utilizes advanced techniques, including Natural Language Processing (NLP) and Social Network Analysis (SNA), to systematically investigate the causes and characteristics of

falling accidents, analyze their interrelationships, and propose effective improvement measures. Through NLP topic analysis, five direct cause topics and eight indirect cause topics were identified, offering a comprehensive classification that enhances understanding of the specific contexts and backgrounds of accidents. The results of SNA provide frameworks for identifying key nodes and relationships among these causes by assessing degree centrality, closeness centrality, betweenness centrality, and eigenvector centrality. These frameworks offer essential insights for preventing falling accidents, assisting relevant departments and companies in reducing the likelihood of incidents, and enhancing safety management standards within the construction industry.

Keywords: Construction Safety Management, Falls From Height Accidents, Natural Language Processing, Social Network Analysis.

NSFC-RGC-071.

Muhammad Huzaifa Raza* (HKU), Svetlana Besklubova, Ekaterina Kravchenko R.Y. Zhong.

Evaluating Cost and Environmental Impact: A Comparative Analysis of 3D Printing and Traditional Construction

Abstract. The construction sector's considerable environmental impact has led to a growing demand for sustainable construction technologies. This study aims to compare the cost and environmental impact of traditional construction and 3D printing construction processes, starting from the supply of raw materials to the final construction and construction waste disposal. Based on the factors identified (raw material, printing equipment, transportation, warehousing, construction and waste disposal), traditional construction and 3D printing value streams are mapped to assess the potential factors or activities contributing to the cost and environmental burden. The results showed that 3D printing offers nearly 80% lower cost at the construction phase than traditional construction. However, 3D printing hardly reduces the total cost by only 0.96% and even produces significantly higher greenhouse gas (GHG) emissions than traditional construction due to the significant transportation cost of raw materials and 3D printing equipment. The higher transportation costs in 3D printing are mainly due to the lack of a well-established market for 3D printing equipment and raw material supply. Futuristic scenario analysis revealed that 3D printing could reduce the total construction cost (starting from raw material and equipment supply to construction waste disposal) by 61% when the infrastructure for 3D printing is established in the same way as traditional construction. The findings of this study explored the sustainability potential of 3D printing and offered insights for its application in construction projects.

Keywords: 3D Printing; Traditional Construction; Cost Analysis; Value Stream Mapping; GHG Emissions.

NSFC-RGC-072.

Xiang T.R. Kong (SZU), Xuemei Yang (SZU), Bing Qing Tan* (SZU).

Scaling Strategy Design of Comprehensive Utilization Enterprises Considering Carbon Trading through Evolutionary Game Theory

Abstract. In the context of accelerating global climate governance, achieving the "dual carbon" goals has become a crucial driving force for China's industrial transformation. This study focuses on the construction waste recycling industry and explores the driving mechanism of the carbon ETS on enterprises' transformation towards economies of scale. By constructing an evolutionary game model between government departments and recycled building materials production enterprises, the study compares and analyzes the decision-making differences of the main actors in scenarios with and without the ETS mechanism, thereby identifying the key variables influencing the equilibrium strategies of government and enterprises and their paths of influence. The results show that: (1) The CCER and carbon quota verification systems can reduce the risk threshold for enterprises' scaling investments by making environmental externality benefits explicit through price signals; (2) The synergistic effect of government fiscal tools and carbon market mechanisms can overcome the diminishing marginal utility dilemma of traditional single policy incentives. Based on these findings, the paper proposes the construction of a "policy support-carbon price guidance" dual linkage institutional framework to provide a reference for developing countries' circular economy industries to align with international green finance standards.

Keywords: Construction Waste, Enterprise Scaling, CCER, Evolutionary Game Theory.

NSFC-RGC-073.

H.H. Cheung (HKU), L.K. Wen* (HKU), Derek. K.C. Tong (HKU), W.Z. Li (HKU), R.Y. Zhong (HKU).

A Digital Twin-enabled Human-Robot Collaboration platform for Intelligent manufacturing

Abstract. Advanced Industry 4.0 technologies enables, manufacturing enterprises to develop intelligent manufacturing systems for optimising production operations and quality. In line with the wave of intelligent manufacturing, repetitive tasks that were originally performed by human in factories, such as simple assembly tasks, are gradually being put into the hands of robots. However, in the intelligent manufacturing environment, though robots can replace humans for some low-level tasks, humans are still responsible for monitoring and decision-making. To facilitate the collaboration of human and robot in smart factory, it is important to establish a bi-directional information exchange flow connecting humans and robots. This paper presents a digital-twin enabled human-robot collaboration platform integrating innovative technologies, such as mixed reality, computer vision to connect humans and robots through a mixed reality-enabled digital twin platform, with the aim of enhancing intelligent manufacturing operations and providing a reference solution for the manufacturing industry in the context of Industry 4.0 and gaining some management insights based on the research. The proposed platform consists of a human-robot collaboration product assembly system integrating computer vision to enable product assembly and a digital twin for the robotic-arm-enabled assembly system to exchange information between with the physical system for purposes, such as monitoring, decision making, and error handling. Finally, a 3D printed product assembly prototype is used to demonstrate the functionality and features of the platform.

Keywords: Digital Twin; Human-Robot Collaboration; Intelligent Manufacturing.

NSFC-RGC-074.

Xinjie Feng* (HKU).

Assessment and Optimization of Construction and Demolition Waste Management based on Data-driven in Hong Kong

Abstract. Rapid urbanization and urban regeneration demands, particularly in China, have driven unprecedented construction industry growth, accompanied by severe environmental challenges from construction and demolition (C&D) waste. In Hong Kong, construction waste constitutes a major portion of landfill- disposed solid waste and significantly contributes to carbon emissions. Despite stringent government policies, construction waste management remains problematic. In an effort to tackle these issues and aid in the achievement of managing construction waste more effectively, this study employs a data-driven method to holistically evaluate and enhance the handling of construction waste in Hong Kong. The research employs a multiple-stage model that amalgamates data envelopment analysis (DEA), the entropy method, and combined predictive models, including the GM(1,1) model, ARIMAX model, and LSTM model. By scrutinizing construction waste data from 1999 to 2022, the study assesses the comparative efficiency of the East, Southeast, and West New Territories landfills and establishes the proportion of each landfill in the total construction waste volume. The predictive models anticipate future trends in construction waste production, offering a scientific foundation for the creation of effective management strategies. Grounded on the prediction outcomes and analyses, specific optimization suggestions are put forward to augment the capability of Hong Kong's construction waste treatment facilities, curtail environmental pollution, and enhance resource utilization. These suggestions cover a broad spectrum of facets, such as policy creation, technological innovation, and the enhancement of management processes. The study highlights the practical effectiveness of the proposed models and algorithms through case studies.

Keywords: Data-Driven Model, Construction and Demolition Waste Management, Data Envelopment Analysis, Entropy Method, Combination Predict Model.

NSFC-RGC-075.

Kexin Yan* (HKU).

Data-Driven Approaches to Synchronize Demand and Inventory Levels

Abstract. With the continuous advancement of economic globalization and the rapid development of Internet technology, the scope of demand of enterprises has been widely expanded through traditional channels and online channels. The traditional inventory decision method assumes that the demand is continuous, stable, and relatively independent when making ordering strategy and inventory level. However, with the new environment of the market, the demands for goods and services are increasingly diversified; hence, the assumptions in the traditional inventory decision method are hard to be met. At the same time, more and more e-commerce companies are accepting supply chain-driven operations because of fierce competition. Therefore, accurate forecasting of demand and formulation of reasonable inventory strategies have become an important part of improving the core competitiveness, particularly for small and medium-sized enterprises (SMEs). The amount of data faced by enterprises is increasing exponentially, and the demand is becoming

more and more fluctuating and random. In the face of massive supply chain data, companies cannot dig out effective information, resulting in the inability to respond quickly to changes in demand. Machine learning can process complex data, mining potential patterns in online data, and making accurate predictions of future trends. This study collects and organizes relevant data from a small and medium-sized electronic product trading company and applies machine learning methods for demand forecasting. It will strive to adopt recent machine learning techniques, including Random Forest (RF), to improve the accuracy within SME demand forecast. Meanwhile, the study will utilize established performance indicators in Root Mean Square Error (RMSE) and Mean Absolute Error (MAE) in assessing if the forecasted values created by the proposed prediction model are valid.

Keywords: Data-Driven, Demand Forecasting, Machine Learning.

NSFC-RGC-076.

Zhengshan Sun * (HKU).

Data-Driven Warehouse Decision-Making System for Hong Kong SMEs

Abstract. Hong Kong SMEs face many challenges in managing their warehouse operations today. Due to the rise of e-commerce, modern warehouses require higher distribution efficiency, more optimized warehouse layouts, and better levels of inventory management. This research is a cross-cutting study that brings together operational research, supply chain management, and industrial engineering. This study provides a comprehensive data-driven warehouse decision-making system. It focuses on three main areas: an inventory classification management model based on ABC analysis; warehouse layout optimization under graph theory (shortest path); and Internet of Things (IoT) technology for real-time smart inventory monitoring. This research aims to address three important challenges of modern warehouse management: inventory classification and picking efficiency, warehouse storage location optimization, and inventory visualization and processing. Firstly, the ABC analysis approach is used to analyze warehouse order processing data to classify inventory items based on a number of data criteria, including goods turnover rate, order frequency, and type of goods. There are three categories, A, B, and C. Each category corresponds to goods with different processing priorities. Different management strategies are used for different goods in this model, and high-value, high-turnover-rate goods are prioritized. ABC analysis approach can effectively provide an inventory turnover rate of goods, which in turn shortens picking time and improves warehouse operational efficiency. Secondly, this study adopts the graph theory approach in operational research to optimize the warehouse layout. The goal is to model the entire warehouse distribution as a weighted directed graph using the shortest path algorithm, where nodes represent storage locations and paths represent goods movement paths. The shortest path algorithm is an algorithm to find the most efficient path between nodes in a network, if the best path can be determined, then the picking distance can be reduced and the efficiency of goods turnover can be improved. Currently owned warehouse layout is relatively simple, in the final report this study can self-build a more complex warehouse network, give relevant assumptions, and calculate the efficiency improved by the optimization of the warehouse layout. Thirdly, an IoT-based inventory monitoring system is designed in this study. The system utilizes radio frequency identification (RFID) sensors, wireless networks, and cloud-based big data to analyze inventory. When the inventory is less than a certain amount it will automatically alarm to remind replenishment. This can significantly improve the accuracy of inventory. In summary, the warehouse decision-making system provided in this study can help Hong Kong SMEs better face warehouse management challenges and make warehouse operations more modern and intelligent.

Keywords: Warehouse Decision-making System; ABC Analysis; Graph Theory; Inventory Management.

NSFC-RGC-077.

Xiufeng Li (TJU), Bo Li* (TJU).

Investment Strategies of IoT Platforms on Smart Device Startups during Innovating New Products

Abstract. IoT platforms provide a vital boost-up in smart device development. To empower smart device startups to innovate new products and expand the value of the platform, platform companies often provide investment support to startups to accelerate their smart device innovation. Based on this, this paper first discusses two investment scenarios: single-source investment and diversified investment. Then, the influence of platform investment funds, competition between startups, and platform value-added on the optimal investment strategy of the platform are analysed. Furthermore, the equilibrium investment strategy of the IoT platform is obtained. The research results of this paper reveal that the competition effect, capital constraint effect, and platform value-added effect will all have a significant impact on the optimal investment strategy. In particular, the greater the value-added effect and the smaller the competition intensity between startups, the platform prefers

diversifying its investment strategies under a larger funds budget. Finally, this paper provides management implications and economic enlightenment from the perspective of technical cooperation and platform empowerment.

Keywords: IoT Platform; Investment Strategies; New Product Innovation.

NSFC-RGC-078.

Weihua Liu (TJU), Jiahe Hou* (TJU), Yang Cheng (AAU).

The Potential of Smart Factory for Reducing Environmental Emissions: the Evidence from Chinese Listed Manufacturing Firms

Abstract. The nature of smart factories to help manufacturing firms reducing environmental emissions has attracted the widespread attention of governments and industries. However, some research also worried that if smart factories were not effectively constructed, they may increase firms' environmental emissions. To address this concern, we use PSM-progressive DID model to analyze the relationships between the construction of smart factories and environmental emissions, based on 144 Chinese listed manufacturing firms. The main findings are as follow. First, the construction of smart factories can lead to the short-term increase of 7.55% GHG emissions (1.001 tCO2e) and 4.12% air pollutants cost (1.011 $) per $M operation cost for firms. Second, the negative impact of smart factory construction on GHG emissions can be partially explained by physical technologies. Third, mimetic institution (industrial maturity of environment management system) can reduce the negative impact of smart factory construction, but coercive institution (government regulation) and normative institution (social media attention) have no significant moderating effect. With these findings, this study provides a clear understanding of how the construction of smart factories influences firms' environmental sustainability and accordingly offers insights for business considering environmental objectives in smart factory development.

Keywords: Smart Factory, Environmental Emissions, Digital Technologies, Institution.

NSFC-RGC-079.

E. KRAVCHENKO* (SFU, Russia), T. MINKINA, M. ZHELNIN.

AI-Powered Prediction and Optimization of Sustainable 3D-Printed Concrete

Abstract. The construction industry is a major consumer of natural resources and a significant contributor to greenhouse gas emissions. The adoption of 3D printing in construction offers a sustainable approach by reducing material waste, improving efficiency, and enabling the incorporation of alternative binders and recycled materials. However, optimizing the composition of 3D-printed concrete remains a critical scientific challenge due to the complex interactions between materials and process parameters. This study employs machine learning models to predict the compressive strength of 3D-printed concrete mixtures incorporating recycled materials. Three machine learning models—Random Forest, CatBoost, and Tabular Prior-data Fitted Network (TabPFN)—were applied to a dataset compiled from literature sources and laboratory experiments. The input variables included material composition, such as cement replacements (e.g., fly ash, slag, silica fume), recycled fine and coarse aggregates, as well as printing parameters. The output parameters were the compressive strength of cast samples and the strength of printed samples tested in different loading directions (X, Y, and Z). Among these models, TabPFN demonstrated the highest predictive performance, achieving a coefficient of determination of 0.974218. The study highlights the potential of AI-driven methods for optimizing 3D-printed concrete formulations, reducing reliance on experimental testing, and accelerating the adoption of sustainable materials in construction. The findings provide a framework for integrating machine learning into the design of eco-friendly, high-performance 3D-printed concrete.

Keywords: Cementitious Materials, Sustainable Mix Design, Machine Learning, Compressive Strength.

NSFC-RGC-080.

Hao Luo* (SZU), Chen Ling (SZU).

Two-Echelon Location and Routing Problem in a Pharmaceutical Logistics Enterprise

Abstract. To enhance the operational performance of supply chains in the pharmaceutical logistics field, the rationality of the pharmaceutical logistics network has recently attracted increasing attention. However, in the retail sector of pharmaceutical logistics, traditional location-routing methods fail to address two major issues: first, the massive volume of end-point demands increases the complexity of the Vehicle Routing Problem (VRP); second, the multi-echelon warehouse network structure leads to nested optimization problems, resulting in significant time costs. This

paper investigates the multi-echelon warehouse network transportation optimization problem in pharmaceutical retail logistics. It proposes a two-stage hybrid clustering continuous location algorithm (TSHCL) to minimize warehousing and transportation costs. To reduce computational time, a combination of weighted K-means clustering and greedy algorithms is employed. To address practical problems, regression equations are used to estimate relevant parameters. The feasibility and effectiveness of the proposed algorithm are validated across different data scales, and computational results demonstrate the superiority of TSHCL in terms of solution quality.

Keywords: Pharmaceutical Retail Logistics; Location and Routings; K-means; Greedy Algorithm.

NSFC-RGC-081.

Yang Xu* (HKU).

From Microscale to Macroscale: Novel and Intelligent Processes in Vat Photopolymerization

Abstract. 3D objects with features spanning scales from the microscale to the macroscale hold significant potential across various applications in biomedical and aerospace fields. However, fabricating such objects remains a significant challenge in additive manufacturing (AM) due to inherent trade-offs between feature resolution, maximum build area, and printing speed. To address these limitations, we introduce two novel and intelligent vat photopolymerization processes: Hopping Light Vat Photopolymerization (HL-VPP) and In-situ Transfer Vat Photopolymerization (In-situ Transfer VPP). HL-VPP overcomes the trade-off between resolution and print area in the XY plane by employing continuous scanning across the build area. By synchronizing linear scanning projection with galvo mirror rotation through a computer vision-based approach, HL-VPP eliminates motion blur and decouples fabrication efficiency from projector refresh rates. This enables ultra-fast curing of multiscale structures with unprecedented precision and scalability. Additionally, the process incorporates advanced modelling to optimize light dose distribution across the build area, ensuring consistent feature resolution even for complex geometries and large-scale structures. In-situ Transfer VPP, on the other hand, enhances resolution in the Z direction by addressing over-curing issues that are commonly encountered in microfluidic device fabrication. By precisely predicting and controlling the light dose during the printing process, this method enables fine-tuned light penetration and curing depth, facilitating the fabrication of intricate microchannels as small as 10 μm. The in-situ transfer strategy dynamically adjusts to variations in geometry and material properties, ensuring high fidelity in reproducing microscale features even within macroscale structures. Together, the computer vision-assisted HL-VPP and the advanced light control techniques of In-situ Transfer VPP significantly expand the capabilities of vat photopolymerization, bridging the gap between microscale precision and macroscale scalability. These advancements redefine the limits of additive manufacturing, paving the way for groundbreaking applications in biomedical devices and aerospace components.

Keywords: Additive Manufacturing, Intelligent Manufacturing, Vat Photopolymerization, Multi-scale.

NSFC-RGC-082.

Yongbing Feng* (BJUT), Guohua Gao (BJUT).

Towards Urban Vertical Farming: Digital Twin-enabled Generative Design for Multi-Layer Cultivation Systems with Solar Light

Abstract. Multi-layer Cultivation Systems (MCS) can intensify food production within or near urban areas. Compared to MCS that use artificial light sources, MCS with solar light (MCS-SL) offers significant advantages in energy conservation. However, it faces the challenge of inter-layer shading, which limits the yield of the system architecture. It is urgent to develop optimal design solutions in the conceptual stage to promote the advancement of this system architecture. Digital twin (DT) technology enables high-fidelity virtual modeling for risk-free simulation, multi-objective optimization, and physical validation, reducing experimental costs and accelerating technology maturation. This study proposes a Digital Twin-enabled Generative Design (DTGD) framework, which can be utilized for analyzing and balancing multiple system architectures during the conceptual stage of the system life cycle. When applied to the design of MCS-AL, it yields an optimal solution with a productivity of 49.78 $\mathrm{kg \cdot m^{-2} \cdot year^{-1}}$. The framework can be further enhanced by leveraging Large Language Models (LLM) to automate the generation of design solutions. Additionally, further research on MCS-SL can be conducted to explore its potential expansion to Urban Vertical Farming (UVF) in urban centers.

Keywords: Digital Twin, Vertical Farming, Model-Based Systems Engineering, System Architecture.

NSFC-RGC-083.

Jiaji Wang (HKU).

Integration of Geometry Physics Neural Operator Solver for Digital Twins of Engineering Structure

Abstract. Digital twins serve as advanced tools that integrate real-time data with simulation capabilities, optimizing infrastructure management and decision-making. This study investigates the integration of the Geometry Physics-informed Neural Operator (GPO) within digital replicas of engineering structures. GPO effectively approximates solutions to partial differential equations in solid mechanics, significantly enhancing the predictive accuracy and efficiency of digital twins for complex infrastructures. Its core components include a neural operator architecture, governing physics equations, and embedded physical information. Numerical experiments demonstrate that GPO accelerates convergence and improves accuracy, outperforming traditional solvers by up to three times across various structural applications. Additionally, GPO excels in integrating physical data and leveraging structural information to provide high-resolution simulations of structural behavior. This integration facilitates rigorous validation and calibration of digital twins, supporting predictive maintenance and design optimization. By combining GPO with established model updating methods, the study boosts simulation efficiency and equips stakeholders with actionable insights, paving the way for smarter and more resilient infrastructure management in the development of Industry 5.0.

Keywords: Neural Operator Solver, Physics-Informed Machine Learning, Digital Twins, Neural Network.

NSFC-RGC-084.

Bolin Chen (NWPU).

A Data-Driven Method for Predicting Abnormal Operating State of Aircraft Assembly System

Abstract. With the rapid expansion of aircraft manufacturing, numerous aircraft models have transitioned into mass production, making on-time delivery of high-quality products a critical objective. However, the dynamic configuration of production factors during assembly line operations often leads to instability or deviations from planned schedules, resulting in abnormal production line conditions. To address these challenges, this study proposed an assembly state indicator prediction model based on the production data. Furthermore, a comprehensive multi-indicator evaluation framework for identifying the abnormal operating state of the aircraft assembly line by analyzing the organizational model of aircraft assembly processes. The proposed approach facilitates timely early warning of potential anomalies, allowing for proactive mitigation of risks and ensuring sustained, stable production line performance. This research contributes to the advancement of intelligent monitoring and control strategies in aircraft assembly operations in data-driven scenarios.

Keywords: Aircraft Assembly Line, State Indicator Prediction, Abnormal Operating State Evaluation.

NSFC-RGC-085.

Ying Yu (ZJNU), Chenglin Yu* (HKU), Chao Ma (ZJNU), Pei Zhao* (ZJNU).

Digital Twin-inspired Efficiency Analysis of Kiva Robotic Warehousing and Manual Picking Systems for Smart Logistics

Abstract. This study presents a digital twin-inspired analysis comparing the efficiency of Kiva robotic warehousing systems and traditional manual picking systems under varying order characteristics. As economic uncertainties prompt logistics companies to reconsider the balance between automation and manual labor, accurately identifying the operational conditions under which each system thrives becomes crucial. This paper introduces the Herfindahl-Hirschman Index (HHI) to quantitatively assess SKU dispersion within orders and evaluates its impact on two key performance metrics: total processing time and total travel distance. A comprehensive simulation model, inspired by digital twin technology, was developed to replicate realistic operational scenarios for both robotic and manual picking methods. Results indicate that robotic warehousing systems significantly outperform manual methods in scenarios characterized by high SKU dispersion (low HHI values). Conversely, manual picking demonstrates superior performance in environments with highly concentrated orders (high HHI values). Additionally, the robotic system displayed greater stability across varying order characteristics. This research defines clear applicability boundaries for each warehousing mode based on quantitative analysis, providing essential guidelines for logistics managers seeking optimal efficiency during periods of economic fluctuation.

Keywords: Digital Twin, Kiva Robotic System, Manual Picking, Warehousing Efficiency,

Herfindahl-Hirschman Index, Smart Logistics.

NSFC-RGC-086.

Wen-Bin Wang (SHU), Hong-Wei Xu* (SHU), Li-Lan Liu* (SHU).

Knowledge-enhanced Large Model-based Fault Diagnosis Method for Aircraft Assembly

Abstract. Fault diagnosis in large passenger aircraft assemblies confronts two critical challenges: complex fault pattern tracing and heightened uncertainty caused by dynamic coupling effects. To address these issues, this study develops a knowledge-enhanced large model framework that synergizes domain expertise with multimodal data analysis, enabling dynamic resolution of fault coupling relationships and precise inference of propagation paths. Firstly, a pre-trained large model is designed for aircraft assembly fault diagnosis, utilizing multimodal data fusion and domain-adaptive training to establish a semantic understanding base that covers assembly processes, failure modes, and related professional knowledge. Next, based on the deep semantic reasoning capability of the big model, the heterogeneous graph spatio-temporal network is designed to construct the dynamically updated aircraft assembly knowledge graph and realise the dynamic resolution of the coupled association of assembly faults. Then integrating knowledge-guided hierarchical reinforcement learning with curriculum learning and Option-based methods, the framework constructs adaptive fault propagation networks to trace nonlinear fault paths. Experimental results demonstrate higher accuracy and interpretability in multi-source scenarios compared to traditional methods and the framework shows stronger robustness and generalization with limited labeled data, particularly excels in handling nonlinear fault coupling and operating in data-sparse environments.

Keywords: Knowledge-enhanced Macromodeling, Aerospace Assembly Fault Diagnosis, Multimodal Data Fusion, Heterogeneous Graph Spatio-Temporal Networks, Knowledge-Guided Hierarchical Reinforcement Learning.

NSFC-RGC-087.

Peng Qian* (HKU).

A Routing Model for Construction and Demolition Waste Recycling in Hong Kong

Abstract. In Hong Kong, the construction industry stands as the predominant generator of solid waste. To tackle this problem, a plethora of studies have been committed to devising more efficient technologies for Construction and demolition (C&D) waste sorting, treatment, and reuse. Enhancing the recycling rate of C&D waste is not only capable of yielding substantial economic advantages but also has the potential to effectively mitigate environmental pollution. In contrast to the conventional recycling methodologies wherein C&D waste is conveyed to off-site facilities for treatment, construction managers are actively investigating the potential of on-site recycling, whereby C&D waste is directly processed at the source. From the vantage point of on-site sorting, extant research has predominantly centred on feasibility analysis and technical issues. However, the challenge pertaining to the reverse logistics network (RLN) in C&D waste recycling, which furnishes overall C&D waste route planning for multiple participants and orchestrates the transportation process among them, remains indistinct. The RLN amalgamates the sources of waste generation, collection, sorting, recycling facilities, and landfills. This study formulates an optimization model for multi-depot vehicle routing problems with time windows (MDVRPTW) in C&D waste transportation, which is proficient in coordinating the involved C&D waste participants and proffering a transportation plan that is cost-effective, environmentally friendly, and resource-conserving. Initially, recycling revenue, economic cost, environmental pollution, and social impact are deliberated to institute this optimization-oriented decision model for MDVRPTW. Subsequently, a method integrating a large neighbourhood search algorithm and a local search algorithm is devised to chart the transportation route for the C&D waste reverse logistics network. Through the case study in Hong Kong and numerical experiments, it has been shown that this method demonstrates superior performance in comparison with conventional methods, including the adaptive large neighbourhood search algorithm and the adaptive genetic algorithm. Finally, a sensitivity analysis considering vehicle capacity, time window, and carbon tax rate is respectively conducted, thereby furnishing management implications to buttress the decision-making process for enterprises in maximizing resource utilization and for the government in carbon emission management.

Keywords: Construction and Demolition Waste; On-site Sorting; Reverse Logistics Network; Route.

NSFC-RGC-088.

Siyang He* (HKU).

Assessing the Environmental Impact of Demolishing Prefabricated Elements through Various

Construction Waste Management Approaches

Abstract. The escalating generation of construction and demolition waste (CDW) in Hong Kong, driven by rapid urbanization, poses critical environmental challenges, including resource exhaustion, land scarcity, and significant carbon emissions. This study evaluates the environmental impact of CDW management strategies for prefabricated concrete and steel elements in high-rise buildings, focusing on circular approaches (recycling, remanufacturing, reuse) versus traditional landfilling. While existing research emphasizes recycling and reuse, this work introduces remanufacturing--an understudied strategy--to bridge the gap in carbon reduction potential during the end-of-life phase of buildings. The primary objectives include developing a carbon emission estimation model to quantify CO2 emissions across strategies, comparing their environmental efficiency, and proposing optimal practices for sustainable CDW management. A quantitative methodology integrates parameters such as material composition, transportation distances, processing techniques, and emission factors derived from industry standards. The model segments emissions into transportation (mass, distance, fuel type) and processing components (energy consumption, landfill gas release), enabling granular analysis. The model assumes unidirectional material flow from demolition sites to treatment facilities and proportional transportation emissions based on material weight and distance traveled. Data is sourced from case study to ensure accuracy and relevance. Key milestones achieved include a refined literature review identifying remanufacturing's untapped potential and preliminary validation of emission formulas. Obstacles ahead involve securing site-specific data for model calibration and addressing uncertainties in landfill gas emission factors. The study's scope remains focused on structural materials, excluding non-structural components to ensure feasibility. Expected outcomes include a systematic carbon footprint comparison, policy recommendations for prioritizing remanufacturing, and a framework to guide Hong Kong's transition toward circular construction practices. This research contributes to advancing CDW management by integrating remanufacturing into lifecycle assessments, aligning with global sustainability goals and the Paris Agreement's emission targets.

Keywords: Construction and Demolition Waste, Prefabrication, Environmental Impact Assessment.

NSFC-RGC-089.

Rui Zhang * (HKU).

Optimization of Traffic Flow for Demolition Waste Collection and Transportation based on Traffic Management System (TMS) in Hong Kong

Abstract. The accelerated urbanization in Hong Kong has led to a surge in the volume of C&D waste, whose transportation efficiency and traffic congestion are becoming increasingly problematic. This study focuses on the path optimization problem of non-inert C&D waste in Kowloon Peninsula, Hong Kong, based on a traffic management system, aiming to improve transportation efficiency and enhance social sustainability through the integration of multi-source data fusion and community feedback. The study firstly analyzes the collected real-time traffic flow, weather and community noise data through IoT sensors and Hong Kong's Environmental Protection Department (EPD) public data to identify inefficient aspects of the existing transportation routes. Based on this, a dynamic multi-objective optimization scheme is proposed: a real-time route planning scheme is generated with the objective of shortest transportation time and highest community satisfaction. In particular, the study verifies the performance advantage of 4D millimeter-wave cameras in complex environments (false alarm rate <2%), and designs a Likert 5-level scale questionnaire to quantify the community's feedback weights on transportation efficiency, noise pollution, and safety, which are transformed into constraints for path planning. The optimized path reduces the average transportation time by 15% and reduces the peak congestion rate by 20%. The future needs to overcome the challenges of real-time sensor data transmission delay (currently 8 minutes delay) and dynamic allocation of multi-objective weights. This study hopes to provide an effective solution for sustainable development and environmental protection in Hong Kong to meet the increasing challenges of urban waste management, and to provide an empirical case for the application of 4D millimeter-wave cameras in high-density cities.

Keywords: Dynamic Path Optimization, TMS, C&D Waste Management.

NSFC-RGC-090.

Juan Wei* (XUST), Haoran Suo, Tingmin Chen, Xuejing Zhang.

Research on Optimization of Solar-heat Pump Composite Heating System based on Virtual Model

Abstract. This paper presents an optimization study of a solar-heat pump composite heating system, focusing on improving system performance, reducing energy consumption, and minimizing environmental impact. The study utilizes Dymola software to establish a simulation model of the system, which is validated through experimental data. In the optimization process, genetic

algorithm is used to determine the optimal configuration and control parameters of system components. The results indicate that the optimized system achieves significant improvements in energy efficiency, with a 10.3% increase in the coefficient of performance (COP) and a 5.3% reduction in lifecycle costs. The findings suggest that the solar-heat pump composite heating system is a viable and sustainable alternative to traditional coal-fired heating systems, particularly in regions with abundant solar resources.

Keywords: Solar Energy, Heat Pump System, Dymola, Genetic Algorithm, Energy Efficiency.

NSFC-RGC-091.

Xi Chen (HUST), Xun Wang (HUST), Gangyan Xu (PolyU), Xuanyu Zhang (PolyU), Wei Li* (HUST).

Hybrid Intelligence-Driven Wise Maintenance of Complex Equipment

Abstract. Maintenance, especially overhaul, is crucial for complex equipment to quickly resume normal operation. However, during the overhaul, issues frequently emerge. These include low efficiency in formulating solutions for fault diagnosis, troubleshooting plan generation, production plan scheduling, and spare parts dispatching, along with under - utilization of resources in scheduling. The cause of these problems is the lack of methods for effectively integrating, applying maintenance data and maintenance knowledge. This paper proposes a hybrid intelligence-driven wise maintenance of complex equipment, which includes four key components: human - machine collaboration, data integration, iterative learning, and knowledge driven operation. This model is capable of collecting and integrating multi – dimensional data within maintenance activities, as well as conducting iteration and training of artificial intelligence (AI) models, and solutions are generated through a knowledge - driven AI agent. The model has been piloted in a maintenance enterprise. The results show that this model can make full use of maintenance data, accelerate the generation speed of solutions, and reduce cost consumption. Nevertheless, certain critical issues need to be resolved to enable its further application in the future.

Keywords: Complex Equipment Maintenance, Wise Maintenance Framework, Human-Machine Collaboration, Artificial Intelligence.

NSFC-RGC-092.

Jiazhen Pang* (PolyU), Pai Zheng (PolyU).

A mobile Spatial Augmented Reality Framework for Bare-eye Information Access in Industrial Metaverse

Abstract. Industrial metaverse has emerged as a prominent area of research within the digital manufacturing field. Its aim is to provide valuable manufacturing knowledge to on-site operators. To achieve this, augmented reality (AR) technology is being applied in industrial scenarios. Currently, the reliance on wearable devices for AR poses an additional burden on operators. Spatial augmented reality (SAR) offers a solution by eliminating the need for wearables. The limitation of predefined projection areas restricts the application flexibility in the industrial metaverse. To address these challenges and enable a natural bare-eye information access of augmented information within the industrial metaverse, this paper presents a mobile spatial augmented reality (SAR) framework. The framework introduces a mobile SAR approach based on the connection with the industrial metaverse. The methods for scene reconstruction, projection layout configuration, and robot posture simulation & control described, supporting the implementation of the mobile SAR. system. Simulation experiments conducted in a 3D engine validate the effectiveness of the proposed projection simulation method. The research outcomes of this paper can enable the industrial metaverse to deliver omnipresent augmented information anywhere in the smart factory, support bare-eye information access in a human-centered manner and ultimately provide the operator an augmented reality experience beyond reality.

NSFC-RGC-093.

Jun Xu (XDU), Handian Liu (XDU), Yusheng Wang (JUFE), Shuaiyin Ma (XUPT).

Integrated Automated Guided Vehicles and Preventive Maintenance for Energy-efficient Flexible Job Shop Scheduling Based on An Improved NSGA-II

Abstract. In contemporary automated manufacturing systems, automatic guided vehicles (AGVs) are essential for enabling automated and efficient transportation of jobs between workstations. This automation minimizes manual intervention and significantly enhances overall productivity. Concurrently, to ensure production stability and reliability, preventive maintenance (PM) activities must be integrated into operational periods. This paper addresses the energy-efficient scheduling

problem in a flexible job shop environment involving finite AGVs and PM activities. A bi-objective mixed-integer programming (MIP) model is formulated to simultaneously minimize the makespan and total energy consumption. To tackle this NP-hard problem, an improved non-dominated sorting genetic algorithm II incorporating a local search strategy (INSGA-II-LS) is developed. The proposed algorithm employs a three-layer encoding scheme to represent solutions and utilizes a rule-based approach to generate a genetically diverse initial population. A novel decoding method is proposed, integrating a greedy insertion strategy, a hybrid AGV selection mechanism, and a dynamic PM adjustment strategy, to transform encoded solutions into feasible schedules. Additionally, a local search strategy is designed to refine solutions and accelerate convergence. Extensive computational experiments validate the effectiveness of the proposed algorithmic enhancements. The results demonstrate that INSGA-II-LS outperforms three widely used multi-objective optimization algorithms. The findings highlight the significant trade-offs between production efficiency and energy consumption, providing valuable insights for sustainable manufacturing planning.

Keywords: Scheduling; AGVs; Preventive Maintenance; INSGA-II-LS.

NSFC-RGC-094.

Peter Kok-yiu Leung (HKUST), Shanjing (Alexander) Zhou* (HKUST), Yawei Du (HKUST), Weitao Che (HKUST-GZ), Jack C.P. Cheng (HKUST).

Comparative Study of VLM Variants for Urban Flooding Digital Twinning

Abstract. Urban flooding increasingly threatens coastal cities like Hong Kong, where typhoons, extreme rainfall, and rising sea levels overwhelm aging drainage systems, as evidenced by Typhoon Saola's devastating 2023 impact. Digital twinning, which creates dynamic virtual replicas of physical systems, offers a transformative approach to simulate flood dynamics and optimize emergency responses. However, current digital twins struggle to integrate multimodal data—such as satellite imagery, IoT sensor networks, and social media alerts—limiting real-time actionable insights. Vision-language models (VLMs), which combine visual processing with natural language understanding, have the potential to enhance digital twins by automating flood extent mapping, risk communication, and evacuation planning. In Hong Kong, complex topography, urban sprawl, and projected 40% increases in rainfall intensity by 2050 amplify the need for such innovations. Yet, VLM adoption faces challenges: general-purpose models lack domain-specific training on Hong Kong's flood patterns, static models fail to contextualize real-time data (e.g., Hong Kong Observatory updates), and existing digital twins silo visual, textual, and sensor inputs. This study bridges these gaps through a comparative analysis of four VLM variants, incorporating fine-tuning (FT) and retrieval-augmented generation (RAG), within Hong Kong's urban flooding digital twin framework. We assess their performance in segmenting floodwater from satellite and street-level imagery in flood-prone areas like Tsim Sha Tsui and Yuen Long. A novel multimodal VLM, developed as a virtual agent with a domain-tailored prompting framework, enhances human-like reasoning by interpreting flood conditions using urban reference objects. Results demonstrate improved accuracy in flood mapping and real-time contextualization, integrating dynamic data streams with historical patterns. However, limitations include scarce severe flood imagery and delays in cloud-based video streaming, impacting inference speed. Future work should integrate multi-modal IoT data and temporal trend analysis to enable predictive flood risk assessments, enhancing urban resilience.

Keywords: Vision-Language Models, VLM, Urban Flooding, Digital Twins.

NSFC-RGC-095.

Sichao Liu* (KTH), Xi Vincent Wang* (KTH), Lihui Wang (KTH).

Vision-Language-Controlled Robotic Manipulation for Collaborative Assembly

Abstract. Collaborative assembly in a human-robot team requires a robot to comprehend both the physical scene and human instructions to perform precise and adaptive manipulation tasks. Open-world object manipulation further introduces challenges in fine-grained scene understanding and reasoning over multimodal vision-language information. Recent advances in vision-language models (VLMs) have demonstrated strong capabilities in common-sense reasoning and open-world perception, yet their application in robot manipulation for collaborative assembly remains underexplored. In this study, we propose a vision-language-controlled manipulation framework that leverages pre-trained VLMs to interpret and infer vision-language information, enabling keypoint affordance-based action generation for robotic assembly tasks. Our approach allows the robot to acquire a fine-grained semantic understanding of the scene and reason about the spatial relations of objects with zero-shot generalization. By prompting the VLM, we extract latent logical representations and control steps from human instructions, integrating common-sense knowledge to guide the manipulation process. A keypoint affordance representation is then introduced to

determine optimal grasping and manipulation points, while the VLM functions as a motion planner, translating affordances and visual observations into structured text-based robot path descriptions. These high-level descriptions are subsequently mapped to low-level controllers, ensuring precise and adaptive execution of assembly tasks. To validate our approach, we conduct a series of experiments across diverse manipulation scenarios, demonstrating its effectiveness through quantitative and qualitative evaluations.

Keywords: Vision-Language Models, Robot Manipulation, Keypoint Affordance Representation, Human-Robot Collaboration.

NSFC-RGC-096.

Zhenyu Liang (HKUST), Weitao Che* (HKUST-GZ), Peter Kok-Yiu Wong (HKUST), Boyu Wang (HKUST), Jack C. P. Cheng* (HKUST).

Digital Twins for Intelligent Management and Operation of the Low-Altitude Economy in Smart Cities

Abstract. As a representative of new productive forces, the development of the low-altitude economy (LAE) plays a crucial role in advancing the construction of smart cities and serves as a significant driver for promoting high-quality development in China. Digital twin technology enables the intelligent management and operation of the low-altitude economy. Therefore, this paper investigates and analyses the current development of LAE digital twins. First, it examines five application scenarios of smart cities' low-altitude economic activities, including urban air mobility, drone-based logistics, environmental monitoring, surveying and mapping, and security and surveillance, while highlighting the supportive role of digital twins in these applications. Second, the paper summarizes four key enabling technologies for realizing LAE digital twins: IoT, 5G communication and edge computing, AI/ML and simulation, and cloud-based platform. These technologies serve as the data acquisition channels, information transmission methods, intelligent analytical core, and integrated operational hub of the digital twin platform, respectively. Third, it analyses the current challenges and limitations of developing LAE digital twins in Hong Kong. Finally, the paper explores the future trends and opportunities for advancing this technology in Hong Kong. This paper provides insights and reference for the implementation and development of LAE digital twins.

Keywords: Low-Altitude Economy, Digital Twin, Smart City, eVTOL, Drone.

NSFC-RGC-097.

Yuqi Huang (HKU), Yonghong Kuo* (HKU).

Digital Twin Simulation Platform of Flexible Production Scheduling System

Abstract. With the ongoing digital transformation of the manufacturing sector, the complexity of manufacturing systems has escalated, accompanied by longer workflows. Traditional approaches typically decompose the system into sub-problems, each optimized independently. While these methods often fail to evaluate the overall performance within the global system. In contrast, the advent of data-driven digital twins presents a novel solution. It facilitates a more realistic and accurate representation of operating equipment, plant infrastructure, and various data streams. This capability enables enterprises to conduct low-cost simulations of complex production modes, driving operation optimization. However, existing digital twin platforms predominantly focus on visualization and real-time data monitoring, often overlooking the potential for top-level applications grounded in the digital twin infrastructure. To address this gap, the present work is driven by the real-world needs of flexible production systems proposed by an intelligent manufacturing robotics enterprise based in Shanghai. Using the Unity engine, we have developed a comprehensive digital twin workshop model encompassing the full operational chain of factory manufacturing and logistics. This model integrates objects such as autonomous mobile robots (AMRs), conveyors, CNC machines, and material buffer zones. Based on this digital workshop, we constructed top-level applications for layout design, intelligent decision-making, and simulated operations. The entire process of the flexible production system is simulated and modeled, with the core components including workshop layout, production scheduling, job task assignment, and multi-AMR path planning. This results in a hybrid simulation system combining multiple agents with discrete event modeling, driven by order data. Moreover, an intuitive layout editing tool and simulation configuration panel have been developed to streamline the simulation process. Ultimately, this work meets the enterprise's simulation needs for flexible workshop production and logistics operations, offering a valuable reference for the design of upper-layer applications in flexible manufacturing systems based on the digital twin platform.

Keywords: Digital Twin, Flexible Manufacturing, Multi-Agent Simulation, Discrete Event Simulation.

NSFC-RGC-098.

Yi Zhang* (NJIT), Haihua Zhu (NUAA), Dunbing Tang (NUAA).

A Sim2real Reinforcement Learning Scheduling Framework based on Digital Twin Workshop Model

Abstract. Scheduling optimization is an important way for discrete manufacturing workshop to achieve efficient production organization, meet personalized user needs, and respond quickly to the market. With the improvement of intelligence and flexibility within the workshop, coupled with frequent dynamic events, the complexity of scheduling problems has become increasingly prominent, which puts higher demands on real-time response capability. How to use technologies such as digital twin and reinforcement learning to depict the evolution of production processes in discrete manufacturing workshops, analyze the complex characteristics of scheduling systems, and achieve resource allocation under dynamic factors through intelligent decision-making methods is a key issue. Therefore, this article proposes a digital twin driven discrete manufacturing workshop scheduling optimization framework, providing reference for the analysis and control of workshop operation status. Firstly, based on the characteristics, a multidimensional digital-twin workshop model is constructed to provide initial training for the scheduling decision strategy model of the intelligent agent, enabling it to possess initial capabilities. Secondly, a real-time mapping mechanism for dynamic behavior is established to achieve synchronization between digital twin model and physical workshop. Finally, combining real-time data with new requirements, a Sim2Real driven reinforcement learning scheduling optimization method is proposed to optimize the scheduling decision model to adapt to dynamic environments.

Keywords: Digital Twin, Workshop Scheduling, Sim2Real, Reinforcement Learning.

NSFC-RGC-099.

HE JING* (HKU).

Develop Simulation Model for an Integrated Environment of Emergency Department and Inpatient Unit

Abstract. To address the growing issue of limited hospital beds and healthcare resources, we aim to develop a generic simulation model for an integrated environment of the emergency department and inpatient units. The model will be appropriately abstracted, capable of reflecting real-world issues with sufficient detail, and not restricted to a specific hospital. In the research process, we need to address the issue of incomplete data provided by the hospital, which leads to the inability to accurately estimate the probability distribution of service activities duration time, by using metaheuristic algorithms. In addition, in terms of simulation software selection, we use Simply library in Python to build the simulation model because Python's widespread use in engineering makes it highly adaptable and compatible with different operating systems. For the convenience and flexibility of the simulation model, we need to create a simple front-end user interface. This interface will allow users to operate the model without the need for any programming.

Keywords: Healthcare Resources, Simulation Model, Emergency Department, Inpatient Unit, Probability Distribution.

NSFC-RGC-100.

Zhixuan Wu, Hui Fu* (GDUT), Yu Cui, Hongpeng Li, Qi Hu, LiRong Huang.

Operation Framework of Multi-Modal Low-Altitude Logistics System Based on Digital Twin

Abstract. The low-altitude economy coupling with multimodal logistics has increasingly emerged as a key driver of economic development across various countries, which exemplifies a new paradigm of productive forces. This study employs Unity3D software to propose a three-layer digital twin framework, consisting of a physical system layer, a simulation engine layer, and an information system layer. By capturing the static and dynamic characteristics of each entity in the physical world and leveraging a bidirectional Python-Unity interface, seamless data interaction and deep integration between the physical and digital worlds are achieved. A case study on a campus logistics scenario validates the feasibility of the proposed multimodal low-altitude logistics framework, which sheds light on the development and operational analysis of digital twin platforms for intelligent low-altitude logistics systems.

Keywords: Low-Altitude, Multimodal Logistics, Digital Twin, Unity3D.

NSFC-RGC-101.

Qiulin Zhu (HKU), Man-Chung Yue (HKU), George Q. Huang (PolyU), Yelin Fu* (SZU).

Advancing ESG Integration in Emerging Markets: A Six-Factor Model for China's A-Share Market

Abstract. With the continuous development of the ESG concept, more investors in China are turning their attention to its influence on stock investments. However, the question of whether the ESG factor positively affects stock returns remains a matter of contention. Therefore, this study examines the impact of ESG factors on stock returns in China's A-share CSI 300 market. By incorporating an ESG factor into the traditional Fama-French five-factor model, the study develops an enhanced six-factor model to analyze the impact of various factors on stock returns. Using industry-level classification within the CSI 300, this study also explores the differentiated effects of ESG on stock returns. The findings highlight that the ESG factor positively impacts stock returns, showing the significant size effect present in the Chinese market and demonstrating that the six-factor model outperforms the five-factor model in explaining excess returns. This study enhances investors' understanding of the significance of ESG, fosters more rational investment decisions, and offers valuable insights for regulatory agencies to promote stable market operations.

Keywords: ESG, Fama and French, Six-Factor Model, A-share Market, Sustainable Investing.

NSFC-RGC-102.

Nuan Wen (NEAU), Qiang Fu (NEAU), Yi-Jia Wang (NEAU), George Q. Huang (PolyU).

Human-Machine-Environment System for Smart Agri-Production

Abstract. The integration of next-generation information technologies into agricultural practices demonstrates significant potential for enhancing the efficiency and effectiveness of agri-production. The existing smart agriculture systems primarily concentrate on the perception, decision-making, and regulation of agricultural machinery and farmland environments. However, agri-production constitutes a cyber-physical system where humans, as critical cognitive agents, impact production outcomes through dynamic interactions with machinery and environments. The human-machine-environment synergies should be captured and utilized for intelligent decision-making for more sustainable agri-production management. This study develops a digital twin-enabled system for smart agri-production with human-machine-environment interactions. A three-layer architecture for agri-production management comprises agricultural IoT infrastructure, intelligent wearable interfaces, and AI-powered decision modules. This system enables the monitoring and warning for drivers, the intelligent control and management of agricultural machines, and also the restoration of farmland environments. The system design philosophy aligns with the trends of agricultural digitization and ecological development, through the collaborative management and control of human, mechanical, and environmental factors within agri-production.

Keywords: Smart Agriculture, Digital Twin, Agricultural Internet of Things, Farm Management.

NSFC-RGC-103.

Yizhi Zhen, Jie Lin, Fangni Zhang* (HKU).

Integrating Unmanned Aerial Vehicles and Public Buses for Parcel Delivery in Urban Area

Abstract. Deploying Unmanned Aerial Vehicles (UAVs) for parcel delivery in urban areas offers faster, more flexible, and cost-effective services while reducing traffic congestion, environmental impact, and improving accessibility. However, UAV efficiency is constrained by limited flight range and battery life, posing challenges in covering large urban areas. Leveraging the dense urban bus networks and the substantial number of buses in operation presents a novel solution: integrating UAVs with public buses. In this approach, buses act as mobile charging stations, enabling en-route UAV recharging and facilitating ride share with buses to enhance delivery efficiency. To optimize UAV routing and recharging schedules, we propose a Mixed Integer Programming (MIP) model. Due to the model's complexity, an Adaptive Large Neighborhood Search (ALNS) heuristic algorithm is employed for efficient problem-solving. Numerical experiments on varying scales show that for small instances, our ALNS heuristic matches Gurobi's optimal solutions in less time. For larger instances, where Gurobi provides only feasible lower bounds within limited time, our ALNS heuristic delivers superior solutions faster. Real-world experiments in Shenzhen's Luohu district further validate the effectiveness of the bus-UAV integration. Compared to UAV-only delivery, our approach reduces average costs by up to 29.53%, and by 18.18% in average compared to charging station-based en-route recharging, demonstrating significant operational advantages.

Keywords: UAV, Routing Problem, Parcel Delivery, Public Bus, ALNS Algorithm.

NSFC-RGC-104.

Mohammad Mehdi Keramati Feyz Abadi, Chao Liu* (Aston Uni), Yuchun Xu.

Energy-Aware Manufacturing through Digital Twin and Reinforcement Learning-Based Control

Abstract. The rising global energy demand has intensified the drive for sustainability within the manufacturing sector—one of the largest consumers of energy worldwide. As manufacturing processes offer significant opportunities for energy savings, Industry 4.0 technologies, particularly Digital Twins (DT) and Artificial Intelligence (AI), have emerged as powerful tools for enhancing energy efficiency in manufacturing systems. While traditional systems often prioritize keeping machines continuously operational to maximize output, this research introduces a DT-based framework designed to optimize energy consumption without compromising productivity. The proposed framework achieves this by intelligently controlling the on/off states of machines within a highly stochastic manufacturing environment. Sources of uncertainty include variable part arrival times, machine processing times, startup delays, machine failures, and repair durations. At the core of the framework are two integrated components: an intelligent control strategy and a dynamic virtual simulation environment. Specifically, model-free Reinforcement Learning (RL) algorithms, such as Proximal Policy Optimization (PPO) and Deep Q-Network (DQN) are employed and fine-tuned using extensive grid searches to develop robust control policies capable of adapting to system uncertainties without requiring full knowledge of the underlying dynamics. Given the multi-objective nature of the problem—balancing productivity and energy efficiency—the design of three critical components plays a central role in guiding the RL agent: the reward function, the rewarding mechanism, and the observation space. This work presents a systematic evaluation of various mathematical formulations for productivity and energy rewards, investigates the impact of reward frequency, and explores the influence of different environmental inputs on agent performance. Due to the trial-and-error nature of RL, which can pose safety and operational risks in real-world settings, a flexible and reliable virtual environment is essential. Therefore, the DT framework incorporates the AnyLogic simulation platform, facilitating extensive testing and optimization of various manufacturing scenarios prior to physical deployment. Ultimately, this study presents a robust, flexible, and generalizable DT-RL integrated solution that effectively balances productivity and energy efficiency in complex manufacturing systems through intelligent machine switching strategies. Overall, this study makes several key contributions: it proposes a novel and generalizable DT-RL integrated framework for intelligent machine switching; it introduces a structured approach for reward and observation design in multi-objective control settings; and it demonstrates the effectiveness of virtual simulation-based training in enabling energy-efficient and adaptive decision-making across manufacturing environments with varying topologies and levels of complexity.

Keywords: Digital Twin, Reinforcement Learning, Energy-Efficient Control, Manufacturing Process, Sustainability, Smart Manufacturing.

NSFC-RGC-105.

Yuming Xu (ZJU), Tao Peng (ZJU), Ray Y. Zhong (HKU), Kendrik Lim (MIT)

An Intelligent Fault Diagnosis Approach For Construction Machinery Based On Enhanced Knowledge Graph

Abstract. The safety risks of construction machinery are crucial for construction site management, most of which stem from hydraulic system faults. However, the knowledge required for such fault diagnosis is extremely complex, and current knowledge-based methods heavily rely on engineering experience, making them time-consuming and error-prone. To tackle this challenge, we propose an intelligent fault diagnosis approach for construction machinery based on enhanced knowledge graph, incorporating emerging technologies, active learning, pre-trained language models, and graph neural networks, to significantly enhance the performance of knowledge graph. Key research contributions are: 1) Active learning-based BERT+Bi-LSTM+CRF fault knowledge extraction. It accurately extracts fault entities and relationships from accumulated fault reports and addresses the challenge of obtaining a large and manually-labelled fault corpus; 2) Word embedding-based fault entity alignment. A two-stage word embedding technique based on the pre-trained language model is proposed to convert the semantic knowledge of fault entities into word embedding, enabling the alignment of fault entities and resolving the issue of discrepant expression of the same fault knowledge; 3) Knowledge graph embedding-based fault knowledge reasoning. NSHPSAGE model is proposed to convert the graph structure information of the fault knowledge graph into graph embedding, with Multi-Head Attention Fusion fusing word and graph embedding into node embedding. The binary operator then generates link embedding, enabling link classification to tackle omissions and errors in complex, multi-hop causation chains; 4) Word embedding-based fault knowledge retrieval. The proposed word embedding model converts the semantic information of the engineer's input into word embedding, enabling the retrieval of relevant fault knowledge and addressing the issue of inconsistent user inputs. The proposed methodology extends fault coverage and enhances the completeness and accuracy of diagnostic results as compared to existing fault diagnosis approaches for construction machinery. The improved performance is validated via a case study featuring a concrete spreader.

Keywords: Intelligent construction site, Construction machinery, Fault diagnosis, Knowledge graph, Pre-trained language model.

NSFC-RGC-106.

Shoeb Ahmed Memon (Bond University), Steve Rowlinson, Adrian Bridge, Waled Shehata

Generative Artificial Intelligence (Genai) In Project Lifecycle: A Systematic Review

Abstract. Generative artificial intelligence (GenAI) has been creating waves, a new model, and promises to bring change to disciplines and industries, which we often learn through news outlets. Construction as an industry, often considered a slow adopter of innovation, is not immune to this change. Construction professionals, organisations, and disciplines are widely responding to the change, from adoption to day-to-day work to enhance construction safety to generate creative alternative architectural design options alternatives. This study took the opportunity to adopt a systematic approach to review GenAI in the project lifecycle and beyond. Using keyword search, the study identified 1013 peer-reviewed articles from ProQuest, Scopus and Web of Science. The search process was filtered based on inclusion and exclusion criteria, and 28 articles were retained for thematic coding in NVivo. Results present a cluster of patterns in which GenAI is identified to impact the project lifecycle. The core themes identified are: (1) Strategic Definition and Brief, (2) Architectural Design, (3) Building Information Modelling, (4) Structural Design, (5) Construction and Demolition, (6) Building Operations and (7) Cities and Urban Governance. Results suggest an increased reliance on GenAI models in the project lifecycle, with a typical trend to use popular models. However, an emergent new trend has been to train lightweight large language models to achieve quicker and more accurate results in construction safety and contract administration.

Keywords: Built Environment, Generative Artificial Intelligence, Construction, Project Lifecycle.

NSFC-RGC-107.

Liang Guo (SWPU), Yuantong Li (SWPU), Xun Xu (UoA), Longkun Luo (SWPU), Changcheng Wan (XHU)

Virtual-Real Mapping Of Devices Based On Strong-Weak Digital Twins— A Case Study Of 3D Printer

Abstract. As a key technology to realize the integration of physical and virtual, the digital twin has been fully recognized and practiced in various industries and fields in recent years. At present, it tends to build or focus on the mapping model with strong correlation between virtual and real. But do all scenarios require strongly associated twins? This report proposes a strong-weak digital twins concept. It aims to solve the twin system deployment and service-oriented agent construction path in cross-platform environment. The proposed strong-weak digital twins integrate the cloud edge collaboration architecture, proposes strong twin and weak twin models, and constructs the device-strong twin-weak twin mapping architecture. Finally, by taking 3D printer as an example, this paper describes how to use strong -weak digital twins to achieve virtualization and service description of devices. The model provides a technical path for service-oriented manufacturing cloud, device agent construction, device collaboration in the meta-universe environment, etc.

Keywords: Digital twin, Agent, Service, 3D Printer

NSFC-RGC-108.

Changhong Liu (GU), Tuxian Ye (GU), Xingxin Yang (GU), Jianxiang Cheng (GU), Dinghao Wang (GU), Ray Y. Zhong (HKU), Tao Zou (GU)

Design And Experimental Analysis Of Bag-Breaking Device For Bagged Garbage Based On Drilling Mechanism And Digital Twin Technology

Abstract. In order to address the issue of low separation efficiency of bagged garbage in the smart city waste collection and transportation system, this study proposes an innovative design scheme for a bag-breaking device integrating digital twin technology. The traditional bag-breaking process has a technical bottleneck: it mixes bag fragments with the garbage, thereby affecting subsequent classification and treatment. In this study, an integrated device with functions of drilling, bag breaking, and intelligent separation was developed by constructing a “physical–virtual” twin system, using SolidWorks 3D modeling and Unity 3D virtual simulation technology. Experimental data show that the bag-cutting mechanism, optimized by the digital twin model, achieves a higher success rate of bag separation, and the synchronization of time and space between the physical entity and the virtual model is nearly error-free. The research also develops an immersive visual monitoring platform based on the Industrial Internet of Things (IIoT), which significantly improves the overall equipment effectiveness (OEE) and effectively extends the mean time between failures (MTBF) of key components through a large number of simulation experiments and optimizations. The research demonstrates that the technical solution can effectively address the issue of debris residue during bagged garbage demolition and provides a new paradigm for the intelligent upgrading of solid waste treatment equipment. The follow-up research will focus on multi-modal

sensing data fusion, cross-working condition digital model library construction, and finite element–digital twin coupling analysis, so as to continuously improve the system adaptability and processing efficiency.

Keywords: Digital Twin; Bag-breaking Device; Drilling; Garbage Sorting; Garbage Bag Recycling; Waste Collection

NSFC-RGC-109.

Y.-J. Wang (NEAU), Y. Gao (NEAU), N. Wang (NEAU)

Recycled Express Packaging In Sustainable Logistics: Investigating Consumer Behavior

Abstract. With the rapid development of e-commerce, traditional single-use express packaging results in severe resource waste and poses numerous challenges for recycling and disposal. Recycled express packaging, as an environmental innovation, can reduce resource consumption and waste generation. The study delves into the key drivers behind consumers' choices to adopt recycled express packaging, particularly focusing on the interplay between altruistic values and rational considerations. Data was collected through a cross-sectional survey involving 2,515 participants, and the analysis was performed employing Partial Least Squares Structural Equation Modeling. We constructed a research model for consumer acceptance of recycled express packaging. According to the findings, public attitude plays the most crucial role, with personal norms, responsibility attribution, perceived behavioral control, and awareness of consequences following in importance. Additionally, there is significant heterogeneity in consumer behavior across different age groups and frequencies of express delivery usage. Based on these results, the study suggests targeted strategies to promote the adoption of recycled express packaging, offering recommendations for government policies, express companies, and e-commerce platforms to foster sustainable logistics practices.

Keywords: Logistics, Recycled express packaging, Acceptance modeling, Rationality, Altruism

NSFC-RGC-110.

Tianyun Jin (HKU), Yuan Qu (HKU), Max Z.J. Shen (HKU)

How Large Are Too Large? Deployment Region Analysis Of Dockless Electronic Bike-Sharing Systems

Abstract. The rapid global adoption of bike-sharing (BS) systems has demonstrated their potential as sustainable urban mobility solutions. Recently, electric bike-sharing (EBS) has emerged as a transformative extension, offering reduced physical barriers and extended travel ranges. However, EBS deployment introduces unique operational challenges. Evidenced by empirical data showing EBS systems typically operate in limited zones compared to city-wide BS networks. This study addresses the critical gap in optimizing EBS deployment by proposing a data-driven framework that leverages bike-sharing data, where BS operates in a large city-wide region and EBS is confined to a limited pilot region. Our predict-then-optimize methodology integrates demand prediction with heuristic-based region selection algorithms to guide scalable EBS expansion. Results demonstrate that the framework effectively transfers BS demand insights to EBS deployment, offering adaptable, explainable decision margins for policymakers. The study contributes practical tools for equitable and efficient EBS scaling while highlighting future directions. By bridging the divide between BS experience and EBS potential, this work supports the creation of inclusive, sustainable urban transport networks.

Keywords: E-bike sharing; Operation region; Data-driven approach; Smart city

NSFC-RGC-111.

Zhongxu Hu (HUST)

Large Language Model-Based Multi-Agent Scheduling Chain for Flexible Job Shop Scheduling Problem

The conference was supported by a grant from the Joint Research Scheme sponsored by the Research Grants Council of the Hong Kong Special Administrative Region, China and the National Natural Science Foundation of China (Reference No. N_HKU7130/24)

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Digital Twin

Digital Twin is a rapid multidisciplinary open access publishing platform for state-of-the-art, basic, scientific and applied research on digital twin technologies. ***Digital Twin*** covers all areas related digital twin technologies, including broad fields such as smart manufacturing, smart city, civil and industrial engineering, healthcare, agriculture, and many others. The journal is open to submissions from researchers, practitioners and experts.

The aim of ***Digital Twin*** is to advance the state-of-the-art in digital twin research and encourage innovation by highlighting efficient, robust and sustainable multidisciplinary applications across a variety of fields. Challenges can be addressed using theoretical, methodological, and technological approaches.

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- Digital twin key technologies and tools
- Digital twin applications and case studies
- Digital twin implementation
- Digital twin services
- Digital twin security
- Digital twin standards

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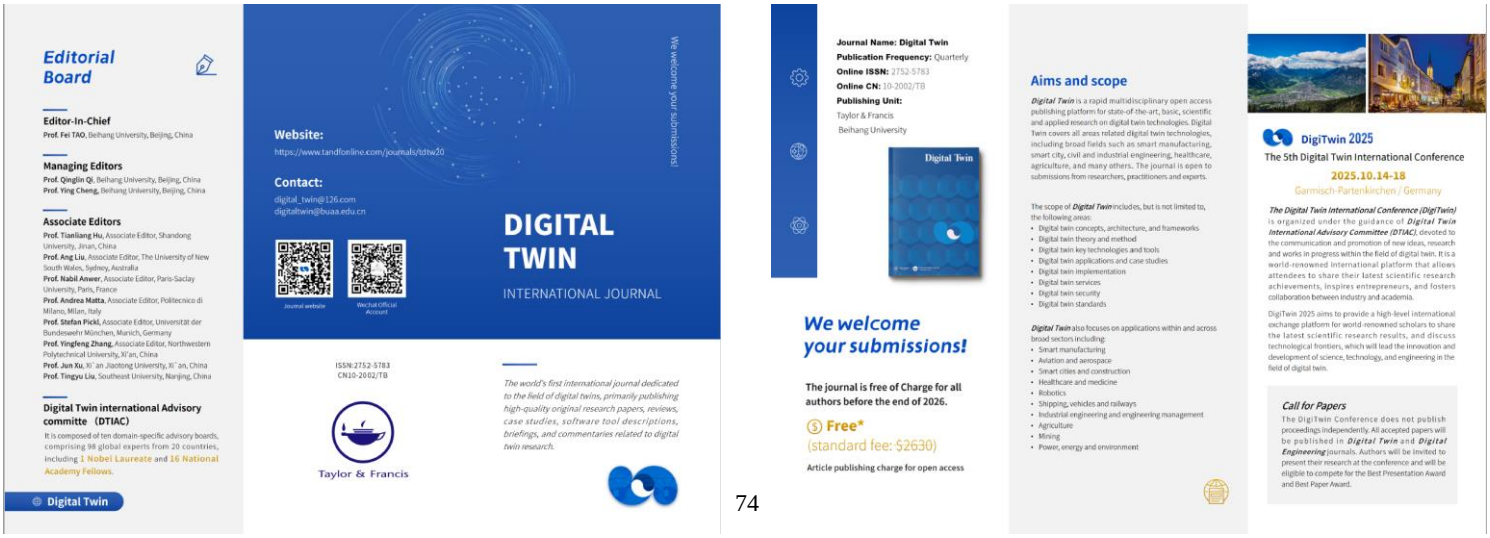
Website: https://www.tandfonline.com/journals/tdtw20/about-this-journal#journal-metrics

Editor-in-Chief: Prof. Fei Tao



The conference was supported by a grant from the Joint Research Scheme sponsored by the Research Grants Council of the Hong Kong Special Administrative Region, China and the National Natural Science Foundation of China (Reference No. N_HKU7130/24)

《工业工程》

一、期刊简介

《工业工程》（Industrial Engineering Journal，简称 IEJ）是中国机械工程学会工业工程分会会刊，由广东工业大学主办，中国机械工程学会协办。自 1998 年创刊以来，本刊始终致力于引领工业工程学术前沿，推动学科理论与技术创新，培养卓越人才，促进工业工程技术在国民经济与社会高质量发展中的深度应用。

作为我国工业工程领域两大核心期刊之一，《工业工程》已入编《中文核心期刊要目总览》（2008、2011、2017、2020 版）、中国科技核心期刊（自然科学卷）（2020~2024 年）、RCCSE 中国核心学术期刊（A-类），并被中国知网、万方数据、日本 JST、俄罗斯 AJ、英国 INSPEC、美国 EBSCO 等国内外权威数据库收录。期刊曾获“全国首届《CAJ-CD 规范》执行优秀奖”“中国高校优秀科技期刊”“广东省优秀科技期刊”等多项荣誉，学术影响力持续提升。2024 年，期刊获批广东省高质量期刊建设项目。

在数字化出版领域，《工业工程》率先构建了“投审稿系统+XML 排版与网刊发布一体化”平台，显著提升了出版效率。自 2024 年 7 月起，期刊实施“录用即网络首发”政策，显著加速了学术成果的传播效率。据中国知网 2024 年数据，期刊复合影响因子达 1.782（工业经济领域 Q1 区），较 2023 年增长 2.8%，充分彰显了其学术价值与行业认可度。

二、2024 年工作业绩

1. 特色专栏与主题推送

为深化领域研究，《工业工程》联合编委和相关领域专家特别策划了 8 个特色专栏，分别为人因工程、工业互联与制造服务管理、晶圆制造过程优化与测试、复杂系统建模与运筹优化、智能制造系统与车间调度优化、可持续运营与供应链管理、质量工程与生产可靠性和绿色供应链管理。专栏共发表论文 31 篇，覆盖智能制造、医疗健康、双碳战略等热点方向。此外，期刊通过精准推送 7 大主题的 39 篇文章，累计推送 244,742 次，有效拓展了读者群体。

2. 学术会议合作

《工业工程》与多个国际国内学术会议建立深度合作，包括首届人本制造学术会议、2024 年第二十届物流系统工程暨第八届管理系统工程学术研讨会首届人本制造学术会议、2024 年第二十届物流系统工程暨第八届管理系统工程学术研讨会、人工智能重塑服务管理：机遇与挑战国际会议、数智物流与供应链管理——数智供应链助力新质生产力发展（DILSCM 2024）学术会议、2024 年中国工业工程年会暨第二十八届工业工程与工程管理国际学术会议暨第十三届工业工程企业应用与实践高峰论坛、2024 年全国先进生产系统理论与应用研讨会暨国际产学研用合作会议智能制造论坛暨大湾区工业工程前沿论坛。这些合作为期刊提供了丰富的学术资源和交流平台。这些合作为期刊注入了前沿学术资源，搭建了产学研交流平台。

3. 首届优秀论文评选活动

为激励高质量学术成果，2025 年 1 月，《工业工程》从 2023~2024 年发表的 209 篇论文中评选出 21 篇优秀论文。评选标准涵盖选题价值、创新性、写作质量、实用性与传播效果，获奖论文主题涵盖供应链管理、智能制造、医疗健康等前沿领域，编辑部为作者颁发荣誉证书及奖金，以资鼓励。获奖论文如下(以刊出期号排序)：

[1] 周涛, 孟祥倩, 陶明. 线下体验服务和保鲜努力双重因素下生鲜电商供应链决策与协调研究[J]. 工业工程, 2023, 26(1): 41-51.

[2] 张钦, 孙丽虹. 考虑公平关切的双渠道供应链平台合作决策[J]. 工业工程, 2023, 26(1): 30-40.

[3] 聂佳佳, 徐晓萱. 竞争环境下生鲜电商企业配送模式选择研究[J]. 工业工程, 2023, 26(2): 1-11.

[4] 邓明君, 代玉珍, 李响. 需求不确定下低碳多式联运路径鲁棒优化[J]. 工业工程, 2023, 26(4): 104-113.

[5] 邓文顺, 刘强, 赵荣丽. 基于数字孪生的生产线分布式近物理集成调试方法[J]. 工业工程, 2023, 26(5):

124-130.
[6] 罗利, 廖虎昌, 向杰, 房圆晨. 数智时代下工业工程理论与方法在医疗健康管理领域的创新应用综述[J]. 工业工程, 2024, 27(1): 10-24.
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[9] 江志斌, 周利平. 面向智能制造的生产运作管理：挑战、科学问题、关键研究及部分新进展[J]. 工业工程, 2024, 27(1): 1-9.
[10] 王康周, 王冬冬, 豆垒, 薛林. 工业互联网场景下运营管理研究综述[J]. 工业工程, 2024, 27(2): 1-13.
[11] 陈彩华, 佘程熙, 王庆阳. 可信机器学习综述[J]. 工业工程, 2024, 27(2): 14-26.
[12] 高艺平, 王浩, 李新宇, 高亮. 基于深度智能视觉的表面缺陷检测研究进展[J]. 工业工程, 2024, 27(2): 27-36, 66.
[13] 王铁旦, 胡艺朋, 彭定洪. 用户感性偏好导向的智能语音交互设计评价方法[J]. 工业工程, 2024, 27(2): 57-66.
[14] 杨剑锋, 崔少红, 段家琦, 王宁. 基于 SMOTE-IKPCA-SeNet 深度迁移学习的小批量生产质量预测研究[J]. 工业工程, 2024, 27(2): 98-106, 157.
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[17] 刘琦铀, 林丽婷, 张成科. 基于区块链和消费者敏感的农业供应链融资上链决策研究[J]. 工业工程, 2024, 27(4): 60-69.
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[21] 李建斌, 柴小玲, 罗晓萌. 医药健康企业数字化转型与生态系统构建——基于 1 药网的案例研究[J]. 工业工程, 2024, 27(6): 1-12.

三、2025 年刊文方向

《工业工程》将持续聚焦国家重大战略和工程需求，响应新质生产力发展需求，弘扬技术与管理相结合的学科特色，通过关注前沿趋势、报道创新方法、探讨新兴观点、推广新型应用，来推动学术繁荣发展、促进技术深度应用，并引领工业工程学科创新发展。重点刊文方向包括：

一是新趋势：新质生产力发展需求大背景下，工业工程学科发展动态及人才培养的新趋向阐析。

二是新方法：人工智能、数字孪生技术等在高端制造、供应链管理与生产服务中的知识挖掘新策略探索。

三是新论点：运筹优化与大模型的竞合发展轨迹，以及大模型与小模型在不同应用场景中的选择，元联网与智联网的应用场景新观点。

四是新应用：智能制造灯塔工厂、智慧供应链管理等典型企业案例的分享；以及工业工程理论、方法在自动驾驶人机协作、低空物流配送等领域的应用新成效等。

《工业工程》始终以学术卓越与技术落地为核心，致力于成为工业工程领域的知识枢纽与创新引擎。未来，期刊将携手全球学者与行业专家，共同探索学科前沿，推动产学研深度融合，为构建现代化产业体系贡献智慧与力量。

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《中国管理科学》

《中国管理科学》是由中国科学院主管，中国优选法统筹法与经济数学研究会与中国科学院科技战略咨询研究院共同主办的学术期刊。期刊由华罗庚教授创办于 1984 年 12 月，原名《优选与管理科学》为季刊，1993 年更名为《中国管理科学》并改为双月刊，2014 年变更为月刊。

《中国管理科学》是我国管理科学领域最有影响力的学术期刊之一，秉承华罗庚教授提出的“36 字”办刊方针。期刊主要为高等院校、科研院所科研工作者，企事业部门管理人员，政府部门管理人员等提供学术成果交流平台。 期刊刊登论文主题涉及有一般管理理论与方法、管理决策与优化、管理系统工程、信息管理与信息系统、管理心理与行为科学、数据科学与智能管理、物流与供应链管理、服务科学与工程、技术创新与管理、工程与项目管理、风险与应急管理、工业工程、生产运作管理、交通运输管理、财务管理与金融工程、医疗与健康管理、资源与环境管理、社会管理工程、战略管理、电子商务与营销管理、质量与可靠性管理、人力资源管理等研究领域，以反映我国管理科学的最新研究成果，促进学术交流。

期刊被《FMS 管理科学高质量期刊推荐列表》收录为 T1 级期刊，被国家自然科学基金委员会管理学部认定管理科学 A 级重要期刊，还被《中文社会科学引文所引（CSSCI）》、《北大中文核心期刊目录》、《中国科学引文数据库(CSCD)》、《中国科技信息所科技论文统计源期刊（ISTIC）》等引文数据库收录，被《中国学术期刊光盘版（CNKI）》全文收录，在期刊主页上全文开放获取。

期刊曾获得多项荣誉，2009 年、2011 年荣获“百种中国杰出学术期刊”称号，2008 年、2011 年荣获“中国精品科技期刊”称号，2012-2014 年度和 2015-2017 年度连续两次入选“中国科协精品科技期刊工程项目—期刊学术质量提升项目”，2018 年度入选“中文科技期刊精品建设计划项目—学术创新引领项目”，2012 年至 2021 年连续 10 年荣获中国知网“最具国际影响力学期刊奖”。2019 年《中国管理科学》首批入选《智库期刊群 1.0 版》，本刊还是人大复印报刊资料、新华文摘等文摘类报刊的重要来源期刊。

《中国管理科学》编辑部长期以来积极主办、协办各种高端学术会议，由《中国管理科学》编辑部参与主办的“中国管理科学学术年会”自 1999 年首届开始已经连续举办了 25 届，现已成为国内管理学界精品学术会议。2014 年至今连续 8 次举办“《中国管理科学》期刊与学者学术交流论坛”。和兄弟期刊一起联合举办的“管理科学期刊发展论坛”，已经成为管理科学类期刊发展交流的重要平台。

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