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Research Article

An Integrated Soft Systems Framework for Sustainable Manufacturing: Evidence from the Indonesian Footwear Industry

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Abstract
The footwear sector is a major contributor to Indonesia's labour-intensive economy but faces complex challenges in balancing economic performance with environmental sustainability and social considerations. Previous research has predominantly relied on static linear optimization approaches, which may not adequately capture the dynamic socio-technical interactions within manufacturing ecosystems. This study addresses these limitations by developing an integrated conceptual framework for sustainable manufacturing systems using the Soft Systems Methodology (SSM). The main novelty of this study lies in its methodological integration, which combines VOSviewer bibliometric analysis, qualitative problem structuring (Rich Picture and CATWOE), and system dynamics modelling (Causal Loop Diagram / CLD). This methodology structures the problem through seven stages that identify nine key variables and synthesize them into five main subsystems: the global market, the workforce and work environment, raw materials, production processes, and outputs. This study also reveals key feedback loops including a Reinforcing Loop (R1) related to labour productivity and Balancing Loops (B1 and B2) related to environmental impact and automation. These findings identify the systemic archetype of "Limits to Growth," demonstrating that the adoption of ICT automation without improving worker skills and fostering cultural adaptation will result in high operational costs. To address this, a strategic roadmap containing six action recommendations was developed. This framework also offers advantages over other conventional static assessment models by predicting operational bottlenecks before interventions are implemented, and it has a high degree of transferability to other labour-intensive manufacturing sectors in developing countries.

Keywords: Soft Systems Methodology; Sustainable Manufacturing; Footwear Industry; Systemic Transformation; Circular Economy.

INTRODUCTION

The The Sustainable Development Goals (SDGs) Progress Report 2023 reveals that more than 50% of assessed SDG targets are progressing weakly or insufficiently, while approximately 30% have stalled or regressed. Only about 12% of the targets are currently on track to be achieved by 2030 [1]. Indonesia ranks 75th globally, with an SDG score of 70.16, and faces the challenge of aligning its manufacturing sector with sustainability objectives [2]. The footwear industry is an important pillar of Indonesia's economy, employing approximately 1.4 million workers and contributing 1.1 billion pairs to global footwear production in 2021 [3]. However, the scale and labor-intensive nature of these operations are also associated with challenges such as worker absenteeism, dependence on inorganic materials, and the generation of non-biodegradable solid waste.

Previous research on the footwear industry has largely focused on optimization techniques, including line balancing and integer programming, as well as the evaluation of operational performance indicators. While these approaches can improve specific aspects of manufacturing performance, they often fail to capture the complex interactions, feedback mechanisms, and stakeholder perspectives that characterize labor-intensive manufacturing systems. Although Soft Systems Methodology (SSM) has been widely applied to address complex organizational and socio-technical problems, its integration with bibliometric knowledge mapping and causal-loop modelling for sustainable manufacturing in the footwear industry remains limited.

This study addresses this gap by developing an integrated conceptual framework for analysing sustainability challenges in the footwear manufacturing sector. The novelty and main contributions of the study are threefold. First, methodological integration is achieved by combining bibliometric analysis using VOSviewer with qualitative problem structuring through Rich Picture and CATWOE analysis and system dynamics modelling through Causal Loop Diagrams (CLDs). Second, socio-technical integration is established by identifying causal relationships between social factors, including work culture, occupational safety and health, and compensation, and operational performance and costs. Third, the distinctive modelling perspective extends conventional sustainability assessments by incorporating the "Limits to Growth" concept to identify potential operational constraints and feedback mechanisms associated with the implementation of sustainability interventions.

METHODOLOGY

Sustainable manufacturing is a key driver in this study, which encompasses social, environmental, and economic sustainability variables [4]. Social sustainability consists of manufacturing practices focused on workers and their impact on productivity and well-being. Environmental sustainability refers to manufacturing practices aimed at minimizing waste, including waste materials and pollution [5]. Meanwhile, economic sustainability focuses on corporate productivity, including quality and competitiveness [6]. Collectively, these three variables support the concept of sustainability in the footwear industry, which is a critical factor for the industry's competitiveness.

This study follows the seven steps of the Soft Systems Methodology (SSM), namely (1) understanding the complexity of the situation, (2) describing the unstructured system, (3) defining basic activities, (4) formulating a conceptual model, (5) comparing the model with the real-world situation, (6) conducting a review, and (7) taking corrective actions, as shown in Figure 1. SSM also incorporates visual techniques and cognitive maps to facilitate problem structuring and decision-making, using tools such as rich pictures, CATWOE analysis, and causal loop diagrams [7].

Stage 1: Identification of Unstructured Situations – Using VOSviewer software, this stage visually maps relevant keywords from previous research in the footwear industry, drawing on network data for literature keyword analysis [8-14]. In this study, VOSviewer was used to analyze and present the context and knowledge within the footwear industry.

Stage 2: Uncovering the Problem – Using a rich picture, this stage illustrates the nature of the problem and helps in understanding complex situations. The tool captures context and impact of scenarios which often difficult for documentation, so that providing the comprehensive overview to the stakeholders. This is important to understand, evaluate, and make the decisions [9]. A rich picture also presents a holistic view of the relationships among actors at various levels and can identify stakeholder needs [10].

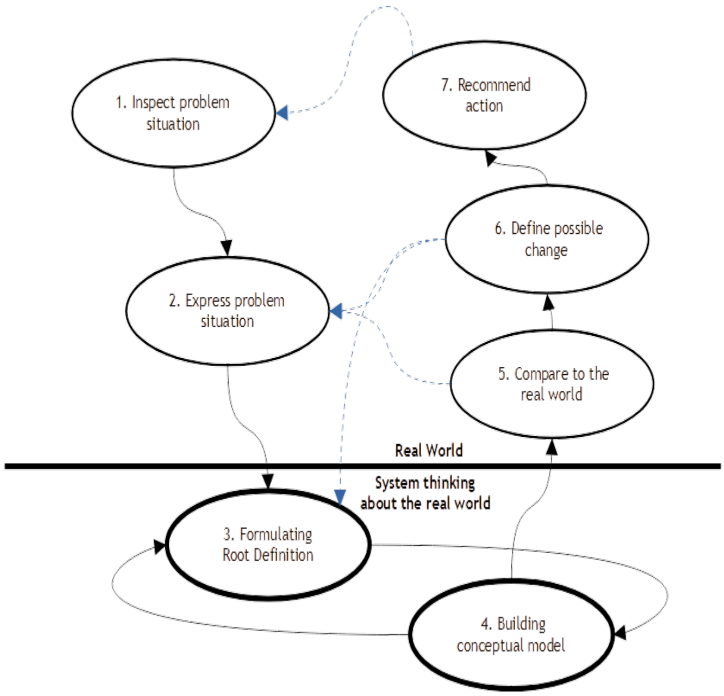

Figure 1. Seven Stages of Soft System Methodology

Stage 3: Formulating the Root Definition – This stage involves identifying the system using the CATWOE method (Customer, Actor, Transformation, Worldview, Owner, Environment). CATWOE outlines the party responsible for the system (O), how the system's transformation converts inputs into outputs (T) achieved by one or more actors (A), the system's perspective (W), the customers (C) who benefit, and the environmental context (E) in which the transformation occurs. The transformation (T) and worldview (W) are evaluated using the 3E criteria: efficacy, efficiency, and effectiveness. This stage also includes the identification of stakeholders.

Stage 4: Conceptual Model – Using a Causal Loop Diagram (CLD) to identify and map the dynamic relationships within a problem, as well as to visually represent the cause-and-effect relationships among the system's variables [11]. This model must include monitoring and control activities to ensure the system's effectiveness, efficiency, and usability. CLDs are widely used to solve problems through a systems approach that accounts for dynamic complexity [12]. The CLD model also illustrates the cause-and-effect relationships among factors within the system, represented by curved lines with arrowheads connecting the system's components [13]. Data analysis using CLD follows these steps [14]: (1) Identify the problem by examining environmental factors that directly or indirectly impact ongoing business processes; (2) Select the "Limits to Success (Growth)" pattern—where business processes face growth barriers for various reasons; (3) Design the CLD. After identifying relationships between variables and service quality, the loop diagram is created using the Vensim application.

Stage 5: Compare with the Real World – This stage involves a gap analysis between the actual conditions of the footwear industry and the conceptual model of the subsystems and stakeholder perspectives. The identified gaps are then analyzed in Stage 6: Change Plan and proceed to Stage 7: Recommendations.

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RESULTS AND DISCUSSION

Stage 1: The Problem Situation

VOSviewer use to map the distribution of keywords from publications over the past 10 years (2014–2023) from 165 paper. The settings in the system include: type of analysis = Co-occurrence, unit of analysis = Keywords, counting method = Full counting, and minimum number of occurrences = 1. The distribution landscape of keyword is illustrated in the Figure 2.

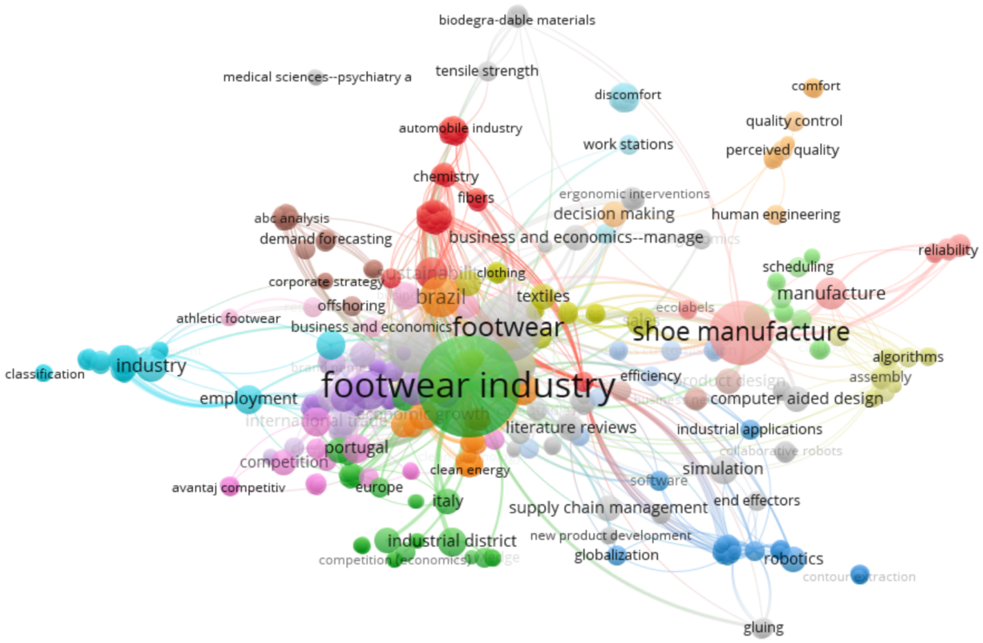

Figure 2. Overlay of Footwear Industry

In Figure 2 above, keywords are represented by circles, lines, and colours where larger circles indicate more dominant keywords, while the distance between two circles, as indicated by the lines, signifies the strength of the overall relationship. VOSviewer generated 28 clusters, each marked with a different colour, and identified 648 keywords from 156 articles.

These keywords were grouped to identify key situations and variables. Table 1 displays the most dominant keywords in each cluster, including their frequency and total link strength [15]. This link strength represents the cumulative strength of the relationships between a given keyword and other keywords. For example, Cluster 1, "industry and manufacturing," has 174 occurrences and a total link strength of 2,287, indicating a high level of usage and connectivity of this keyword with other keywords.

Table 1. The Problem Situation of the Footwear Industry

Cluster	Dominant Keywords	Sum of weight	Sum of weight
1	Industry manufacturing	174	2287
2	Method	119	1545
3	Materials	82	1737
4	Automation	68	942
5	Country origin	47	667
6	Production system	37	544
7	Market and demand	33	416
8	Global economy	30	429
9	Quality	29	404
10	HSE & ergonomics	29	421
11	Workforce	28	350
12	Competitiveness	27	383
13	Lean	19	261
14	Product development	18	253
15	Sustainability	15	265
16	Supply chain	15	157
17	Financial	15	222
18	Corporate strategy	14	147
19	Waste management	13	235
20	System reliability	11	152
21	Product	11	154
22	Mass customization	10	113
23	Inventory	9	162
24	Innovation	9	128
25	Absenteeism	8	103
26	Planning and scheduling	7	77
27	Social impact	5	105
28	Copyright	5	134

Stage 2: Expressing the Problem Situation.

To gain a comprehensive and holistic understanding of the situation, a "rich picture" framework, as shown in Figure 3, was used. This method involves secondary grouping based on field similarities and the SIPOC (Supplier, Input, Process, Output, Customer) principle [16]. The process identify 5 subsystems of footwear industry: (1) global market and demand (clusters of 1, 5, 7, 8, 12), (2) workforce and work environment (clusters of 10, 11, 25, 27), (3) raw materials (clusters of 3, 16), (4) production process (clusters of 4, 6, 9, 13, 14, 15, 20, 22, 23, 24, 26), and (5) the output (clusters of 17, 18, 19, 28).

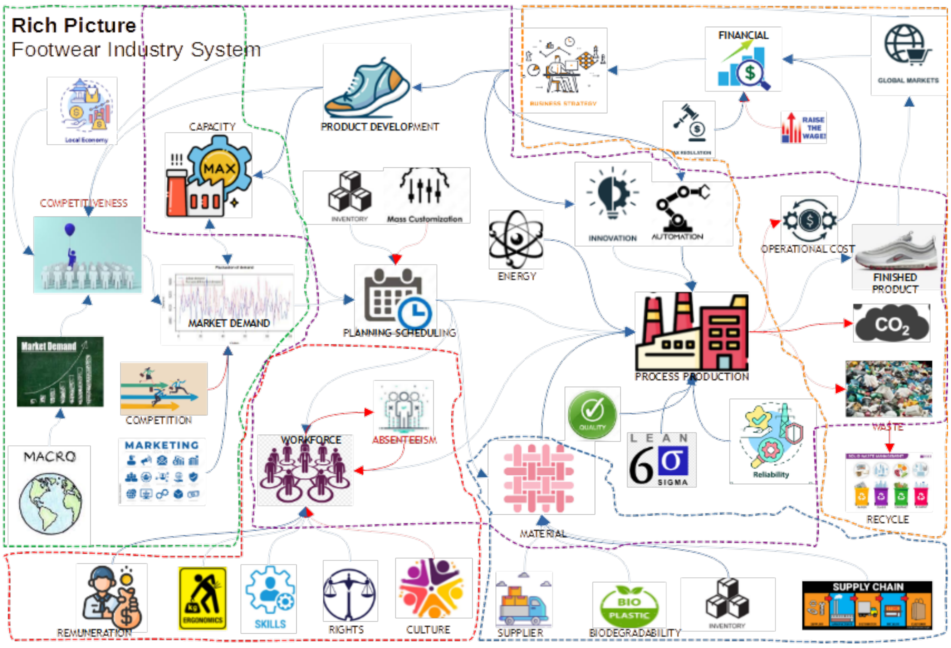

Figure 3. The Rich View of the Footwear Industry

From the rich view, we can identify five problem group area in footwear industry are: (1) global market competitiveness, (2) labor shortages, (3) green raw materials, (4) manual production processes, and (5) inorganic waste. These five subsystems align with findings from Stevenson et al. (2018), which indicated that the transformation for sustainable industrial requires the multidimensional approach which bridges the global market requirement with the local production constraints. The rich picture mapping has validated that the need to view the footwear industry as a complex socio-technical system, rather just a linear manufacturing chain [17].

Stage 3: Formulating the Root Definition.

Before formulating the root definition, stakeholders were identified using the problem owner, problem user, problem customer, and problem solver approach. The problem owner is the individual with the authority to address the problem and make decisions regarding it. The problem user is the party directly affected by the problem and has a stake in its resolution. The problem customer is the person who will use the solution, while the problem solver is responsible for finding and implementing that solution [18].

Table 2 depict the summary of the stakeholder identification. After identifying the stakeholders, the CATWOE methodology is used to define the root definition for each subsystem. A root definition is a high-level statement that summarizes the problem situation from the perspectives of customers, the actors involved in the transformation, the nature of the transformation itself, the actors' worldviews, the owner of the situation, and the environment in which the situation occurs [19]. This definition serves as a conceptualization of the situation, a research hypothesis, and a vision for the necessary transformation [18].

Table 2. Stakeholder Identification

Problem Category	Global Market	Manpower	Material	Production Process	Output
Owner	Buyer	Business owner	Business owner	Business owner	Bussiness owner
Customer	Buyer	Management	Management	Management	Buyer, Society
User	Bussiness owner	Employee	Supplier	Management	Management
Solver	Management	Management	Management	Management	Management

In Subsystem 1 (Global Market and Demand), the CATWOE elements identify global footwear buyers and business owners as Customers for financial sustainability; manufacturing and supply chain management as Actors; and the accurate and timely fulfillment of market demand as the form of Transformation. The proposed Worldview emphasizes the importance of competitiveness in quality, delivery, and cost, under the Owner of senior management and the Environment consisting of macroeconomic conditions. Based on this, Root Definition 1: in this subsystem, senior management is responsible for a system involving all levels of management and supply chain workers to transform raw materials into finished products to meet global market demand, with competitiveness as a key factor for business, social, and environmental sustainability.

In Subsystem 2 (Workforce and Work Environment), the Customer focuses on production management to optimize output efficiency, with Actors including employees, labor unions, management, Occupational Health, Safety, and Environment (HSE), and Industrial Engineering [20, 21]. Transformation is achieved through skills development, fair compensation, and a supportive work environment, grounded in the Worldview that worker health and safety are key to productivity. This system is overseen by senior management as the Owner within an Environment that contributes to the local economy and reduces unemployment. Thus, Root Definition 2: senior management is responsible for managing the workforce by involving the participation of all personnel to support production quality and efficiency, thereby enhancing business sustainability, social resilience, and minimizing absenteeism.

In Subsystem 3 (Raw Materials), customers include senior management and the local community, while actors consist of suppliers as well as the procurement, quality, and design teams. Transformation is achieved through planning the conversion of raw materials into efficient components, grounded in the Worldview that solid waste must be minimized by using sustainable materials. Responsibility as the “Owner” is shared by company management and suppliers, while “Environment” relates to the impact of raw materials on the environment and the local economy. Root Definition 3: Company management and suppliers ensure the efficient use of environmentally friendly raw materials to minimize procurement costs and environmental impact.

In Subsystem 4 (Production Process), the Customer consists of business owners and brand buyers, with Actors including all levels of management, workers, and suppliers. Transformation focuses on processing materials into high-quality footwear through an integrated process, driven by the Worldview that production efficiency is the key to competitiveness. Oversight falls under senior management as the Owner, while the Environment is influenced by the availability of labour, skills, and equipment. Root Definition 4: Senior management oversees labour-intensive manual production to produce high-quality footwear, which is crucial for competitiveness.

In Subsystem 5 (Outputs and Outcomes), customers are represented by business owners and brand owners, while actors include manufacturing management, suppliers, and the government. The Transformation aims to produce high-quality footwear while minimizing waste, with the Worldview that efficient manufacturing is a pillar of industrial competitiveness. Business owners act as Owners within an Environment that encompasses positive impacts on business, society, and the environment. Root Definition 5: Business owners oversee the production of high-quality footwear to achieve financial success and global competitiveness while minimizing environmental impact.

Social resilience within the labor subsystem aligns with the findings of Mani et al. (2018), who state that social sustainability in labor-intensive industries is a driver of long-term economic performance [22]. Furthermore, by establishing the "Problem Owner," this model reinforces the theory that top management commitment is a crucial factor in the successful integration of sustainability.

Stage 4: Conceptual Model

The conceptual model uses a Causal Loop Diagram (CLD), developed with Vensim PLE v.32, as shown in Figure 4. Observations identified 28 variables, detailed in Stage 2.

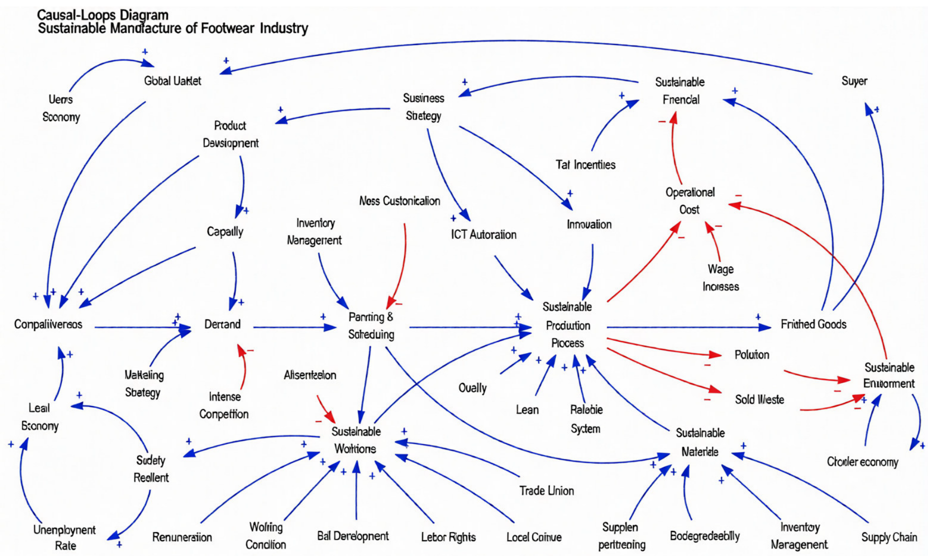

Figure 4. Causal-Loop Diagram of Sustainable Manufacturing Practices

Based on Figure 4, there are nine main variables, along with influencing variables and outcome variables for each main variable. The mapping of relationships among these variables is explained as follows: For the Competitiveness variable, a positive local economy, product development, and capacity will have a positive impact on competitiveness. For the Demand variable, a positive marketing strategy, capacity, and competitiveness coupled with a decrease in the level of competition will have a positive impact on demand. For the Planning & Scheduling variable, effective inventory management, demand, and a reduction in mass customization due to changeovers will have a positive impact on workforce management, production processes, and raw material procurement.

For the Sustainable Workforce variable, positive compensation, working conditions, skills development, workers' rights, and local culture will contribute to social resilience, reduce absenteeism, and improve production processes. Under the Sustainable Materials variable, effective planning and scheduling, supplier partnerships, design, inventory management, and supply chain management will have a positive impact on production processes.

For the Sustainable Production Process variable, positive workforce management, planning and scheduling, automation, innovation, quality, lean practices, machine reliability, and sustainable raw materials will enhance sustainable production processes, although they may increase operating costs and waste.

Under the Finished Goods variable, sustainable production processes will have a positive impact on business finances, the supply chain, and the global market. Regarding the Sustainable Business Finance variable, increased revenue and favourable tax regulations, coupled with reduced operating costs, will positively influence business strategies in adopting automation, innovation, and product development. Regarding the Product Development variable, positive business strategies will enhance capacity and competitiveness.

The dynamic relationship observed between automation and operating costs in the CLD aligns with the "Limits to Growth" archetype identified by Senge (2006). This finding supports the argument by [23] that technology adoption in sustainable manufacturing must be balanced with eco-green strategies to prevent systemic inefficiencies and waste accumulation.

Feedback Loops in Conceptual Models

The Causal Loop Diagram in Figure 4 illustrates unidirectional cause-and-effect relationships and forms several feedback loops that control the dynamics of the manufacturing system:

Reinforcing Loop - R1 Labor Productivity: Increased compensation, improved working conditions (occupational safety and health/ergonomics), and skill development positively enhance the Sustainable Workforce. A stable and competent workforce reduces absenteeism, which in turn improves the smoothness of planning and scheduling and strengthens the efficiency of the sustainable production process. This increase in production output has a positive impact on finished goods and sustainable financials, which then provides the company with greater financial capacity to further increase investment in worker compensation and welfare.

Balancing Loop - B1 / Limits to Growth: Efforts to improve the Sustainable Production Process through the adoption of ICT automation and innovation aim to increase efficiency. However, automation implemented without adequate worker skills and adaptation to local culture will trigger an increase in operational costs (due to maintenance costs, downtime, or resistance to technology). This rise in operational costs puts pressure on sustainable financial health, which ultimately limits the company's capacity to continue investing in automation [23].

Balancing Loop - B2 Environmental Burden: An increase in the volume of sustainable production processes naturally carries the risk of increasing solid waste and pollution. The accumulation of this waste damages the sustainable environment, which triggers pressure from buyers and government regulations (tax incentives). This pressure forces companies to implement a circular economy and adopt sustainable materials to reduce the impact of waste to levels that are safe for the system.

Stage 5: Compare to the Real World

Comparing models with real-world scenarios to understand the dynamics of the problem and identify changes, which facilitates in-depth analysis and recommendations for improvement [24]. Field observations and expert discussions provide insights into current conditions.

Table 3. Real World Analysis

Subsystem	Root Definition	Real World
Global Market and Demand	The industry needs to commit to meet the global market demand and align it with efficient manufacturing processes and supply chains, competitiveness for quality, lead time, and production costs, also contribute to business, social, and environmental sustainability.	In the current condition, its characterized by a stability local economy which control inflation; but competitiveness remains hampered by labor issues, slow progress development of environmentally friendly materials, and logistics costs.
Workforce and Work Environment	The industry needs to focus to efficient workforce and active participation, prioritizing skills and competencies, also ensuring worker safe, health, and rights; reduce absenteeism; lower unemployment; boost purchasing power; minimize environmental impact.	In the current situation, its characterized by demands for annual wage increase, tense work environment, lack emphasis to skills, this leads to the gap change over, lack management attention on workers' rights, also cultural factors that affect attendance to work.
Raw Materials	The industry must focus on efficient procurement of raw materials, minimizing procurement costs, reducing inorganic solid waste,	The current situation highlights the need for better integration and collaboration with suppliers regarding material quality to reduce waste, a stronger focus on environmentally

Subsystem	Root Definition	Real World
	promoting a circular economy, and preventing environmental pollution.	friendly materials in product design, and the risk of raw materials expiring due to overstocking.
Production Process	The industry must involve all levels of management, workers, labor unions, and suppliers in implementing integrated, synchronized, efficient, and productive production processes to produce high-quality footwear and generate financial profits, which serve as key factors in competitiveness.	Current conditions underscore the need to optimize scheduling processes to minimize changeovers, the need to further implement innovation and automation as substitutes for manual labor, the use of green energy (such as solar panels) to support production, and the adoption of Quick Changeover (SMED) for machinery and equipment.
Output & Outcome	The industry must focus on producing high-quality footwear while minimizing CO2 emissions and waste, generating financial profits to ensure business sustainability and competitiveness in the global market, receiving government support through tax incentives, and contributing to the achievement of government targets.	The current situation is characterized by ineffective recycling of raw materials, limited implementation of the circular economy and reverse logistics, the absence of an "Eco-product" logo on packaging, and a focus on competitiveness and marketing strategies for green production.

Stage 6 & 7: Define Possible Changes and Recommendations

The gap between the conceptual model and the current condition resulting an action plan as shown in Table 4.

Table 4. Action Plan

Subsystem	Recommendations
Global Market and Competitiveness	A resilient local economy, characterized by controlled inflation and the resolution of labour issues, is essential for enhancing global competitiveness.
Workforce and Work Environment	Prioritizing safety, comfortable working conditions, and workers' rights to increase employee engagement, while ensuring the availability of critical skills and competencies to support productivity and quality.
Raw Materials	Initiatives to identify environmentally friendly alternative raw materials must be prioritized, in line with circular economy initiatives such as reuse, recycling, and redesign, starting with auxiliary materials such as packaging and extending to primary raw materials.
Production Process	Implementing smart technologies and information systems to automate manual labor is crucial for business sustainability and competitiveness.
Output & Outcome	Environmentally friendly, green, and sustainable strategies must be implemented to enhance brand competitiveness in footwear production and supply chain management.

Interpretation of Causal Dynamics and Unexpected Findings

The Causal Loop Diagram (Figure 4) reveals nonlinear interactions not captured in standard linear optimization models. One key (unexpected) finding in this study is the interaction between the adoption of ICT automation and increased operational costs. When companies invest in automation to replace manual labour without addressing workers' skill levels and local culture, there is a surge in maintenance costs and a risk of technology rejection, which actually reduces efficiency. This aligns with the systemic archetype of "The Limits to Growth", where efforts to drive growth (automation) are constrained by the limits of workers' social adaptive capacity. Therefore, eco-green strategies and worker competency enhancement programs (Skill Development) must be positioned as enabling variables before technology is implemented.

Unlike previous optimization studies [25-27] which assumed that increased capacity would always be directly proportional to efficiency, the CLD approach demonstrates a nonlinear relationship: the adoption of technology without social readiness will actually reduce productivity.

Framework Transferability and Limitations

This integrated SSM framework which tested in footwear industry in Indonesia has transferability degree to other labour-intensive manufacturing sectors in other developing country, such as the textile, apparel, and furniture industries [25, 26]. That sector has similar socio-technical characteristics, which are high reliance to manual labour, has high fluctuations in demand [27], and has challenges related to raw material waste. This paper also notes several limitations. The structuring of variables within this framework is heavily influenced by the characteristics of labor regulations and port logistics dynamics in Indonesia. To apply this framework to industrial environments in other countries or sectors with high levels of automation, recalibration of the "Environment" variable in the CATWOE analysis and the addition of a specific emissions compliance variable are necessary.

CONCLUSION

This study successfully developed a robust conceptual model for sustainable manufacturing in Indonesia's footwear industry through the application of the Soft Systems Methodology (SSM). By synthesizing bibliometric data using VOSviewer, this study integrated twenty-eight independent variables into a comprehensive Causal Loop Diagram (CLD) centred on the nine key pillars of manufacturing: Competitiveness, Demand Management, Manufacturing Scheduling, Sustainable Workforce, Sustainable Raw Materials, Sustainable Production, Finished Products, Sustainable Business Finance, and Product Development.

Utilizing the Rich Picture framework, this study categorizes the industrial landscape into five critical subsystems and outlines five systemic interactions ranging from raw material toxicity to labour shortages that hinder sustainable growth. The study's key contribution is the transition from linear industrial modelling to a systemic perspective involving multiple stakeholders. With this identify the key stakeholders through CATWOE analysis, this study proposes the six strategic recommendations: including digital transformation, initiatives for circular economy, and social resilience strategy which can align to economic profitability with social justice and environmental stewardship.

These findings can give a roadmap for the business owners and the policymakers to enhance the Indonesia's global competitiveness. This study also demonstrates that the integration of SSM with analytical tools such as VOSviewer and Vensim can provide a replicable framework for addressing complex issues in other labor-intensive manufacturing sectors. Future research should focus on quantitative simulations of these causal relationships to further validate the long-term impacts of the proposed interventions.

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CONFLICT OF INTERESTS

The authors confirm that there is no conflict of interest associated with this publication. The research was conducted in the absence of any commercial, financial, or personal relationships that could be construed as a potential conflict of interest. All authors have reviewed and approved the final manuscript for submission.

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