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A Systematic Framework for the Integration of Lean, Green, and Human Factors for Sustainable Production

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ABSTRACT

In response to environmental and social impact challenges and the need for enhanced operational efficiency, this study focuses on integrating Lean, Green, and Human Factors and Ergonomics (HFE) in production systems. The paper introduces a novel conceptual model named Ergo-Green Lean, providing a comprehensive framework for integrating these paradigms. The study identifies successful integration strategies through a brief literature review, highlighting the potential benefits and implementation challenges. The proposed model and novel framework, developed through focus group discussions with relevant stakeholders, aims to enhance triple-bottom-line sustainability in a production environment to achieve a competitive edge in the market. The study concludes by emphasizing the need for further empirical validation and exploration of deeper integration possibilities, positioning Ergo-Green Lean as a promising path toward sustainable development in diverse industrial settings.

Keywords: Sustainable manufacturing, Green, Lean, Ergonomics, Climate change

INTRODUCTION

In today's world, industrial development has positively and negatively impacted human beings. Pollution, greenhouse gas emissions, and excessive use of resources are some of the negative impacts of this development (Imran *et al.*, 2023). The concept of sustainability has emerged to address these issues. Sustainable development seeks to improve the triple-bottom-line impact of organizations, including social, economic, and environmental impacts. Green manufacturing is a crucial aspect of sustainability that promotes responsible production and consumption of goods and services. Green is being integrated with other strategies such as green and lean, green supply chain, and green construction to reduce environmental impacts of processes (Chen *et al.*, 2023; Kaswan *et al.*, 2023; Owusu-Manu *et al.*, 2023; Silva and Gomes, 2023).

In addition to environmental impacts, organizations' other big challenge is staying competitive. Many business organizations implement lean, a

multi-faceted socio-technical philosophy focusing on continuous improvement and waste reduction, to enhance operational efficiency, organizational performance, and competitiveness (Manfredsson, 2016). Research suggests that successful implementation of lean requires extensive focus on the social aspects of lean in addition to technical aspects (Bortolotti, Boscari and Danese, 2015). With the undoubted success of lean in improving operational efficiency and waste reduction, it has mixed effects on workers' quality of life. The negative impacts reported in the literature include increased job stress and demand, low skill utilization, mild depression, job dissatisfaction, job strain, and awkward working posture (Bouville and Alis, 2014; Sakthi Nagaraj and Jeyapaul, 2018). The negative impacts of the workers lead to an overall decline in operational efficiency and organizational performance (Sobhani, Wahab and Neumann, 2015). Studies show that organizational performance can be improved by integrating lean manufacturing with human factors and ergonomics (HFE) (Jarebrant *et al.*, 2016; Tortorella, Vergara and Ferreira, 2017; Sakthi Nagaraj *et al.*, 2019).

Integration of two paradigms (i.e., lean and green, lean and HFE, green and HFE) has been proven a successful strategy to improve key performance indicators (KPIs) for both of the philosophies (Garza-Reyes *et al.*, 2014; Saravia-Pinilla, Daza-Beltrán and García-Acosta, 2016; Sakthi Nagaraj *et al.*, 2019). However, there is a dearth of research studies on integrating lean, green, and HFE (Kanan *et al.*, 2023). Keeping in view this research gap, the current study answers the following research question:

How can lean, green, and HFE be integrated to provide the benefits of all three paradigms and improve the overall sustainability of the production systems?

This study provides the conceptual model for integrating lean, green, and HFE and a comprehensive framework for implementing this integrated approach, named Ergo-Green Lean (Mehmood, 2021). The rest of the paper is organized as follows. The next sections provide a brief literature survey on integrating lean-green, lean-HFE, and green-HFE. Then, the methodology for developing the conceptual model and implementation framework is presented. The next section provides the conceptual model for Ergo-Green Lean, followed by its implementation framework. Conclusions are provided at the end.

LITERATURE REVIEW

The literature review is split into three sections, each discussing the integration of green, lean and HFE paradigms in the light of existing literature.

Green and Lean

Although Lean and Green philosophies were developed based on different dimensions, they share common goals. Lean focuses on reducing the seven deadly wastes or Muda (Womack and Jones, 1997), reducing energy and raw material consumption (Baumer-Cardoso *et al.*, 2020), a significant objective of Green. Similarly, Green identifies seven wastes, and minimizing them can reduce waste, as defined by Lean (Kurdve and Bellgran, 2021).

Besides their focus on waste reduction, Lean and Green maintain synergies in product design and reducing lead time (Larson and Greenwood, 2004). However, some studies suggest that Lean and Green may sometimes diverge depending on the sector, implemented practices, and measured KPIs (Dües, Tan and Lim, 2013; Carvalho *et al.*, 2017). For example, the Kanban system requires frequent deliveries, which may cause greater fuel consumption and increase carbon footprint (Cusumano, 1994). Negative impacts include higher carbon footprints while implementing just-in-time (JIT) (Venkat and Wakeland, 2006) and increased consumption of water while implementing quick changeover (Baumer-Cardoso *et al.*, 2020). Detailed analysis of the research literature reveals that most studies conclude that "Lean works as a catalyst for Green," and implementation tools and techniques of Lean go beyond economic benefits and improve triple-bottom-line sustainability (Weingarten, Fynes and Onofrei, 2013; Johansson and Sundin, 2014; Garza-Reyes, 2015a).

Lean and HFE

Integrating lean and ergonomics results in waste reduction, lead time reduction, work-in-process inventory reduction, and increased employee satisfaction and productivity (Botti, Mora,and Regattieri, 2017; Brito *et al.*, 2020). Fraser *et al.* (2006) created a model to examine the implementation of cellular manufacturing, which found that an integrated approach provided a better understanding of the implementation phases and allowed workers to be value-added links in product and process improvement. Lean and Ergo-VSM have been reported to improve role clarity, physical factors, and lead time by combining ergonomics with VSM (Jarebrant *et al.*, 2016; Sakthi Nagaraj *et al.*, 2019).

Green and HFE

Since the 1990s, there has been a growing interest in expanding the scope of ergonomics to include environmental considerations (Nickerson, 1992). This interest has gained significant momentum in recent years, with the emergence of themes such as Eco-Ergonomic (Brown, 2007), Green Ergonomics (Thatcher, 2013), HFE and Sustainability (Zink and Fischer, 2013), and Ergoecology (García-Acosta *et al.*, 2014). Green Ergonomics, as conceptualized by Thatcher (2013), specifically focuses on ergonomic interventions prioritizing nature. It emphasizes the bi-directional connections between nature and human systems and seeks to answer two major questions: how can ecosystem services be enhanced to benefit human well-being, and how can ergonomic design and evaluation be used to preserve, conserve, and restore nature? Empirical studies conclude that integrated implementation of Green and HFE can improve environmental performance, workers' well-being, psychological factors at work, and employee productivity (Norton, Ayoko, and Ashkanasy, 2021; Rahmat *et al.*, 2023).

In the light of the above discussion, it's important to integrate lean, green and HFE philosophies to implement and sustain triple-bottom-line (TBL) sustainability. Very recently, due to changing climate conditions, the integration

of environmental sustainability in line with economic and social sustainability has grasped the attention of researchers, practitioners, and policy makers. Hence, this research is mainly focused on establishing the need for the integration and development of a framework that can help attain sustainability in the manufacturing production environment.

Integration of Lean, Green, and HFE

The integration of lean, green, and HFE, named Ergo-Green Lean, is a novel concept that was firstly developed by our team in 2021 (Mehmood, 2021). Later, the team developed an empirical case study to capture practical insights about its usefulness and implementation challenges. It was concluded that Ergo-Green Lean approach can improve the KPIs of all three paradigms, e.g. in the given case these were: lead time, process time, carbon footprint, energy efficiency, job satisfaction, and job stress (Kanan *et al.*, 2023). In continuation with the previous work, this study contributes by providing a comprehensive integration based conceptual model and the development of an implementation framework for Ergo-Green Lean approach.

METHODOLOGY

To achieve the objectives of this research study, five focus group discussions were conducted with relevant experts from academia and industry. The expert profiles are given in Table 1. The conceptual model and implementation framework were developed in two and three focus group discussions, respectively.

Table 1. Participants in focus group discussions.

Position	Number	Areas of Expertise
Senior academician and researchers	6	ergonomics, technology road mapping, lean manufacturing, HFE, process safety and risk analysis, energy engineering, engineering entrepreneurship, lean start-ups, operations management, environmental management
Mid-level academicians and researchers	4	operations management, ergonomics, technology deployment, innovation management, HFE
Industry representatives (top management)	8	sustainability, innovation management, technology road mapping, SME clusters, HFE, environmental management systems, supply chain management
Industry representatives (middle management)	10	environmental management system, energy efficiency, business development, cleaner production, social compliance, lean manufacturing, HFE

CONCEPTUAL MODEL FOR LEAN, GREEN AND HFE INTEGRATION

The conceptual model for Ergo-Green Lean, the integration of lean, green, and HFE, is given in Figure 1. Ergo-Green Lean is conceptualized to achieve triple-bottom-line sustainability by integrating the principles of ergonomics, green, and lean. This model was created through focus group discussions and incorporates tools and techniques from all three paradigms to improve productivity, reduce resource usage, lower costs, and enhance quality and customer satisfaction. Implementing ergonomics, green, and lean production systems separately may result in incompatibilities and inefficient resource usage (McDonald, Mors, and Phillips, 2003). By integrating all three principles, organizations can gain a competitive edge in the market. Additionally, integrating these paradigms can help implement an integrated management system. An integrated management system can provide a better infrastructure for managing multiple stakeholders and meeting conflicting requirements, such as top management, functional managers, employees, customers, suppliers, regulatory authorities, and the community (Wright, 2000).

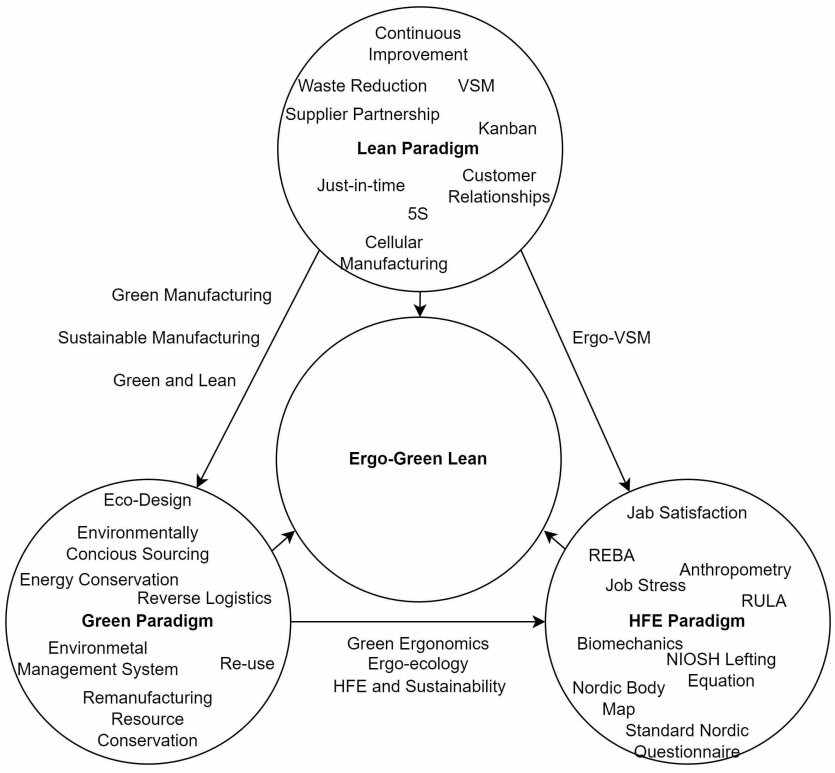

Figure 1: Conceptual model for Ergo-Green Lean.

IMPLEMENTATION FRAMEWORK FOR ERGO-GREEN LEAN

The Ergo-Green Lean implementation framework is based on a plan-do-check-act (PDCA) cycle. The initial version of the framework was developed

through multiple brainstorming sessions, and after preparing an initial version, three focus group discussions were conducted to finalize it. The framework has three parts: stakeholder representation, practices, and procedures. Figure 2 shows the complete implementation framework for Ergo-green Lean. Organizations have various stakeholders, including employees, suppliers, customers, government, shareholders, NGOs, and the community (Sarkis, Gonzalez-Torre and Adenso-Diaz, 2010). High-quality employees are the most important stakeholders, as they are essential for better value creation and organizational performance. Involving employees in new initiatives empowers them to learn and develop innovative ideas, making implementing new technologies and solving problems easier (Govindan *et al.*, 2016; Malviya, Kant, and Gupta, 2018). For the successful implementation of Ergo-Green Lean, involving all stakeholders is vital. Each stakeholder has a specific role, with management providing resources and required support and academia providing technical support. Effective communication and cooperation among stakeholders are crucial.

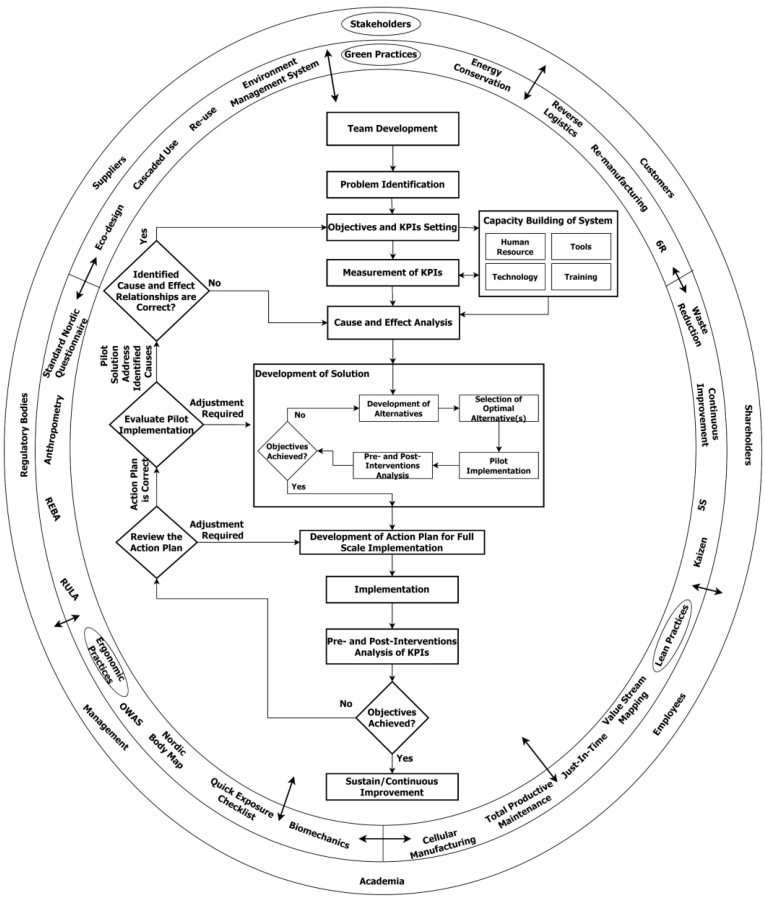

Figure 2: Implementation framework for Ergo-Green Lean.

Lean, green, and HFE concepts represent different approaches with distinct sets of practices. While the framework includes important practices from all three paradigms, the specific practices may vary depending on the local problems and constraints encountered during the planning phase.

Implementing the Ergo-Green Lean approach starts by forming a team with representatives of all stakeholders to identify the problem and set objectives and KPIs. Capacity building begins with technology acquisition training and KPI measurement. Root cause analysis follows, after which solutions are developed and tested at a small scale. If successful, an action plan is made for full-scale implementation; otherwise, the process is repeated. Finally, the solution is implemented at the system level, with pre-and post-intervention KPIs measured. Best practices are documented for future reference, and the process is repeated until objectives are achieved.

CONCLUSION

This study proposes a comprehensive model and framework to integrate Lean, Green, and HFE to achieve triple-bottom-line sustainability. The goal is to offer organizations a holistic strategy to deal with the challenges of industrial development while promoting sustainability in its true spirit. The approach, Ergo-Green Lean, aims to achieve operational efficiency, waste reduction, and social well-being at work simultaneously. Further research is being conducted to validate this approach empirically in different industrial settings. Real-world case studies and longitudinal analyses can provide valuable insights into the long-term impact and effectiveness of the Ergo-Green Lean approach. The framework could be enhanced by exploring deeper integration possibilities, such as incorporating Industry 4.0 technologies and investigating emerging trends and technologies, which would contribute to the continuous evolution of sustainable production systems. Ergo-Green Lean represents a path toward sustainable development by synergizing lean, green, and HFE principles.

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