HSI for Enhancing Manufacturing Resilience: A Simulation-Based Approach

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Abstract. This early-stage research addresses an essential need to deepen our understanding of enhancing manufacturing resilience by focusing on internal factors such as workforce, manufacturing processes, and physical assets. Employing Human-Systems Integration (HSI) principles, the study focuses on the assembly operator within the assembly cell in a real manufacturing process environment. Recognizing insufficiencies in standards concerning human strain and its connection to performance, the study will eventually propose a simulation model for decision-making. The aim is to deepen understanding and enhance manufacturing resilience through risk management by considering human factors and continuously improving the design interface of the manufacturing process. Through simulation, the study will experiment with changes in different parameters related to human factors and assess their effects on process performance. The focus is on the assembly operator's physical performance and force generation, considering variables like gender, age, individual differences, and injury recovery timelines. By analyzing the force generation of human operators with various variables, we aim to address the effects of changes on performance. The simulation is aimed at building decision-making scenarios and assessing the impact of changes on performance. In the context of HSI in manufacturing, the study promotes system design that incorporates technical and human aspects into manufacturing processes. This integration aims to proactively contribute to the development of a resilient manufacturing system by fostering adaptability and robustness to address diverse challenges.

Introduction

The manufacturing sector has shown an increased interest in better understanding factors related to risk management (RM) and resilience. They encompass various aspects in business and ensure that the company is well-prepared to meet production requirements even when unexpected events are faced (Brocal et al. 2019; Kusiak 2020). While the scope in manufacturing resilience is often the external business environment, various internal aspects, such as materials and components and their availability, manufacturing processes and other physical assets, productivity, capacity, quality, sustainability, workforce, and social factors should not be overlooked (Kusiak 2020). In this study, our scope is limited particularly to internal factors such as the workforce and manufacturing processes with their physical assets, such as technologies, tools, and jigs. In this context, the role of the human as an organizational factor is crucial to enhance systems resilience. If these factors are not proactively addressed in RM, it can result in underperformance where human factors serve as a crucial link between various risk types (Brocal et al. 2019; Oduoza 2020).

In manufacturing, business development has strongly leaned on technological development, often associated with the Industry 4.0 phenomenon. Industry 4.0 promotes digitalization as the key to enhancing manufacturing performance (Dolgui, Sgarbossa & Simonetto 2022). In this regard, achieving optimal synergy between the human and the technology is crucial. It is essential to maintain the balance between humans and technologies, with human involvement ensured in personalized production. The forthcoming Industry 5.0 is expected to elevate the level of collaboration between humans and technologies, particularly within the manufacturing sector, where technologies will handle monotonous tasks while the human workforce undertakes tasks that require creativity (e.g., Duggal et al. 2022). Improving both human and organizational performance can be achieved by implementing RM strategies within complex systems (Brocal et al. 2019). Although there is proof that these new technologies have reduced physical labor in manufacturing, there is also evidence that they have introduced new kinds of risks for productivity, health, and safety. The literature particularly associates these risks with cognitive, psychosocial, and physical domains (Guastello 2014) related to human interactions between people and the system (Zorzenon, Lizarelli & de Moura, 2022).

Even though in general new technologies make people's lives easier by reducing physical strain, they have also brought new kinds of risks. There are various manifestations of human physical stress, and they are linked to both workplace health issues and physical activities such as force generation in human-phase work performance (Cutlip & Ciou 2012; Schaub & Schaefer 2021, 356-360). Sophisticated modeling approaches are a crucial tool for comprehending issues related to human factors that may lead to organizational weaknesses, underperformance, accidents, or disruptions in complex systems (Brocal et al. 2019; Oduoza 2020). To achieve the objectives of this study, we aim to answer the following research questions: 1) How does implementing HSI principles in manufacturing processes enhance resilience? 2) What key human factors significantly influence assembly operator performance? And 3) How can a simulation be utilized to continuously improve the RM and design interface of manufacturing processes?

Background

In an organizational context, resilience can be defined in various ways, such as a company's ability to resist systematic discontinuities and adapt to new risk environments (Burnard & Bhamra, 2011), or as the organization's capacity to withstand unexpected changes, discontinuities, and risks (Carvalho et al. 2016). Engineering resilience emphasize the ability of systems to navigate complexity and balance productivity with safety. Resilience offers tools for proactive RM, recognizing the inherent complexity of system operation and the corresponding requirement for performance variability. This perspective is particularly crucial when addressing the risk-related needs of sociotechnical systems (Patriarca et al. 2018). The traditional approach to RM for safety emphasizes the avoidance of any form of performance variability (Steen & Aven 2011), where performance develops through people, planning, and processes (Oakland et al. 2021, 117). In manufacturing, a common concern about process optimization is how to ensure that machines and personnel are logically organized to optimize production efficiency and meet performance goals (Collier & Evans, 2021, 84-85).

Assembly operator's physical performance and force generation

In particular, working tasks that require repetitive actions at high frequency and/or awkward body positions can lead to fatigue, discomfort, and musculoskeletal disorders. Effective risk assessment and management aim to minimize these health effects by considering factors such as the duration of exposure, frequency of actions, force application, postures, and the availability of recovery periods (Occihipinti & Colombini 2021, 315-317). Skeletal muscle serves a primary role in force generation (Cutlip & Ciou 2012, 60). Physical performance is based on skeletal muscle force production. In compressive force, human strength depends on age and gender. Women's maximum muscle strength is approximately two-thirds that of men's, peaking at age 30 and declining by 20% by age 60. Additionally factors like force angle, grip height, and shoulder joint angle influence force generation. These individual differences present challenges in creating universally suitable designs. Risk assessment, using a three-zone model for load categorization, suggests no action or else redesign and organizational changes (Launis & Lehtelä 2011, 72-75, 201; Schaub & Schaefer 2021, 356-360). Hand tools play also a crucial role in force transmission, emphasizing the need for optimal design in risk prevention (Guastello 2014, 185). Further considerations regarding the operator's physical performance and force include limited knowledge of factors associated with the risk of further injury upon return-to-work after an injury. There is a need to determine the risks and follow-up effects when the operator is working while recovering (Cutlip & Ciou 2012, 78).

Study approach and expected results

Simulation is a technique that employs representative or artificial data to model various conditions likely to occur during the actual performance of a system. It allows users to experiment with processes or operating procedures without risking real-world system performance (Bozarth & Handfield 2019, 201). As part of the conceptual framework for process modeling and simulation, we undertake the following crucial steps: constructing a simulation model of the process, executing the simulation model, examining performance measures, and assessing alternative scenarios (Laguna & Marklund 2005, 95). Our modeling example is based on a real manufacturing process in Nokia Mobile Networks' radio prototype production. We will employ model-based systems engineering utilizing the Cameo Systems Modeler tool and Systems Modeling Language (SySML) to visualize the manufacturing process. This visualization forms the basis for an experimental design by defining the parameters' context for data generation in simulation runs. From a theory-building perspective, the visualized design acts as an operational version of the theoretical taxonomy (McDonald et al., 2018). Through simulation, we experiment with changes by using parameters related to human operator force generation, and the effects on performance, in response to changes in various variables. The parameters include variables such as gender, age, individual differences, and injury recovery timelines (Cutlip & Ciou 2012; Launis & Lehtelä 2011). As a result of this early-stage research, we expect to 1) create a model and 2) test its functionality by simulating it with different parameters. Based on the accumulated knowledge, we will be able to participate in discussions on how the implementation of HSI principles in manufacturing processes enhances resilience, as well as how human factors significantly influence the performance of assembly operators. As this study is in its early stages, we anticipate having results by spring 2024.

References

Bozarth, CC & Handfield, RB 2019, *Introduction to Operations and Supply Chain Management,* 5th edn, Pearson Education Limited, Harlow (UK).

Brocal, F, Gonzales, C, Komljenovic, D, Katina, PF & Sebastián, MA 2019, 'Emerging Risk Management in Industry 4.0: An Approach to Improve Organizational and Human Performance in the Complex Systems', *Complexity,* vol. 2019, pp. 1-13.

Burnard, K & Bhamra, R 2011, 'Organisational Resilience: Development of a Conceptual Framework for Organisational Responses', *International Journal of Production Research* 49 (18), 5581-5599.

Carvalho, AO, Ribeiro, I, Cirani, CB S & Cintra, RF 2016, 'Organizational Resilience: A Comparative Study between Innovative and Non-innovative Companies Based on the Financial Performance Analysis', *International Journal of Innovation* 4 (1), 58-69.

Collier, DA & Evans, JR 2021, *Operations and Supply Chain Management,* 2nd edn, Cengage Learning Inc, Boston, MA (US).

Cutlip, RG & Ciou, SS 2012, 'Skeletal Muscle Physiology and Its Application to Occupational Ergonomics', in A Bhattacharya & JD McGlothlin (eds.), *Occupational Ergonomics: Theory and Applications,* CRC Press, Taylor & Francis Group, Boca Raton, FL (US), pp. 56-85.

Dolgui, A, Sgarbossa, F & Simonetto, M 2022, 'Design and Management of Assembly Systems 4.0: Systematic Literature Review and Research Agenda', *International Journal of Production Research* 60 (1), 184-210.

Duggal, AS, Malik, PK, Gehlot, A, Singh, R, Singh Gaba, G, Masud, M & Al-Amri, JF 2022, 'A Sequential Roadmap to Industry 6.0: Exploring Future Manufacturing Trends', *IET Communications* 16 (5), 521-531.

Guastello, SJ 2014, *Human Factors Engineering and Ergonomics: A Systems Approach,* CRC Press, Taylor & Francis Group, Boca Raton, FL (US).

Kusiak, A 2020, 'Open Manufacturing: A Design-for-Resilience Approach', *International Journal of Production Research* 58 (15), 4647-4658.

Laguna, M & Marklund, J 2005, *Business Process Modeling, Simulation and Design,* Pearson Prentice Hall, Upper Saddle River, NJ (US).

Launis, M & Lehtelä, J 2011, *Ergonomia,* Työterveyslaitos, Helsinki (FI)..

Macdonald, JR, Zobel, CW, Melnyk, SA & Griffis, SE 2018, 'Supply Chain Risk and Resilience: Theory Building through Structured Experiments and Simulation', *International Journal of Production Research* 56 (12), 4337-4355.

Occihipinti, E. & Colombini, D 2021, 'Repetitive Actions and Movements of the Upper Limbs', in W Karwowski, A Szopa & M. M Soares (eds.), *Handbook of Standards and Guidelines in Human Factors and Ergonomics,* CRC Press, Taylor & Francis Group, Boca Raton, FL (US). pp. 315-328.

Oduoza, C. F 2020, 'Framework for Sustainable Risk Management in the Manufacturing Sector', *Procedia Manufacturing* 51, 1290-1297.

Patriarca, R, Bergström, J, Di Gravio, G & Constantino, F 2018, 'Resilience Engineering: Current Status of the Research and Future Challenges', *Safety Science* 102, 79-100.

Schaub, KG & Schaefer, P 2021, 'Ergonomics of Manual Handling – Part 2: Pushing and Pulling', in W Karwowski, A Szopa & MM Soares (eds.), *Handbook of Standards and Guidelines in Human Factors and Ergonomics,* CRC Press, Taylor & Francis Group*,* Boca Raton, FL (US). pp. 343-362.

Steen, R & Aven T 2011, 'A Risk Perspective Suitable for Resilience Engineering', *Safety Science* 49 (2), 292-297.

Zorzenon, R, Lizarelli, FL & de A Moura, DBA 2022, 'What Is the Potential Impact of Industry 4.0 on Health and Safety at Work', *Safety Science* 153, 1-18.

Biography

M.Sc. (Tech), M. Eng. **Tero Sotamaa** works as a doctoral researcher at the University of Oulu, Finland. His doctoral thesis work focuses on the field of risk management and resilience in industrial companies and their supply networks. Mr. Sotamaa has held various operational and middle management positions within several automotive organizations outside academia.

Ari Teppo is a product manager at Nokia Corporation. During his long career at Nokia (since 1989), he has led various teams and organizations on manufacturing technologies and quality assurance. In addition to current product owner position, he has led multiple development projects on Model-based Systems Engineering, trained the organization to model-based approach and created modeling architecture framework for use of team of architects. Ari is a member of the board in Finnish Systems Engineering society FINSE.

Adjunct professor, D.Sc. (Tech.) **Arto Reiman** is a research team leader at the University of Oulu, Finland. His research team focuses on well-being at work and productivity under the discipline of Industrial Engineering and Management in the Faculty of Technology. Reiman acted as the chair of the Finnish Ergonomics Society for four years in 2019-2022. In addition, he has been in the Board for the Nordics Ergonomics and Human Factors Society for three years. For many years, Reiman has also participated in national ergonomics standardization activities.

Elina Parviainen has worked as an HF/E engineer in the international company and as an entrepreneur in the field of industry HFE. She has broad experience in integrating HF/E and systems engineering in industrial contexts. She has been the president of the Nordics Ergonomics and Human Factors Society as well as the president of the Finnish Ergonomics Society. She also acted as the Development and Promotion Committee chair (2019-2024) in the International Ergonomics Association Executive committee and works as a Process analyst at MEYER Turku.