Transforming warehouse operations for sustainable growth

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Abstract. This study aims to improve process cycle efficiency and reduce CO_2 emissions at KUI, an Indonesian manufacturer of undercarriage components for hydraulic excavators and bulldozers. Facing capacity constraints at the assembly plant, the project targeted reducing five types of waste such as waiting, motion, overprocessing, defects, and transportation while strengthening warehouse and production management. This supports KUI's global expansion strategy, especially in the Southern Hemisphere and North America, requiring improved competitiveness through efficiency process.

A mixed-method supply chain approach was applied using Sustainable Value Stream Mapping and Process Activity Mapping, supported by implementing a Vertical Warehouse, RFID technology, and Automated Guided Vehicles (AGV) within a smart warehouse management system. HIRARC and REBA frameworks were also integrated to address safety risks and strengthen management control.

The first phase increased process efficiency from 52% to 58%, raised warehouse capacity by 9.6%, reduced costs by 23.2%, and cut CO_2 emissions by 0.96 tons annually. The second phase, focused on the roller area, achieved an additional 2.43-ton CO_2 reduction plus 1.47 tons per year in further savings, with productivity reaching 60%. These results show that combining smart warehouse technologies with sustainable management tools can significantly enhance operations, environmental responsibility, and global competitiveness.

Keywords: Green Supply Chain, 7 Waste, Sustainable Value Stream Mapping, Process Activity Mapping, Vertical Warehouse, RFID, AGV

Introduction

The manufacturing industry in Indonesia continues to grow rapidly and serves as a key indicator of national economic development. According to Statistics Indonesia (BPS), the number of medium- and large-scale manufacturing companies is projected to reach 32,000 by 2025. In addition, the sector recorded a year-on-year growth of 4.55% in the first quarter of 2025. This positive trend has led to increasingly intense competition, prompting companies to seek strategies for operational improvement to remain competitive.

One relevant strategy is the Business Level Strategy, which refers to a coordinated set of actions used by companies to gain a competitive advantage by leveraging their core competencies in specific markets (Porter, 1985). This strategy is particularly important for PT Komatsu Undercarriage Indonesia (KUI), a global manufacturing company currently expanding into the Southern Hemisphere and North America, especially in the large-sized undercarriage product segment. To support this expansion, KUI must enhance operational efficiency and strengthen its management practices.

However, KUI continues to face several inefficiencies in its warehouse operations, including waiting time, unnecessary motion, rework, material defects, and inefficient transportation. These issues have resulted in low Process Cycle Efficiency (PCE), increased costs for external warehouse rental, high energy consumption due to forklift use, and elevated CO_2 emissions.

To address these challenges, KUI has begun implementing supply chain innovations such as Radio Frequency Identification (RFID), Automated Guided Vehicles (AGVs), and a Vertical Warehouse system. These technologies aim to improve storage efficiency, increase distribution accuracy, and reduce the company's environmental impact, ultimately supporting its competitive position in the global market.

A review of the company's supply chain—particularly in the process stage—revealed significant waste, primarily caused by poor material placement and excessive inventory. This has led to difficulties in material retrieval, increased forklift use, and negative impacts on safety, cleanliness, and carbon emissions.

This situation highlights the importance of an organization's ability to detect and learn from internal conditions, as explained by Teece et al. (1997) through the concept of dynamic capabilities. Companies must go beyond relying on intuition and instead build structured systems for collecting information, conducting cross-functional analysis, and making sustainable decisions aligned with strategic goals.

Field verification revealed several key issues:

- Unsafe pallet stacking, creating fall and collision hazards (classified as Level 2 risk according to HIRARC),
- Additional costs due to outdoor material storage requiring shot blasting,
- High CO_2 emissions from fuel-powered forklifts due to inefficient retrieval,
- External warehouse rental costs reaching USD 7,513.1 per month due to overcapacity.

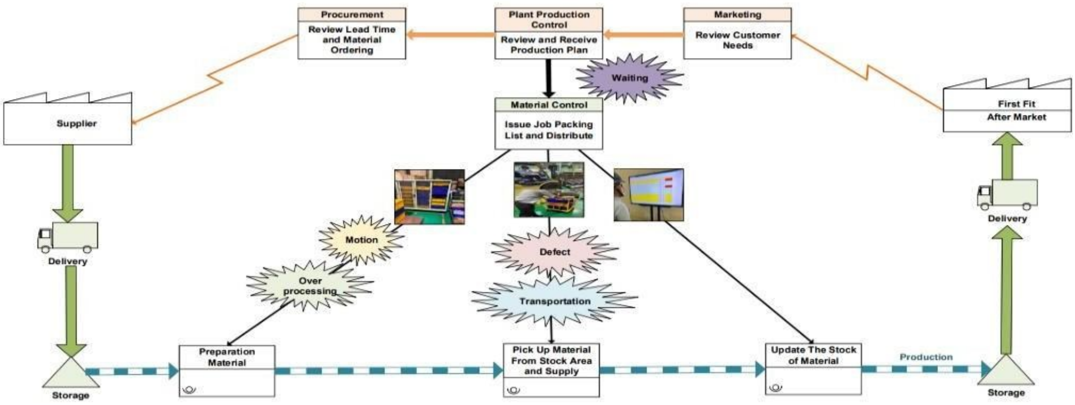

Figure 1. Supply Chain Process Analysis (Warehouse and Waste Analysis)

These issues emphasize the need for an appropriate managerial approach to improve warehouse operations. According to Casson (1997), the ability of middle management to process internal and external information is essential for managing operational complexity and maintaining competitiveness. Therefore, a structured management system supported by digital innovations such as RFID, AGVs, and Warehouse Management Systems (WMS) is crucial for enhancing efficiency and supporting long-term business growth.

Considering these conditions, this study seeks to support the company's global expansion strategy by improving its operational competitiveness, particularly in warehouse operations. The research is guided by the following questions:

1. How can warehouse performance be improved through strategies focused on operational efficiency, cost control, and environmental impact reduction?
2. How can storage systems and material handling processes be optimized to support operational effectiveness and sustainability?

3. What managerial initiatives can integrate productivity improvements with environmental responsibility?

To answer these questions, the research aims to:

1. Evaluate the role of management in improving warehouse systems, including space utilization, operational efficiency, and logistics cost reduction.
2. Analyze how process mapping and automation technologies support sustainability and the achievement of ESG (Environmental, Social, and Governance) goals.
3. Examine the relationship between waste reduction, workplace safety, and productivity, and how these elements influence delivery accuracy and energy efficiency.

Sustainable manufacturing is built upon three main pillars: environmental, economic, and social. The environmental pillar emphasizes responsible use of natural resources and effective waste management (Amaranti, 2017). The economic pillar focuses on cost efficiency, competitiveness, and optimal resource allocation. The social pillar involves employee welfare, adequate training, and safe working conditions (Sudrajat, 2018). In practice, sustainable manufacturing helps prevent pollution, ensures the safety of workers and customers, and improves overall business performance (Ahmad & Aditya, 2019). The adoption of sustainable lean manufacturing further strengthens this approach by reducing waste, minimizing environmental impact, and promoting eco-friendly processes aligned with all three pillars (Debnath, 2022).

Methods

combined with the Dynamic Capabilities framework (Teece, 1997) and principles of Strategic Management to respond to the operational dynamics of the supply chain and ensure the sustainability of business processes at PT Komatsu Undercarriage Indonesia (KUI).

The main objective is to develop a Smart Warehouse system that is not only efficient but also supports the goals of a sustainable supply chain and carbon emission reduction, as part of continuous improvement efforts to enhance the company's competitiveness. This approach is carried out through the following systematic stages:

- **Initial Analysis and Problem Identification (Sensing)**
  Aligned with the sensing capability within the dynamic capability's framework, this stage focuses
  on identifying operational issues and potential improvement opportunities.

1. Conducting Process Activity Mapping (PAM) to distinguish between value-added and non-value- added activities.
2. Applying Sustainable Value Stream Mapping (SVSM) to detect resource waste across economic, social, and environmental dimensions within the material flow process.
3. Analyzing issues related to the three pillars of sustainability, including:
   - High material searching time.
   - Excessive and uncoordinated forklift movement.
   - Limited storage capacity (suboptimal space utilization).
4. Identifying efficiency needs using SLQDC indicators (Safety, Law, Quality, Delivery, Cost) to support organizational competitiveness and management objective.

- **Strategy Formulation and Smart Warehouse Concept Development (Shaping)** In line with the Strategic Management framework, this stage aims to define the direction of transformation through a technology-based strategy.

1. Designing the Smart Warehouse concept by integrating:
   - Vertical Warehouse (VW) for vertical space optimization.
   - RFID for real-time tracking.
   - AGV (Automated Guided Vehicle) for internal distribution automation.
2. Applying the principle of strategic fit to ensure alignment between the technology design, the actual organizational structure, and business processes for enhanced efficiency.
3. Engaging internal stakeholders (warehouse, maintenance, and IT teams) as part of internal alignment and organizational learning efforts.

- **Prototype Development and Testing (Transforming)**
  At the transformation stage, controlled trials are conducted to test the organization's dynamic capabilities in implementing change.

1. Utilizing key performance indicators (KPIs), such as:
   - Reduction in material searching time.
   - Improvement in space utilization.
   - Decrease in non-value-added movements.
   - Estimated reduction in CO_2 emissions based on SVSM.
2. Evaluation is carried out through gap analysis between the existing condition and post-intervention results.

- **Evaluation, Feedback, and System Iteration**

1. Gathering user feedback from operators, planners, and the delivery team regarding system functionality.
2. Applying a continuous improvement approach based on the PDCA (Plan-Do-Check-Act) cycle to refine the system.
3. Assessing system adoption readiness using indicators of absorptive capacity and organizational readiness.

- **Smart Warehouse System Implementation (Digital Transformation)**

1. Full-scale implementation across all KUI warehouses and involving staff training
2. Adjustment of Standard Operating Procedures (SOPs) and work structure based on re-mapping of processes after system deployment.
3. Measurement of long-term impacts on supply chain efficiency and sustainability indicators.

Results and Discussion

- **Initial Analysis and Problem Identification (Sensing)**

The analysis results reveal several operational issues that affect supply chain efficiency and sustainability,
potentially reducing the company's competitiveness:

1. **Process Activity Mapping (PAM)**
   Non-value-added activities were identified, particularly in material research, resulting in a Process Cycle Efficiency (PCE) of 52% categorized as efficient enough, but with room for improvement.
2. **Sustainable Value Stream Mapping (SVSM)**
   Resource inefficiencies were observed, including forklift waiting time, high energy consumption, and suboptimal space utilization due to difficulties in locating materials. These issues are reflected in the *three bottom line* indicators, which fall into the red and yellow zones.
3. **Key Issues**
   1. Material searching takes up 30% of each shift.
   2. Work processes remain inefficient and largely manual.
   3. Limited storage capacity has led to the need for additional warehouse rental.

- **Strategy Formulation and Smart Warehouse Concept Development (Shaping)**

The smart warehouse strategy and concept will be divided into three improvement areas, each serving different supporting functions to enhance efficiency and competitiveness, including:

1. **Strategic Plan: Vertical Warehouse Implementation**
   To enhance operational efficiency and reduce waste, particularly warehouse rental costs. Material Control team has developed a strategy to optimize storage capacity through the construction of a Vertical Warehouse.
   This proposed initiative is expected to:
   1. **Increase storage capacity by 8%**, from 12,361 tons to 13,350 tons, by transitioning from rented
      warehouse space to KUI's internal facilities.

2. **Optimize vertical space utilization** to better align with growing production demands.
3. **Reduce long-term operational costs** and strengthen the integration between storage systems and production flow.

2. Strategic Plan: Implementation of RFID and AGV

As part of the transformation toward a Smart Warehouse and in line with the company's digital transformation efforts, two key technologies will be implemented: RFID (Radio Frequency Identification) and AGV (Automated Guided Vehicle).

The main objectives of this initiative include:

- **Improving efficiency** through an environmentally friendly automated system for material handling and distribution.
- **Enhancing accuracy and speed** in material retrieval by implementing RFID, which enables real- time material identification.

- **Prototype Development and Testing (Transforming)**

Efficiency improvements are achieved by eliminating waste through reducing additional costs for warehouse rental with the use of Vertical Warehousing, increasing productivity, and lowering CO_2 emissions by implementing Automated Guided Vehicles (AGV). Additionally, the implementation of Radio Frequency Identification (RFID) technology helps eliminate manual searching processes, thereby speeding up the retrieval of required materials. The adoption of Radio Frequency Identification (RFID) technology further streamlines operations by eliminating manual searches, accelerating material identification and retrieval. These measures not only optimize supply chain efficiency but also promote sustainability related to aspect economic, social, and environmental factors.

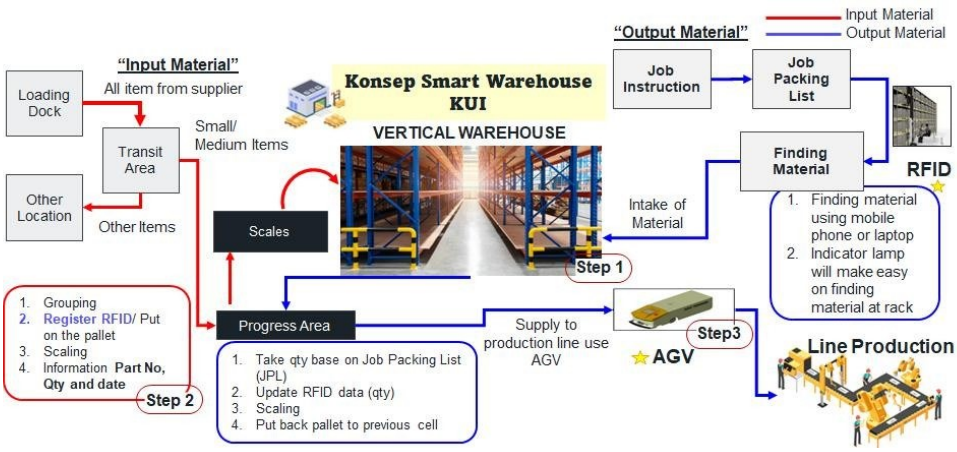

Figure 2. Innovative Solutions for Efficiency and CO_2 Emission Reduction

The goal of this process is to ensure that all aspects and impacts of the implementation are well- planned and executed optimally.

- **Evaluation, Feedback, and System Iteration**

The Smart Warehouse initiative is expected to deliver tangible improvements in operational performance, sustainability, and competitiveness by enhancing workplace safety, improving material storage quality, reducing logistics and space costs, and supporting environmental goals through lower CO_2 emissions and the use of eco-friendly technology.

- **Smart Warehouse System Implementation**

This implementation as planned according to the following schedule:

Table 1. Schedule Activity Implementation

No	Activities	Month					
		1	2	3	4	5	6
1	Recognizing current situation and setting the goals	V					
2	Creating Action plan		V				

3	Analysis of cause and effect			V			
4	tion of Vertical warehouse, RFID and AGV and expand				V	V	
5	Verifying the effect						V

The management of KUI has approved this improvement project; therefore, to achieve the established targets, the schedule above must be completed on time. By adopting this phased approach, we ensure that the AGV implementation is not only effective in enhancing operational efficiency but also contributes positively to environmental sustainability. The improvement project will be implemented with 2 phase as below:

1. Phase-1 – Link Area (Pilot Project)

In the initial phase, the Vertical Warehouse will directly deliver pre-prepared materials to the production line in the Link area.

2. Phase-2 – Roller area

Building on the positive impact of Phase-1, the AGV system will be further developed in the next phase. This includes extending the AGV route by an additional 60 meters to enhance operational efficiency and further reduce CO_2 emissions.

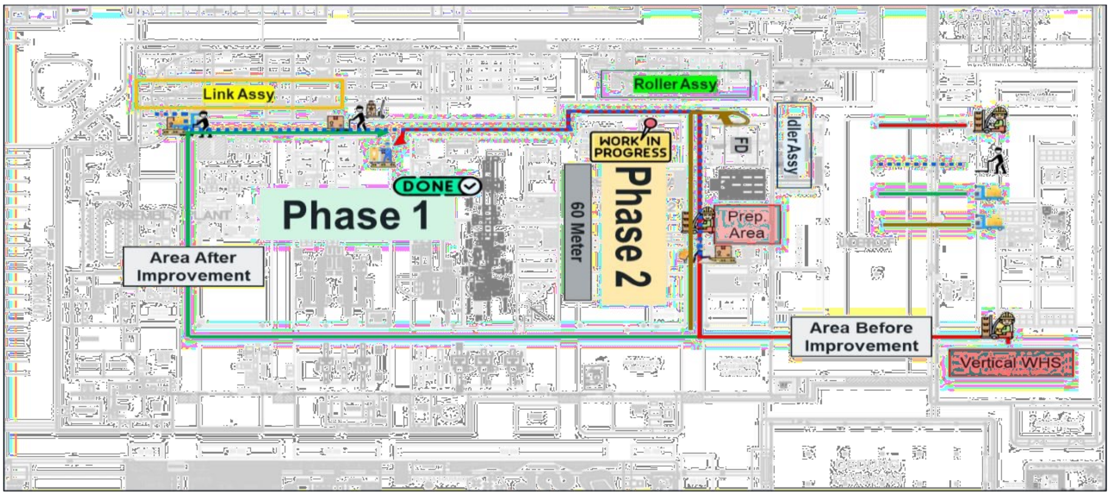

Figure 3. Location of Implementation Phase 1 and

Phase 2 The ROI calculation of this improvement project of Vertical

warehouse as below:

Table 2. Table of Cost, Investment and ROI

Cost (1 USD = 15,240 IDR)

No	Activity Description	Amount IDR	Amount USD	Remark
1	Rental Warehouse	22.500.000	1.476	Per Month
2	Trucking	42.000.000	2.756	Per Month
Total Cost		64.500.000	4.232	
Estimation ROI			14 Month	

Investment (1 USD = 15,240 IDR)

No	Activity Description	Amount IDR	Amount USD	Remark
1	Vertical Whs	900.000.000	59.055	1x Invest
2	Reach Truck	13.000.000	853	Per Month
Total Cost		913.000.000	59.908	

The construction of the Vertical Warehouse as a solution to address this issue is expected to deliver a Return on Investment (ROI) within 1.4 years, allowing the investment to be recouped in a relatively short period. The Investment of AGV for 1 unit as below:

Table 3. Table of detail investment (1 unit AGV)

No	Item		Qty	Unit	Unit Price	Total
1	AGV TKD 1500 G1 (1 way)		1	set	385,000,000.00	385,000,000.00
	Detail Perunit :					
	Body Steel 4mm finishing powder coating		1	unit		
	Drive Unit motor 48 Volt 100 watt		1	set		
	Mainboard AGV TKD		1	unit		
	Obstacle Sensor HOKUYO PBS-03JN		1	unit		
	Magnetic sensor (TKD made)		1	unit		
	Pin Hook (TKD made)		1	set		
	LED Lamp (for indicator)		1	set		
	Baterry Lithium 48 volt 80 ah		1	pcs		
	Manual Batery Charger Lithium		1	pcs		
2	Magnetic tape (25 meter/roll)		40	roll	4,000,000.00	160,000,000.00
3	Protector tape vinil (30 meter/roll)		40	roll	4,200,000.00	168,000,000.00
4	RFID tag		200	pcs	35,000.00	7,000,000.00
5	Spare Batery Lithium 48 volt 80 ah + Laci		1	unit	10,000,000.00	10,000,000.00
6	DELL PC + Software AGV TEKADE (for traffict & Dispatch System)		1	unit	125,000,000.00	125,000,000.00
7	Wireless Calling Button		5	unit	5,000,000.00	25,000,000.00
8	Trolley AGV		4	unit	6,500,000.00	26,000,000.00
9	Installation AGV only		1	lot	125,000,000.00	125,000,000.00
Step 1						1,031,000,000.00
Step 2						1,041,000,000.00

We can conclude that this improvement project is visible. The investment in Automated Guided Vehicles (AGVs) achieves a *Return on Investment* (ROI) of 0.88 years. This is calculated from labor cost savings of IDR 196,242,858 per person for six employees, compared to a total investment of IDR 1,041,000,000. This indicates that the AGV investment can be recovered in less than a year, making it an efficient and highly valuable solution for operations.

The implementation of the warehouse transformation program has led to remarkable improvements in both operational efficiency and sustainability. Process Cycle Efficiency (PCE) increased from 52% to 60%, while CO_2 emissions were successfully reduced by 2.43 tons per year. The integration of a Vertical Warehouse expanded storage capacity by 8%, eliminating the need for external warehouse rentals and supporting better space utilization. At the same time, the adoption of RFID and Automated Guided Vehicles (AGV) accelerated material retrieval processes and enhanced distribution accuracy.

Significant gains were also seen in workplace safety and ergonomics, as indicated by reductions in HIRARC and REBA scores—signaling a safer, more comfortable working environment. These improvements not only reduced operational costs but also aligned closely with the company's digital transformation objectives.

Moreover, the Transforming Warehouse Operations for Sustainable Growth initiative underscored the importance of designing systems that are user-friendly, reliable, and tailored to actual operational needs. By supporting efficient workflows and maintaining compliance with safety standards, the initiative has contributed to smoother process flows and overall improvements in performance. This holistic approach has strengthened KUI's ability to adapt to future industrial challenges while promoting long-term sustainable growth.

Figure 4. Transforming Warehouse Operations

Conclusion

Based on the results of data processing and analysis of the results of the research that has been carried out, the conclusions obtained are as follows:

1. The increase in storage capacity through the implementation of Vertical Warehouse, along with RFID and AGV, has significantly improved operational efficiency, reduced logistics costs, and lowered carbon emissions. The results show a 9.6% increase in warehouse capacity (surpassing the initial 8% target), process efficiency improved from 52% to 60%, costs decreased by 23.2%, and CO_2 emissions were reduced by 2.43 tons per year. These outcomes placed sustainability indicators in the green and yellow zones, reflecting a positive contribution to the economic, social, and environmental pillars.
2. The optimization of high frequency material movement using AGVs directly contributed to a CO_2 reduction of 23.2 tons per year. This demonstrates that the material handling process has been effectively aligned with sustainability objectives and supports environmentally responsible operations.
3. Managerial initiatives such as waste analysis, improved workplace safety, and attention to ergonomics and employee well-being have proven to enhance operational efficiency while positively impacting performance and the working environment. These efforts reflect a commitment to integrating productivity with long-term sustainability and employee safety.

This also demonstrates the company's ability to improve its competitiveness, as stronger warehouse efficiency has directly supported production output and contributed to improved sales performance.

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