Proceedings of the 2022 Winter Simulation Conference
B. Feng, G. Pedrielli, Y. Peng, S. Shashaani, E. Song, C.G. Corlu, L.H. Lee, E.P. Chew, T. Roeder, and P. Lendermann, eds.

ENABLING KNOWLEDGE DISCOVERY FROM SIMULATION-BASED MULTI-OBJECTIVE OPTIMIZATION IN RECONFIGURABLE MANUFACTURING SYSTEMS

Carlos Alberto Barrera Diaz
Henrik Smedberg
Sunith Bandaru
Amos H.C. Ng

Intelligent Production Systems Division
University of Skövde
Box 408 Högskolevägen
Skövde, 54128, SWEDEN

ABSTRACT

Due to the nature of today's manufacturing industry, where enterprises are subjected to frequent changes and volatile markets, reconfigurable manufacturing systems (RMS) are crucial when addressing ramp-up and ramp-down scenarios derived from, among other challenges, increasingly shortened product lifecycles. Applying simulation-based optimization techniques to their designs under different production volume scenarios has become valuable when RMS becomes more complex. Apart from proposing the optimal solutions subject to various production volume changes, decision-makers can extract propositional knowledge to better understand the RMS design and support their decision-making through a knowledge discovery method by combining simulation-based optimization and data mining techniques. In particular, this study applies a novel flexible pattern mining algorithm to conduct post-optimality analysis on multi-dimensional, multi-objective optimization datasets from an industrial-inspired application to discover the rules regarding how the tasks are assigned to the workstations constitute reasonable solutions for scalable RMS.

1 INTRODUCTION

In the current competitive market, manufacturing companies are frequently challenged by demand variations, and therefore they often need to address fluctuating production volumes. Consequently, the efficiency of a manufacturing system in reacting and adjusting its capacities and functionalities to cope with the volumes and demands changes constitutes a critical challenge for production organizations (Dou et al. 2021; Koren et al. 2017; Koren and Shpitalni 2010). To tackle, among other challenges, those caused by the demand and volume changes, Koren et al. 1999 first introduced the concept of reconfigurable manufacturing systems (RMS). RMS are production systems capable of adding/removing resources and modifying their capabilities to efficiently cope with expected or unexpected market shifts (Diaz et al. 2020; Koren et al. 2018). In such a manner, RMS are responsive manufacturing systems that, cost-effectively through reconfigurations such as the arrangement of machines or the process plan, can provide the required functionalities for several demand periods (Diaz et al. 2021). In a nutshell, RMS are essential to the current manufacturing industry to achieve high flexibility, fluctuating production volumes, flexible batches, and the required short life cycles for today's competitive market (Bortolini et al. 2018). Studies suggest that this type of system provides better performance in terms of scalability, productivity, responsiveness, and cost when compared to traditional production systems (Freiheit et al. 2003; Gu 2017).

978-1-6654-7661-4/22/$31.00 ©2022 IEEE

alternatives". *International Journal of Computer Integrated Manufacturing* 25(3):211–229.

Mourtzis, D., M. Doukas, and D. Bernidaki. 2014. "Simulation in manufacturing: Review and challenges". *Procedia CIRP* 25:213–229.

Ng, A. H. C., J. Bernedixen, M. U. Moris, and M. Jägstam. 2011. "Factory flow design and analysis using internet-enabled simulation-based optimization and automatic model generation". In *Proceedings of the 2011 Winter Simulation Conference*, edited by S. Jain, R.R. Creasey, J. Himmelspach, K.P. White, and M. Fu, 2181–2193. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Niño-Pérez, E., Y. M. Méndez-Vázquez, D. E. Arias-González, and M. Cabrera-Ríos. 2018. "A simulation–optimization strategy to deal simultaneously with tens of decision variables and multiple performance measures in manufacturing". *Journal of Simulation* 12(3):258–270.

Pehrsson, L., M. Frantzén, T. Aslam, and A. H. C. Ng. 2015. "Aggregated line modeling for simulation and optimization of manufacturing systems". In *Proceedings of the 2015 Winter Simulation Conference*, edited by L. Yilmaz, W K. V. Chan, I. Moon, T. M K. Roeder, C. Macal, and M D. Rossetti, 3632–3643. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Renzi, C., F. Leali, M. Cavazzuti, and A. O. Andrisano. 2014. "A review on artificial intelligence applications to the optimal design of dedicated and reconfigurable manufacturing systems". *The International Journal of Advanced Manufacturing Technology* 72(1):403–418.

Rösiö, C., and K. Säfsten. 2013. "Reconfigurable production system design–theoretical and practical challenges". *Journal of Manufacturing Technology Management* 24(7):998–1018.

Touzout, F. A., and L. Benyoucef. 2018. "Multi-objective sustainable process plan generation in a reconfigurable manufacturing environment: exact and adapted evolutionary approaches". *International Journal of Production Research* 57(8): 2531–2547.

Tripathi, S., D. Muhr, M. Brunner, H. Jodlbauer, M. Dehmer, and F. Emmert-Streib. 2021. "Ensuring the Robustness and Reliability of Data-Driven Knowledge Discovery Models in Production and Manufacturing". *Frontiers in Artificial Intelligence* 4:22.

Wang, W., and Y. Koren. 2012. "Scalability planning for reconfigurable manufacturing systems". *Journal of Manufacturing Systems* 31(2):83–91.

Xu, J., E. Huang, L. Hsieh, L. H. Lee, Q. S. Jia, and C. H. Chen. 2016. "Simulation optimization in the era of Industrial 4.0 and the Industrial Internet". *Journal of Simulation* 10(4):310–320.

AUTHOR BIOGRAPHIES

CARLOS ALBERTO BARRERA DIAZ received a B.Sc. degree in Electrical Engineering from the University of Malaga, Spain, a B.Sc. degree in Automation Engineering, and his Master's degree in Industrial Systems Engineering from the University of Skövde, Sweden, where he is currently pursuing his Ph.D. degree with the Intelligent Production Systems Division. His research interests include design, modeling, simulation, and multi-objective optimization to analyze manufacturing systems. His email address is carlos.alberto.barrera.diaz@his.se.

HENRIK SMEDBERG received his B.Sc. degree in Informatics and Master's degree in Automation Engineering from the University of Skövde, Sweden, where he is currently pursuing a Ph.D. within the Division of Intelligent Production Systems. His research interests include the application of knowledge discovery techniques both for decision support in multi-objective optimization and in algorithms for knowledge-driven optimization. His email address is henrik.smedberg@his.se.

SUNITH BANDARU is a Senior Member, IEEE, and an Associate Professor at the Division of Intelligent Production Systems, University of Skövde, Sweden. He received his Bachelor's degree (2006) in Mechanical Engineering from Jawaharlal Nehru Technological University, India, and Masters (2008) and Ph.D. (2013) degrees from IIT Kanpur, India. His research interests lie at the intersection of evolutionary computation, machine learning, and data mining. His email address is sunith.bandaru@his.se.

AMOS HC NG is a Professor of Automation Engineering at the Division of Intelligent Production Systems, University of Skövde, Sweden. He is also a Visiting Professor at the Division of Industrial Engineering and Management, Uppsala University, Sweden, and the CEO of Evoma AB. His research interests include the applications of simulation, multi-objective optimization, and artificial intelligence for the design, analysis, and improvement of production/health-care/business systems. His email address is amos.ng@his.se.