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OR and analytics for digital, resilient, and sustainable manufacturing 4.0

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Today and looking into the near future, digital technologies, such as blockchain (Cai et al., 2021; Choi, 2019, 2020; Fan et al., 2020; Zheng et al., 2022), 3D printing (Arbabian & Wagner, 2020), artificial intelligence (Cui et al., 2021; Grover et al., 2022; Sun et al., 2021), digital twins (Burgos & Ivanov, 2021; Ivanov & Dolgui, 2021), big data analytics (Ban & Rudin, 2019; Choi et al., 2018), augmented reality (Li et al., 2020), cyber-physical systems (Battaia et al., 2018; Panetto et al., 2019) are playing a critical role in production operations. In fact, manufacturing systems will be more and more efficient with the advance of digital technologies (Olsen & Tomlin, 2020). At the same time, increased uncertainty, complexity, and vulnerability of global supply chains and operations have highlighted the importance of further research in operations resilience. Finally, the focus of companies on increased sustainability poses new challenges in designing and managing manufacturing systems in the age of Industry 4.0 (Choi et al., 2022; Fragapane et al., 2022; Ivanov et al., 2021; Jiang et al., 2021; Rai et al., 2021).

This special issue publishes contributions from the operations research (OR) community in the following areas and at the intersections of those areas, namely manufacturing and supply chain digitalization, resilience, and sustainability. The application areas of OR and analytics to digital, resilient, and sustainable manufacturing systems may contain descriptive and diagnostic analyses, predictive simulation and prescriptive optimization, real time control, and adaptive learning. Examples of OR and analytics applications include logistics and supply chain control with real-time data, inventory control and management using sensing data, dynamic resource allocation in Industry 4.0 customized assembly systems, improving forecasting models using big data, machine learning techniques for process control, network visibility and risk control, optimizing systems based on predictive information (e.g., predictive maintenance), combining optimization and machine learning algorithms, and supply chain risk analytics.

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With the advance of computational technologies and digital systems, success in modern manufacturing systems design and control will become more and more dependent on analytics algorithms, combining optimization and simulation modelling. Initially intended for process automation, business analytics techniques now disrupt markets and business models and have a significant impact on manufacturing systems development. Digitalization and Industry 4.0 would significantly influence the optimization techniques in the manufacturing domain as well as the performance of manufacturing systems. With the help of optimization and simulation approaches, current research generates new knowledge on manufacturing systems design and control. However, new digital technologies create new challenges for the applications of quantitative analysis techniques to manufacturing and open new ways and problem statements for these applications.

In the digital age, operations functions such as sourcing, manufacturing, and logistics as well as sales data are distributed among very different systems, such as enterprise resources planning (ERP) systems, radio frequency identification (RFID), 5G, sensors for Internet of Things (IoT), and blockchain (Choi et al., 2022; Dolgui et al., 2020; Dolgui and Ivanov 2022). Big data analytics would help process the raw data and convert it to be meaningful information used by artificial intelligence algorithms in the cyber systems and managers in the physical systems. As such, a new generation of simulation and optimization models is arising and evolving into decision-support systems that combine simulation, optimization, and data analytics. This also relates to the future development of metaverse.¹

Between August 28–30, 2019, the 9th IFAC Conference MIM conference was organized by the third author of this preface at the Berlin School of Economics and Law in Germany. The participants very much appreciated the wonderful atmosphere and excellent organization. The goal of this regularly scheduled conference is to present and discuss current topics in analytics, manufacturing technologies, supply chain management and the plentitude of applications and opportunities in a changing digital environment.

The papers featured in this special issue present some of the results of this conference. Out of the numerous high-quality submissions, only 11 papers remained after a thorough and rigorous review process. The articles are listed below in alphabetical order of the corresponding first authors. As a remark, the length of each summary does not reflect relevance or importance.

The paper *A real-time integrated optimization of the aircraft holding time and rerouting under risk area* by Linlin Chen, Shuihua Han, Chaokan Du, and Zongwei Luo presents a real-time optimization method to cope with flight delays caused by, e.g., bad weather conditions or other disruptions. The idea of their proposed method is to allow rerouting and updating positions every few minutes, introducing intermediate target points. They also consider factors such as the relative position and relative velocity.

In the paper *Refurbished products and supply chain incentives* by Zhixin Chen, Shijian Hong, Xiang Ji, Ruixia Shi, and Jie Wu, the key research question is on how online retail platforms and new retail technologies have enabled retailers to sell remanufactured products in multiple markets. This study examines supply chain members' incentives for remanufactured products in a two-channel supply chain. The authors analytically examine the conditions under which the retailer is willing to sell remanufactured products and the impact of remanufactured products on profits in three different cases, i.e., selling in the local market, selling across markets, and selling in two markets. The manufacturer controls the sales of remanufactured products through a wholesale price contract if the retailer is limited to its local

¹ The popular social media platform Facebook changed its name to be Meta recently because of its ambition in metaverse.

market. The authors uncover that if the retailer has access to a cross-border market, supply chain members have different incentives for remanufactured products.

Bo Feng, Jixin Zhao, and Zheyu Jiang describe in their paper *Robust pricing for airlines with partial information* the dynamic pricing optimization problem with residual capacity of air cargo by the regionally dominating airline as a leader–follower game where the smaller airlines follow the dominating one. The authors develop a robust two-period dynamic pricing OR model to minimize the maximum possible regret.

The paper *Designing dynamic reverse logistics network for post-sale service* by Shraddha Mishra and Surya Prakash Singh examines a multi-country production–distribution network that also provides services such as repairs and remanufacturing focusing on the warranty-driven post-sale services. Their mixed-integer nonlinear model formulation considers hybrid facilities that can serve both as a warehouse for forward supply chain operations and as a collection and repair center for the reverse supply chain function. The product can also be repaired by a manufacturer. Under this setting, the developed model allows managers to find the optimal network configuration comprised of the optimal locations/allocations of the existing/new facilities, the distribution of returned products for refurbishing and remanufacturing, and the capacity expansion of the existing plants and warehouses to facilitate remanufacturing and repair services.

Ruilin Pan, Qiong Wang, Zhenghong Li, Jianhua Cao, and Yongjin Zhang in their paper *Steelmaking-continuous casting scheduling problem with multi-position refining furnaces under time-of-use tariffs* examine the production scheduling problem of energy-intensive enterprises with multi-position refining furnaces under time-of-use tariffs. They first formulate a mixed-integer nonlinear programming optimization model that aims to minimize jobs completion time, machines idle time, and total electricity costs subject to the double-position characteristics and some additional process constraints. Their proposed model is solved by a Lagrangian relaxation algorithm based on a subgradient algorithm. Further, an interior point algorithm is adopted to solve sub-problems obtained by job-level and batch-level decomposition. The authors prove computationally the performance of the job-level decomposition and demonstrate its superiority compared to a commercial solver.

In *Measuring and eliminating the bullwhip in closed loop supply chains using control theory and Internet of Things*, the author Christos I. Papanagnou considers a closed-loop supply chain system including the customers, retailer, distributor, and manufacturer. Customers are allowed to return products to the retailer. The ordering policy is decentralized based on inventory levels and demand. The objective is to determine the relationship between the replenishment policy, return rates, and reasons for triggering the Bullwhip effect by the ordering policy. Moreover, the author studies the impact of using IoT on inventory variance and Bullwhip effect. One key finding is that the use of IoT can effectively dampen the Bullwhip effect.

Sustainability performance predictions in supply chains: grey and rough set theoretical approaches is the title of the paper by R. Rajesh where he formulates a periodic prediction model based on grey theory. The author estimates a company's indicators based on historical sustainability performance of supply chains. He applies the rough set theory to evaluate the results and generates important insights.

Silvestro Vespoli, Guido Guizzi, Elisa Gebennini, and Andrea Grassi study in their paper *A novel throughput control algorithm for semi-heterarchical industry 4.0 architecture* production control in a semi-hierarchical manufacturing environment that is typical in the Industry 4.0 era. The authors propose a cascade control algorithm considering the work-in-progress inventory as the primary control lever for achieving a specific throughput target. In particular,

their proposed approach allows managers to enhance the throughput that is controlled on the basis of order arrivals.

In the paper *An effective multi-objective whale swarm algorithm for energy-efficient scheduling of distributed welding flow shop*, Guangchen Wang, Xinyu Li, Liang Gao, and Peigen Li consider the welding flow shop optimization problem that can be considered as a form of permutation flow shop. As an increase in the number of machines may reduce the makespan but also increases the energy consumption, the major research question is to find the right balance of these two objectives. The problem is decomposed into three subproblems, namely the allocation of jobs to different factories, the scheduling in each factory, and the determination of the number of machines for it. A swarm algorithm is used to minimize the energy consumption and the makespan.

The paper *Differential game analysis of carbon emissions reduction and promotion in a sustainable supply chain considering social preferences* by Liangjie Xia, Yongwan Bai, Sanjoy Ghose, and Juanjuan Qin examines the impact of consumer low-carbon awareness and social preferences, including relationship and status preferences, on emissions reduction and promotion. In the setting with one manufacturer and one retailer, the authors analytically conduct a differential game analysis for several scenarios. Their key findings are related to the benefits of the cost-sharing contracts for the overall supply chain.

An increasing number of companies are selling their products not only in the traditional way but through third-party sellers on online platforms. In the resale mode, the platform buys products from the manufacturer at a wholesale price and then resells them to consumers. In the marketplace mode, the platform gives the manufacturer access to sell directly to consumers and charges the manufacturer a commission. Quite obviously, online sales also have an impact on offline sales. Yugang Yu, Xue Li, and Xiaoping Xu look in their paper *Reselling or marketplace mode for an online platform: the choice between cap-and-trade and carbon tax regulation on cap-and-trade and carbon tax schemes* as a measure to control emissions. In their study, the government provides carbon credits to businesses at no cost, and businesses can buy carbon credits, buy or sell at an emissions trading price through an emissions trading market. In this case, the environmental policy thus influences production decisions. The authors reveal the influence of resale and marketplace operations on profits, carbon emissions and social welfare of the corresponding supply chain system.

It is our great honor and pleasure to have guest-edited this important special issue in *Annals of Operations Research* (ANOR). Before closing, we would like to thank Professor Endre Boros, the Editor-in-Chief of ANOR, as well as the publications managers of AOR Katie D'Agosta and Ann Pulido for supporting us in organizing this special issue. We sincerely thank all the ad-hoc reviewers for providing critical reviews. We also thank all the authors for their excellent contributions. Tsan-Ming Choi would like to acknowledge the support by Yushan Fellow Program (NTU-110VV012).

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