University of Roehampton London

DOCTORAL THESIS

IMPACT OF HYBRID LEAN APPLICATION ON SUSTAINABILITY PERFORMANCE ACROSS ORGANISATIONAL HIERARCHIES

ANALYSING THROUGH THE LENS OF THEORY OF SWIFT, EVEN FLOW

Nayak, Rakesh

Award date:
2023

Awarding institution:
University of Roehampton

IMPACT OF HYBRID LEAN APPLICATION ON SUSTAINABILITY PERFORMANCE ACROSS ORGANISATIONAL HIERARCHIES: ANALYSING THROUGH THE LENS OF THEORY OF SWIFT, EVEN FLOW

By

RAKESH NAYAK

A Thesis

Submitted In Partial Fulfilment Of The Requirements For The Degree of

Doctor of Philosophy (PhD)

Roehampton Business School

University of Roehampton

2023

CONTENTS

The papers have their original page numbers. They are included in the order shown.

Abstract

This research portfolio explores the application of 'hybrid lean' principles, combining lean thinking with green, agile, and circular economy concepts, to enhance sustainability performance across different organisational levels. The research rationale stems from the need to extend lean thinking beyond traditional productivity improvement and investigate its impact on sustainability performance. To achieve this, the portfolio presents findings from four published articles conducted between 2017-2022, adopting a mixed-methods approach that includes single case studies, qualitative interviews, quantitative observations, and comprehensive literature reviews.

The portfolio adopts a theory-building approach, utilising the Theory of Swift, Even Flow, which emphasises the importance of reducing waste and achieving a smooth and continuous flow for increased efficiency, to analyse the effects of hybrid lean practices on sustainability performance at the process, supply chain, and systems level. At the process level, lean-green practices improve both productivity and sustainability performance by streamlining production processes and incorporating sustainable procurement. At the supply chain level, applying hybrid lean-agile strategies optimises logistics and reduces waste, contributing to overall sustainability performance within a humanitarian supply chain context. At the systems level, reconfiguring processes and supply chains aligns with the principles of hybrid lean and circular economy, fostering a culture of sustainability within the food systems.

The research's contributions are three-fold, impacting theory, practice, and policy. The theoretical expansion of the Theory of Swift, Even Flow, demonstrates how hybrid lean applications effectively contribute to both productivity and sustainability performance. Managerial insights are offered to organisations considering hybrid lean practices, aiding in a better understanding of their impact on sustainability performance. Lastly, policy implications are drawn by studying system linkages and waste flows through a hybrid lean-circular economy paradigm providing a valuable foundation for further exploration in the field, driving advancements in sustainable practices across various organisational levels.

ACKNOWLEDGEMENTS

This thesis is dedicated to my beloved wife, who has been my pillar of support and my source of strength throughout this challenging journey.

I would like to express my deepest gratitude to my supervisors, Professor Wantao Yu and Professor Mohammed Rafiq for their unwavering guidance, expertise, and invaluable support throughout my doctoral journey. Their insightful feedback, patience, and encouragement have been instrumental in shaping my portfolio and growth as a scholar.

I am indebted to my parents for their unconditional love, support, and resolute belief in my abilities and I am eternally grateful for their presence in my life. A special mention goes to my daughter, Miheeka, who has been my guiding light and the driving force behind my determination to complete this Ph.D. Her infectious laughter, innocent presence, and boundless energy brought immeasurable joy to my life, reminding me of the importance of cherishing the moments and finding happiness in the journey. I hope that she will grow up in a world where curiosity, education, and perseverance are celebrated.

Lastly, I want to dedicate this Ph.D. to my beloved wife, whose staunch belief in my abilities, patience, understanding, and sacrifices have been the driving force behind my success. I am profoundly grateful for her unconditional love, support, encouragement, and sacrifices, without which this achievement would not have been possible.

To all those mentioned above and to the countless individuals who have supported me in various ways, whether through words of encouragement, friendship, or assistance, please accept my heartfelt gratitude. Your support has played a pivotal role in shaping my academic and personal growth, and for that, I am forever grateful.

TABLE OF CONTENT

APPENDICES

LIST OF TABLES

LIST OF FIGURES

1. Introduction

Lean is a way of thinking about creating needed value with fewer resources and less waste – primarily through process redesign and the integration of employees, management, suppliers, and customers into the quality management process (Womack et al., 1990). The lean philosophy or lean thinking, largely derived from the Toyota Production System, is oriented toward achieving the shortest possible cycle time with the fewest possible resources by eliminating waste (Womack and Jones, 1996). As a practice, lean consists of continuous experimentation to achieve more value with less or zero waste.

In recent years, organisations have faced mounting pressure from stakeholders to enhance their sustainability performance in response to rapid climate changes, an increasing population with limited resources, growing consumer awareness, and stricter regulations (Choudhary et al., 2019; Singh et al., 2021). Customers, particularly, now demand socially and environmentally responsible products and practices, compelling companies to adopt innovative approaches to remain competitive (Sony and Naik, 2020; Garza-Reyes, 2015). Consequently, sustainability performance has become a crucial factor in determining an organisation's competitiveness (Wong and Wong, 2014).

To address these challenges, the concept of 'hybrid lean' has emerged as a powerful solution, combining lean principles with other concepts like green (Lean-green), agile (Lean-agile or Leagile), and circular economy (Lean-CE or Circular Lean) (Duarte and Cruz-Machado, 2014; Cherrafi et al., 2018; Zhou, 2016). By integrating these approaches, organisations can improve sustainability performance while simultaneously enhancing productivity. However, implementing hybrid lean has been hindered by conceptual limitations in previous research (Siegel et al., 2022) and the complexity of methodologies requiring substantial investments, posing barriers for organisations (Agan et al., 2013; Ghadge, et al., 2017).

Lean-green is a business approach that combines lean principles with environmentally sustainable practices to achieve operational efficiency and reduce environmental impact. Lean-agile (leagile) in humanitarian supply chains context refers to a hybrid approach that combines lean efficiency with agile responsiveness to improve disaster relief operations and sustainability by reducing waste and response time. Whereas, Lean-circular economy or Circular Lean in food systems refers to integrating lean principles with circular economy approaches to co-create new values while also minimising waste, optimise resource use, and create a sustainable infinite closed-loop system for food production and consumption.

At a process level, recent research has shown that carbon emissions or footprint could be considered as one of the indicators for performing comprehensive environmental assessments without having to engage with unnecessary complex datasets (Genovese et al. 2017). However, there is a dearth of empirical research, which has performed a simple, yet robust analysis of operational efficiency while increasing environmental performance, that is, successfully integrating lean and green approaches for continuous improvement (Lorenz et al. 1999; Singh, Garg, and Sharma 2011; Dal Forno et al. 2014). Paper 1 and 2 have addressed these gaps by proposing simple tools to integrate lean and green concepts to increase sustainability performance in SMEs as well as large-scale manufacturing.

In the supply chain context, the research gap in 'hybrid lean' applications lies in understanding how the principles of lean can be combined with other concepts in a systematic way to increase operational excellence and sustainability performance across the different supply chain processes. For instance, in humanitarian supply chain and logistics for relief distribution, the agile concept has been predominantly used as a priority in response to disaster to be effective in reaching out to victims and impacted areas with relief material in the shortest possible time (Oloruntoba and Gray 2006; Charles, Lauras, and Wassenhove 2010; Scholten, Scott, and Fynes 2010; Kunz and Reiner 2012). However, many times lack of coordination among humanitarian supply chain actors leads to delayed response to the requirement of the victims, poor pre-disaster planning, high response lead time, adapting push-supply chain model, and poor inventory management that results in loss of time, lives, resources, and assets (Cozzolino, Rossi, and Conforti 2012; Kunz and Reiner 2012). This necessitates a hybrid lean-agile (leagile) application to enhance the overall operational performance of Humanitarian Logistics and Supply Chain Management (HLSCM) including sustainability parameters (e.g., reduced resource waste, low response time). Paper 3 addresses this gap by presenting a novel framework to combine agile and lean practices (i.e., leagile) to maximise the synergies and minimise the trade-offs for increasing the overall sustainability performance of HLSCM.

At a systems level, where different processes, supply chains, industries, disciplines, and stakeholders interact, much of the previous research has looked into improving sustainability performance through a 'reductionist approach' i.e., reducing the environmental impact (Genovese et al., 2017). Lean thinking also takes this approach of 'reducing or removing non-value-added activities from the processes, which is one of the reasons that recent research has started contributing toward literature combining synergies of lean and green concepts as they are seen as a natural alignment (Garza-Reyes, 2015; Choudhary et al., 2019; Huo, Gu, and Wang, 2019; Dieste et al., 2019). In parallel, there has been a growing literature on Circular Economy (CE) paradigm for improving sustainability performance (Kalemkerian et al., 2022). However, most of the previous research on CE has not been able to clearly differentiate circular supply chains from environmentally sustainable or green supply chain management literature and their main focus still remains to reduce environmental impact by delaying cradle-to-grave material flow. CE is more than just reducing environmental impact or delaying the cradle to grave material flows, it is also about reusing and transforming those products in an infinite closed-loop chain that is self-sustaining (Genovese et al., 2017; Mangla et al., 2018). This calls for interdisciplinary research to understand system linkages, waste flows, and how waste from one industry could be a resource for another in an infinite loop to reduce, reuse, recycle, redesign, remanufacture, and repair products for a circular system to function. There is a lack of research integrating different concepts and disciplines that can contribute towards mapping waste flows within a system and interlinkages for a circular system to function (Kalemkerian et al., 2022). Integrating lean thinking with the CE paradigm (i.e., Hybridising Lean) offers an opportunity to map waste flows at a systems level, determine their root causes for reducing waste, and advance the application of lean thinking beyond the removal of non-value-added activities to redesign the system to be circular. This is a new area of research and a departure point for Paper 4 to explore hybrid-lean (e.g., Lean-CE) applications in the context of food systems and provide future research directions. Studying food systems offer a good context to map systems' food losses and waste (FLW) through lean tools and redesign pathways for those FLW to be circular in a system.

1.1. The Portfolio

Through this portfolio, the researcher addresses the gap as highlighted in the introduction section through an in-depth comprehensive literature review and empirical studies involving hybrid lean applications for improving process-level sustainability performance in both SMEs [Paper 1] and large manufacturing companies [Paper 2]. In addition, lean applications are demonstrated to improve sustainability performance at a supply chain level by integrating lean principles with agile in the humanitarian supply chain [Paper 3] and sustainability performance at the systems-level by integrating circular economy principles with lean thinking within food systems [Paper 4].

Furthermore, this portfolio brings together findings from these four published works and presents analyses through the lens of the Theory of Swift, Even Flow. The theory of swift, even flows rightly aligns with the core principle of lean thinking, aimed at achieving a seamless and uninterrupted flow of work or value to enhance quality and productivity within a factory. It also focuses on eliminating non-value-added activities, disruptions, variability, bottlenecks, defects, and waste that impede the flow and lead to inefficiencies (Schmenner and Swink, 1998). By optimising the flow, organizations can reduce lead times, enhance productivity, boost customer satisfaction, and make the most efficient use of resources. The theory of swift, even flow enables the analysis and enhancement of processes to establish a smooth and highly efficient workflow (Schmenner and Swink, 1998). Since the scope of research in this portfolio has expanded beyond standalone alone applications of lean, the applications of hybrid-lean simultaneously expand the theory of swift, even flow ('theory-expansion') to include sustainability performance at different organisational levels beyond the original productivity focus at a factory level, as a new theoretical contribution.

Besides theoretical contribution, these four papers have provided managerial implications for practical use. At the time of conducting this study, there was scant research that demonstrated the hybrid application of lean with other concepts such as sustainability and agility in a way that was easier for businesses to use and measure their productivity. These papers have adopted in-depth case studies method to provide detailed analysis of hybrid lean applications to improve sustainability performance at different organisational levels, process or factory level [Paper 1, 2] to supply chain level [Paper 3] and systems level [Paper 4] in a way that it is also relevant for practical use. For instance, there are more than 600 indicators for measuring the environmental impact of a product and using such a complicated set of indicators goes against the recommendations of Lorenz et al. (1999) who suggested that the ecological measures should be easy to measure and implement for practical relevance. It is thus, difficult for companies, particularly SMEs with limited resources, to measure their production systems' performance using a variety of indicators as well as design and implement improvement strategies. Utilising simple indicators such as carbon footprint, Paper 1 demonstrates that concurrent deployment of the green and lean paradigms through the Green Integrated Value Stream Mapping (GIVSM) tool, is a simple, practical, and effective approach to improve the sustainability performance of SMEs. Similarly, Paper 2 demonstrates how cycle time reduction can contribute towards a synergistic improvement of lean and sustainability performance.

While earlier studies have also tried to integrate lean tools with devise hybrid approaches such Green Value Stream Mapping (GVSM), Sustainable Value Stream Mapping (SVSM), Environmental Value Stream Mapping (E-VSM), and Sustainable Manufacturing Mapping (SMM), each approach has distinct characteristics regarding focus, purpose, scope, data integration, stakeholder involvement, short-term vs. long-term sustainability approach, scalability, complexity level, transferability to other industries, capital and time investment, and skill level required to operate. **Table 1** presents a comparative analysis of five approaches - GVSM, SVSM, E-VSM, SMM, and GIVSM - for lean and green waste analysis.

Among the discussed tools, GIVSM (Entire organisational strategy) stands out with its novelty. It integrates productivity and sustainability performance across the entire organisation, encompassing various organisational levels and industry sectors. GIVSM requires low capital and time investment, and its operation demands a lower skill level. Unlike GVSM, which is limited to greening the IT functional area, and SVSM, which faces challenges in adapting to diverse value streams and processes, GIVSM offers broader applicability and addresses long-term sustainability outcomes effectively.

SMM is specifically designed for sustainable manufacturing processes, making it applicable to diverse manufacturing sectors while E-VSM focuses on the environmental impact of the value stream, but its scalability and complexity across industries need further testing.

Organisations can choose the most suitable approach based on their specific needs and resources, considering the unique strengths and challenges of each tool. GIVSM's innovative nature, integration of productivity and sustainability, and flexibility across different sectors make it an attractive option for organisations seeking an encompassing and efficient lean and green waste analysis solution.

Table 1. Comparative Analysis of different hybrid lean tools

Aspect	GVSM	SVSM	E-VSM	SMM	GIVSM
Focus	Greening the IT functional area	Sustainability across the value stream	Environmental aspects in value stream	Sustainable manufacturing processes	Entire organisational strategy
Purpose	Identify waste and greening opportunities	Improve overall sustainability	Address environmental impact	Optimize manufacturing sustainability	Integrate productivity and sustainability performance
Scope	IT department and service delivery	Value stream and its functions	Environmental factors in the process	Entire manufacturing processes	Entire organisational processes
Data Integration	May include IT-specific metrics	Integrates sustainability metrics	Focuses on environmental data	Integrates sustainability data	Integrates process, product, customer, supply chain and sustainability data
Stakeholder Involvement	Primarily IT-focused stakeholders	Cross-functional and all stakeholders	Cross-functional involvement	Stakeholders-manufacturing process involved	Multi-stakeholder involvement
Short term vs Long-term Sustainability	Focus on short-term and long-term impact	Limited focus on long-term sustainability outcomes	Emphasis on long-term sustainability	Emphasis on long-term sustainability	Focus on long-term adaptability
Scalability to organisational levels	Untested	Untested	Untested	Limited testing	Scalable
Complexity level	High	High	Medium	High	Low
Transferability to other Industries	Limited applicability outside IT	Difficulty in adapting SVSM to diverse value streams and processes.	Environmental focus in different industries	Applicable to diverse manufacturing sectors	Transferable to diverse industry sectors
Capital Investment	High	High	High	High	Low
Time investment to generate impact	Long duration	Long duration	Medium	Medium	Low
Skill level required to operate	High	High	High	High	Low

Paper 3 demonstrates the practical relevance of decoupling points between lean and agile and the theory of postponement to improve the overall efficiency and effectiveness of the HLSCM, enhancing sustainability performance through reduced resource waste, optimised response time, and improved coordination among supply chain actors. Whereas, Paper 4 provides policy implications of studying system linkages and waste flows through a hybrid lean circular economy paradigm where food loss and waste from one industry could be a new value/ resource for another in an infinite loop to reduce, reuse, recycle, redesign, remanufacture, and repair products for a circular system to practically function.

The researcher, through his 15+ years of experience as a lean practitioner, contributed towards the design of research, literature review, detailed analysis, and discussion in all the published papers. In this portfolio, the researcher explains the novelty and significance of contributions from these papers and aligns them using the Theory of Swift, Even Flow, which supports and underpins this portfolio of research.

2. Aims and Research Questions

The motivation of this research is to contribute towards the academic literature on applications of lean thinking to improve productivity as well as sustainability performance through critical review and empirical research, while also demonstrating theoretical contributions, and managerial as well policy implications of its hybrid application. In this context, this research aims *to investigate how hybrid lean applications can be operationalised at different organisational levels (from process level to supply chain, and systems level) to improve their sustainability performance*. To achieve this aim, the study attempts to answer the following research questions (RQs):

RQ1: How hybrid lean (Lean-green) can be applied through the use of simple tools to enhance process-level sustainability performance of manufacturing operations in both SMEs and large organisations? [Paper 1 and 2][1]

RQ2: How hybrid lean (Lean-agile) can be applied at a supply chain level to enhance the sustainability performance of humanitarian operations during a disaster response? [Paper 3]

RQ3: How hybrid lean (Lean-CE) can be applied to enhance sustainability performance at a systems level (e.g., food systems)? [Paper 4]

All three RQs above have been investigated, answered, and published in four high-quality (three in ABS 3* and one in high impact, *Sustainability*) journals. In this portfolio, the researcher presents these studies through a coherent methodology, and discussion, and explains their theoretical as well as managerial, and policy implications.

3. Research Design and Methodology

3.1. Stages and Timeframe of Research

The initial research was planned in 2016 to investigate the impact of hybrid lean-green for improving productivity and sustainability performance at a factory/ process-level unit of analysis [Paper 1, 2] followed by a more complicated unit of analysis where supply chain-level applications of hybrid lean and agile were investigated to improve its productivity and sustainability performance in 2018 [Paper 3] and finally a systems-level unit of analysis was chosen to conceptualise the applications of hybrid circular-lean for improving its productivity and sustainability performance in 2020 [Paper 4]. These different hybrid-lean applications were context dependent and were applied in three different case industries to offer in-depth cross-case analysis. Finally, to progress from contextual understanding of hybrid-lean applications

[1] References to the publications submitted for the portfolio are in square brackets [ ] whereas, references to other papers by the author and to other papers are in round brackets ( ).

towards a generalisability of its application, a theoretical lens (Theory of Swift and Even Flow) was used to analyse all the unit of analysis in this portfolio between 2022-2023.

3.2. Justification for Research Methods

Three out of four papers submitted for this Ph.D. [1, 2, 3] utilised an exploratory single in-depth case study approach with a structured observation method in the form of a Gemba walk. A single case study approach is appropriate for exploring a specific phenomenon in-depth, while the structured observation method allows for the collection of objective data in a real-world setting. This allowed for a holistic examination of the hybrid lean applications within these case organisations with its real-life context, providing rich and detailed insights into their processes and operational strategies. This approach was particularly valuable as the research questions required a deep understanding of the interplay between variables and the multiple data sources. Another reason to use the single case study method in these papers was that it can generate comprehensive and nuanced findings, contributing to theory-building, and theory expansion while offering practical implications. While generalisability may be limited with the single case study approach, but the focus on context and complexity enhances the validity and authenticity of the study, making it a suitable choice for exploring complex real-world situations such as sustainability performance without trading off the productivity enhancement (Eisenhardt, 1989).

Two of the three papers focused on process and factory-level applications of lean in two organisations: (i) a UK-based packaging manufacturing SME [1] and (ii) an India-based large public sector engineering and manufacturing company [2], whereas the third paper focused at a supply chain (humanitarian) level performance in one of the cyclone-hit regions in India [3]. A case study approach was adopted as it provides an opportunity to gain a deeper understanding of processes by getting a *good picture of locally grounded causality*' (Miles and

Huberman 1994). Such a method allows studying the problem and the context to deduce both cause and effect (Leonard- Barton 1990) and this could be very helpful in formulating strategies of improvement for a given case. This process aided with studying the phenomenon in its natural setting and focused on contemporary events. This approach also provides a holistic view to researchers through the use of sources of evidence while observing a certain chain of events within a case study scenario (Yin 2003; Mohd Noor 2008). Moreover, based on the nature of "how" questions being asked in this research, a qualitative in-depth exploratory single case study approach seems to be more suitable (Saunders, Lewis, and Thornhill 2009; Silverman 2013). The real motive to select this method was the diligence and wholeness of the data collected through qualitative methods that allow any inconsistencies and irregularities to be captured (Saunders, Lewis, and Thornhill 2009; Holloway, Wheeler, and Holloway 2010). This sense of comprehensiveness in data also helps in effectively establishing the context surrounding the observations (Miles, Huberman, and Saldana 2014).

A single detailed case study has been validated as a research methodology that is widely used in the field of operations management, particularly for Value Stream Mapping (VSM) analysis including cycle time reduction, where the focus of the study cannot be detached from the organisational context where it occurs (Alaya 2016; Garza-Reyes 2015; Garza-Reyes et al. 2016; Parthanadee and Buddhakulsomsiri 2014). Such an approach is a helpful methodology for evaluating the applicability of methods and tools geared to improve organisational performance (Kitchenham, Pickard, and Pfleeger 1995; Alaya 2016). The selection of the organisations was based on the availability of data and the willingness of organisations to participate in the study.

In selecting case companies for the single case study method, several criteria and screening requirements were employed to ensure the relevance, richness, and uniqueness of the chosen case companies in terms of addressing the research gaps. The selection of these case companies was primarily based on the following factors:

- ***Relevance to research objectives***: The case companies were selected based on their alignment with the research gaps, research questions and objectives. They represented real-world business problems that were crucial to understanding the impact of hybrid lean applications.
- ***Willingness to participate***: The researcher selected case companies that were willing to participate in the study and provide access to relevant data and information required for the research, including Gemba walk for structured observations and interviews.
- ***Ethical considerations***: Ethical considerations played a vital role in selecting the case companies. The companies were approached with respect for their confidentiality and consent, ensuring compliance with research ethics and data protection regulations.
- ***Data availability and willingness to share data***: Availability of relevant data was one of the major criteria for selecting these case companies. The chosen case companies had ample data such as internal documents, financial records, and other sources necessary for analysis and to address the research questions comprehensively.
- ***Uniqueness and diversity of the cases***: The case companies exhibited distinct characteristics or contexts in terms of organisational level, industry they represent and complexity of the problems they face. They offered a variety of perspectives and insights and ensured comprehensive examination of the research problem, allowing for comparisons and cross case analysis.
- ***Significance and impact***: The significance of case companies in their respective industries or sectors were observed and its potential to have a notable impact on studying hybrid lean applications was analysed while selecting them. This was done to

ensure that the findings have practical implications and contribute meaningfully to existing theories or expand them.

- ***Complexity and exemplification***: The complexity of the selected cases, various dimensions and challenges of the hybrid lean applications they accounted for, and opportunity for exploring the research questions comprehensively were some of the bases for selecting the case companies.
- ***Time and resource constraints***: Practical considerations such as potential duration of the projects and available in-house resources to support the execution of pilot studies also influenced the selection of the case companies.

As the fourth paper was focused on extending the application of lean thinking to a systems level, which is still underexplored in scientific literature, a conceptual framework to combine lean with the circular economy was developed using a systematic literature review instead of adopting a single case study.

Table 2. Research Methodology: Cross-Case Analysis

Research Methodology	**Paper 1**	**Paper 2**	**Paper 3**	**Paper 4**
Research Question	RQ 1	RQ 1	RQ 2	RQ 3
Hybrid Lean Tools/ Approaches	Lean-Green (Enhanced Sustainability performance through **Reductionist Approach:** by reducing non-value-added activities (lean) and reducing environmental impact, delaying cradle to grave (green))	Sustainable-Lean (Enhanced Sustainability performance through **Reductionist Approach:** by reducing non-value-added activities (lean) and reducing socio-environmental impact (sustainability))	Lean-Agile (Enhanced Sustainability performance through **Reductionist Approach:** by reducing non-value-added activities (lean) and reducing response time (agility))	Lean-CE or Circular Lean (Enhanced Sustainability performance through **new value co-creation approach** in an infinite loop of use-reuse of resources)
Organisation Levels	Process	Process	Supply Chain	Systems
Industry focus	SMEs Manufacturing in a developed country	Large Manufacturing in a developing country	Humanitarian Logistics and SCM	Food Systems
Research Design	Single Case Study	Single Case Study	Single Case Study	Conceptual Framework
Data Collection Method	Semi-structured interviews, Focus group discussions,	Gemba walk (structured observation data),	Semi-structured interviews, Focus group discussions,	Systematic literature review, Document analysis

	Gemba walk (structured observation data), Document analysis	Semi-structured interviews, Document analysis	Multi-stakeholders workshops, Document analysis	
Primary Data Type	Process data, Procurement data,	Process data	State warehouse data, Disaster mitigation process data, Procurement data, Field data	N/A
Secondary Data Type	Case company financial data; Carbon footprint data; Industry reports; Grey literature	Case company financial data, ecological footprint data, equipment data	Governmental review reports	Existing literature, Grey literature
Data Analysis	Value Stream Mapping; quantitative analysis for carbon footprint; Green Integrated VSM, RCA of lean and green waste	Process cycle time analysis, ecological footprint analysis	Stakeholder mapping, process mapping including identification of bottlenecks, value-added and non-value-added activities, material and information flow; RCA for bottlenecks	Thematic content data analysis; RCAs for food loss and waste in developed and developing countries

3.3 Data Collection and Analysis

A systematic approach for data collection and analysis was used for all the four papers (see Figure 1). Multi-methods approach was used for data collection. It included qualitative data, such as semi-structured interviews, multi-stakeholder workshops, and analysis of relevant documents, along with quantitative structured observation data of the production process. Gemba Walk was used as a structured observation method to gather objective data on the implementation of lean manufacturing practices in organisations. The researcher observed the production process in real-time and collected data on key performance indicators such as cycle time, lead time, inventory levels, throughput, defect rates, electricity and water consumption, and waste generation. The observation took place on the shop floor, allowing for the collection of data in a real-world setting. Gemba walk was conducted using a pre-designed observation protocol that outlined the key areas and processes to be observed and the data to be collected. The protocol included a description of the areas and processes observed, the types of data to be collected, and the methods for collecting and analysing the data. The protocol was pilot tested to ensure its effectiveness and validity.

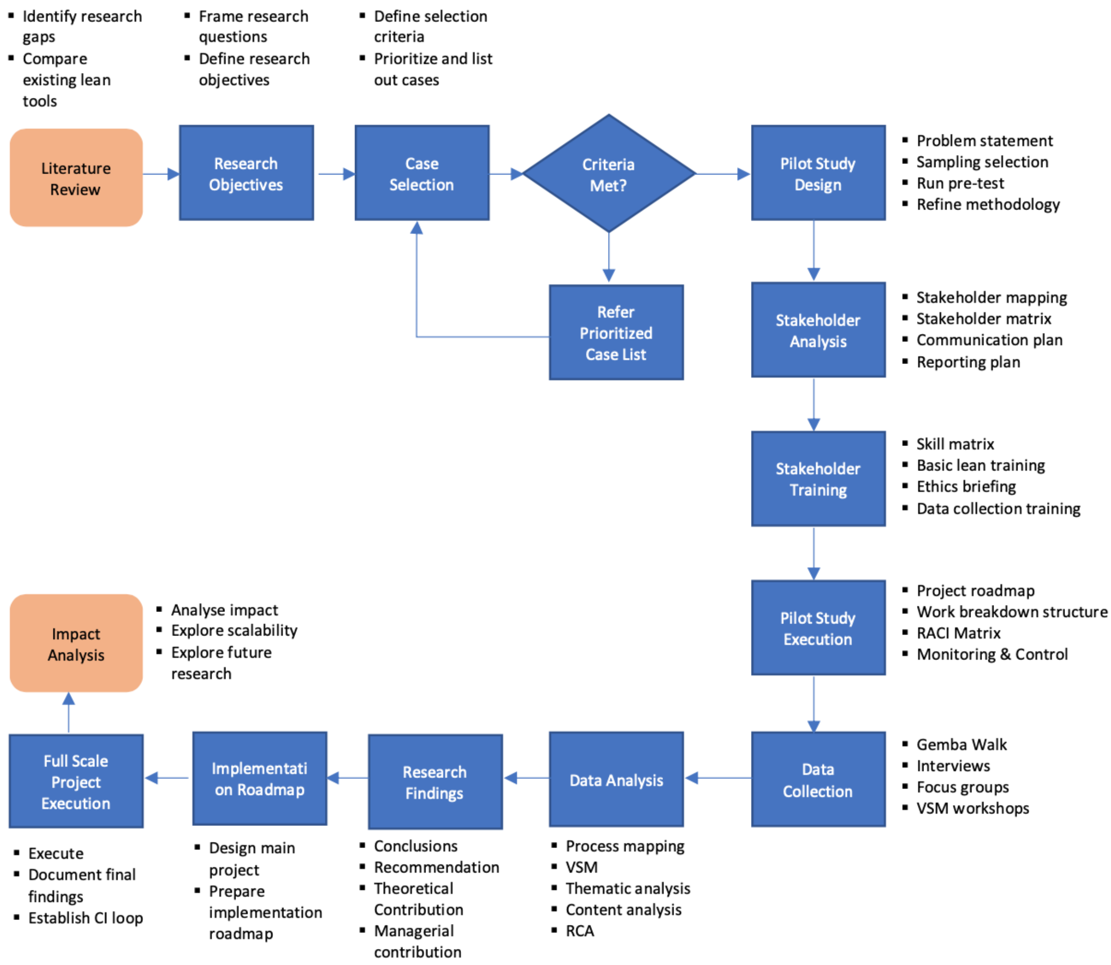

Figure 1. Systematic Approach of Data Collection and Analysis Process for Case Studies

Semi-structured interviews were conducted to collect data from the respondents to facilitate informality and openness about the information sharing regarding the current practices and inefficiencies in the system as well as experiences of the different stakeholders including the beneficiaries (Eriksson and Kovalainen 2008; Saunders, Lewis, and Thornhill 2009). Such interviews also provide flexibility to interviewers to investigate some of the pre-defined questions in detail while skipping or omitting questions where appropriate (Saunders, Lewis, and Thornhill 2009). **Appendices A, B** and **C** provide interview protocols employed for data collection in Paper [1], [2], and [3], respectively.

Limitations such as the researcher's biases as well as participants' reluctance to be completely honest to a stranger (Salkind 2006) were addressed through opportunities created by the interviewers for capturing extemporaneous conversation, covering themes that were considered important to concerned respondents (Mason 2002).

A mixed purposeful sampling technique was used for interviewing stakeholders who were running the processes [Paper 1, Paper 2], and were involved in the supply chain either for preparedness and planning for response to disaster or were the victims of the disaster [Paper 3]. In addition, multi-stakeholder workshops and Gemba walks (i.e., observations with granular quantitative data collection) were conducted for facilitating the data triangulation by combining three data collection methods for deriving evidence to achieve the objectives of the study in an exploratory case study (Patton 2002).

Paper [4] collected data from 62 published high-quality articles for presenting a systematic literature review on interdisciplinary research for a circular economy where lean was integrated with the CE paradigm within food systems.

3.3.1 *Data Coding and Thematic Analysis*

The researcher coded the data using the same protocol to embed the data from the case studies in the literature on lean, productivity and sustainability performance. First, transcripts and case memos were analysed to identify meaningful units of first-order descriptive codes from each case to capture emerging themes from the phenomena explored (Barratt et al., 2011). Subsequently, the descriptive codes were grouped into abstract categories using phrasal descriptors from the respondents' terminology (Ketokivi and Mantere, 2010). Next, the researcher analysed the emerging codes related to root cause analysis from each case using a constant comparative approach to group together themes with similar properties and dimensions and reconcile emerging variations (Barratt et al., 2011).

The analytic induction process was then used to develop analytical themes. The objective was to ensure that the themes developed were related, relevant to the given case, had sufficient explanatory power, and applicable to other substantive areas (Strauss and Corbin, 1998 p.147). To this end, previous studies' classification schemes were initially adopted as category labels to analyse three initial interview transcripts, followed by a second level of template analysis to enhance code density and theoretical abstraction (Bansal and Corley, 2012). For instance, in Paper [1], root cause analysis for lean and green waste were coded as *materials*, *methods*, *machine, management*, *measurement*, and *environment* from a combination of literature on lean-green management (Garza-Reyes, 2015, Garza-Reyes et al., 2016) and the interview transcripts. Likewise, root cause analysis for major bottlenecks in efficient and effective humanitarian logistics and supply chain management (HLSCM) were coded as *material flow*, *information flow, risk assessment*, *distribution*, *governance,* and *human resources* from a combination of literature on HLSCM (Cozzolino et a., 2012; Jabbour et al., 2017) and the interview transcripts. An example of the coding scheme used is captured in Appendix **D** and **E**.

Following the coding process, the findings were contextualised and explained in relation to hybrid lean impact on productivity and sustainability performance through: (1) process, stakeholders and value stream mappings, (2) identification of bottlenecks, non-value added and value-added activities in the 'as-is' and 'future' state from factory processes to systems level, (3) Root cause analysis of inefficiencies within the factory processes [Paper 1, Paper 2], supply chains [Paper 3] and system [Paper 4], and (4) extending scientific contributions by transitioning from data to theory expansion (theory of swift and even flow) in this portfolio at three different unit of analysis (factory process-level, supply chain level and systems level).

3.4 Rationale for selecting three industries

The rationale behind selecting the three industry sectors for this research is as follows:

3.4.1 Manufacturing: Factory process-level applications [Paper 1 and Paper 2]

Manufacturing industries spur investments and encourage the building of infrastructure in a country, and support roughly 1-in-6 services jobs. The rationale behind choosing two case companies from the manufacturing industry for this research lies in the fact that lean applications would be most matured within these industries if applied correctly as it had given birth to lean thinking several decades ago. Therefore, owing to its broadest application in manufacturing, examining the factory process-level productivity which combines efficiency and sustainability performance was an opportunity to investigate how lean could contribute to enhancing sustainability performance. Moreover, the amount of contributions of SMEs towards delivering the UK's overall productivity, and the dearth of literature in providing practical tools for them to monitor and improve their sustainability performance added to the rationale for focusing on one of the UK's packaging manufacturing SMEs [Paper 1]. Similarly, there was a lack of research in identifying simple tools for a hybrid lean-green application in a developing country context, and focusing on a larger manufacturing company here made a good rationale as this provided a testbed for identifying improvements in productivity and sustainability where the manufacturing processes were mature, and generalisability of the hybrid applications was a possibility [Paper 2].

3.4.2 Humanitarian Logistics and Supply Chain Management (HLSCM): Supply Chain level application [Paper 3]

While lean applications have mostly focused on factory process-level improvements, there has been a growing interest in management literature to extend the application of lean across the different operations and processes within supply chains to improve their overall performance. Commercial supply chains have extensively used applications of agility and lean to improve their performance i.e., become effective and efficient (Naylor, Naim, and Berry 1999; Christopher and Towill 2000; 2001; Mason-Jones, Naylor, and Towill 2000a, b). However, most of the research in disaster relief management has primarily focussed on agility (Oloruntoba and Gray 2006; Charles, Lauras, and Wassenhove 2010; Scholten, Scott, and Fynes 2010; Kunz and Reiner 2012). This is not surprising, given that the priority in any disaster is to be effective in reaching out to victims and impacted areas with relief material in the shortest possible time. However, many times the lack of coordination among humanitarian supply chain actors delays response to the requirement of the victims thereby impacting pre-disaster planning, and response lead time. This negatively affects the push supply chain model, and poor inventory management resulting in loss of time, lives, resources, and assets (Cozzolino, Rossi, and Conforti 2012; Kunz and Reiner 2012). This provided a good context for investigating another hybrid application of lean and agile (leagile) in improving the overall performance of the supply chain where the primary objectives are to be effective but at the same time, different types of lean waste across the supply chain could be reduced to be more efficient and sustainable [Paper 3].

3.4.3 Food Systems: a systems-level application [Paper 4]

Lean, which is regarded as a philosophy or culture rather than just a collection of tools and techniques (Hines et al., 2004), can encourage systems thinking through the collaboration of all value chain actors to achieve a collective goal (Halloran et al., 2014) such as enhancing overall productivity or sustainability. Lean thinking, which is also defined as “a system that utilises fewer inputs and creates the same outputs while contributing more value to customers” (Womack et al., 1990), aligns with some of the principles of the circular economy such as reducing, reuse, and recycling. However, the research which extends the application of lean to an entire system, which is a complex interaction of different processes, operations, and supply chains, is still in its infancy. Food systems, where ~33% of all edible food produced for human consumption in the world or over $940 billion worth of food is either wasted or lost along the food supply chains annually (Gustavsson et al. 2011), provided a good rationale for investigating applications of lean thinking at a systems-level. There is a lack of research that extends applications of lean beyond the management literature to provide deeper insights into ‘how’ the waste from a complex system, such as food systems, could be reduced, reused, and recycled for enhancing the overall sustainability or circular economy performance at a systems-level [Paper 4].

3.5 Theoretical Lens and Rationale

Initially, three theories: The Theory of Constraints, Theory of Performance Frontiers, and The Theory of Swift, Even Flow were considered to provide a coherent and comprehensive narrative that links the four published papers to demonstrate how they collectively contribute to the central theme of research and showcase the significance of the overall research. After comparative analysis for alignment with the research **(**Table **2),** The Theory of Swift, Even Flow was selected for inclusion in the portfolio due to its relevance to lean productivity and its potential scalability to include sustainability performance.

The theory of Swift, Even Flow is applied to analyse four published papers that align well with lean principles. The theory states that the faster and smoother the flow of materials through a process, the more productive the process is within a factory (Schmenner and Swink, 1998). The theory is guided by five laws: the law of scientific methods, the law of bottlenecks, the law of factory focus, the law of quality, and the law of variability. As the focus of the papers is on hybrid applications of lean, the portfolio attempts to expand this theory to include sustainability performance at the supply chain and systems level besides productivity at the factory focus (see Table 2 for details).

Law of scientific methods: The scientific methods are used to eliminate non-value-added work and improve the speed and efficiency of value-added steps in Papers 1, 2, 3, and 4. Papers 1, 2, 3, and 4 identify and reduce lean wastes, resulting in swifter material flow and improved sustainability performance. Paper 4 extends this law beyond the removal of non-value-added activities to include the value-creation process through a circular economy.

Law of bottlenecks: suggests that productivity is improved by eliminating or better-managing bottlenecks. Papers 1, 2, and 3 are more aligned with this law and identify bottlenecks in factory production lines and supply chains, resulting in faster material flow and improved sustainability performance.

Law of factory focus: suggests that factories that focus on a limited set of tasks are more productive. Papers 1, 2, and 3 demonstrate the benefits of grouping similar products and processes to improve material flow, remove bottlenecks, and enhance sustainability performance. Paper 4 further extends the factory focus of grouping tasks to grouping wastes of one industry (e.g., food) as a resource for another (e.g., pharmaceuticals).

Law of quality: suggests that productivity improves as quality is improved and waste declines. Papers 1 and 2 are more aligned with this law than the other two papers and they address defects and non-conformance to sustainability metrics, resulting in improved productivity and sustainability performance.

Law of variability: suggests that the greater the random variability, the less productive the process. Papers 3 and 4 are more aligned with this law as they identify and reduced variability in material and information flow, leading to increased productivity and improved sustainability performance of supply chains and at a system level.

The expansion of these laws to include sustainability performance helps to understand and improve productivity and sustainability at various organisational levels, from factory processes to supply chains and systems. These are presented under the three respective themes.

Unlike the Theory of Constraints, which focuses solely on productivity improvement via removal of constraints or bottlenecks (Goldratt and Cox, 1984), and the Theory of Performance Frontiers, which emphasises on maximising the outputs from a given set of inputs, thereby pushing performance limits (Samuelson, 1947), the Theory of Swift, Even Flow offers a unique framework of five laws to consider different scopes of productivity ranging from reducing non-value added activities, grouping of the tasks to identification/ elimination of bottlenecks to reducing variability and enhancing quality (Schmenner and Swink, 1998) (Table **2**). This framework of five laws also provided an opportunity of expanding its theoretical application to include sustainability along with productivity as well as offered a scope of scaling the theoretical initial contribution from factory-level productivity to a supply chain and systems level application.

In conclusion, the Theory of Swift, Even Flow was considered as it is a valuable addition to the portfolio, offering a framework of five laws for generalising the findings of the four papers focusing on different types of hybrid-lean applications to enhance both productivity and sustainability across multiple units of analyses.

Table 3: Comparative analysis of theories considered

Theory	Focus	Approach	Application	Key Idea	Alignment
Theory of Constraints	Identify and eliminate bottlenecks or constraints	Optimize the weakest link to improve throughput and efficiency	Manufacturing, project management	Constraints limit system's performance; removing them enhances it	Aligns with the Paper 2 (Law of bottleneck)
Theory of Performance Frontiers	Achieve superior performance by pushing boundaries	Expand definition of a production frontier	Primarily in manufacturing	Maximum output from a set of inputs, considering dimensions such as cost, product range, and quality	Alignment with Paper 1 Paper 2
Theory of Swift, Even Flow	Reduce waste, variability, bottlenecks, and non-value-added activities while improving flow, quality, and productivity	Ensure smooth and continuous flow with improved quality in processes	Process level, and scalable to supply chain, and systems level application	Five laws application framework for enhancing productivity and potential to contribute towards sustainability performance	Alignment with all 4 papers

4 Discussion

In operations management literature, lean thinking has been used as one of the popular concepts for improving the productivity and efficiency of organisations as it focuses on waste reduction, process improvement, and removal of non-value-added activities, which can also enhance sustainability (Shah and Ward, 2003; Sundar et al., 2014). Given the changing climate, increasing population, resource depletion, increasing consumer awareness, and strict regulatory environment, organisations are facing pressures to improve their sustainability performance across their operations: from processes to systems (Choudhary et al., 2019; Singh, Singh, and Khamba 2021). In this context, operations management literature has seen emerging concepts of hybrid lean where lean thinking application is extended and combined with other concepts, inter alia green (Lean-green), agile (Lean-agile or Leagile), circular economy (Lean-CE), to provide a synergistic impact for improving sustainability performance. Through the four published works, this portfolio demonstrates that the application of hybrid lean can lead to even greater sustainability performance at multiple organisation levels: process and factory-level to supply chain-level and systems-level.

4.1 RQ 1: Hybrid lean thinking and process- and factory-level sustainability performance

RQ 1 explores the impact of hybrid lean applications as a combination of lean and green [Paper 1] and Sustainable-Lean [Paper 2] to improve the overall sustainability performance at a process level. While lean thinking improves operational efficiency, reduces waste, and increases value and productivity in manufacturing operations, when applied with green or environmental and socio-economic improvement metrics, such hybrid lean thinking demonstrated synergistic impacts in reducing wastes, resources, and carbon emissions. This resulted in enhancing environmental sustainability performance, along with improving productivity for better economic performance in manufacturing organisations, for both SMEs [Paper 1] and large ones [Paper 2]. Paper [1] provided a novel framework where both 'productivity' through the traditional value stream mapping tool was combined with measuring key sustainability performance (e.g., reduced carbon footprint) across the value stream as Green Integrated VSM (GIVSM). Whereas, Paper [2] reduced the cycle time through the identification and removal of constraints using the theory of constraints in combination with lean, resulting in enhancing productivity as well as sustainability performance (e.g., reduced energy emissions, water, and waste). Both these articles extended the theory of Swift, Even Flow from productivity focus to include sustainability performance at the factory and process level in manufacturing operations, aligning mainly with laws of scientific methods, bottlenecks, factory focus, and quality. Some of the sub-themes regarding how hybrid lean at the process and factory level were able to enhance sustainability performance through the lens of the theory of swift, even flow (and their laws) are highlighted below:

4.1.1 *Identifying and eliminating waste for maximising resource efficiency*

In alignment with the law of scientific methods, papers [1] and [2] demonstrate how hybrid lean thinking can help organisations identify and eliminate waste (or non-value-added activities), such as overproduction, waiting, motion, etc. in their manufacturing processes, thereby enhancing productivity through resource efficiency including labour (or Full Time Equivalent – FTE employed in a factory). These papers also demonstrate how hybrid lean application was able to reduce energy consumption, material waste, greenhouse gas emissions, and exposure of employees to hazardous waste, among others contributing to sustainability performance and thereby extending the law of scientific methods. Enhancing sustainability performance was achieved through tool applications such as GIVSM [Paper 1], 5S, and kaizen events or by removing constraints such as cycle time reduction by application of the theory of constraints in Paper [2]. The later resulted in doubling the productivity of the process and reducing the environmental impact per product by 50%. The GIVSM [Paper 1] helped in increasing the overall resource efficiency by decreasing the number of FTEs employed from 20 to 9 (i.e., 55% productivity enhancement), and by reducing the operational lead-time by 63%. At the same time, GIVSM also enhanced environmental performance by decreasing the average carbon footprint by 77%, showing a synergistic effect of lean-green applications and extending the law of scientific methods.

Moreover, in alignment with the law of factory focus, these two papers were able to group tasks and products which facilitated easier identification of bottlenecks and enhanced the productivity of the overall process by removing the bottlenecks or the constraints.

4.1.2 *Implementing sustainable procurement process and design principles*

There was one misalignment between lean and green initiatives found in Paper [1] as a result of improving operational efficiency, there was an increased demand for energy needed for moulding extra units of pallets (reusable transit packaging). Paper [1] contributed to filling the gap in the literature on overcoming the misalignments between lean and green through a sustainable procurement process and design principles, extending the law of scientific methods. Paper [1] suggested that reinvesting the cost and carbon savings into sustainable procurement that includes low-carbon raw material manufacturing, low carbon transportation, reducing packaging, sustainable energy usage, designing products for end-of-life recycling (e.g., recycled polymers used as raw material in comparison to the virgin polymer as in Paper [1]) and local supplier selection while making it a part of continuous improvement cycle can help to overcome misalignments between lean and green initiatives. The proposed hybrid GIVSM tool is, therefore, helpful in determining synergies and misalignments between lean and green waste and encourages organisations to incorporate sustainability principles into the procurement processes and design of their products.

4.1.3 *JIT and collaboration with (local) suppliers and customers*

In alignment with the laws of scientific methods and bottlenecks, the lean thinking concept in Paper [1] and [2] emphasise the importance of Just-in-Time (JIT) production to overcome the bottlenecks in the 'flow' of material production and delivery. This reduces inventory waste, storage requirements, transportation costs, and waiting time which aligns well with the law of scientific methods. Paper [1] extends these laws by emphasising the importance of collaboration with local suppliers, and customers to enhance sustainability performance through joint product development, supplier sustainability assessments through procurement contracts, and customer engagement on sustainability issues. This further aligns well with the law of quality and enhances the ‘productivity’ and ‘swiftness’ of a given process linked with minimising defects and waste across the processes, thereby reducing the need for rework and waste (Liker and Meier, 2006)).

4.1.4 *Engaging employees and stakeholders in improving quality, productivity, and sustainability performance*

In alignment with the law of quality, hybrid lean thinking in Paper [1] emphasises the importance of engaging employees and other stakeholders in its continuous improvement process of Plan-Do-Check-Act (PDCA) to reduce the defects and waste for improving the overall quality. Paper [2] also highlights the importance of employee training for a lower turnover rate which enhances overall productivity. Integrating sustainability parameters, such as removal of green waste, less exposure to hazardous material, fatigue reduction, etc. with quality management supports extension of this law. This can be achieved through team-based problem-solving, suggestion systems, employee training and development, and knowledge transfer for wider deployment.

4.1.5 *Adopting a life cycle approach*

To further extend the impact of hybrid lean thinking at the process and factory level, this portfolio suggests organisations consider the entire life cycle of their products and processes, from raw material extraction to end-of-life disposal. This would cut across all the five laws of the theory of swift, even flow and help in identifying hotspots (bottlenecks) for environmental impact, opportunities to reduce non-value-added activities, defects, waste, overall environmental impact and increase economic and social benefits.

Overall, these two papers demonstrated that a hybrid lean-green approach could be a powerful approach for manufacturing organisations to enhance their process- and factory-level sustainability performance. By identifying and eliminating non-value-added activities, bottlenecks, and waste, maximising resource efficiency, adopting sustainable procurement process and design principles, engaging employees and stakeholders, adopting a life cycle approach, and collaborating with (local) suppliers and customers, organisations can improve their productivity as well as sustainability performance.

4.2 RQ 2: Hybrid lean thinking and supply chain-level sustainability performance

When applied at a supply chain level, Paper [3] demonstrated hybrid lean thinking can help organisations, in a given supply chain, achieve operational excellence by increasing efficiency and effectiveness, which in turn can improve the sustainability performance of a supply chain. The findings of Paper [3] suggest that leagile strategy complemented with the decoupling of material and information flow in the case organisation, played a vital role in enhancing sustainability performance during disaster management, particularly in the context of a cyclone. Leagile contributions towards improving sustainability performance were many folds:

- ***Rapid Response:*** Improved agility at the downstream supply chain enabled swift decision-making and responsiveness to changing conditions, allowing the decision makers to quickly assess the cyclone's impact and mobilise resources to affected areas. By decoupling material and information flow, real-time data on needs and efficiently allocated resources could be gathered, ensuring a faster and more targeted response in affected areas.
- ***Efficient Resource Management:*** Lean practices helped optimise the use of resources such as relief materials, reducing waste and unnecessary stockpiling. With limited available resources, lean and agile strategies ensured that relief materials reach the right

places, to the right victims, at the right time, minimising resource consumption and promoting sustainability while reducing the loss of lives.

- ***Flexibility in Procurement:*** Agile supply chains at the downstream quickly adapted to fluctuations in demand and supply in uncertain events such as cyclone. In the aftermath of a cyclone, when local markets, road networks, communication channels and infrastructure are disrupted, a leagile approach allowed sourcing of relief materials from diverse suppliers and markets – both at block level and state level, both from public and private sources, reducing dependencies and ensuring continuous supply to the needy.
- ***Minimising Transportation Delays:*** By decoupling material and information flow, relief materials could be pre-positioned strategically, closer to disaster-prone areas such as district headquarters, blocks, and panchayat offices. This minimised transportation delays and ensured timely delivery of essential supplies, reducing the environmental impact of transportation and increasing efficiency.
- ***Collaborative Networks:*** Agile strategy encouraged collaboration among humanitarian organisations, governments, private vendors, and local communities. By sharing information and resources, and decoupling material flows, a more coordinated and efficient humanitarian response could be achieved, enhancing overall sustainability.
- ***Customised Relief Operations:*** Combining lean and agile strategies allowed for tailoring relief operations to specific needs, localities, and communities. By gathering real-time information, responses could be tailored based on changing circumstances, effectively allocating resources and manpower where they were most needed.
- ***Reducing Environmental Impact:*** It was found that decoupling material flow could reduce the need for excessive transportation, storage and associated life time emissions from food waste, and material wastage. Lean practices, such as waste reduction and

efficient resource use, contributed to minimising the environmental impact of relief operations.

- ***Empowering Local Communities:*** Leagile approach encouraged decentralised decision making, and fostered local engagement and empowerment starting from panchayat level to state level. By involving local communities in relief efforts and decision-making, the case organisation could build capacity and resilience within the affected communities, promoting sustainable recovery and development.

In conclusion, the leagile strategy, complemented with the decoupling of material and information flow, significantly improved sustainability performance within a humanitarian supply chain during a post-cyclone disaster management. This integrated approach ensured efficient resource management, rapid response, flexibility, collaboration, and continuous improvement, all contributing to a more sustainable and effective humanitarian response in the face of natural disasters.

The portfolio further demonstrates how hybrid lean i.e., leagile applications in Paper [3] are aligned with the theory of swift and even flow and extends its application from factory-level productivity to include supply chain-level productivity as well as sustainability performance through laws of scientific methods, bottlenecks, factory-focus, quality, and variability. These are briefly explained through the following five sub-themes (see sections 4.2.1 – 4.2.5):

4.2.1 ***Identification of decoupling points and the principle of postponement***:

Lean and agility are two strategies that are used to bolster supply chains in different situations. Lean is applicable where markets have foreseeable demand, limited variety, and long product life cycle, whereas, agility is applied best in a volatile environment with a large variety and short product life cycle (Rahimnia and Moghadasian 2010; Agarwal, Shankar, and

Tiwari 2006). However, the Paper [3] demonstrated that both these principles can work within the same supply chain in different situations by considering the ‘decoupling’ approach through postponement in unpredictable demand with longer lead times (Scholten, Scott, and Fynes 2010; Christopher 2005; Childerhouse and Towill 2000). The decoupling point in a supply chain separates the part of the supply chain oriented towards customer orders or here the victims in a humanitarian context [paper 3] from the part of the supply chain based on the planning or preparedness phase in a humanitarian context (Naylor, Naim, and Berry 1999).

Such hybrid lean-agile strategy to decouple for maintaining swift and even flow of value centred around victims expands the scope of the theory of swift, even flow through the laws of quality and variability. Paper [3] expands the scope of the law of quality to include conformance to service expectations of victims in humanitarian supply chains and identifies several defects in ‘preparedness and response phase’. For instance, two decoupling points were identified which were subject to the scale and impact of a disaster to maintain the swift flow of material and information in the supply chain (Paper [3]). They demonstrated two scenarios – one with a disaster with limited impact on few of the districts within the state and another resembling to a national calamity where assistance of the federal government is sought. In a volatile or uncertain situation, such as a cyclone, a hybrid ‘leagile’ strategy was applied where leanness was decoupled from downstream supply chain process and applied upstream (i.e., closer to state-level warehousing) whereas agility was applied downstream (i.e., closer to the affected area or victims) to meet the demands of shorter lead time and demand variability from the end-users or victims, resulting in a more efficient and effective humanitarian supply chain (operational response), thereby expanding the concept of the ‘even flow’ of value in the law of variability. In other words, lean application at the upstream aligns well with the law of quality, where a pull system is created to overcome the waste from the push supply chain and expands this law by including conformance to service expectations of victims which also lowers the defects and wastes contributing to the overall sustainability performance. While agile application at the downstream aligns well with the law of variability to handle the demand variability from the victims, and by applying lean-agile strategy, expands this law by creating a feedback information loop from downstream to upstream decoupling point.

Besides decoupling, the concept of postponement was also found beneficial for the case organisation in the Paper [3] keeping in mind the scale of uncertainty and various inefficiencies identified in the research in alignment with laws of scientific methods and bottlenecks. By using the principle of postponement, public sector humanitarian organisations could overcome the bottlenecks associated with inventory management and apply effective demand-led inventory management as a cost-effective substitute for pre-positioning supplies. It enabled the assignment of relief supplies as agile as appropriate.

4.2.2 *Just-In-Time (JIT) for maximising resource efficiency of supply chain*

Identification of decoupling points (see section 4.2.1) facilitated applications of JIT at the right points for maximising resource efficiency by reducing inventories, and relief material waste, including perishable materials such as food in alignment with the law of quality. In paper [3] lean principles were applied to minimise inventory levels and material waste at a state and local level (closer to the affected area) by ensuring that the right amount of relief material is available when needed and that not all the material are being ‘pushed’ through the supply chain without prior knowledge of the need. By applying lean practices such as Just-In-Time (JIT) inventory management in combination with Kanban, organisations were able to reduce inventory costs, storage space requirements, and material wastage across the supply chain. Moreover, a combination of JIT delivery, demand-driven logistics, and managing demand-variability from victims helped to reduce relief material waste, in particular perishable items, optimising the use of resources and ensuring that they are distributed efficiently. This resulted in lower costs, enhanced productivity as well as better sustainability performance, thereby expanding laws of quality and variability through the addition of sustainability dimension.

4.2.3 *Improving material and information flow through the Leagile framework*

In alignment with laws of scientific methods and bottlenecks, Paper [3] identified lean wastes through stakeholder mapping and process mapping that included the identification of bottlenecks, material flow, information flow, and value-added and non-value-added activities. For instance, in Paper [3] case organisation, the emergency relief material was partly procured from the upstream state government warehouses and partly from the local standby reserves – including wholesalers, rice mills, food processing units, and petrol pumps. The analyses showed that accurate assessment of the amount, variety, frequency, and proportion of material required from state government warehouses and private standby reserves was a great challenge to ensuring seamless and timely delivery of relief material. This led to a variety of lean wastes, such as longer lead time, wastage of perishable items, high inventory of some items, and at the same time unavailability of some important material for the victims. The effective management of demand and capacity during a disaster was used to shorten the supply chain to deliver relief material quickly in the impacted regions. While lean was used to maintain the threshold capacity for humanitarian operations, agility was implemented to set out priorities of material flow at a time of disaster to ensure a rapid response is maintained at the impacted locations. Decoupling points described in 4.2.1 were used to maintain a seamless 'flow' of materials during a disaster.

Agile methodologies were also applied to enhance the flow of information between central and local relief teams, and stakeholders, including the victims, enabling a decentralised decision-making for effective and efficient response (see section 4.2.4 for details). This helped to improve decision-making, reduce waste and ensured that relief efforts are more aligned with the needs of affected communities. Reconfiguring the supply chain to improve relief material flow and information flow resulted in an improvement in the overall sustainability performance of the humanitarian operations, thereby expanding laws of scientific methods and bottlenecks.

4.2.4 *Decentralised decision-making to improve the sustainability (effectiveness and efficiency) of disaster response*

In alignment with the law of factory focus, the grouping of tasks and decision-making through agile methodologies were used to decentralize decision-making for enhancing the response of multiple local relief teams during a disaster. In alignment with the law of scientific methods, empowering local teams to work collaboratively, make informed choices through real-time data, and rapidly respond to changing local needs of the affected area, organisations within that humanitarian supply chain ensured that relief efforts were more effective and maintained a ‘swift flow’. In combination with agile, lean approaches were applied to help local organisations in the supply chain to be efficient and sustainable by resourcing and distributing the right materials to the victims, applying the principle of postponement, and enabling JIT logistics towards the end of the supply chain, thereby reducing relief material wastage, and minimise the overall environmental impact of the relief operations, expanding the laws of scientific methods, bottlenecks, and quality.

4.2.5 *Developing cross-functional teams and community engagement to enable continuous improvement for sustainable disaster response*

In alignment with the law of variability, paper [3] demonstrated that cross-functional teams can be developed that include members from different departments or organisations involved in humanitarian operations and supply chains at various levels (from central to state to local gram panchayat level) to create an ‘even flow’ of materials and information. This approach ensures that everyone involved in the project has a shared understanding of the goals and objectives and works collaboratively to achieve them. Moreover, agile methodologies can be applied to engage affected communities in the relief operation, seeking their frequent input and feedback to ensure that relief efforts align with local values and customs. This approach can help to build trust, reduce waste, and ensure that relief efforts are culturally appropriate and sustainable, thereby expanding the law of variability. Finally, agile methodology can be used to continuously improve the sustainability performance of a relief operation, by frequent iterations and feedback loops, incorporating them in their standard operating protocols and continuous improving their training materials for future response, regular assessments of resource use and waste generation, finding ways to reduce them and acting on them. This can lead to a more sustainable relief operation with a lower environmental impact.

Overall, Paper [3] demonstrated that hybrid applications of lean-agile principles can be a powerful approach for organisations to achieve operational excellence and create a more sustainable disaster response operation that is better equipped to respond to the needs of affected communities while reducing its environmental impact. The portfolio further explains the findings by aligning and expanding the theory of swift and even flow in the above sub-themes. Paper [3] recommendations can be used by both public and private sector organisations dealing with humanitarian emergencies. This research also informs guiding principles of the UN Sendai Framework for Disaster Risk Reduction to include a leagile framework to create sustainable disaster response and achieve both effective and efficient responses to disasters in its priorities for action.

4.3 RQ 3: Hybrid lean thinking and systems-level sustainability performance

The circular economy in food systems refers to a regenerative approach that aims to minimise waste, maximise resource efficiency, and close material loops within the entire food value chain (Jurgilevich et al., 2016). It involves adopting practices that promote the reuse, recycling, and repurposing of food by-products and waste to create value and reduce environmental impact. Whereas, the circular supply chain in food systems is a subset of the circular economy principles, focusing specifically on the efficient and sustainable management of food products and by-products throughout the supply chain. It involves designing processes and practices that ensure food waste is minimised, and food by-products are repurposed or reintegrated back into the value chain. This includes practices such as food waste reduction, composting, bioenergy production, and the creation of animal feed from food surplus.

When applied at a systems-level, hybrid lean thinking can help organisations address complex sustainability challenges by identifying and addressing systemic issues across the organisation and its value chain. Paper [4] demonstrated how interdisciplinary research could facilitate hybridising circular economy praxis with lean principles for creating a lean circular economy food system, expanding the laws of scientific methods, bottlenecks, factory focus, quality, and variability. Here are some ways the lean circular economy in Paper [4] was hybridised and contributed in theory expansion to enhance the overall sustainability performance at a food systems level.

4.3.1 *System thinking*

The concepts of circular economy and circular supply chain share common objectives and principles. Their synergy lies in minimising waste, optimising resource usage, and creating value from by-products and reusing the products in an infinite loop. However, misalignment can occur as circular supply chain of a commodity, such as any food, focuses only on this sector and the supply chains can be shorter or longer connecting one country to another while circular economy adopts a localised systems thinking approach connecting many sectors in a symbiotic way. Circular economy deals with many stakeholders in the entire system beyond the primary actors of the supply chain a system (e.g., policy makers, local councils, recycle industry, different small businesses, etc.), and the loop of circularity is smaller to provide maximum value to stakeholders in a given region. Shorter food supply chains connecting to shorter other supply chains in a region can address these misalignments through a system thinking approach and co-create new values that keeps the system nature positive beyond just reducing the impact.

The integration between lean thinking and the circular economy strategy within food systems involves a collaborative effort to optimise resource usage, minimise waste, and promote circularity throughout the entire food system. Lean thinking emphasises the elimination of non-value-added activities, inefficiencies, streamlining processes, and reducing waste in food production, processing, and distribution. On the other hand, the circular economy strategy focuses on closed-loop systems where food loss/ wastes and by-products are repurposed, recycled, or reused to extract maximum value as well as generate new values within the system.

Hybrid lean thinking and circular economy (CE) approach encourages organisations to adopt a holistic and systems thinking approach to sustainability, expanding the lean application from reducing non-value-added activities in a given organisation to co-create new values by interconnecting not just different processes within an organisation and its value chains but the also other industries in a systems-level. This approach also extends the laws of scientific methods and quality. Therefore, by adopting hybrid circular lean approach, the food industry can achieve a more sustainable and resilient system, by not just reducing its environmental impact (and delaying cradle-to-grave) but also co-create new values for the other industries in a system. This involves analysing the inputs, processes, outputs, and outcomes of the entire system to identify inefficiencies, reduce waste, reuse them through lean approach, and co-create new values from CE approach while positively affecting the overall systems' level environmental performance (rather than just reducing the impact). A 'waste' generated in one part of the system (i.e., from one organisation or different supply chain nodes) can be a new value and reused as a ‘resource’ in another part of the system (i.e., by a different organisation or even different industry) and an infinite loop of circularity is created to reduce, reuse, recycle, rethink, redesign and remanufacture materials within a given system. In this regard, besides removing waste and other non-value-adding activities from lean thinking, hybrid application with CE also promotes the reconfiguration of supply chains and processes to co-create new value to the actors within a given system in an infinite loop of use-reuse, contributing towards the expansion of laws of scientific methods and quality.

4.3.2 *Root-cause analysis and continuous improvement cycle*:

In alignment with laws of scientific methods and quality lean tools such as the Fishbone diagram (or Root Cause Analysis; RCA), Paper [4] demonstrated a deeper level of understanding of the key causes of various food systems-level inefficiencies generating food losses and waste (FLW) under a different context (developed and lower developed countries) affecting the overall swift flow of the material and information. The findings of the paper [4] suggest that the occurrence of FLW across the food systems varies greatly by region and product. In developed countries (DCs), FLW hotspots were found to occur at the retail and consumption stages whereas in lesser developed countries (LDCs), hotspots are concentrated at the production and post-harvest stages. In DCs, the root causes for food waste at the retail stage were associated with high-quality standards due to which food items not perfect in shape or appearance were rejected, inadequate inventory management due to inaccurate forecasting demand resulting in produce exceeding their best-before or use-by dates. At the consumer level, inefficient purchase planning, the incorrect interpretation of best-before and use-by dates, the cooking of oversized meals, and the lack of leftover usage contributed to the large amounts of waste were identified as the main causes leading to food waste. Whereas, in LDCs poor harvesting techniques, the lack of standardisation (from farming practices to sorting/ grading and cold chain facilities), inadequate infrastructure (storage and cooling facilities, food processing facilities, roads, data, disintegrated supply chains, market connectivity) and packaging was identified as the major drivers for food loss.

Such in-depth RCA, which utilised data from multiple disciplines, provided a strong foundation for identifying and proposing appropriate mitigation strategies under different countries' contexts to continuously identify and eliminate waste from the various supply chain nodes, thereby expanding laws of scientific methods and quality. Hybridising RCA with CE principles of 6Rs (Reduce, Reuse, Recycle, Rethink, Redesign, and Remanufacture), also enabled to propose strategies for continuously reducing carbon emissions at various nodes of supply chains to enable zero-waste food systems, and therefore, improve overall systems-level environmental outcomes. Furthermore, such hybrid lean-CE thinking promotes developing multiple shorter closed-looped supply chains and feedback loops for continuous improvement cycles as a core value to drive sustainability performance at the systems-level which is different from the reductionist approach of lean-green strategies.

4.3.3 *Technological and socio-institutional innovations*:

Hybrid lean thinking encourages organisations to embrace innovation as a key driver of enhancing productivity and sustainability performance. This can involve adopting new technologies, materials, processes, and supply chains to improve efficiency through innovative lean thinking and when combined with CE principles can drive socio-institutional innovations, expanding the theory of swift and even flow beyond productivity and factory focus. CE can help in creating new innovative strategies for multistakeholder governance, models for community sharing of technologies and equipment by multiple organisations (e.g., reprocessing machinery being shared by different stakeholders in the same locality/

community), innovative policies and new business models that generate value while contributing towards better sustainability performance at systems-level. Recent research on the Circular Lean approach also highlights the key innovative differences between deploying a lean-green strategy which is mainly about reducing waste in contrast to the circular lean is more about value creation (Kalemkerian et al., 2022).

4.3.4 *Metrics and performance measurement*

Hybrid lean thinking promotes the use of metrics and performance measurement to track progress toward sustainability goals. This can involve developing key performance indicators (KPIs) that measure environmental, social, and economic impacts across the entire value chain and using data analytics to identify opportunities for improvement. Paper [4] highlights the issues related to the heterogeneity of definitions, metrics, and measurement protocols and the lack of standards for data collection for food loss and waste (FLW). It, therefore, calls for the co-development of more interdisciplinary research and frameworks, and global protocols to measure FLW, given a large number of variables and country specificities, to achieve the harmonisation of definitions and measurement methods. Such an approach expands the law of factory focus and variability where instead of grouping tasks within a factory for enhancing productivity or reducing variability in product specifications, different indicators are grouped to form standards that allow us to measure the sustainability of a system while avoiding variability in measuring sustainability performance.

4.3.5 *Interdisciplinary and Cross-functional Collaboration*:

Paper [4] emphasises the importance of interdisciplinary and cross-functional collaboration and communication to achieve sustainability goals at a systems level through a hybrid lean CE approach. This can involve creating multidisciplinary teams to address complex interdisciplinary sustainability challenges and engaging stakeholders across the different organisations and their value chains to co-create solutions at a systems level. Paper [4] expands the laws of scientific methods and quality by presenting a case on identifying different types of wastes and reconfiguring the supply chains to reduce, reuse, and recycle avoidable wastes, currently generated from potato industries, for new value creation for different industries at the systems level.

Overall, hybrid lean-CE thinking can be a powerful approach for organisations to enhance sustainability performance at a systems level. By adopting a holistic and systems thinking approach, promoting cross-functional collaboration, continuous improvement, innovation, and metrics and performance measurement, organisations can identify and address systemic issues across their value chains, drive innovation, and create sustainable value for stakeholders. Such a hybrid lean-CE approach, therefore, can contribute towards co-creating frameworks for aligning firm-level objectives of being lean and productive with an overall systems-level goal of being circular and sustainable.

5 Contributions to theory, practice, and policy

The four papers included in this research portfolio have made significant contributions to theory, practice, and policy regarding the impact of hybrid lean applications on sustainability performance. Firstly, they have expanded the theoretical framework of the Theory of Swift, Even Flow by demonstrating how hybrid lean can contribute to both productivity and sustainability, while also identifying areas for future research. Secondly, these papers provide valuable insights for organizations considering the implementation of hybrid lean practices, offering a better understanding of how such applications can enhance sustainability performance. Thirdly, the research findings have important policy implications [Paper 4]. It highlights the need for multi-faceted policy approaches to address food waste prevention, including legislation to improve food redistribution rates and the establishment of coherent surplus food redistribution systems. Additionally, paper 4 emphasizes the importance of investment in infrastructure, such as storage, transportation, and cooling facilities, particularly in low-income countries, to reduce food losses and improve food security. Overall, this portfolio of studies contributes to the advancement of theory, informs practical implementation, and provides policy recommendations for promoting sustainability through hybrid lean applications as detailed in the following sections.

5.1 Theoretical Contributions: The Theory of Swift, Even Flow

The findings of the four published works are analysed through the lens of The theory of Swift, Even Flow to present the coherence between hybrid lean applications for improving sustainability performance at various organisation levels, i.e., from a factory process-level to supply chain and system-level. Through the lens of the theory of Swift, Even Flow, four papers demonstrate how hybrid lean applications were used to identify value-added and non-value-added activities and bottlenecks across different organisation levels. This theory holds that "*the more swift and even the flow of materials through a process, the more productive that process is*" (Schmenner and Swink, 1998). Schmenner and Swink (1998) describe that the productivity for any process could be associated with "*labour productivity, machine productivity, materials productivity, or total factor productivity and that these rise with the speed by which materials flow through the process, and it falls with increases in the variability associated with the flow, be that variability associated with the demand on the process or with steps in the process itself*".

This theory is guided by five laws: **(i)** ***Law of scientific methods***: associated with value-added and non-value added work (i.e., eliminating waste so that material can move 'swiftly' through the process), **(ii)** ***Law of bottlenecks***: associated with bottlenecks in the 'flow' of material production, **(iii)** ***Law of factory focus***: associated with the 'productivity' and ‘swiftness’ of a given process linked with the number of ‘tasks’ within a factory; **(iv) *Law of quality***: associated with the total quality management for enhancing ‘productivity’ and ‘swiftness’ of a given process linked with minimising the ‘defects’ or ‘waste’ across the processes, **(v) *Law of variability***: associated with variability in either the demand on the process or with the process’s operations steps that effects the ‘even flow’ of the material.

Lean thinking principles cut across all the five laws of Theory of Swift, Even Flow and hybrid-lean application offers an opportunity to expand this theory. The researcher attempts to explain the findings of the four papers by expanding theory (‘theory-expansion’) applications related to factory-level productivity to also include system-level sustainability performance. The researcher revisits the above laws and explains how each of them applies to papers [1-4] and proposes expanding these laws which predominantly focus on operation management (OM) performance to include sustainability which is being studied increasingly in the OM literature post-2010. For instance, the researcher attempts to expand the application of this theory from factory-level processes to supply chain which is made up of different processes, and systems-level which is made up of different supply chains. Furthermore, the definition of ‘productivity’ included within the laws of factory focus and quality is expanded to include ‘sustainability’ as one of the parameters for measuring the productivity of a given process or system.

5.1.1 Law of scientific methods

This law suggests that ‘the scientific methods are means by which non-value-added motions and steps are removed from what labour does and by which value-added steps can be done more quickly and with less exertion’ (Schmenner and Swink, 1998). According to the theory of Swift, Even Flow, ‘*all work can be divided into either value-added work or non-value-added work*’. Anything that adds waste to the process is non-value-added, including the classic seven wastes of Lean 'Shigeo Shingo: overproduction, waiting, transportation, unnecessary processing steps, stocks, motion, and defects' (Hall, 1987, p. 26). Given this understanding, materials can move more swiftly through a process if the non-value-added, wasteful steps of the process are either eliminated or greatly reduced. This law further expands lean principles by introducing "value-added" activities, taking a step further from lean reductionist approach to new value identification. In alignment with this law, Paper [1] identified value-added and non-value activities in process, information, and material flow at the factory level by using Value Stream Mapping (VSM) and segregated them into seven types of lean wastes. Reducing these lean wastes resulted in 'swifter' flow of the material within the production line (i.e., shorter lead time). Paper [2] aligned with this law by adding a new value-added process step that speeds up the 'flow' of material within a factory production line without putting stress on the workforce, resulting in twice the output in the same amount of time.

This factory-level focus of identifying seven lean wastes in Paper [1] is further expanded into a supply-chain-level focus in Paper [3], where the researcher identifies 'eight' types of lean wastes (the eighth being non-utilisation or misutilisation of talent). Reducing these lean wastes resulted in a 'swifter' flow of relief material through the humanitarian supply chain (i.e., shorter lead time). Reducing these wastes also further contributed towards an improved flow of information resulting in shorter lead time for material flow.

Furthermore, Papers [1] and [2] expand the contribution of this law through the identification of 'green wastes' and propose enhancing sustainability performance at the factory level. This is achieved through either the removal of non-value-added activities (e.g., reducing transportation distance; integration of process steps in Paper [1] resulting in five process steps instead of nine) or introducing new value-added activities such as sustainable procurement in paper [1], reduced resource consumption through new process steps which doubled the output with the same number of inputs in Paper [2]). Paper [1] also proposes a new integrated lean-green hybrid tool e.g., GIVSM to measure sustainability performance in addition to the overall productivity.

In addition, Paper [3] focuses on the efficiency of the material flow from one end of the supply chain to another as well as the effectiveness of the information flow for immediate disaster response. This paper, therefore, helps in extending the 'productivity' focus from a factory production line to consider 'supply chain productivity' within a humanitarian supply chain. It also enhances the sustainability performance of the supply chain in terms of reducing material waste including transportation and inventory, humanitarian rescue, and lower lead time. Finally, Paper [4] expands the focus toward identifying material wastes (in this case food losses and waste) at a systems level and investigates their root causes for waste elimination through lean thinking. Moreover, lean thinking is integrated with circular economy principles to expand from just the removal of non-value-added activities to value creation by converting the wastes into value-added products enhancing both the system's productivity and sustainability performance.

Scientific methods are suggested to have their biggest impact on bottleneck operations i.e., when the main constraints are removed from the process, the process is swifter.

5.1.2 Law of bottlenecks

This law suggests that 'an operation's productivity is improved by eliminating or by better managing its bottlenecks' (Schmenner and Swink, 1998) or the 'constraints'. The theory of Swift, Even Flow suggests that the 'materials can move swiftly only if there are no bottlenecks or other impediments to flow in the way'. For this, 'throughput time' is considered a useful measure for the speed of the flow. Throughput time is defined as the total time from the 'point where materials for a unit of the product are first worked on until that unit is completed and supplied to either the customer or to a finished goods warehouse'.

In alignment with this law, Papers [1] and [2] were able to identify the 'bottlenecks' within the factory production line using lean tools, such as value stream mapping. Paper [1] was able to improve productivity by better-managing bottlenecks, such as material type and long waiting time associated with raw material procurement while the Paper [2] eliminated the bottleneck by adding capacity (parallel production line) to enhance productivity.

In addition to the operation's productivity, both Papers [1] and [2] were able to demonstrate synergies with sustainability performance. For instance, in Paper [1], changing the raw material procurement strategy towards sustainable procurement, where virgin polymer from an international supplier was replaced by recycled polymer procurement from a local supplier, resulted in more than double reduction in carbon footprint. Whereas, in Paper [2] sustainability performance was improved by utilising the same amount of resources but doubling the process output (curing process) through cycle time reduction, resulting in double the savings of energy and water use.

Paper [3] identified bottlenecks or constraints at supply chain level where the relief material was released from the 'state warehouse' to the 'victims' of the humanitarian disaster. The bottlenecks, such as, timely information flow between federal and state government agencies, replenishment of relief material at the time of the disaster, and location of warehouses were better managed by redesigning communication flow and better-managing procurement, and warehouse location planning. The study further expands the law of bottlenecks to improve the management of material flow by establishing 'decoupling' points through the hybrid application of lean and agile (i.e., Leagile) – resulting in better sustainability performance by eliminating the requirement to store large inventories, hence, reducing the food waste at the warehouses.

In paper [4], the lack of identification of the 'reuse' potential of the generated waste acted as a bottleneck to complete the circularity of the supply chains at a systems level. Better managing the avoidable food waste at different nodes of the supply chains by identifying potential reuse by other industries resulted in a lower volume of waste at the landfill.

5.1.3 Law of factory focus

This law suggests that 'factories that focus on a limited set of tasks will be more productive than similar factories with a broader array of tasks' and therefore relates productivity with the number of tasks involved in producing a product. Schmenner and Swink (1998) suggest that 'by grouping like products together the flows of materials for those products are exposed to view more easily and naturally and this permits the identification of bottlenecks and of non-value-added steps and facilitates their removal'.

In alignment with this law, Paper [1] demonstrated that the reduction in the number of tasks from nine to five within the value stream through integration and realignment can result in increasing productivity (e.g., savings of 11 FTE resulting in 55% more resource efficient and 63% decrease in operational lead-time; see section 4.1.1). In Paper [2], the bottleneck was identified by grouping products and focusing on the curing process, facilitating easier removal of the constraint. In Paper [3] similar processes in the supply chain were grouped to increase the visibility of the information and material flow that facilitated the removal of bottlenecks in the flow of relief material and information for timely response.

Expanding this law in Paper [1], different categories of green wastes were identified and grouped as a result of non-value-adding activities that increased their visibility as CO_2e and facilitated their removal to enhance sustainability performance. Similarly, in Paper [2] green wastes (e.g., energy, water, waste) were identified and grouped as ecological footprint and used as a metric for sustainability performance. In Paper [3] facilitation of removing bottlenecks from information and material flow expanded into inculcating parameters of sustainability performance within the humanitarian supply chain. Paper [4] demonstrated grouping similar products and their by-products (waste) facilitated a mechanism for removing bottlenecks related to circularity, specifically the 'reuse' of avoidable food waste.

5.1.4 Law of quality

This law defines quality as '*conformance to specifications, as valued by customers' and emphasises that 'productivity can frequently be improved as quality is improved and as waste declines, either by changes in product design or by changes in materials or processing*' (Schmenner and Swink, 1998). Quality creates temporary bottlenecks that result in reworks, scrap, machine downtime, and interrupted flow of materials, among other defects. Schmenner and Swink (1998) suggest that '*good quality is essential to the swift, even flow of materials as it helps both to lower variability and avoid bottlenecks*'.

In alignment with this law, Paper [1] identified that there were 28,743 defects per a million opportunities in the production line (moulding) leading to reworking (e.g., remoulding) using lean VSM tool. Paper [2] considered the ecological footprint (green waste) from the production line as a defect (Goyal *et al*., 2019).

As an expansion to this law, besides productivity, Paper [1] also identified 3.29 tonnes of CO_2e emitted while reworking those defects. Using the GIVSM, more than 50% of the defects were reduced, which also resulted in reducing 2 tonnes of CO_2e. Paper [2] integrates non-conformance to sustainability metrics in a production line as a type of defect for quality management (Goyal *et al*., 2019) and achieves a 50% higher sustainability performance as a result of reduced cycle time.

Paper [3] expands the scope of this law to include conformance to service expectations of victims in humanitarian supply chains and identifies several defects in the 'preparedness and response phase'. For instance, defects such as centralised decision-making, spoilage of food material during transportation and in warehouses, spillage during distribution, loot in transit, and political favouritism caused either interruption in the flow of relief material or resulted in scrap, contributing towards lean-green wastes. Similarly, Paper [4] identifies defects related to non-conformance to customers' expectations regarding food shapes, sizes, and colours resulting in rejection and scrap. Reducing waste by redesigning processes within a supply chain and reconfiguring supply chains within a system resulted in improvement in productivity and sustainability performance at both the supply chain and systems levels.

5.1.5 Law of variability

This law highlights the importance of "Even Flow" in the theory and suggests that, "*the greater the random variability, either demanded of the process or inherent in the process itself or in the items processed, the less productive the process is*." It further emphasises productivity measures as "*labour productivity measures, machine productivity measures, materials productivity measures, or total factor productivity measures*" (Schmenner and Swink, 1998). This law, which is derived from queuing theory and can easily be verified by simulation (Conway et al., 1988), states that the less the variability in the material flow within a process the more productivity, and productivity falls with increases in the variability in the flow.

In alignment with this law, Paper [1] identified through the VSM that there were variability in material as well as information flow in the pally manufacturing process, which resulted in higher lead time, cycle time, and inventories, all of which are lean wastes. The variability in the production line also negatively impacted productivity by causing delays, machine downtime, and remoulding (rework) – which are also classified as lean wastes. As an expansion to this law, Paper [1], in addition to productivity, also identified that variability in demand for material, and variability in production line also resulted in higher carbon emissions affecting sustainability performance through the amount of waste generated, higher waiting time, consumption of more energy, water, other resources than planned, and lower capacity utilisation, leading to higher costs and a larger environmental impact. The Paper [2] identified bottlenecks in the production line that were caused by variability in the process leading to higher cycle time, reduced throughput, and then lowered cycle time and ecological footprint through systematic reduction – resulting in 50% higher sustainability performance.

The Paper [3] expands the scope of this law to include conformance to service expectations of victims in humanitarian supply chains and identifies several causes of variability in relief material and information flow that impacts the performance of humanitarian operations during a disaster. While the variability in relief material flow affected the in-time requirements of the disaster victims (lean), variability in information flow resulted in lesser coordination and ineffective operational decision making (agile) affecting the overall efficiency and effectiveness of the disaster response.

Similarly, Paper [4] identifies variability in circularity in food systems owing to factors such as variability in food production and distribution, consumer behaviour, regulatory requirements, market demand, crop production, material flows, interactions, inputs, and outputs within an agro-ecosystem. The variability in circularity can be reduced by a holistic approach considering all aspects of the system, from production to distribution to consumption.

Therefore, the Theory of Swift, Even Flow (TSEF) provided a useful framework for understanding the impact of hybrid lean on sustainability performance, by emphasising the importance of identifying and reducing non-value-added activities in production processes, improving productivity at the factory level, reducing bottlenecks in the flow of value, reducing variability, and improving quality of products and processes. Such hybrid lean practices can not only improve ‘productivity’ outcomes at factory processes but also support the transition towards a more sustainable future at the systems level as explained in Table 4. In addition, the researcher presents a coherent understanding of the alignment and extension of each of the five laws in TSEF in Table 4, highlighting the key theoretical contributions of this portfolio.

Table 4. Alignment and expansion of Theory cutting across the portfolio of published work

Alignment and expansion of Theory cutting across the portfolio of published work									
Theory of Swift, Even Flow	**Paper 1**		**Paper 2**		**Paper 3**		**Paper 4**		**Impact**
Laws	**Alignment**	**Expansion**	**Alignment**	**Expansion**	**Alignment**	**Expansion**	**Alignment**	**Expansion**	**Cross-case Analysis**
Law of Scientific Methods	Identification of 7 types of lean waste through VSM (value added and non-value added)	Adding green waste to VSM and developing GIVSM	Adding a new value-added process step to speed up the flow of materials in the production line	Identification of green waste and potential to reduce resource consumption and hence improve sustainability performance	Identification of 7 types of lean waste through VSM at the factory level	Adding one more waste type-utilisation of talent at the supply chain level	Identification of lean wastes and their causes through RCA (Ishikawa diagram)	Implementation at a system level (food systems)	Swifter flow of materials and information by removing non-value-adding activities and addition of value-adding process steps.
Law of Bottlenecks	Better managing bottlenecks in procurement (type of material selection and long waiting time)	Adding sustainability parameters to procurement strategy and raw material selection	Eliminated the bottleneck by adding capacity (parallel production line) to increase productivity	Adding sustainability parameters to double the process (curing) outputs with the same resource in- cycle time reduction	Bottlenecks in material flow, information flow, and replenishment of relief material	Redesigning information flow, procurement, and identifying decoupling points by hybrid use of lean and agile at a supply chain level	Bottlenecks in the reuse of generated waste at different nodes by other industries	Identification of potential causes of waste and their reuse potential at the systems level to complete the cycle of circularity	1- Elimination of constraints and better management of bottlenecks demonstrated in improved sustainability performance at different org levels– 2 - Less waste at the landfill
Law of Quality	Defects in moulding leading to rework	Adding CO_2e as green waste and using GIVSM to reduce the green waste through the reduction in defects	Considers ecological footprint from the production line as a defect	Integrates sustainability with quality management to measure sustainability performance through the reduction in ecological footprint in the production line	Contaminated food, interrupted flow of relief material, and failure to meet timely distribution are considered defects	Expanded to cover conformance to service expectations and humanitarian supply chain performance during a time of disaster	Non-conformance to customer expectations of certain food shapes, sizes, and colours results in rejection and scrap	Waste reduction through process redesigning resulting in improvement of productivity and sustainability performance at a systems level	1- Reduction of 2 tonnes of CO_2e annually 2- Resulting in lower lead time and cycle time 3- Improved service quality for humanitarian operations

Law of Factory Focus	Tasks were reduced to 5 in total from 9 in numbers within the value stream through integration and realignment - resulted in easier identification of bottlenecks and NVAs	Expanded to include green waste as a result of NVAs and facilitated their removal to increase sustainability performance	The bottleneck was identified by grouping products and focusing on the curing process and it facilitated the removal of the bottleneck	Expanded to include social sustainability related to workers and community along with an ecological footprint and used as a metric to measure sustainability performance	Similar processes were grouped to increase the visibility of information and material –low - that facilitated the removal of bottlenecks in the flow of relief material and information for timely response	Facilitation of removing bottlenecks from information and material flow expanded into inculcating parameters of sustainability performance within the supply chain	--	Grouping of similar products and resultant wastes to facilitate a mechanism for removing bottlenecks related to circular–city - enhancing sustainability performance	1- Streamlining of the processes resulted in improved visibility and identification of bottlenecks and non-value-added steps and to facilitates their removal
Law of Variability					Identifies several causes of variability in relief material and information flow that impacts the performance of humanitarian operations during a disaster	Improved flow of relief material and information can enhance sustainability performance by reducing waste and response time during a disaster	Identifies variability in circularity in food systems owing to factors such as variability in food production and distribution, consumer behaviour, etc.	Optimising efficiency and minimising waste through less variability can increase the circularity of the system and create a more sustainable and resilient food system	1- Less variability resulted in improved productivity and sustainable performance within a factory, at a supply chain, and at a systems-level

5.2 Managerial implications

Hybrid lean applications, combining lean principles with green, agile, and circular economy concepts, offer significant managerial contributions within sustainable manufacturing, humanitarian supply chains, and food systems. In sustainable manufacturing, managers can leverage hybrid lean approaches to optimise processes, reduce waste, and enhance environmental performance. Integrating lean with green practices allows for the adoption of eco-friendly manufacturing techniques, sustainable sourcing, and the use of renewable materials.

In humanitarian supply chains, hybrid lean applications enable managers to respond efficiently to emergencies and allocate resources effectively. Incorporating lean with agile principles ensures flexibility and adaptability to rapidly changing circumstances, facilitating quick delivery of aid and better coordination among stakeholders. By embracing the right balance between lean and agile strategies, and introducing decoupling points, managers can repurpose resource deployment, minimize waste, and create more resilient and sustainable humanitarian supply chains by responding promptly to shifts in demand.

Within food systems, hybrid lean applications can empower managers to think beyond the reductionist approach of reducing environmental impact and optimise production, reduce, reuse, recycle, rethink, redesign, and remanufacture products for a circular system to practically function. The findings provide valuable insights for managers in developed countries (DCs) and lesser developed countries (LDCs) to identify the specific hotspots and root causes of FLW within their food systems. By employing RCA and hybridising it with circular economy (CE) principles, managers can propose appropriate mitigation strategies, such as improving inventory management, reducing waste at retail and consumption stages in DCs, and addressing issues like poor harvesting techniques, lack of standardisation, and inadequate infrastructure in LDCs. This hybrid lean-CE approach promotes continuous improvement, the reduction of carbon emissions, and the development of infinite closed-looped supply chains to drive sustainability performance through new value creation at the systems level.

In all three domains, hybrid lean applications contribute to sustainability by promoting resource efficiency, waste reduction, responsiveness, and an infinite loop of circular economy, ultimately driving positive environmental and social impacts.

5.3 Policy implications

The findings of the research [Paper 4] have several policy implications. Firstly, to achieve the target set by SDG 12.3 of halving per capita food waste, a multi-faceted policy approach is necessary, along with mitigation strategies. This should involve addressing multiple prevention mechanisms simultaneously and considering national circumstances and cultural diversities, as food wastage patterns may vary across regions and countries.

Secondly, in high-income countries like the UK, urgent legislation should be implemented to improve food redistribution rates and ensure that surplus food is directed to people rather than being sent for anaerobic digestion. This requires governmental support through fiscal incentives and the development of a coherent surplus food redistribution system. Moreover, retailers in both high-income and low-income countries should reconsider strict cosmetic standards for fruits and vegetables, as they contribute to food waste. Campaigns and information providers should address knowledge gaps that drive wasteful practices, such as educating consumers about shelf-life and the usage of leftovers. In low-income countries, there is a need for investment in improved storage, transportation, and cooling infrastructure, as well as increased access to food processing, packaging, and new markets for smallholder farmers. Governments and private sector investors can play a crucial role in improving storage, cold chain facilities, and transportation infrastructure.

Additionally, providing improved financing and credit to small-scale farmers can help them diversify or scale their production according to demand. Collaborative initiatives and partnerships, such as the 'Farm to Market Alliance' and the International Fund for Agricultural Development, can contribute to reducing food losses and improving food security and income for smallholder farmers.

6 Conclusion, limitations, and future research

The portfolio's four papers have made a significant contribution by illustrating how the application of hybrid lean thinking can enhance productivity and sustainability performance across various levels: factory process level, supply chains, and systems level. These papers have successfully established crucial connections between lean principles and other concepts such as agility, environmental impact analysis, and the circular economy within three different industries at micro, meso, and macro levels. Moreover, these papers have garnered substantial attention from the academic community, accumulating over 231 citations. The portfolio fills a critical void in the existing literature, as previous research on lean applications predominantly focused on large-scale manufacturing industries in developed economies. In contrast, this portfolio showcases the extensive utilisation of hybrid lean practices in small and medium-sized manufacturing enterprises, emerging economies' manufacturing industries, humanitarian logistics and supply chains, and the food systems.

By integrating the findings of the four papers in the portfolio, the researcher presents a comprehensive analysis using the theory of Swift, Even Flow (TSEF). TSEF, a fundamental concept in lean manufacturing, highlights the criticality of identifying and minimizing inefficiencies, including non-value-added activities, bottlenecks, wastes, defects, and process variability, to improve productivity at the factory level. The combination of lean practices with green, agile, and circular economy principles in a hybrid approach leads to an even greater reduction in inefficiencies, resulting in significant improvements in sustainability performance beyond the factory level, encompassing various organisational levels such as supply chains and systems-level.

In the context of the factory level, the implementation of hybrid lean practices, including GIVSM (as discussed in paper 1) and cycle time reduction (as discussed in paper 2), alongside just-in-time (JIT) production and sustainable procurement from local suppliers, adopting a life-cycle approach, and providing training or upskilling opportunities for employees, has enabled organisations to improve both their factory process-level productivity and sustainability performance. Enhanced productivity has been achieved through the identification and reduction of non-value-added activities, lead time, defects, inventory waste, transportation time, and labour requirements for similar tasks, such as aggregating tasks. On the other hand, sustainability performance has been enhanced through sustainable and recycled material procurement, the reduction of transportation emissions by sourcing from local suppliers to minimize distances, and the reduction of energy and water consumption in the manufacturing line. These sustainable procurement and production practices at the factory level, such as utilising recycled materials sourced locally, shed light on how pursuing sustainability at the firm level can contribute to the broader objective of achieving circularity and sustainability at the system level (as discussed in paper 4) by promoting the reuse and recycling of materials and sourcing from local suppliers within value chains.

In Paper 3, the implementation of hybrid lean combined with agile practices (Leagile Framework) at the supply chain level has proven beneficial for organisations in humanitarian supply chains. This implementation has led to the achievement of operational excellence by increasing efficiency and effectiveness, ultimately improving sustainability performance. Various strategies have contributed to these positive outcomes, including the identification of decoupling points and the principle of postponement, just-in-time (JIT) material procurement and delivery to maximize resource efficiency, supply chain reconfiguration to enhance the flow of relief materials and information while reducing waste through the Leagile framework. Additionally, the development of cross-functional teams, community engagement, and decentralized decision-making have further enhanced overall productivity in humanitarian supply chains. These efforts have facilitated continuous improvement, ensuring a sustainable and effective response to disasters.

In Paper 4, the implementation of hybrid lean thinking combined with circular economy (CE) principles has proven effective at the systems level. This approach has enabled the identification of inefficiencies across entire food systems by considering the interconnectedness of processes within an organisation, its value chain, and other industries and organisations. The paper highlights that the integration of CE principles with lean thinking goes beyond eliminating non-value-adding activities and waste, as it also promotes the reconfiguration of supply chains and processes to achieve sustainability outcomes in the form of value creation through the 6Rs (Reduce, Reuse, Recycle, Rethink, Redesign, and Remanufacture) at a systems level. To facilitate this transition, the author identifies the root causes of inefficiencies within food systems and proposes strategies such as technological and socio-institutional innovations in supply chain configurations, business models, and policy frameworks. Additionally, addressing the heterogeneity of definitions, metrics, and measurement protocols, as well as the lack of standards for data collection on food loss and waste (FLW), is crucial. The paper also emphasizes the importance of building interdisciplinary and cross-functional teams to deliver both productivity and sustainability outcomes at the systems level.

In conclusion, the implementation of hybrid lean practices yields substantial benefits for sustainability performance across different organisational levels. By adopting the perspective of the Theory of Swift, Even Flow, and its five laws, it becomes evident that the reduction of inefficiencies, encompassing non-value-added activities and variabilities, is essential for attaining both productivity and sustainability objectives.

6.1 Limitations and future research direction

The current research has certain limitations that should be acknowledged. Firstly, the utilisation of a single in-depth case study approach in three out of four papers may have restricted the generalisability of the findings. This limitation hinders the ability to prove the effectiveness of the methodology for applying the proposed interventions in different contexts, such as various industries or countries (Garza-Reyes et al., 2016). However, this limitation also opens up opportunities for future research. Replicating the methodology in similar or different industrial contexts would contribute to generalising and validating the effectiveness of the proposed interventions. Similarly, replicating the research in different countries would provide additional insights into the role of culture and governance in facilitating the successful application of lean principles across various organisational levels.

Additionally, the study's limitations include a small sample size, as only one organisation was examined, and the potential for observer bias during the Gemba walk. To minimise bias, the researcher received training to objectively observe the production process and accurately document the data. Moving forward, future research should aim to address these limitations and explore new avenues. The effectiveness of the proposed interventions should be investigated in diverse contexts, industries, and countries to establish their applicability and robustness. Replicating the methodology across multiple case studies or industries would provide valuable insights into the similarities and differences in implementing hybrid lean concepts. Comparing outcomes and challenges in different contexts would enhance understanding and guide practitioners in effectively implementing hybrid lean approaches.

While the current research predominantly relied on qualitative methods, incorporating quantitative analysis in future studies would complement the findings. In-depth measurement and quantification of specific performance indicators, such as throughput, lead time, resource savings, waste reduction, or productivity improvements, would offer more objective and quantitative evidence of the impact of hybrid lean approaches.

Given the complexity of sustainability and circular economy concepts, future research could foster interdisciplinary collaborations by integrating disciplines such as engineering, environmental science, and social sciences. This interdisciplinary approach would provide a more comprehensive understanding of waste flows, system linkages, and the potential for circular systems. Furthermore, conducting longitudinal studies over an extended period would enable researchers to assess the long-term sustainability performance and impact of hybrid lean approaches. This would provide valuable insights into the sustainability of the interventions and their ability to drive continuous improvement over time.

In the future, more emphasis could be placed on assessing the economic implications of implementing hybrid lean approaches, using cost-benefit analyses. This holistic understanding of the potential benefits and challenges associated with these approaches would be valuable. Lastly, future research could explore the integration of digital technologies, such as data analytics, artificial intelligence, and the Internet of Things (IoT), with hybrid lean approaches. Understanding the impact of these technologies on efficiency, effectiveness, and sustainability outcomes would contribute to further advancements in this field.

Overall, addressing these limitations and pursuing future research directions would enhance the knowledge, practical application, and policy implications of hybrid lean approaches in various contexts, industries, and countries.

References

Agan, Y., M. F. Acar, & A. Borodin. (2013). "Drivers of Environmental Processes and Their Impact on Performance: A Study of Turkish SMEs." Journal of Cleaner Production, 51, 23–33.

Agarwal, A., R. Shankar, & M. K. Tiwari. (2006). "Modeling the Metrics of Lean, Agile, and Leagile Supply Chain: An ANP-Based Approach." European Journal of Operational Research, 173(1), 211–225.

Alaya, L. B. F. (2016). "VSM a Powerful Diagnostic and Planning Tool for a Successful Lean Implementation: A Tunisian Case Study of an Auto Parts Manufacturing Firm." Production Planning & Control, 27(7–8), 563–78.

Charles, A., M. Lauras, & L. V. Wassenhove. (2010). "A Model to Define and Assess the Agility of Supply Chains: Building on Humanitarian Experience." International Journal of Physical Distribution & Logistics Management, 40(8/9), 722–741.

Cherrafi, A., Garza-Reyes, J.A., Kumar, V., Mishra, N., Ghobadian, A., & Elfezazi, S. (2018). "Lean, Green Practices and Process Innovation: A Model for Green Supply Chain Performance." International Journal of Production Economics, 206, 79-92.

Cherrafi, A., S. Elfezazi, A. Chiarini, A. Mokhlis, & K. Benhida. (2016). "The Integration of Lean Manufacturing, Six Sigma, and Sustainability: A Literature Review and Future Research Directions for Developing a Specific Model." Journal of Cleaner Production, 139, 828–846.

Childerhouse, P., & D. Towill. (2000). "Engineering Supply Chains to Match Customer Requirements." Logistics Information Management, 13(6), 337–345.

Choudhary, S., R. Nayak, M. Dora, N. Mishra, & A. Ghadge. (2019). "An Integrated Lean and Green Approach for Improving Sustainability Performance: A Case Study of a Packaging Manufacturing SME in the U.K." Production Planning & Control, 30(5–6), 353–368.

Christopher, M., & Denis R. Towill. (2000). "Supply Chain Migration from Lean and Functional to Agile and Customised." Supply Chain Management: An International Journal, 5(4), 206–213.

Christopher, M., & D. Towill. (2001). "An Integrated Model for the Design of Agile Supply Chains." International Journal of Physical Distribution & Logistics Management, 31(4), 235–246.

Cozzolino, A., S. Rossi, & A. Conforti. (2012). "Agile and Lean Principles in the Humanitarian Supply Chain: The Case of the United Nations World Food Programme." Journal of Humanitarian Logistics and Supply Chain Management, 2(1), 16–33.

Dieste, M., R. Panizzolo, J. A. Garza-Reyes, & A. Anosike. (2019). "The Relationship between Lean and Environmental Performance: Practices and Measures." Journal of Cleaner Production, 224, 120–131.

Duarte, S., & Cruz-Machado, V. (2014). "Lean and Green Supply Chain Performance: A Balanced Scorecard Perspective." Proceedings of the Eighth International Conference on

Management Science and Engineering Management Advances in Intelligent Systems and Computing, 280, 645-654.

Eisenhardt, K. M. (1989). "Building Theories from Case Study Research." Academy of Management Review, 14(4), 532–550.

Eriksson, P., & A. Kovalainen. (2008). Introducing Qualitative Methods: Qualitative Methods in Business Research. London. SAGE.

Garza-Reyes, J. A. (2015). "Lean and Green- A Systematic Review of the State-of-the-Art Literature." Journal of Cleaner Production, 102, 18–29.

Garza-Reyes, J. A., B. Villarreal, V. Kumar, & P. M. Ruiz. (2016). "Lean and Green in the Transport and Logistics Sector- A Case Study of Simultaneous Deployment." Production Planning & Control, 27(15), 1221–1232.

Genovese, A., A. A. Acquaye, A. Figueroa, & S. L. Koh. (2017). "Sustainable Supply Chain Management and the Transition towards a Circular Economy: Evidence and Some Applications." Omega, 66, 344–357.

Ghadge, A., M. Kaklamanou, S. Choudhary, & M. Bourlakis. (2017). "Implementing Environmental Practices within the Greek Dairy Supply Chains: Drivers and Barriers for SMEs." Industrial Management & Data Systems, 117(9), 1995–2014.

Goldratt, E. and Cox, J. (1984). “The Goal: Excellence in Manufacturing.” North River Press, Great Barrington.

Goyal, A., Vaish, D. C., Agrawal, R., Choudhary, S., & Nayak, R. (2022). "Sustainable Manufacturing through Systematic Reduction in Cycle Time." Sustainability, 14, 16473.

Gustavsson, J., Cederberg, C., & Sonesso, U. (2011). "Global Food Losses – and Waste - Extent, Causes, and Prevention." Rome, Italy: Food and Agriculture Organization of The United Nations. http://www.fao.org/3/a-i2697e.pdf.

Hall, R. W. (1987). Attaining Manufacturing Excellence. Dow Jones–Irwin, Homewood, IL.

Halloran, A., Clement, J., Kornum, N., Bucatariu, C., & Magid, J. (2014). "Addressing Food Waste Reduction in Denmark." Food Policy, 49, 294–301.

Hines, P., Holweg, M., & Rich, N. (2004). "Learning to Evolve: A Review of Contemporary Lean Thinking." International Journal of Operations & Production Management, 24(10), 994-1011.

Holloway, I., Wheeler, S., & Holloway, I. (2010). Qualitative Research in Nursing and Healthcare. Chichester, West Sussex, UK: Wiley-Blackwell.

Huo, B., M. Gu, & Z. Wang. (2019). "Green or Lean? A Supply Chain Approach to Sustainable Performance." Journal of Cleaner Production, 216, 152–166.

Jurgilevich, A., Birge, T., Kentala-Lehtonen, J., Korhonen-Kurki, K., Pietikäinen, J., Saikku, L., & Schösler, H. (2016). "Transition towards Circular Economy in the Food System." Sustainability, 8(1), 69.

Kalemkerian, F., Santos, J., Tanco, M., Garza-Reyes, J. A., & Viles, E. (2022). "Analysing the Alignment between the Green Lean and Circular Strategies: Towards a Circular Lean Approach." Journal of Manufacturing Technology Management, 33(6), 1059-1079.

Kitchenham, B., L. Pickard, & S. L. Pfleeger. (1995). "Case Studies for Method and Tool Evaluation." IEEE Software, 12(4), 52–62.

Kunz, N., & G. Reiner. (2012). "A Meta-Analysis of Humanitarian Logistics Research." Journal of Humanitarian Logistics and Supply Chain Management, 2(2), 116–147.

Leonard-Barton, D. (1990). "A Dual Methodology for Case Studies: Synergistic Use of a Single Longitudinal Site with Replicated Multiple Sites." Organization Science, 1(3), 248–266.

Liker, J. K., & Meier, D. (2006). The Toyota Way Fieldbook: A Practical Guide for Implementing Toyota's 4Ps. New York, London: McGraw-Hill.

Lorenz, C. M., A. J. Gilbert, & W. P. Cofino. (1999). "Indicators for Transboundary River Basin Management." In Environmental Indices: System Analysis Approach, edited by Pykh, Y.A., Hyatt, D.E., Lenz, R.J.M., 313–328. Oxford, UK: EOLSS Publishers Co. Ltd.

Mangla, S.K., Luthra, S., Mishra, N., Singh, A., Rana, N.P., & Dora, M. (2018). "Barriers to Effective Circular Supply Chain Management in a Developing Country Context." Production Planning & Control, 29(6), 551–569.

Mason-Jones, R., B. Naylor, & D. R. Towill. (2000). "Engineering the Leagile Supply Chain." International Journal of Agile Management Systems, 2(1), 54–61.

Mason, J. (2002). Qualitative Researching. London: SAGE. Miles, M. B., & A. M. Huberman. (1994). Qualitative Data Analysis. 2nd ed. Thousand Oaks: Sage.

Miles, M. B., A. M. Huberman, & J. Saldana. (2014). Qualitative Data Analysis: A Methods Sourcebook. London: SAGE.

Naylor, J. B., M. M. Naim, & D. Berry. (1999). "Leagility: Interfacing the Lean and Agile Manufacturing Paradigm in the Total Supply Chain." International Journal of Production Economics, 62(1–2), 107–118.

Noor, K. B. M. (2008). "Case Study: A Strategic Research Methodology." American Journal of Applied Sciences, 5(11), 1602-1604.

Oloruntoba, R. & Gray, R. (2006). "Humanitarian Aid: An Agile Supply Chain?" Supply Chain Management: An International Journal, 11(2), 115–120.

Parthanadee, P., & Buddhakulsomsiri. J. (2014). "Production Efficiency Improvement in Batch Production System Using Value Stream Mapping and Simulation: A Case Study of the Roasted and Ground Coffee Industry." Production Planning & Control, 25(5), 425–446.

Patton, M. Q. (2002). "Two Decades of Developments in Qualitative Inquiry." Qualitative Social Work: Research and Practice, 1(3), 261–283.

Rahimnia, F., & M. Moghadasian. (2010). "Supply Chain Leagility in Professional Services: How to Apply Decoupling Point Concept in Healthcare Delivery System." Supply Chain Management: An International Journal, 15(1), 80–91.

Salkind, N. J. (2006). Exploring Research. 6th ed. Upper Saddle River: Prince-Hall. Saunders, M., P. Lewis, & A. Thornhill. (2009). Research Methods for Business Students. 5th ed. Harlow, United Kingdom: Pearson Education.

Samuelson, P. A. (1947). “Foundations of Economic Analysis.” Cambridge, Mass.: Harvard University Press.

Schmenner, R.W. & Swink, M.L. (1998). "On Theory in Operations Management." Journal of Operations Management, 17, 97-113.

Scholten, K., P. S. Scott, & B. Fynes. (2010). "(Le)Agility in Humanitarian Aid (NGO) Supply Chains." International Journal of Physical Distribution & Logistics Management, 40(8/9), 623–635.

Shah, R., & Ward, P. T. (2003). "Lean Manufacturing: Context, Practice Bundles, and Performance." Journal of Operations Management, 21(2), 129-149.

Siegel, R., Antony, J., Govindan, K., Garza-Reyes, J. A., Lameijer, B., & Samadhiya, A. (2022). "A Framework for the Systematic Implementation of Green-Lean and Sustainability in SMEs." Production Planning & Control, 1–19.

Silverman, D. (2013). Doing Qualitative Research: A Practical Handbook. 4th ed. SAGE. ISBN 978–1446260159.

Singh, B., S. K. Garg, & S. K. Sharma. (2011). "Value Stream Mapping: Literature Review and Implications for Indian Industry." The International Journal of Advanced Manufacturing Technology, 53(5), 799–809.

Singh, C., Singh, D., & Khamba, J. S. (2021). "Understanding the Key Performance Parameters of Green Lean Performance in Manufacturing Industries." Materials Today: Proceedings, 46(1), 111-115.

Sony, M. & Naik, S. (2020). "Industry 4.0 Integration with Socio-Technical Systems Theory: A Systematic Review and Proposed Theoretical Model." Technology in Society, Elsevier, 61(C).

Sundar, R., Balaji, A. N., & Satheesh Kumar, R. M. (2014). "A Review of Lean Manufacturing Implementation Techniques." Procedia Engineering, 97, 875-1885.

Womack, J. P., Jones, D.T., & Roos, D. (1990). The Machine That Changed the World: The Story of Lean Production. New York: Free Press.

Womack, J. P., & Jones, D. T. (1996). Lean Thinking: Banish Waste and Create Wealth in Your Corporation. Simon and Schuster.

Wong, W. P., & Wong, K. Y. (2014). "Synergizing an Ecosphere of Lean for Sustainable Operations." Journal of Cleaner Production, 85, 51-66.

Yin, R. K. (2003). Case Study Research: Design and Methods. Sage. Thousand Oaks, California.

Zhou, B. (2016). "Lean Principles, Practices, and Impacts: A Study on Small and Medium-Sized Enterprises (SMEs)." Annals of Operations Research, Springer, 241(1), 457-474.

Appendix A.

<u>Paper 1 Interview Protocol:</u>

Focal areas for interviews, with some questions customised during the interview based on the role of employees in packaging manufacturing production or procurement process and follow-up questions added when necessary.

Interview invitation (All interviewees)
You are invited to take part in this study. Please read this explanatory statement in full before deciding whether or not to participate in this research. Recent pressures from stakeholders for running environmentally sustainable businesses globally, have created new expectations for organisations in the oversight of lean and green practices used in their factory processes and their supply chains. We are interested in identifying the hotspots of process inefficiencies, non-value-added activities, and associated carbon footprint hotspots in your packaging manufacturing process to identify factory and process-level improvement opportunities from the perspective of professionals such as yourself. We also want to explore the root causes of the inefficiencies that exist and the opportunities arising from overcoming these inefficiencies, and the role you envisage for the people and current processes including procurement function in addressing sustainability performance.

[Invitations included details of data protection, privacy, consent, and policies for withdrawal from the interview at any time].

Interview Questions (not necessarily asked in this order).

Overview of the employees' experience in manufacturing/ procurement process and decision-making process related to productivity and sustainability outcomes of a given product within the case organisation.

1. Key process steps (map) information, your role and involvement in pally manufacturing process.
2. Describe your overall in-factory working experience.
3. Describe why you joined this company, your interactions and relationships with other members/ departments while managing the pally manufacturing process (use examples).
4. Explain how your operations and practices (related to process efficiency, defects, lead time, waste, energy consumption during your shift) differ from those during other shifts.
5. Describe the challenges that you have encountered in pally manufacturing production e.g., methods of production, factory layout, machines being used, defects OR forecasting (customers, raw material demand) OR procurement of raw materials from different suppliers, and trainings for lean, best management practices for high sustainability standards (use examples).
6. (Follow-up questions; for instance, if the above Q5 answer is related to Defects) In practice, when and how defects are detected? What happens when detected/ why?
7. In your opinion, what are the main bottlenecks and key improvement areas for productivity and sustainability (carbon emissions) (use examples).
8. In your opinion, what are the options for minimising defects across different shifts, changes for future procurement process, improving scheduling and other parameters (that are critical to quality in your opinion, use examples).
9. Describe your involvement in decision-making process.
10. Your thoughts on the decision process and decision outcome.
11. Other topics you would like to discuss, or any questions?

Appendix B.

Paper 2 Interview Protocol:

Focal areas for interviews, with some questions customised during the interview based on the role of employees in large manufacturing production process and follow-up questions added when necessary.

Interview invitation (All interviewees)
You are invited to take part in this study. Please read this explanatory statement in full before deciding whether or not to participate in this research. Recent pressures from stakeholders for running environmentally sustainable businesses globally, have created new expectations for organisations in the oversight of lean and sustainability practices used in their factory processes and their supply chains. We are interested in identifying the constraints of process efficiencies, associated environmental sustainability (electricity, water, material) and social sustainability (employees wellbeing, local community impact) impacts of operations to identify factory and process-level improvement opportunities from the perspective of professionals such as yourself.

[Invitations included details of data protection, privacy, consent, and policies for withdrawal from the interview at any time].

Interview Questions (not necessarily asked in this order).

Overview of the employees' experience in manufacturing process related to productivity and sustainability outcomes of a given product within the case organisation.

1. Key process steps (map) information, your role and involvement in impregnation and/ or curing process.
2. Describe your overall in-factory working experience.
3. Describe key productivity and associated economic concerns/ constraints in impregnation and/ or curing process.
4. Describe key environmental concerns in impregnation and/ or curing process.
5. Describe key social concerns in impregnation and/ or curing process.
6. In your opinion, what are the options for minimising these concerns and enhancing productivity and sustainability (use examples).
7. Other topics you would like to discuss, or any questions?

Appendix C.

Paper 3 Interview Protocol:

Focal areas for interviews, with some questions customised during the interview based on the role of stakeholders in preparedness or response phase of humanitarian logistics and supply chain management, and follow-up questions added when necessary.

Interview invitation (All interviewees)
You are invited to take part in this study. Please read this explanatory statement in full before deciding whether or not to participate in this research. Recent years have seen increasing climate-related humanitarian disasters, such as a recent Cyclone Titli in your state. While much of the emphasis of the organisations in humanitarian supply chain is to be responsive and effective in responding to the disasters, recent research has also emphasised the need to be efficient and sustainable too while dealing with disaster management. We are interested in identifying the hotspots and root causes of humanitarian supply chain inefficiencies associated with material flow and distribution, information flow, role of people and their decision-making process, risk management approaches, governance system, non-value-added activities in preparedness and response phases, associated wastes in humanitarian logistics and different supply chains nodes to identify supply chain-level improvement opportunities from the perspective of professionals such as yourself. We also want to explore viable options for improving both effectiveness and efficiency of the disaster management system and opportunities arising from such options, and the role you envisage for the people and current processes in a future sustainable disaster management system.

[Invitations included details of data protection, privacy, consent, and policies for withdrawal from the interview at any time].

Interview Questions (not necessarily asked in this order).

Overview of the stakeholders' experience in humanitarian logistics and supply chain management and decision-making process related directly to efficiency and effectiveness (and indirectly to sustainability) outcomes within the case study of cyclone Titli preparedness and response management system.

1. Describe your role and involvement in disaster management for cyclone Titli (specifically in terms of your role in humanitarian logistics and supply chain management during preparedness and/ or response phase)
2. Describe supply chain configuration (map) for material and/ or information flow during preparedness and/ or response phases of Titli or similar disaster management system (use examples where and how materials/ information is being pulled or pushed/ why?)
3. Describe the role of key stakeholders (main public sector; private sector, including volunteers, and media) across the supply chain and decision-making process/ model during preparedness and/ or response phases of Titli.
4. Describe your overall working experience in preparing and handling this cyclone (pain points for effectiveness and efficiency, examples).
5. Describe why you joined this department, your interactions and relationships with other members/ departments while preparing and/ or handling cyclone (use examples).
6. Explain what learnings were incorporated from the previous disasters management into managing this cyclone, and how/ why it was (or was not) incorporated?
7. Describe the challenges that you have encountered in disaster management system for Titli e.g., material flow and distribution, information flow, role of people and their decision-making process, risk management approaches, governance system, non-value-added activities in preparedness and/ or response phases, overall effectiveness of the

operations, overall efficiency of the operations and trainings for best disaster management practices related to UN SENDAI framework (use examples).

8. (Follow-up questions; for instance, if the above Q7 answer is related to loss of lives, material wastes) In practice, when and how (process and people) requirements for relief supplies for certain communities/ affected area are established, prioritised, and communicated? What is the time lag between need/ priority establishment and delivering of the required supplies/ why?
9. In your opinion, what were the main bottlenecks and key improvement areas for enhancing effectiveness and efficiency of disaster management system in case of Titli (use examples).
10. Describe your involvement in decision-making process.
11. Your thoughts on the decision process and decision outcome (use examples).
12. Other topics you would like to discuss, or any questions?

Appendix D:

Example of coding for root cause analysis of lean-green waste

Descriptive codes on lean-green waste causes	Analytical sub-category	Analytical Category
"Excessive lead time for procuring raw materials resulted in overstocking of inventory to avoid stockouts, leading to waste of valuable resources" **- Supply Chain Coordinator**	Raw materials procurement lead time	Materials efficiency
"*Lack of real-time visibility into inventory levels caused delays in identifying and addressing excess stock, resulting in waste and potential losses*" – **Operations Supervisor 1**	Inventory waste	
"*Quality control issues were quite common due to inconsistent inspection processes, leading to variations in product quality and customer complaints*" – **Quality Assurance Manager**	Quality Control	Production Methods efficiency
"We do not have advanced production or procurement strategy … we do weekly batch schedules; this follows the actual flow of customer demands, but it keeps fluctuating and really nowhere close to lean… we have a large volume of work-in-progress (WIP), long-waiting time for procurement, disorderly flows, transportation delays, multiple storage areas … a high lead- time, despite our short cycle time" – **Procurement Manager**	Grouping of scheduling with procurement, transportation	
"*Inefficient cooling and curing processes during moulding resulted in deformities and defects in the pally manufacturing, leading to increased waste and costs*" – **Quality Assurance Manager**	Moulding defects	Machine efficiency
"We noticed that some operators lacked adequate training in moulding techniques, contributing to defects in the final product" – **Training Instructor**	Operator's incompetency	
"*The information flow between different departments was slow, causing delays in decision-making and longer waiting times for materials and resources*" – **Supply Chain Manager**	Information flow lag	Management Strategy
"*Many of our employees are not familiar with lean and green principles, and this might be leading to inefficiencies in our processes and wastes*" – **Production Manager**	Training (Lean/Green)	
"*We are still working on setting up KPIs for what it means to be productive, green; what targets we should be working on and how do we monitor progress towards let's say waste reduction... We know we need better coordination between customers' demands and raw material procurement and this can reduce our lead time, enhance productivity but then it's also about establishing baseline data*" – **Operations Director**	Productivity metrics	Performance Measurement
"*We are a small company, but we understand that mapping energy and material waste flows is critical for our sustainability performance and claims we make … we need something simple and not too technical to identify areas for improvement, quantify carbon (emissions) and lower the overall footprint of our factory*" – **Training Instructor**	Carbon footprint Mapping	
"*The disorganized layout of workstations and storage areas are resulting in unnecessary movement, time and energy wastage, impacting overall productivity and environmental sustainability*" – **Operations Supervisor 2**	Unorganised work area	Working Environment
"*The current factory layout lacks logical flow, causing confusion among workers and resulting in increased setup times and material handling waste*" – **Operations Supervisor 1**	Factory Layout	

Appendix E:

Example of coding for root cause analysis of operational inefficiencies and ineffectiveness in HLSCM

Descriptive codes on lean-green waste causes	Analytical sub-category	Analytical Category
"*One of the major issues we encountered with the push supply chain was the excess inventory build-up in certain locations while other regions faced shortages*" - **Mill Operator (sub-divisional level)**	Push Supply Chain	Materials Flow efficiency
"*Our current route planning methods for logistics of distributing relief materials often rely on traditional, pre-defined routes … our drivers do not have real-time data … there is often delays due to sudden route closures, lack of mobile communications during that time*" - **Logistics Company Owner 1**	(Re)route planning	
"*We get orders from higher officials which are often too rigid, and they do not really consider how things can quickly change on the ground. Not having enough autonomy to make decision makes it challenging to adapt to the changing circumstances and prioritize urgent tasks effectively*" - **Gram Panchayat Official 2**	Top-down instructions	Information Flow efficiency
"*There were communication gaps and a lack of information sharing between BDOs and Sarpanch (Gram Panchayat Official), making it difficult for us to work together efficiently. It's crucial for us to have a unified approach for minimising causalities as well as waste all over the place*" - **Ward member 4**	Inter-agency coordination	
"*It was very difficult for us to manage Titli's recovery operations as there were no proper metrics or SOPs in place to assess and manage risk effectively, so while all of us were trying to help in our best possible way with local knowledge we have, it would have been helpful to all of us to follow a similar approach to mitigate risks*" - **Ward member 3**	Lack of metrics and SOPs	Risk Management
"*We need a precise understanding of the extent of damage and needs on the ground to ensure targeted aid and timely support reach and we often do not have this from the team working there … we end up working either on our past experiences at the start of relief operations … there are lags in information being passed on to us*" - **Sub-divisional Admin**	Inaccurate impact assessment	
"*The delayed mobilisation of aid and relief teams left us feeling stranded and helpless during the critical hours after the cyclone struck*" - **Beneficiaries 6**	Timely mobilisation	Human Resources
"*The lack of technical expertise among relief workers was evident during the recovery operations as many of them were volunteers. It slowed down crucial tasks and hindered the quality of assistance provided*" - **Beneficiaries 5**	Lack of technical expertise	
"*We have a multi-layered administration leading to a lot of bureaucratic hurdles, this in turn cause delays in decision-making and hinders our ability to respond swiftly*" - **Block Development Officer 1**	Multi-layered administration	Governance
"*Having all decisions made centrally meant that local contexts and needs were often overlooked, resulting in less efficient material flow and resource allocation*" - **Local NGO 1**	Centralised decision making	
"*In some cases, relief materials were hoarded by influential individuals, leaving vulnerable communities without timely mobilization of resources … we sometimes have had to divert essential supplies for somebody higher up personal gain*" - **Driver 2**	Power politics and relief distribution corruption	Materials Distribution Efficiency and Efficacy

"*Due to inaccurate assessment of the extent of damage, relief supplies were either insufficient or excessive in some areas, causing wastage and resource mismanagement … Lack of coordination and communication between agencies during impact assessment also led to duplication of efforts and confusion in the distribution of relief supplies*" - **Local NGO 2**	Inaccurate damage assessment	