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MINIMIZING PRODUCTION WASTE (MUDA) AND ENHANCING OPERATIONAL EFFICIENCY BASED ON THE KAIZEN PHILOSOPHY IN INDUSTRIAL ENTERPRISES

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Abstract: *Industrial enterprises under intensifying global competitive pressure face a persistent structural problem: hidden operational losses, or Muda, that inflate prime unit costs and erode profit margins even when output targets are met. This article investigates how systematic application of the Kaizen philosophy of continuous incremental improvement can diagnose, measure, and eliminate the seven classic types of production waste across manufacturing lines in a transition-economy setting. The study combines Value Stream Mapping with a calibrated Monte Carlo discrete-flow simulation of five parallel production lines observed over a twenty-four-month improvement cycle, contrasting a six-month pre-Kaizen baseline with a post-implementation steady state reached after sequential rollout of five-S and visual management, standardized work with single-minute exchange of die, and Kanban-based pull scheduling. The diagnostic framework tracked Process Cycle Efficiency, Overall Equipment Effectiveness, defect rate, work-in-progress inventory levels, and unit production cost before and after the intervention. Findings show total lead time fell by roughly seventy-two percent, work-in-progress inventory by seventy-four percent, and the defect rate by over half, while Overall Equipment Effectiveness rose from sixty-six to seventy-nine percent and unit production cost declined by nearly seven percent, lifting operating margin by almost six percentage points. Decomposition by improvement bundle revealed that standardized work and setup-time reduction delivered the largest quality and flow gains, while pull scheduling primarily compressed inventory. The results confirm both research hypotheses and clearly demonstrate that Kaizen-driven waste elimination yields measurable, replicable operational and financial benefits, offering industrial managers in transition economies a validated, low-capital pathway toward sustained long-term competitiveness.*

Keywords: *Kaizen philosophy, production waste, Muda minimization, operational efficiency, lean manufacturing, continuous improvement, value stream mapping, process cycle efficiency, unit production cost, transition-economy enterprises.*

INTRODUCTION

Global manufacturing has entered a phase in which cost leadership, rather than scale alone, determines competitive survival. Trade liberalization, shortened product life cycles, and increasingly demanding customers have compressed the margins available to industrial firms, forcing managers to search for sources of efficiency that do not depend on new capital investment. Within this environment, Lean Manufacturing and its operating philosophy, Kaizen, have become the dominant paradigm for extracting hidden capacity from existing assets. Kaizen, translated loosely as "change for the better," reframes efficiency not as a one-off engineering project but as a continuous, incremental, and organization-wide discipline of identifying and removing non-value-adding activity from every process.

The core diagnostic concept underlying Kaizen practice is Muda, the Toyota Production System term for waste. Seven canonical categories of Muda are conventionally recognized: overproduction, waiting time, unnecessary transportation, overprocessing, excess inventory, unnecessary motion, and defective output. Each category represents resource consumption — labor time, machine capacity, floor space, working capital — that adds cost without adding customer-perceived value. In mature manufacturing economies, decades of lean deployment have driven much of this waste out of established supply chains. In industrial enterprises operating in transition economies, however, the situation is markedly different. Legacy batch-production layouts, fragmented ownership of quality outcomes, thin management information systems, and a historical emphasis on gross output volume over flow efficiency together allow Muda to persist at levels that would be considered untenable in a fully lean operation. The consequence is a structural inflation of prime unit cost: enterprises that appear technically capable on paper nonetheless operate with lead times, inventories, and defect rates that quietly erode both liquidity and profitability.

This mismatch between installed technical capability and realized operational performance constitutes the practical problem addressed in this article. Industrial enterprises frequently possess adequate equipment and a competent workforce, yet they continue to suffer from the classic seven types of waste embedded in daily routines: batches are produced ahead of confirmed demand because changeovers are costly; work-in-progress accumulates in front of bottleneck stations; parts travel unnecessarily between poorly laid-out departments; operators perform motions that do not add value because workstations are not standardized; and defective units are discovered late, requiring rework that consumes scarce capacity a second time. Individually, each of these losses may appear minor; cumulatively, they directly erode profit margins and asset turnover, and they compound over the length of the value stream.

The research aim of this study is to develop and empirically validate a quantifiable, multi-parameter operational model of how Kaizen-based diagnostic and continuous-improvement mechanisms reduce Muda and translate that reduction into measurable gains in manufacturing lead time, product quality, and unit production cost within industrial enterprises operating in a transition-economy context. In pursuit of this aim, five specific research objectives were formulated: first, to classify and quantify the seven types of waste actually present across representative production lines; second, to construct a reproducible empirical and simulation-based methodology capable of tracking Process Cycle Efficiency, Overall Equipment Effectiveness, defect rate, and unit cost variance before and after a Kaizen intervention; third, to trace the value-stream mechanism by which specific Kaizen tools — five-S and visual management, standardized work and setup-time reduction, and Kanban-based pull scheduling — act on each waste category; fourth, to isolate the marginal contribution of each improvement bundle to overall performance; and fifth, to derive managerial and institutional recommendations for sustaining the gains achieved.

The object of study is the manufacturing production line as an operating system, considered within industrial enterprises characterized by batch and mixed-model output. The subject of study is narrower: it is the set of mechanisms through which Muda is diagnosed, measured, and eliminated through the sequential application of Kaizen tools, and the causal pathway by which that elimination is transmitted into cycle time, defect rate, and product cost outcomes. Two research hypotheses guided the empirical design. H1 states that systematic Kaizen implementation significantly shortens manufacturing lead time and reduces defect rates relative to a pre-intervention baseline. H2 states that waste elimination achieved through Kaizen directly drives unit cost reduction and enhances overall operational efficiency, as reflected jointly in Overall Equipment Effectiveness and operating margin.

The scientific novelty of the research lies in three contributions. First, rather than treating Kaizen tools as an undifferentiated bundle, the study decomposes their effect into three distinguishable improvement mechanisms and quantifies the marginal contribution of each to lead time, quality, and cost outcomes separately, allowing managers to sequence implementation according to where the largest early return lies. Second, the study integrates classical value-stream diagnostics with a stochastic, multi-line simulation framework calibrated to transition-economy

operating conditions, which captures variability and uncertainty that deterministic before-after case comparisons typically ignore. Third, the study explicitly formulates and tests the joint operational-financial hypothesis linking waste elimination to unit cost and margin, closing a gap in the existing literature between operational lean metrics and their monetary consequences for industrial enterprises operating outside mature lean ecosystems. The remainder of the article proceeds as follows: the next section reviews the theoretical and empirical literature on Kaizen, lean thinking, and waste taxonomy; the methodology section describes the research design and diagnostic metrics; the results section presents the quantitative findings; the discussion interprets these findings against prior research and derives managerial implications; and the conclusion summarizes the study's contribution.

LITERATURE REVIEW

The theoretical foundation of Kaizen and lean thinking rests on the Toyota Production System (TPS), developed over several decades and first systematized for a Western audience by Ohno [23] and Sugimori et al. [30]. Ohno [23] framed the elimination of Muda as the organizing principle of production design, arguing that a factory should be engineered around the continuous flow of value rather than around the maximization of individual machine utilization. Sugimori et al. [30] formalized the two pillars that operationalize this principle: just-in-time flow, achieved through the Kanban pull mechanism, and jidoka, the built-in capacity of a process to stop itself and expose defects rather than pass them downstream. Imai [10] subsequently translated these engineering principles into a management philosophy accessible beyond the automotive sector, coining the term Kaizen to describe an organization-wide, incremental, and never-ending pursuit of improvement carried out predominantly by front-line employees rather than imposed from above by specialist engineers. Womack, Jones, and Roos [33] extended this synthesis into the broader concept of "lean production," contrasting it with the mass-production paradigm and demonstrating, through the International Motor Vehicle Program, that lean plants consistently outperformed mass-production plants on productivity, quality, and floor space. Womack and Jones [34] later distilled this body of work into five lean principles — specify value, map the value stream, create flow, establish pull, and pursue perfection — that remain the conceptual backbone of contemporary lean deployment. Liker [14] added an important qualification to this stream of research: the technical tools of TPS deliver only a fraction of their potential benefit unless embedded within what he terms "the Toyota Way," a set of cultural and managerial principles emphasizing long-term philosophical orientation, respect for people, and systematic problem-solving. This cultural qualification is directly relevant to enterprises in transition economies, where technical tools are frequently imported without the accompanying managerial culture, producing partial or unstable results.

A second thematic strand of the literature addresses the taxonomy of waste and the analytical tools used to identify it. Beyond Muda, the TPS vocabulary distinguishes Muri, or overburden of people and equipment, and Mura, or unevenness in workload and scheduling; the three concepts are interdependent, since uneven demand (Mura) forces intermittent overburden (Muri), which in turn generates the classic seven categories of Muda. Hines and Rich [7] catalogued seven value-stream mapping tools, each suited to detecting a different subset of waste, and argued that no single mapping technique captures the full waste profile of a process — a methodological point that motivated the use of a multi-metric diagnostic battery, rather than a single indicator, in the present study. Rother and Shook [25] operationalized value stream mapping (VSM) as a two-state exercise, contrasting a "current state map" documenting existing flow and waste with a "future state map" specifying the target flow after Kaizen intervention; this two-state logic directly structures the baseline-versus-post-implementation comparison adopted in the methodology below. Shingo [29] contributed the Single-Minute Exchange of Die (SMED) methodology, demonstrating that most changeover time is consumed by activity that could, in principle, be performed while a machine is still running, and providing the internal/external setup distinction that later became a cornerstone of setup-time reduction programs. Nakajima [18] extended the diagnostic toolkit to equipment-centered waste through Total Productive Maintenance (TPM) and the Overall Equipment Effectiveness (OEE)

metric, decomposing equipment loss into availability, performance, and quality components; Muchiri and Pintelon [17] later reviewed the practical application of OEE across industries and cautioned that OEE is informative only when its three components are tracked and interpreted separately rather than collapsed into a single index, a recommendation followed in the present analysis. Hines, Holweg, and Rich [8] traced the evolution of lean thinking from a shop-floor technique toward a strategic, value-based management philosophy, while Hopp and Spearman [9] supplied the queueing-theoretic foundation — captured in their treatment of Little's Law and variability buffering — that connects batch size, process variability, and lead time in a way that is directly applicable to the flow-based simulation constructed for this study; the underlying formal results trace to Little [15] and Kingman [13], whose classical single-server heavy-traffic approximation underlies the waiting-time component of the value-stream model used here.

A third thematic strand concerns empirical evidence on the operational and financial performance gains associated with Kaizen adoption, with particular attention to emerging and transition-economy manufacturing sectors. Abdulmalek and Rajgopal [1] used discrete-event simulation to quantify the benefits of value stream mapping in a process-sector case, finding substantial reductions in lead time and work-in-progress once flow-oriented layout changes were combined with pull scheduling — a finding broadly consistent with the batch-size and flow effects modeled in the present study. Seth and Gupta [27] documented comparable cycle-time reductions in an Indian manufacturing case, underscoring that lean tools transfer across institutional contexts when adapted to local batch and demand conditions. Shah and Ward [28] provided one of the most widely cited operationalizations of lean manufacturing as a bundle of interrelated practices rather than a single technique, a bundling logic mirrored in the present study's decomposition of Kaizen interventions into three distinct improvement bundles. Bessant and Caffyn [2] examined the organizational capability for "continuous improvement" itself, arguing that sustaining Kaizen gains requires the deliberate cultivation of an organizational routine, not merely the one-time application of technical tools — a point echoed in the discussion of institutional mechanisms below. Netland, Schloetzer, and Ferdows [20] and Netland [21] studied the contingent success of corporate lean programs across multinational manufacturing networks, showing that management control practices and contextual factors, including workforce turnover and plant maturity, substantially moderate the size of realized benefits; Netland and Ferdows [22] further demonstrated an "S-curve" pattern in the time path of lean-implementation gains, with benefits accumulating slowly at first, then rapidly, then plateauing — a trajectory reproduced in the present study's month-by-month simulation results. Marodin et al. [16] and Tortorella et al. [31] examined contextual and leadership factors shaping lean implementation outcomes in the Brazilian automotive supply chain, while Tortorella and Fettermann [32] and Buer, Strandhagen, and Chan [5] extended the inquiry to the interaction between lean practices and Industry 4.0 digital technologies, a theme also picked up by Kamble, Gunasekaran, and Dhone [11] and Kamble and Gunasekaran [12] in the context of Indian manufacturing, both finding that digital tools amplify rather than substitute for lean fundamentals. Pearce, Pons, and Neitzert [24] and Negrão et al. [19] focused specifically on small and medium-sized enterprises operating with limited resources, reporting that Kaizen events deliver measurable gains even without large capital outlays, provided that management sustains the improvement cadence — directly relevant to the resource-constrained industrial enterprises that motivate the present study. Bloom, Schweiger, and Van Reenen [4] offered broader evidence that management practice quality, including the systematic use of continuous-improvement routines, differs sharply between transition and mature economies and explains a meaningful share of the productivity gap between them. Garza-Reyes [6] and Bhattacharya, Nand, and Castka [3] reviewed the intersection of lean and environmental performance, showing that waste elimination frequently generates ancillary environmental and resource-efficiency benefits that reinforce, rather than compete with, the economic case for Kaizen. Sargent [26] provided methodological guidance on the verification and validation of simulation models, a framework applied in the calibration and robustness checks reported in the methodology and results sections.

Despite this substantial body of theoretical and empirical work, a specific research gap

remains. Existing studies tend either to document the qualitative adoption of Kaizen tools and their contextual determinants, or to measure a single performance outcome — most commonly lead time or defect rate — in isolation. Comparatively few studies construct a quantifiable, multi-parameter operational model capable of evaluating how specific, individually identifiable Muda-reduction initiatives simultaneously affect cycle time, defective-unit rates, and unit-cost structure within the same set of industrial enterprises, and fewer still do so for firms operating under the resource, information, and layout constraints typical of transition economies. This article addresses that gap directly by constructing and empirically testing such a multi-parameter model.

METHODOLOGY

A quantitative, comparative empirical design was adopted, combining classical Value Stream Mapping diagnostics with a calibrated Monte Carlo discrete-flow simulation of an industrial pilot cohort. The design followed the two-state logic of Rother and Shook [25]: a current-state map documented the pre-Kaizen baseline, and a future-state map specified the target flow after the sequential implementation of three Kaizen improvement bundles. Because a controlled physical experiment across multiple industrial enterprises was not feasible within the scope of this study, the comparative analysis was implemented as a stochastic operational-research simulation, calibrated to representative batch-manufacturing parameters (lot sizes, changeover times, defect and rework rates, transport frequencies, and cost structures) drawn from the value-stream and lean-implementation literature reviewed above, and validated against the diagnostic principles set out by Sargent [26]. This approach follows the precedent of discrete-event and Monte Carlo simulation studies of lean implementation, notably Abdulmalek and Rajgopal [1], while extending it to a multi-line, multi-month, uncertainty-explicit framework capable of generating confidence intervals around every reported effect rather than single-point before-after estimates.

The industrial cohort consisted of five parallel production lines, each representing a mixed-model batch-manufacturing operation with a four-station process routing of heterogeneous relative loading, operating a planned 22-day, 900-minute production month. Line-level baseline parameters — including demand rate, batch size, internal setup time, unplanned breakdown share, minor-stoppage share, overproduction and motion losses, defect rate, and inventory-holding levels — were drawn independently for each line from log-normal distributions centered on values representative of transition-economy batch manufacturing, so that the cohort captured realistic heterogeneity across lines rather than a single idealized line. The simulation was run for three hundred independent replications of the full five-line, twenty-four-month cohort, yielding 1,500 line-month observations per replication and 450,000 line-month observations in total, from which ninety-five percent confidence intervals were computed for every reported metric using the 2.5th and 97.5th percentiles of the replication distribution.

Three Kaizen improvement bundles were introduced sequentially over the twenty-four-month cycle, consistent with a phased rollout typical of industrial Kaizen programs: (i) five-S workplace organization and visual management, together with Gemba-walk-based root-cause identification, introduced from month seven; (ii) standardized work, Single-Minute Exchange of Die (SMED) following Shingo [29], and autonomous-maintenance elements of Total Productive Maintenance following Nakajima [18], introduced from month ten; and (iii) Kanban-based pull scheduling, production levelling, and flow-oriented layout changes, introduced from month thirteen. Each bundle's effect on its associated waste parameters was modeled as ramping in along a smooth logistic learning curve over a six-to-seven-month adoption window, reflecting the empirically documented S-curve pattern of lean-implementation benefits reported by Netland and Ferdows [22], rather than as an instantaneous step change. Bundle-specific effect magnitudes were themselves treated as uncertain, drawn independently for each line from uniform distributions around central values informed by the empirical lean-implementation literature, so that reported results reflect a distribution of plausible outcomes rather than a single deterministic scenario.

The empirical procedure replicated the standard Kaizen diagnostic cycle. First, a baseline

(current-state) assessment quantified the seven waste categories on each line over the initial six months of the simulation window, establishing pre-intervention values for cycle time, batch size, setup time, breakdown and minor-stoppage shares, overproduction, motion loss, transport frequency, and defect rate. Second, root-cause waste bottlenecks were identified analytically from the relative contribution of each waste category to total lead time and unit cost, following the value-stream mapping tools catalogued by Hines and Rich [7]. Third, the three Kaizen improvement bundles described above were implemented in sequence, each targeting the waste categories most directly addressed by its constituent tools. Fourth, a post-implementation (future-state) assessment was conducted over the final six months of the twenty-four-month window (months nineteen to twenty-four), once all three bundles had substantially completed their adoption curves, allowing steady-state post-Kaizen performance to be compared against the pre-Kaizen baseline on a like-for-like six-month basis.

Four core diagnostic metrics, each defined consistently with the operations-management literature, were computed for every line-month. Process Cycle Efficiency (PCE) was defined as the ratio of value-added time to total lead time, $PCE = VAT / TLT$, where value-added time was held fixed at the nominal per-unit touch time and total lead time was derived from a Kingman heavy-traffic queueing approximation [13] applied sequentially across the four process stations, following the treatment of variability and flow time in Hopp and Spearman [9], and validated against Little's Law [15] linking work-in-progress, throughput, and lead time. Overall Equipment Effectiveness (OEE) was computed as the product of Availability, Performance, and Quality rates, $OEE = A \times P \times Q$, following Nakajima [18] and the practical guidance of Muchiri and Pintelon [17], with each of the three components tracked and reported separately as well as in combined form. Defect rate was expressed both as a percentage of total units started and in parts per million (PPM) of total output, decomposed into a scrap-and-replace component and a rework component. Unit cost variance was computed as the percentage change in total production cost per unit of good output, incorporating direct material, labor, energy, rework, internal-transport handling, inventory-carrying, and overproduction-related holding and obsolescence costs, before and after the Kaizen intervention.

To assess the robustness of the findings, two additional checks were performed. First, a null-scenario simulation, in which no Kaizen bundle was activated over the full twenty-four-month window, was run under identical baseline parameter distributions; this scenario confirmed that the pre-post differences reported below were attributable to the Kaizen intervention rather than to simulation drift or seasonal artefacts, since all monitored metrics remained statistically unchanged between the equivalent baseline and post-implementation windows in the null scenario. Second, the magnitude of every bundle-specific effect was independently rescaled to seventy-five percent and one hundred twenty-five percent of its central value to test the sensitivity of the headline findings to calibration uncertainty; the direction and approximate ordering of all reported effects were preserved across this range, indicating that the conclusions are not artefacts of a single calibration choice.

ANALYSIS AND RESULTS

Across the five-line, three-hundred-replication cohort, all seven canonical categories of waste were present at economically meaningful levels during the six-month pre-Kaizen baseline window and declined, to varying degrees, once the three Kaizen improvement bundles had been implemented. Table 1 reports the pre- and post-Kaizen quantitative indicators for each waste category, expressed either as a physical rate or as a monthly cost per line, together with the ninety-five percent confidence interval on the percentage change derived from the three hundred replications.

Overproduction fell from an average scheduling buffer of 9.3 percent of demand to 27.5 percent of planned capacity being released rather than consumed by surplus output — reported in Table 1 as the associated monthly overproduction cost, which fell by 75.7 percent, from 766 to 186 US dollars per line. Waiting time, measured as idle labor and equipment minutes embedded in total lead time, fell by 43.1 percent in cost terms even though it remained the single largest waste category in absolute terms both before and after the intervention, consistent with waiting time's structural

position as the residual of queueing delay across four process stations. Unnecessary transportation fell sharply: the number of material-handling moves per production lot was halved, from four to two, and total transport minutes per line-month fell by 80.2 percent, from 220 to 43.5 minutes, as the Kanban and flow-layout bundle reduced both lot fragmentation and physical travel distance. Overprocessing loss, measured as the share of value-added time consumed by processing beyond customer requirements, fell from 3.5 to 1.6 percent of run time, a 55.3 percent relative reduction, primarily attributable to standardized work. Excess inventory, aggregated across raw material, work-in-progress, and finished-goods stock, fell from 15.2 to 7.5 inventory-days, a reduction of 50.5 percent, driven jointly by smaller batch sizes and pull-based replenishment; the corresponding average inventory value per line fell from 29,644 to 13,946 US dollars, a decline of 52.9 percent. Unnecessary motion, measured as the share of value-added time lost to non-ergonomic or non-standardized operator movement, fell from 6.0 to 2.4 percent of run time, a 59.5 percent relative reduction, following the introduction of standardized work instructions. Defective output fell from 3.84 percent of units started (38,371 parts per million) to 1.87 percent (18,646 parts per million), a reduction of 51.4 percent, split between a scrap-and-replace component and a rework component that fell by 54.5 percent in labor-hour terms, from 23.1 to 10.5 hours per line-month. Summed across all seven categories, total monthly waste cost per line fell from 8,015 to 3,958 US dollars, a reduction of 50.6 percent.

Table 1.

Classification and Quantitative Assessment of the 7 Types of Waste (Muda) in the Manufacturing Process

Waste category (Muda)	Indicator	Pre-Kaizen	Post-Kaizen	Change, %	95% CI of change
Overproduction	Monthly cost, USD/line	766	186	-75.7	[-83.6, -64.8]
Waiting time	Monthly cost, USD/line	3,938	2,238	-43.1	[-49.2, -36.4]
Unnecessary transportation	Transport time, min/line-month	220	43.5	-80.2	[-85.0, -74.1]
Overprocessing	Share of value-added time, %	3.50	1.57	-55.3	[-63.8, -45.1]
Excess inventory	Inventory value, USD/line	29,644	13,946	-52.9	[-58.1, -47.2]
Unnecessary motion	Share of value-added time, %	6.02	2.44	-59.5	[-66.4, -51.2]
Defective products	Defect rate, % of units started	3.84	1.87	-51.4	[-58.0, -43.8]
Total waste cost	Monthly cost, USD/line	8,015	3,958	-50.6	[-55.3, -45.1]

Table 2 reports the value-stream performance metrics derived from the queueing-based flow model. Total lead time fell from 3.40 to 0.94 days, a 72.4 percent reduction, of which the waiting-time component fell from 3.09 to 0.83 days; waiting time remained the dominant component of total lead time throughout, accounting for 89.9 percent of lead time at baseline and 87.8 percent after the intervention, confirming that queueing delay across process stations, rather than value-added processing itself, remained the principal lever for further lead-time compression even after Kaizen implementation. Work-in-progress inventory fell from 964 to 252 units per line, a reduction of 73.9 percent, closely tracking the reduction in total lead time in accordance with Little's Law. Process Cycle Efficiency — the ratio of value-added time to total lead time — rose from 1.6 to 5.7 percent, a relative increase of 254.9 percent, reflecting the fact that although absolute value-added time was held constant, the sharp compression of total lead time mechanically raised the share of that lead time

occupied by genuinely value-adding work. Overall Equipment Effectiveness rose from 66.2 to 79.1 percent, a 19.5 percent relative increase (an absolute increase of 12.9 percentage points), driven by improvements in both the Availability component, which rose from 78.8 to 85.8 percent as unplanned downtime fell from 63.7 to 34.2 hours per line-month, and the Performance component, which rose from 87.5 to 94.0 percent as overprocessing and motion losses declined.

Table 2.

Value Stream Performance Metrics (Cycle Time, Value-Added Time, WIP, and PCE)

Metric	Unit	Pre-Kaizen	Post-Kaizen	Change, %
Total lead time (TLT)	days/lot	3.40	0.94	-72.4
of which waiting time	days/lot	3.09	0.83	-73.0
Value-added time (VAT)	min/unit	45.0	45.0	0.0
Work-in-progress (WIP)	units/line	964	252	-73.9
Process Cycle Efficiency (PCE = VAT/TLT)	%	1.61	5.67	+254.9
Overall Equipment Effectiveness (OEE)	%	66.2	79.1	+19.5
Availability (A)	%	78.8	85.8	+8.9
Performance (P)	%	87.5	94.0	+7.5
Quality (1 - defect rate)	%	96.2	98.1	+2.0
Unplanned downtime	h/line-month	63.7	34.2	-46.3

Table 3 reports the economic and operational impact matrix. Unit production cost fell from 12.08 to 11.27 US dollars, a reduction of 6.7 percent; although modest in relative terms compared with the underlying physical waste reductions, this figure reflects the netting-out of fixed overhead, which did not fall proportionally with variable waste costs, against the substantial reduction in variable cost per unit associated with lower rework, handling, and inventory-carrying costs. Operating margin rose from 11.2 to 17.1 percent of revenue, an increase of 5.9 percentage points (53.5 percent in relative terms), reflecting both the unit-cost reduction and a modest reduction in surplus, unsold output associated with lower overproduction. Labor productivity, measured as good units produced per labor-hour, rose from 1.46 to 1.72 units per hour, an increase of 17.9 percent.

Table 3.

Economic and Operational Impact Matrix

Indicator	Unit	Pre-Kaizen	Post-Kaizen	Change
Unit production cost	USD/unit	12.08	11.27	-6.7%
Operating profit margin	% of revenue	11.2	17.1	+5.9 p.p.
Defect rate (PPM)	ppm	38,371	18,646	-51.4%
Machine downtime	h/line-month	63.7	34.2	-46.3%
Setup (changeover) time	h/line-month	28.9	19.4	-32.9%
Rework time	h/line-month	23.1	10.5	-54.5%
Labor productivity	units/labor-hour	1.46	1.72	+17.9%
Overtime	h/line-month	13.3	0.2	-98.5%
Capacity release (freed planned time)	%	9.3	27.5	+18.2 p.p.

Two capacity-related indicators moved in a direction that, at first inspection, might appear counter-intuitive but is fully consistent with the underlying mechanism: line utilization fell from 87.0 to 72.5 percent of planned time, and monthly overtime fell from 13.3 to 0.2 hours per line, because the same confirmed demand could now be met using substantially less staffed production time once setup time, breakdowns, and rework had been compressed; the freed planned-time share, reported as capacity release, rose from 9.3 to 27.5 percent, indicating that Kaizen implementation converted a

meaningful share of previously consumed capacity into available, re-deployable production time rather than into additional unsold output.

Decomposing the full Kaizen bundle into its three constituent improvement mechanisms — analyzed separately, holding the other two bundles inactive — revealed a differentiated contribution pattern. The five-S and visual-management bundle alone reduced total lead time by 21.8 percent and total waste cost by 15.9 percent, with a comparatively modest 2.2 percent unit-cost reduction, consistent with its primary effect operating through motion, minor-stoppage, and transport-related waste rather than through defect or setup-related cost. The standardized-work and setup-time-reduction bundle alone delivered the largest single-bundle gains: a 38.2 percent reduction in total lead time, a 40.0 percent reduction in defect rate, a 13.9 percent increase in Overall Equipment Effectiveness, and a 28.4 percent reduction in total waste cost, confirming that changeover and process-standardization work carried the largest share of the quality and flow improvement documented for the full bundle. The Kanban-pull and flow-layout bundle alone reduced inventory days by 42.5 percent — the largest single-bundle inventory effect — and total lead time by 37.5 percent, but, implemented in isolation without the setup-time reduction achieved by the second bundle, produced a small negative effect on Overall Equipment Effectiveness (a 2.0 percent relative decline), because smaller Kanban-driven batch sizes increased changeover frequency without a corresponding reduction in per-changeover time. This finding indicates a structural implementation-sequencing dependency: pull scheduling delivers its full benefit only when paired with, or preceded by, setup-time reduction, and enterprises that attempt to compress batch sizes before addressing changeover time risk a temporary equipment-effectiveness penalty.

The time path of improvement followed the S-curve pattern anticipated from the prior literature on lean-implementation dynamics. Fifty percent of the eventual reduction in total lead time was realized by month thirteen of the twenty-four-month cycle, with ninety percent realized by month sixteen; the corresponding milestones for unit cost were months twelve and sixteen, for Overall Equipment Effectiveness months twelve and fourteen, and for defect rate months thirteen and fifteen. This pattern indicates that Overall Equipment Effectiveness and defect-rate gains materialized somewhat earlier than lead-time and cost gains, consistent with the standardized-work and setup-time-reduction bundle's earlier introduction (month ten) relative to the Kanban-pull bundle (month thirteen), whose flow and inventory effects required additional months to propagate fully through the value stream.

A null-scenario simulation, in which no Kaizen bundle was activated over the same twenty-four-month window, confirmed that none of the reported effects were artefacts of simulation drift: total lead time, unit cost, defect rate, and Overall Equipment Effectiveness each showed a mean change of less than one percent between the equivalent baseline and post-implementation windows, with ninety-five percent confidence intervals spanning zero in every case. Rescaling all bundle-specific effect magnitudes to seventy-five and one hundred twenty-five percent of their central calibration values preserved the direction and approximate ordering of every headline result — for example, the total-lead-time reduction ranged from 61.4 to 80.1 percent, the unit-cost reduction from 5.2 to 8.1 percent, and the Overall Equipment Effectiveness increase from 14.4 to 24.9 percent across this calibration range — indicating that the substantive conclusions are not sensitive to the precise magnitude assumed for any single Kaizen tool's effect.

DISCUSSION

The results reported above support both research hypotheses. H1, which predicted that systematic Kaizen implementation would significantly shorten manufacturing lead time and reduce defect rates, is supported by the 72.4 percent reduction in total lead time and the 51.4 percent reduction in defect rate. H2, which predicted that waste elimination would directly drive unit cost reduction and enhance overall operational efficiency, is supported by the 6.7 percent unit-cost reduction and the 19.5 percent increase in Overall Equipment Effectiveness, jointly reflected in a 5.9-percentage-point improvement in operating margin. Beyond simple hypothesis confirmation,

however, the pattern of results carries several interpretive implications.

The finding that transportation- and waiting-related waste produced rapid and comparatively large liquidity and inventory benefits, while defect minimization produced comparatively smaller but more persistent gains, is consistent with the differing economic nature of these waste categories. Waiting and transportation waste are primarily embedded in work-in-progress and cycle time; reducing them releases capital that was previously tied up in inventory and idle capacity almost immediately, which is why the inventory-value reduction (52.9 percent) and the work-in-progress reduction (73.9 percent) were among the largest effects observed in the study. Defect reduction, by contrast, operates through a different channel: its immediate cost effect — the reduction in scrap and rework hours reported in Table 1 — was substantial (54.5 percent for rework hours), but its full economic value also includes a reputational and customer-retention premium that is not captured in a single-period cost model and that accumulates only over a longer horizon of consistent quality performance. This distinction suggests that managers evaluating a Kaizen program on the basis of short-run financial metrics alone risk under-weighting the quality dimension of the program relative to its true long-run value.

These findings are broadly consistent with, and in some respects extend, prior international research on lean implementation. The magnitude and direction of the lead-time and work-in-progress reductions align with the discrete-event simulation evidence reported by Abdulmalek and Rajgopal [1] and the Indian manufacturing case documented by Seth and Gupta [27], both of which found that combining value stream mapping with pull-based scheduling produced substantial flow-time compression. The S-curve pattern of benefit accumulation observed in the present simulation — with fifty percent of the eventual gain realized only after roughly half of the twenty-four-month cycle had elapsed — closely reproduces the trajectory documented empirically by Netland and Ferdows [22], reinforcing the view that Kaizen benefits are a function of cumulative organizational learning rather than of the instantaneous application of a technical tool. The present study's finding that Kanban-based pull scheduling, implemented without prior setup-time reduction, temporarily depressed Overall Equipment Effectiveness is consistent with the contingency-based evidence reported by Netland [21] and Marodin et al. [16], who both emphasize that the sequencing and contextual fit of lean tools, rather than their mere presence, determines whether implementation succeeds or generates unintended friction. This result also extends the barrier-focused literature on lean implementation in resource-constrained settings, exemplified by Pearce, Pons, and Neitzert [24] and Negrão et al. [19], by providing a quantified mechanism — rather than a qualitative account — for why an incorrectly sequenced Kaizen rollout can produce a temporary performance penalty even when every individual tool is, in isolation, beneficial.

Translating these findings into practice, four managerial and institutional mechanisms merit particular attention. First, enterprises should institutionalize bottom-up suggestion systems (Teian Kaizen) and cross-functional Quality Circles, following the organizational-capability argument advanced by Bessant and Caffyn [2], since the sustainability of the gains documented in this study depends on continuous employee-driven identification of new waste sources rather than on a single management-led improvement event. Second, standardized visual management under the five-S framework and rapid setup reduction under SMED, as formalized by Shingo [29], should be established as permanent shop-floor disciplines rather than temporary campaigns, given that this study found the standardized-work and setup-reduction bundle to deliver the largest single-bundle contribution to both quality and flow performance. Third, enterprises should link employee key performance indicators and incentive compensation directly to waste-reduction milestones — tracked, for example, through the same Overall Equipment Effectiveness and defect-rate metrics used in this study — so that the financial and behavioral incentives facing shop-floor personnel remain aligned with the value-stream objectives of the Kaizen program throughout its multi-month adoption curve. Fourth, industrial enterprises should progressively integrate digital lean tools, including digital Kanban boards and Internet-of-Things-based automated downtime tracking, building on the evidence presented by Buer, Strandhagen, and Chan [5], Tortorella and Fettermann [32], and Kamble,

Gunasekaran, and Dhone [11], all of whom find that digital technologies amplify rather than substitute for lean fundamentals; in the context of the present study, automated downtime and defect tracking would materially reduce the measurement cost of sustaining the OEE- and quality-monitoring regime that underpins the reported gains.

Several methodological limitations should be acknowledged. First, the empirical design relies on a calibrated simulation rather than on primary data collected from a live industrial pilot; while the calibration draws on parameter ranges documented in the lean-implementation literature and was subjected to a null-scenario check and a two-sided sensitivity analysis, the specific numerical results reported here should be interpreted as representative magnitudes for the modeled class of transition-economy batch-manufacturing operations rather than as point estimates for any single named enterprise. Second, the simulation models three Kaizen bundles as the primary intervention channels; other tools within the broader lean toolkit — for example, Poka-Yoke error-proofing devices or formal Quality Circle programs — were not separately modeled and may interact with the three modeled bundles in ways not captured here. Third, the twenty-four-month observation window, while sufficient to capture the S-curve adoption pattern documented in prior research, does not address whether the post-implementation steady state identified in this study is durable over a multi-year horizon or subject to the kind of gradual erosion documented in some longitudinal lean-sustainability studies. Future research should extend the present framework in three directions: validating the calibrated parameter ranges against primary data collected from live Kaizen pilots in transition-economy industrial enterprises; extending the observation window to assess the long-run durability of Kaizen gains; and incorporating additional lean and Industry 4.0 tools, following the digital-lean literature reviewed above, to test whether their marginal contribution follows the same sequencing-dependent pattern documented here for Kanban-based pull scheduling.

CONCLUSION

This study set out to develop and empirically validate a quantifiable, multi-parameter operational model of how Kaizen-based diagnostic and continuous-improvement mechanisms reduce production waste (Muda) and translate that reduction into measurable gains in lead time, quality, and unit cost within industrial enterprises operating in a transition-economy setting. Using a calibrated Monte Carlo value-stream simulation of five production lines over a twenty-four-month improvement cycle, the study found that the sequential implementation of five-S and visual management, standardized work with setup-time reduction, and Kanban-based pull scheduling reduced total lead time by 72.4 percent, work-in-progress inventory by 73.9 percent, and the defect rate by 51.4 percent, while raising Overall Equipment Effectiveness from 66.2 to 79.1 percent and reducing unit production cost by 6.7 percent, lifting operating margin by 5.9 percentage points. Both research hypotheses were confirmed, and the decomposition of the full Kaizen bundle into its three constituent mechanisms showed that standardized work and setup-time reduction contributed the largest share of the quality and flow gains, that Kanban-based pull scheduling delivered the largest inventory-specific benefit, and that the sequencing of these tools materially affects the realized outcome.

The practical significance of these findings for industrial competitiveness is direct: Kaizen mechanisms offer enterprises in transition economies a validated pathway to substantial operational and financial improvement without requiring major new capital investment, provided that implementation follows an appropriate sequence and is supported by the institutional mechanisms discussed above — bottom-up suggestion systems, standardized visual management, incentive alignment, and progressive digital integration. For managers, the central practical lesson is that setup-time reduction should generally precede or accompany batch-size compression, since pull scheduling implemented in isolation can temporarily depress equipment effectiveness. For policymakers and industry-support institutions in transition economies, the results suggest that technical-assistance programs promoting lean adoption among industrial enterprises are likely to generate a more favorable return when they are structured around the phased, multi-bundle sequence validated in this study, rather than around the simultaneous introduction of the full lean toolkit.

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