Guest editorial: "Integration of Lean Six Sigma with industry 4.0 to augment organizational efficiency and effectiveness"

The power of advanced analytics significantly enhances Lean Six Sigma (LSS) projects. Leveraging Industry 4.0 technology expedites data collection, boosts data availability, accelerates data collection processes and streamlines the analysis of phenomena.

Most of the LSS tools are based on data to analyse the problem and data is very essential to understand the existing state of a process and to make desired improvement to that process. Industry 4.0 helps in eliminating human error in data collection process and therefore better and faster reliable decisions can be made. In addition, it provides the infrastructure to potentially enhance the Operational Excellence (OPEX) capability of an organisation both at the operational and enterprise level. Performance and operational data metrics can transmit in real time through the Cyber Physical Systems (CPS) network enabling enhancements at the operational level. Through the integration of LSS and Industry 4.0, numerous benefits have been identified such as forecasting process defects in complex processes, enhancement of product and service quality and significant cost reduction.

Aligned with the thought process of exploring the integration of Industry 4.0 and LSS, this Special Issue delves into the current state of research in this area. What benefits stem from this fusion? What challenges loom over this integration? The aim is to delve deeper into the amalgamation of LSS and Industry 4.0, uncovering challenges, benefits and success factors crucial for implementation and sustainability.

The first contribution addressed the research objectives: To investigate how manufacturers can foster insights and improvements from real-time data among shop-floor workers by developing organisational "learning-to-learn" capabilities based on both the lean- and action learning principle of learning through problem-solving and further extrapolated findings on how action learning can enable the complementarity between Lean and industry 4.0. These objectives had been addressed in the study by Henrik Saabye and Daryl John Powell in their paper titled "Fostering insights and improvements from IIoT systems at the shop floor: a case of industry 4.0 and lean complementarity enabled by action learning". The findings reported that enabling shop-floor workers to use real-time data include developing three consecutive organisational building blocks of learning-to-learn, learning-to-learn using real-time data and learning-to-learn generating real-time data and helping others to learn.

The second contribution addressed the research objective: To analyse the current state of research to identify the link between Lean Manufacturing and Industry 4.0 (I4.0) technologies to map out different research themes, to uncover research gaps and propose key recommendations for future research, including lessons to be learnt from the integration of Lean and I4.0. These objectives had been addressed in the study by Sameh M. Saad, Ramin Bahadori, Chandan Bhovar and Hongwei Zhangin their paper titled "Industry 4.0 and Lean Manufacturing – a systematic review of the state-of-the-art literature and key recommendations for future research". The findings from the study include identification of five main research themes, and development of a thematic map to explore the following: the relationship between Lean Manufacturing and I4.0; Lean Manufacturing and I4.0

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implication on performance; Lean Manufacturing and I4.0 framework; Lean Manufacturing and I4.0 integration with other methodologies; and application of I4.0 technologies in Lean Manufacturing.

The third contribution addressed the research objective: To explore the integration of Industry 4.0 technologies with LSS practices in the manufacturing sector for enhanced process improvement. This objective had been addressed in the study by Arish Ibrahim and Gulshan Kumar their paper titled "Selection of Industry 4.0 technologies for Lean Six Sigma integration using fuzzy DEMATEL approach". The findings of this study suggest that the integration of key technologies like modelling and simulation, artificial intelligence (AI) and machine learning, big data analytics, automation and industrial robots and smart sensors is crucial for achieving OPEX when combined with LSS.

The fourth contribution addressed the research objective: To explore the potential application of blockchain technology in LSS project through a proposed blockchain-LSS (BLSS) model. This objective had been addressed in the study by Rajeev Rathi, Mahipal Singh, Jiju Antony, Jose Arturo Garza-Reyes, Rekha Goyat, Alireza Shokri in their paper titled "Integration of blockchain and Lean Six Sigma approach for operational excellence: a proposed model". The findings revealed that the prime function of the proposed BLSS model is the information sharing among the project team and real-time monitoring, transparency, traceability and immutability in the Define-Measure-Analyse-Improve-Control phase. Also, the project team and industry employees can trace the success of the project at every moment, resulting in trust buildup and the elimination of fake data.

Fifth contribution addressed the research objective: To design a hybrid model of knowledge-based performance management system (KBPMS) for facilitating Lean Six-Sigma (L6s) application to increase contractor productivity without compromising human safety in Indonesian upstream oil field operations that manage ageing and life extension (ALE) facilities. This objective had been addressed in the study by Rahadian Haryo Bayu Sejati, Dermawan Wibisono and Akbar Adhiutama in their paper titled "The collaborative approaches of the knowledge-based performance management system and lean six sigma to improve contractor productivity and safety performances". The key finding was that KBPMS-L6s concept had given an improved hierarchy for strategic and operational levels to achieve a performance benchmark to manage ALE facilities in Indonesian upstream oil field operations. Sixth contribution addressed the research objective: To explore the relationship between Lean manufacturing and Industry 4.0 for small and medium size enterprises in Japan and Brazil. This objective had been addressed in the study by Osamu Tsukada, Ugo Ibusuki, Shigeru Kuchii and Anderson Tadeu de Santi Barbosa de Almeida in their paper titled "Is Lean manufacturing maturity a prerequisite for industry 4.0? Survey of SMEs in Japan and Brazil". In the quantitative study, 90% of respondents practice Lean manufacturing, while 40% incorporate Industry 4.0 principles. In the qualitative study in Brazil, four managers highlighted that Lean manufacturing is a fundamental prerequisite for Industry 4.0. They emphasised that eliminating waste is essential for productivity, even with advanced digitalisation technologies.

Seventh contribution addressed the research objective: To provide a framework to guide quality practitioners with the implementation of digitalisation in their existing practices. This objective had been addressed in the study by Rose Clancy, Ken Bruton and Dominic T.J. O'Sullivan, Aidan J. Cloonan in their paper titled "The HyDAPI framework: a versatile tool integrating Lean Six Sigma and digitalisation for improved quality management in Industry 4.0". The finding was that the implementation of the proposed HyDAPI framework in an industrial case study led to increased efficiency, reduction of waste, standardised work, mistake proofing and the ability to root cause non-conformance products.

Exciting developments in LSS 4.0 and digitalisation tools are reshaping the landscape for small and medium-sized enterprises and service-oriented businesses. However, more intensive research is needed to establish a standard definition for LSS 4.0 and development of a comprehensive and holistic framework. The integration of LSS and I4.0 remains unexplored territory, with a scarcity of impactful case studies. Guest editors are eager to see pioneering case studies from diverse manufacturing and service companies in the coming years.

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