

LEAN MANUFACTURING AND TOTAL WASTE MANAGEMENT: AN INTEGRATED FRAMEWORK FOR PRODUCTION AND ENVIRONMENTAL WASTE REDUCTION

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ABSTRACT

Lean manufacturing, developed and widely associated with the Toyota Production System, is a management philosophy centred on the systematic identification and reduction of non-value-adding activities. This paper examines lean manufacturing from the broader perspective of total waste management, with particular attention to production losses and hazardous wastes that may remain outside conventional operational-waste calculations.

The paper develops a conceptual classification of production wastes and proposes an extended total-waste-cost framework that incorporates hazardous waste and treatment costs as an explicit component of production cost. An illustrative metal-piping example shows that excluding hazardous-waste treatment costs understates the reported waste cost. The paper also reviews selected lean tools—including 5S/7S, Just-In-Time, Gemba walks, Value Stream Mapping, bottleneck analysis, Kanban, Kaizen and smart-manufacturing technologies—and discusses their potential contribution to waste reduction. Because the paper is conceptual and uses an illustrative example rather than field data, the proposed framework requires empirical validation across manufacturing settings.

Keywords: Lean manufacturing; total waste management; waste cost; hazardous waste; environmental impact; Just-In-Time; Value Stream Mapping; Kaizen; smart manufacturing.

INTRODUCTION

Lean manufacturing is a continuous-improvement philosophy that seeks system-wide efficiency rather than isolated optimisation of individual operations. A process that appears

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highly productive at one stage may reduce overall performance if it creates bottlenecks, excess inventory, defects or other non-value-adding activities elsewhere in the value stream. Accordingly, lean management focuses on the performance of the entire value stream, from inputs to delivery, rather than on maximising the output of individual departments. The central concern is to increase customer value while reducing activities that consume resources without creating corresponding value.

Lean manufacturing can therefore contribute to lower production costs, shorter lead times, improved quality and more responsive operations. Its environmental significance is also potentially important because material losses, defective products, unnecessary movement, excess inventory and hazardous wastes consume resources and may generate additional treatment or disposal costs.

The present paper extends this discussion by treating waste not only as an operational inefficiency but also as a measurable cost category. In particular, hazardous waste and the cost of its safe treatment are considered a form of potentially hidden waste that should be visible in managerial cost analysis. The paper is conceptual in nature and proposes a framework for subsequent empirical testing.

The Importance of Reducing Cycle Time

There are numerous reasons to reduce cycle time and waste, some of which are less obvious than others. Cycle time refers to the length of time it takes to convert raw materials into finished goods, and the length of this cycle determines the company's ability to convert assets into profits. A company able to reduce cycle times more than its competitors will be able to respond more quickly to market demands and thus gain a larger market share. Some of the many benefits of reducing cycle times include:

- Innovation opportunities
- Better distribution positioning
- Increased productivity
- Higher customer satisfaction
- Advantaged profitability potential

Existing lean manufacturing literature extensively addresses operational waste, process flow, quality improvement and environmental performance. However, the explicit incorporation of hazardous-waste generation and its treatment/disposal cost into a unified total-waste-cost formulation remains comparatively underdeveloped. The present paper therefore proposes an extended framework that treats hazardous waste as a financially measurable component of production waste rather than solely as an environmental compliance issue.

METHODOLOGICAL APPROACH

This study adopts a conceptual and framework-development approach. It synthesises

the waste categories described in this paper, relates them to established lean principles and tools, and formulates an extended total-waste-cost expression that includes hazardous-waste treatment. The numerical metal-piping example is illustrative rather than an empirical case study. No primary data, statistical testing or comparative field study is presented; consequently, the proposed framework should be regarded as a conceptual model requiring validation in real manufacturing environments.

Lean production does not treat waste reduction as an isolated objective; rather, waste is reduced by improving flow, quality, reliability and the alignment of production with demand. The waste categories below extend the conventional operational perspective by including material, process, storage, packaging, equipment-related and hazardous-waste costs. Some categories overlap with one another, so they should be defined consistently before measurement to avoid double counting.

Lean production does not focus exclusively on total waste reduction; total waste is minimized or eliminated more as an inevitable by-product of better production flow. It may seem obvious that total waste hurts productivity and profitability, increases production cost, and additionally has a negative impact on the environment. Part of the waste generated is disposed of into the environment, which then harms flora and fauna. But the importance of reducing total waste is often underappreciated, and there are numerous areas of waste that go overlooked.

Lean manufacturing typically focuses on the waste types below, which together constitute Total Waste Management.

- a. **Received Raw Material Defects:** A defective part caused by poor quality inputs, user error, or other problems is costly and easily avoided.
- b. **Received Defective Auxiliary Materials (grease, oil, chemicals and similar consumables):** the receipt of defective auxiliary materials generates additional cost.
- c. **Poor Storage of Auxiliary Materials:** poor storage of chemicals or oils causes additional cost.
- d. **Adjustment Defects:** This type of waste is generated while changing over between different product sizes. For example, when a production line finishes making 500 mm-diameter pipe and is then changed over to fix a 720 mm mould, adjustment defects occur during the start-up of the 720 mm run. Zero defects are not always achievable immediately, but working toward elimination is possible.
- e. **Overproduction:** Overproducing irrespective of demand or capacity is wasteful and does not consider the customer.
- f. **Waiting:** Bottlenecks occur due to oversupply or undersupply and should be handled through better supply chain and personnel management.
- g. **Not Utilizing Talent:** Waste occurs when the skills of the workforce are underutilized or

misapplied. Human talent is a highly valuable and often overlooked resource.

- h. Transportation:** Movement to and from docks and warehouses is an area of potential waste that can be reduced by better layout and better-aligned process flow.
- i. Inventory Excess:** Numerous factors can lead to excessive inventory, which, in a mass-production paradigm, might appear as productivity but does not benefit the overall process.
- j. Motion Waste:** Even the repetitive motions of employees on the assembly line can diminish productivity and contribute to waste.
- k. Excess Processing:** Avoid redundancy and unnecessary steps.
- l. Poor Packaging:** Poor packaging of the product causes defects.
- m. Poor Transportation to Customer:** Poor transportation of the finished product to the customer (damaged products are sometimes disposed of into the environment, which may cause negative environmental impact).
- n. Poor Storage in Company Warehouse:** Poor storage of the final product in company storage causes defects.
- o. Poor Storage in Customer Warehouse:** Poor storage of the final product in customer storage causes defects. Given the scarcity of raw materials, poor storage of finished product may require additional production, leading to greater consumption of raw materials.
- p. Equipment-Failure Defects:** Defects arising from equipment failure.
- q. Hazardous Liquids and Gases:** Waste arising from equipment operation. This waste must be treated and minimised rather than disposed of into the environment; its cost is part of total waste cost. Increased untreated waste may cause environmental pollution. Most companies worldwide currently dispose of this type of waste into the environment; the cost of any penalty for such disposal is linked directly to the cost of the product produced by the equipment concerned.

CALCULATING COST

Proposed Total Waste Cost (TWC) = RMW + AMW + PPWW + AWW + SPW + FPWW + PTWW + HWW

- Raw-material waste cost (RMW)
- Auxiliary-material waste cost (AMW)
- In-process product waste cost (PPWW)
- Adjustment/changeover waste cost (AWW)
- Equipment spare-parts waste cost (SPW)
- Final-product waste cost (FPWW)

- Packaging/tightening waste cost (PTWW)
- Hazardous-waste and treatment cost (HWW): In this framework, HWW represents the identifiable cost of hazardous material handling, treatment, recovery and/or compliant disposal associated with production. It is treated as a potentially hidden component of total waste cost, but the measurement boundary should be defined clearly to prevent overlap with ordinary production, environmental-compliance or maintenance costs.
- Hazardous waste and gases produced from production – HW_w : This is termed the “hidden waste” and must be calculated as a waste cost and included in total waste cost. Production cost must include total waste cost, covering this *hidden cost*.

Example

A company producing metal piping calculated its total waste cost as follows:

- Raw material waste – RMW = \$300
- Auxiliary material waste – AMW = \$700
- In-process product waste – PPWW = \$200
- Adjustment waste – AWW = \$80
- Equipment spare-parts waste – SPW = \$150
- Final product waste – FPWW = \$250

The seven non-hazardous categories total \$1,910. When the illustrative hazardous-waste treatment/utilisation cost of \$800 is included, the proposed total waste cost becomes \$2,710. Thus, in this example, excluding HWW would understate total waste cost by \$800, or approximately 29.5% of the proposed total. The example demonstrates the accounting significance of the proposed category; it does not establish the prevalence or magnitude of hazardous waste across manufacturing industries.

THE BENEFITS OF LEAN MANUFACTURING FOR REDUCING TOTAL WASTE

Lean principles can benefit both large and small or medium-sized manufacturers when they are adapted to the characteristics of the production system. The potential benefits discussed here include lower inventory and material losses, shorter cycle and lead times, fewer defects, better use of workforce capability, and improved responsiveness. These benefits should be presented as expected outcomes of implementation rather than universal effects, because their magnitude depends on context and execution.

While many assume lean manufacturing only benefits large, repetitive, mass-production operations, small and medium-sized manufacturers can also benefit. Lean manufacturing principles can impact the average producer in a powerful way that extends beyond financial gains. Some of the many benefits of adopting lean manufacturing for the management and reduction of total waste include:

- Lean identifies value as defined by customer demand, leading to more satisfied customers

and also minimising product and service waste from the customer's perspective.

- Lean removes wastes such as excess inventory, transportation, and others.
- Lean shortens cycle time and increases production, leading to reduced waste in process.
- Lean brings about greater employee morale and buy-in; greater morale reduces waste generated by employee error.
- Lean reduces raw-material waste through effective inventory management.
- Lean reduces the amount of space needed for production.
- Lean increases cash on hand.
- Lean focuses on pull- (demand-based) flow manufacturing rather than push.
- The five commonly presented lean principles—value, value stream, flow, pull and perfection—provide a useful organising framework for the discussion.

Lean manufacturing is more than a way to make products — it is a school of thought. While many lean principles make up this school of thought, much of the system's power is contained in five primary concepts, most famously articulated in the 1990 book *The Machine That Changed the World* by James Womack, Daniel T. Jones, and Daniel Roos. Understanding these five lean manufacturing principles enables a business to transform into a lean production operation:

- I. Specify value as perceived by the customer:** Value must be perceived through the customer's eyes — not merely the product a company can provide, but the end solution the customer actually wants.
- II. Identify the value stream:** Rather than thinking in terms of departments, lean-oriented companies visualise the value stream as an interconnected flow of processes that provide value, excluding steps that do not directly contribute to it.
- III. Make value flow through the value stream:** The focus must be on value-adding steps; if non-value-adding steps are necessary, they should run simultaneously with value-adding steps, never before them.
- IV. Pull value through the value stream:** Avoid inventory-management waste by shifting to single-piece flow that produces on demand.

LEAN MANUFACTURING TOOLS FOR WASTE MANAGEMENT AND REDUCTION

Lean manufacturing uses a portfolio of complementary tools rather than a single technique. Their suitability depends on process characteristics, product variety, demand stability, workforce capability and organisational maturity.

Lean production is about getting the most out of every resource and continually finding better ways to do things. Numerous lean manufacturing tools have been developed and

refined in this pursuit; some of the most widely used are described below:

- 5S (Sort, Set in Order, Shine, Standardize, Sustain) is the widely recognised formulation. Some organisations extend 5S by adding Safety and/or Spirit; such extensions should be identified as organisational adaptations rather than presented as universally standard components of lean manufacturing.

In this paper, the extended 7S formulation is used to emphasise workplace organisation, safety and organisational culture. Its effectiveness should be assessed through observable workplace and performance indicators rather than assumed from adoption alone.

- Now, 7S is a system emphasising cleanliness and organisation in the workplace through seven standards: Sort, Set in order, Shine, Standardize, Sustain, Safety, and Spirit.
 - a. **Sort:** keep the workplace free of all unnecessary items.
 - b. **Set in order:** everything should be arranged for each workplace to ensure maximum ease and efficiency.
 - c. **Shine:** everyone is responsible for keeping their workspace clean and tidy.
 - d. **Standardize:** roles and tasks should be standardised in lists and schedules to promote good habits.
 - e. **Sustain:** ensure everyone is committed to the long-term goal.
 - f. **Safety:** an effective tool for hazard, injury, and fatality prevention. A safe working environment is established by integrating 7S with an occupational health and safety management system (e.g. OHSAS 18001 / ISO 45001), addressing unsafe acts and unsafe conditions that could otherwise damage equipment, personnel, and the environment, and that undermine quality management.
 - g. **Spirit:** recognises the impact of organisational culture and the importance of respect for employees, including morale and shared purpose, as the seventh element of the methodology.

Just-In-Time (JIT)

Just-In-Time, or Just-In-Sequence (JIS), is a form of lean manufacturing and a logistics method for inventory control. JIT is a system of manufacturing what the customer wants, in the quantity the customer wants, when the customer wants it. This allows the reduction or elimination of buffers or inventory, using delivered components within minutes of their delivery.

Gemba Walks

Gemba means “the real place” in Japanese and refers to the factory floor in manufacturing, or any place where value is created. In lean manufacturing philosophy, a “Gemba walk” is a regular site visit by management, allowing it to develop a real feel for the process and any issues that need addressing.

Value Stream Mapping

This tool involves creating a flow diagram depicting every step in the value process. Such a map allows evaluation of all steps to identify waste and inefficiency and to reduce manufacturing time.

Bottleneck Analysis

The goal is to identify the weakest link, or bottleneck, holding back the speed of the overall process. Lean manufacturing often uses bottleneck analysis to determine the slowest processes and steps in the manufacturing stream; speeding up just one or two functions can often dramatically speed up the entire process.

Continuous flow seeks to minimise interruptions, queues and batch-related delays so that work moves smoothly through the value stream. It does not imply that a factory must operate 24 hours a day; the appropriate operating schedule depends on demand, capacity, maintenance requirements, labour arrangements and process economics.

Closely associated with Kanban and JIT, this tool integrates all production elements through ongoing examination, evaluation, and improvement. To provide stability and continuity, continuous flow usually means running the factory 24 hours a day with no interruption and very little waste, the opposite of batch production.

Lean By-products: Agility, Competitiveness, and Quality

By following lean principles, adopting these tools, and reducing key wastes, manufacturers who specialise in lean concepts create highly desirable by-products. Lean production results in agility in meeting the competitive demands of a swiftly evolving marketplace. The focus on total expense and value, rather than on single-component costs, not only eliminates waste and inefficiency but also promotes quality and customer-driven solutions.

The faster products flow through an organisation from start to finish, the faster the company can respond to market demands and satisfy the consumer; the more efficient the process, the more quality the company can afford for each dollar spent. Lean manufacturing enables producers to navigate a changing market with precision and agility, producing streamlined, simplified operations that remain competitive in modern manufacturing.

Kanban

This Japanese word for “sign” refers to a system of using cards or signs to indicate the phases a product moves through: to do, doing, and done. Using this visual “pull” system, it becomes easier to manage only the parts needed for a specific production run, eliminating the need for excess inventory or backlogged products.

Modern technologies—including cyber-physical systems, the Internet of Things, artificial intelligence, big-data analytics, cloud computing, simulation, virtual/augmented reality and digital twins—can support lean practices by improving visibility, monitoring, prediction and process control. Their contribution should nevertheless be evaluated in

relation to measurable waste reduction and total cost, rather than assuming that digitalisation automatically produces leaner operations.

Modern technologies — Cyber-Physical Systems (CPS), the Internet of Things (IoT), Artificial Intelligence, Big Data, Cloud Computing, Simulation, Virtual Reality (VR), Augmented Reality (AR), and Digital Twins — applied to manufacturing as “Smart Manufacturing,” lead to more effective management of manufacturing, reducing total waste while also improving overall quality.

Kaizen refers to continuous, incremental improvement. In the context of this paper, Kaizen can be directed towards materials, equipment, procedures, workforce practices, quality, safety and environmental performance. Continuous improvement should be supported by clearly defined and measurable indicators.

Proposed composite KPI: $KPI = w_1(APC) + w_2(QC) + w_3(HSE)$, where $w_1 + w_2 + w_3 = 1$ after appropriate normalisation of the component indicators.

The original additive expression ($KPI = APC + QC + HSE$) requires methodological justification because the three components may have different units and scales. A weighted, normalised index is more defensible conceptually, but the weights, normalisation method and validation procedure must be specified and tested empirically. Therefore, the proposed KPI should be presented as a framework for future validation, not as an established universal formula.

CONCLUSION

This paper argues that lean manufacturing can be examined more comprehensively when production waste and environmentally significant waste are considered within a common cost framework. The proposed Total Waste Cost (TWC) expression extends the categories discussed in the paper by explicitly including hazardous-waste handling and treatment costs. The illustrative metal-piping example shows the managerial consequence of this inclusion: the non-hazardous waste categories total \$1,910, whereas inclusion of the illustrative \$800 hazardous-waste treatment cost raises the total to \$2,710. The example therefore demonstrates how excluding hidden waste-related costs can understate the economic burden associated with production waste.

The paper also reviews a range of lean tools—5S/7S, Just-In-Time, Gemba walks, Value Stream Mapping, bottleneck analysis, continuous flow, Kanban, Kaizen and digital manufacturing technologies—and explains how they may contribute to waste reduction, process stability and resource efficiency. However, the study is conceptual and does not provide primary empirical data, statistical validation or comparative evidence across firms. The proposed waste-cost categories and the composite KPI therefore require operational definitions, measurement protocols and empirical testing before they can be treated as generalisable models.

Future research should validate the Total Waste Cost framework through case studies

and multi-company datasets, examine the interaction between operational and hazardous-waste costs, establish rules for avoiding double counting, and test whether reductions in identified waste categories are associated with improvements in cost, quality, delivery, safety and environmental performance. Such validation would strengthen the paper's contribution to multidisciplinary research by connecting lean management, industrial engineering, environmental management and performance measurement.

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