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Evaluating Readiness for OEE Aligned with Industry 4.0 in Pakistan's Dates Packaging Industry: A Systematic Literature Review

Ayaz Ali Mandan[1,2*], Khairur Rijal Bin Jamaludin[1], Sikander Ali Mandan[1], Syed Ali Raza Shah[3], Abid Akbar Soomro[4]
[1]Faculty of Artificial Intelligence, Universiti Teknologi Malaysia (UTM), Kuala Lumpur 54100, Malaysia, [2]Benazir Bhutto Shaheed University of Technology and Skill Development, Khairpur Mirs, Sindh, Pakistan, [3]National Institute of Public Administration (NIPA), Quetta, [3]Department of Mechanical Engineering, Balochistan University of Engineering and Technology, Khuzdar, Pakistan, [4]PETRONAS Carigali Sdn Bhd , Tower 1, Petronas Twin Towers, Kuala Lumpur City Center, 50088 Kuala Lumpur, Malaysia
Email: abidakbar_soomro@petronas.com.my, abid.akbar28@gmail.com
* Corresponding Author Email: ayazmandan@gmail.com

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Abstract
In the dates packaging industry, where changeovers, micro-stoppages, and seal/label integrity drive export acceptance, Overall Equipment Effectiveness (OEE) is the pivotal, integrative metric that aligns operational improvement with IR4.0 capabilities. This PRISMA-guided systematic review (2015–October 2025) evaluates the technological, organizational, and workforce readiness of Pakistan's dates packaging SMEs to implement OEE in an IR4.0 paradigm, identifies adoption enablers/barriers, and proposes a phased roadmap. Searches across Scopus, Web of Science, Xplore, and ScienceDirect (supplemented by policy/industry sources) included food/agri-food/packaging or comparable discrete-manufacturing studies reporting OEE (or Availability/Performance/Quality) and/or IR4.0 technologies (IoT/IIoT, CMMS, machine vision, predictive maintenance/TPM 4.0, digital twins). Evidence, synthesized via the Technology–Organization–Environment (TOE) lens and Resource-Based View (RBV) theories, shows that sensitization, PdM/TPM 4.0, vision inspection, and digital twins consistently improve OEE and related KPIs, yet adoption is constrained by leadership, data-governance, infrastructure, and skills deficits. Despite a supportive macro-environment, date-specific OEE and IR4.0 deployments remain emergent. The review provides a concise, connectivity-first roadmap that couples OEE standardization and IR 4.0 with the progressive integration of vision systems and digital twins, underpinned by workforce upskilling and governance, to accelerate export-grade performance.
Keywords: OEE, Industry 4.0, Dates Packaging, Pakistan SMEs, TPM, Predictive Maintenance, Digital Twin, Machine Vision

Introduction

This study is motivated by the increasing demand for operational modernization and export competitiveness in Pakistan's dates packaging industry. Despite favorable macroeconomic and policy conditions, the sector struggles with limited automation, weak maintenance systems, and fragmented data practices. Therefore, this research seeks to address these challenges by evaluating the readiness of SMEs for adopting OEE within an Industry 4.0 framework. It contributes to both theory and practice by developing an integrated roadmap that aligns technological, organizational, and workforce factors with measurable improvements in equipment effectiveness.

Pakistan's export agenda positions dates as a priority horticultural commodity and calls for targeted upgrades in post-harvest handling, processing, and packaging to capture greater value addition (Ministry of Commerce, 2024). The domestic packaging industry, estimated at roughly US$5.4–5.5 billion, remains heavily reliant on imported equipment and external technical expertise, a structure that simultaneously exposes performance gaps and creates modernization opportunities (U.S. Department of Commerce, 2024a, 2024b; VIS Credit Rating Company, 2025). Within this context, Overall Equipment Effectiveness (OEE) the composite of Availability, Performance, and Quality, functions as a unifying operational construct for diagnosing losses and prioritizing improvement at the line level (Koç, 2025; Sathler et al., 2023). Contemporary reviews in food manufacturing demonstrate that aligning OEE programs with Industry 4.0 (IR4.0) capabilities, sensorization, cyber-physical connectivity, and analytics enhances real-time control of quality, traceability, and throughput, thereby elevating line performance (Peres et al., 2025). Domestically, the Pakistan Horticulture Development & Export Company (PHDEC) has amplified sectoral readiness through technical outreach on dates post-harvest management and value-added products, reinforcing a policy trajectory toward export-compliant packaging (PHDEC, 2023a, 2023b).

Despite this enabling macro-environment, plant-level conditions in the early stages have typically featured legacy machinery, limited PLC interoperability, minimal sensor coverage, and fragmented data capture (paper logs or ad hoc spreadsheets), all of which constrain OEE visibility and impede systematic loss elimination (U.S. Department of Commerce, 2024a, 2024b). Weak adoption of computerized maintenance management systems and reactive maintenance cultures have increased unplanned downtime and obscured micro-stoppages, while complex changeovers across SKUs and inconsistent line-clearance practices have depressed OEE's Performance and Quality pillars (Gomaa et al., 2025; Sathler et al., 2023). Concurrently, rising export requirements for quality and traceability have outpaced the deployment of in-line inspection (e.g., seal integrity and label verification) and end-to-end data lineage, elevating the risk of defects and customer returns (Peres et al., 2025; Ministry of Commerce, 2024). At the ecosystem level, SMEs face persistent capability deficits in data engineering, condition monitoring, and cross-functional problem solving; these gaps, compounded by capital constraints and import dependence for spares and upgrades, slow modernization and can entrench vendor lock-in (Angreani et al., 2024; Techanamurthy et al., 2025; U.S. Department of Commerce, 2024a).

Framing "readiness" through the Technology–Organization–Environment (TOE) lens clarifies that successful OEE-aligned IR4.0 adoption rests on: (i) technology and interoperable connectivity (OPC-UA/MQTT), sensors/vision, and maintainable integration patterns; (ii) organization-leadership commitment, KPI governance with a shared OEE data dictionary, TPM/RCM routines, and disciplined problem-solving; and (iii) environment-export driven standards, integrator/vendor ecosystems, and financing instruments (Peres et al., 2025; Gomaa et al., 2025; Ministry of Commerce, 2024). Complementing TOE, the Resource-Based View (RBV) positions maintenance analytics, data engineering, and operator data-literacy as strategic capabilities that transform OEE improvements into a durable advantage (Angreani et al., 2024).

Against this backdrop, the present study pursues a PRISMA-guided systematic literature review to evaluate the technological, organizational, and workforce readiness of Pakistan's dates packaging industry for OEE-aligned I4.0, identify adoption enablers and barriers on the packaging floor, and propose a phased integration roadmap. Building on the synthesis, the research program advances a multi-method, staged strategy: (1) National readiness benchmarking using validated TOE/RBV constructs with relationships to OEE outcomes (Angreani et al., 2024; Techanamurthy et al., 2025); (2) Plant-level baselining of OEE (A×P×Q), standardized loss taxonomies, and shift-wise dashboards to surface bottlenecks and micro-stoppages (Sathler et al., 2023; Koç, 2025); (3) Quasi-experimental intervention pilots introducing TPM 4.0 practices and connectivity-first upgrades (OPC-UA/MQTT gateways, CMMS digitization), with selective deployment of in-line vision and condition monitoring, and before–after evaluation on OEE pillars, downtime, MTBF/MTTR, defects ppm, and changeover time (Gomaa et al., 2025; Peres et al., 2025); (4) Digital-twin proof-of-concepts to explore SKU sequencing, SMED scenarios, and line-balancing effects on throughput and OEE Performance (Abdurrahman et al., 2025); and (5) Synthesis to policy and practice, yielding a financing-aware adoption roadmap (connectivity → PdM/vision → digital twin/MES) aligned with export and traceability priorities (Ministry of Commerce, 2024; U.S. Department of Commerce, 2024a). This strategy operationalizes an OEE-anchored, connectivity-first trajectory that simultaneously addresses legacy constraints and builds organizational and human capabilities, thereby de-risking digital transformation while accelerating export-grade performance in Pakistan's dates packaging sector.

Background

Pakistan's dates value chain has strategic importance for export diversification, with recent policy instruments emphasizing post-harvest management, processing, and packaging upgrades to unlock value addition and compliance with international standards (Ministry of Commerce, 2024). Packaging, as the final transformation step before market entry, concentrates critical quality risks seal integrity, label correctness, contamination control and productivity losses-micro-stoppages, speed losses, and changeover delays that making it a focal point for operational excellence programs (Sathler et al., 2023). Within this operational theatre, Overall Equipment Effectiveness (OEE) offers a canonical composite of Availability, Performance, and Quality that enables loss taxonomy, benchmarking, and governance across heterogeneous packaging assets (Koç, 2025).

Concurrently, Industry 4.0 (IR4.0) technologies industrial connectivity (OPC-UA/MQTT), sensorization and condition monitoring, computerized maintenance management systems (CMMS), machine vision, predictive maintenance (PdM) and TPM 4.0 routines, and line-level digital twins have reoriented continuous improvement from periodic reporting to near real-time control and decision support (Gomaa et al., 2025; Peres et al., 2025; Abdurrahman et al., 2025). In food and packaging contexts, these enablers consistently reduce unplanned downtime, shorten changeovers, and lower defect rates, thereby improving OEE pillars and stabilizing throughput and quality (Peres et al., 2025; Gomaa et al., 2025). Yet the translation of these gains to small and medium-sized enterprises (SMEs) depends on organizational capabilities, leadership commitment, KPI governance, and workforce skills rather than technology alone (Angreani et al., 2024; Techanamurthy et al., 2025).

The Pakistan packaging sector is sizable but remains equipment-import dependent, a structure that introduces modernization opportunities alongside capability and supply-risk challenges (U.S. Department of Commerce, 2024a, 2024b; VIS Credit Rating Company, 2025). Sectoral initiatives led by the Pakistan Horticulture Development & Export Company (PHDEC) have promoted technical upgrading in dates through outreach on harvest, post-harvest handling, and value-added products, signaling policy momentum toward export-compliant packaging practices (PHDEC, 2023a, 2023b). Despite this enabling macro-environment, plant-level realities commonly include legacy PLCs without interoperable data layers, limited sensor coverage, inconsistent CMMS use, and paper-based logbooks, conditions that obscure loss structures and impede systematic OEE improvement (U.S. Department of Commerce, 2024a, 2024b).

From a theoretical standpoint, Technology–Organization–Environment (TOE) and the Resource-Based View (RBV) offer complementary lenses to conceptualize “readiness.” TOE foregrounds technological enablers (connectivity, sensors/vision, integration patterns), organizational levers (leadership, data governance, TPM/RCM), and environmental catalysts (buyer standards, vendor ecosystems, finance), while RBV emphasizes the accumulation of rare, valuable, and hard-to-imitate capabilities such as maintenance analytics, data engineering, and operator data-literacy (Angreani et al., 2024; Techanamurthy et al., 2025).

In dates packaging specifically, the tight coupling between export quality requirements and end-of-line controls makes OEE a pragmatic “north-star” KPI for sequencing IR4.0 investments from connectivity and TPM foundations to vision-enabled quality control and simulation-supported line optimization (Peres et al., 2025; Sathler et al., 2023). Empirically, the international literature documents OEE gains when Lean/TPM and CMMS are integrated with IR4.0 enablers, but context-specific product mix, seasonality, and packaging formats affect transferability and necessitate localized road mapping (Peres et al., 2025; Gomaa et al., 2025). Pakistan’s dates supply is seasonal and heterogeneous, amplifying setup and quality risks and increasing the managerial premium on standardized OEE definitions, shared loss taxonomies, and disciplined changeover (SMED) practice (Sathler et al., 2023; Koç, 2025). Further, financing constraints and vendor lock-in risks call for staged, connectivity-first adoption that demonstrates measurable OEE benefits early, thereby crowding in subsequent investments (U.S. Department of Commerce, 2024a; VIS Credit Rating Company, 2025).

Assessing Readiness for OEE-Aligned Industry 4.0 in Pakistan’s Dates Packaging Sector

This study is intended to systematically assess the readiness of Pakistan’s dates packaging industry to implement Overall Equipment Effectiveness (OEE) within an Industry 4.0 (IR4.0) paradigm and to translate the evidence into a phased, practice-oriented roadmap for dates packaging plant-level adoption. Conceptually, readiness is framed through the Technology–Organization–Environment (TOE) perspective and the Resource-Based View (RBV) to link capability endowments to measurable operational performance (i.e., OEE and its pillars, Availability, Performance, and Quality) (Angreani et al., 2024; Techanamurthy et al., 2025).

First, the research intends to diagnose technological readiness by auditing interoperability (e.g., OPC-UA/MQTT), sensorization and in-line inspection (machine vision), maintenance digitization (CMMS), and data governance required to shift OEE from periodic reporting to real-time control (Gomaa et al., 2025; Peres et al., 2025). Second, it aims to assess organizational readiness, leadership commitment, standardized OEE data dictionaries, TPM/RCM routines, and structured problem-solving as mediators of technology-to-performance translation in SMEs (Koç, 2025; Sathler et al., 2023). Third, it will evaluate workforce readiness, focusing on data literacy and cross-functional skills necessary to sustain predictive maintenance, vision-enabled quality, and continuous improvement (Angreani et al., 2024; Techanamurthy et al., 2025). These assessments are situated within Pakistan's policy and market context, where export strategies prioritize post-harvest upgrading and where the packaging sector's scale and import dependence create both modernization opportunities and constraints (Ministry of Commerce, 2024; U.S. Department of Commerce, 2024a, 2024b).

Empirically, the study will (i) establish OEE baselines and loss taxonomies in representative plants; (ii) identify enablers and barriers of OEE-IR4.0 adoption in SMEs; and (iii) estimate readiness→performance linkages using structural modeling to quantify how TOE/RBV capabilities drive OEE gains (Sathler et al., 2023; Angreani et al., 2024). Building on this diagnosis, the researcher intends to propose and field-test a sequenced roadmap—Phase 1: connectivity and OEE governance; Phase 2: PdM/TPM 4.0 and in-line vision;

Phase 3: digital-twin-supported optimization and MES/ERP integration to accelerate export-grade performance while de-risking digital investments (Peres et al., 2025; Gomaa et al., 2025; Ministry of Commerce, 2024). The overarching intention is to contribute a validated readiness index, causal evidence linking readiness to OEE improvement, and a finance-aware adoption pathway generalizable to agri-food packaging SMEs.

Literature Review

Overall Equipment Effectiveness (OEE)—synthesizing Availability, Performance, and Quality—remains the dominant, line-level productivity KPI in food and packaging manufacturing. Recent benchmark reports based on connected-machine telemetry show wide dispersion across plants and countries but confirm measurable gains when loss accounting is standardized and acted on via daily management and improvement routines (e.g., TPM/Lean), supported by basic digitization (shop-floor data capture, dashboards) (Evocon, 2024). These sources emphasize that before "advanced" Industry 4.0 (I4.0) tools pay off, plants must first establish consistent OEE definitions and loss models to avoid "apples-to-oranges" comparisons that blunt improvement cycles. Within the IR4.0 canon, predictive maintenance (PdM) is consistently linked to Availability improvements by shortening mean time to repair (MTTR) and extending mean time between failures (MTBF) through sensorization, streaming analytics, and ML-based prognostics. Peer-reviewed work focused on SMEs demonstrates practical PdM decision-support systems that integrate heterogeneous sensors and deliver actionable alerts (Pejić Bach et al., 2023). Sector-specific practitioner pieces for food and beverage underline hygiene/compliance advantages (e.g., preventing sanitation breaches due to equipment degradation) alongside downtime reduction—benefits that translate directly into OEE (AssetWatch, 2025). MDPI+1

For Quality (and indirectly Performance through fewer micro-stoppages), inline machine-vision + ML has matured rapidly. Recent reviews in food computing and food engineering document high-speed, non-destructive inspection for packaging defects (seal integrity, label compliance, fill level) and surface anomalies—capabilities increasingly feasible on the line as inference latency drops (Liakos, 2025; Saha et al., 2025; Zhao et al., 2025). In practice, these systems lift first-time-through quality, reduce rework/scrap, and stabilize flow—thus affecting two of the three OEE components. MDPI+2ScienceDirect+2. Digital twins (DTs)—once data plumbing and standards are in place—extend benefits to Performance (and sometimes Availability) by compressing changeovers, de-bottlenecking stations, and enabling "what-if" SKU-mix validation before live deployment. Recent reviews and case-style reports across discrete manufacturing lines and logistics detail DT architectures and report improvements in throughput, scheduling, and ramp-up losses when twins are paired with training and standardized data models (Feng et al., 2024; Liu et al., 2024). MDPI+1

Adoption patterns in SMEs are best explained with Technology–Organization–Environment (TOE) and Resource-Based View (RBV) lenses. Empirical maturity-model research grounded in TOE shows that staged roadmaps—connectivity and data governance first; PdM/vision second; DTs/optimization last—are most feasible for resource-constrained settings (Senna et al., 2023; Wang et al., 2025). Barriers recur across contexts: legacy, heterogeneous equipment; fragmented data; skills gaps; and financing constraints (Gold, 2025). ScienceDirect+2Taylor & Francis Online+2. Within Pakistan's dates value chain, policy and market diagnostics indicate a strategic yet under-modernized packaging segment. Trade-promotion and sector reports highlight export potential and call out gaps in post-harvest handling, grading/sorting, pack integrity, and branding—areas where OEE-aligned I4.0 (connectivity, CMMS/MES, inline vision, PdM) can raise line reliability and quality compliance (TDAP, 2025; TDAP, 2022; PHDEC, 2023–2024).

Broader export-strategy documents similarly stress upgrading packaging and conformance to international standards as prerequisites for value addition (Ministry of Commerce, 2024). Despite the macro opportunity, plant-level digital maturity appears heterogeneous ("islands of automation"), implying that connect → standardize → visualize → improve programs and OEE discipline are necessary precursors to DT-level optimization. Commerce.gov.pk+4TDAP+4TDAP+4

Synthesis: Across food/packaging, a pragmatic bundle—connectivity + OEE standardization + TPM/PdM + inline vision—delivers near-term gains; digital twins amplify benefits after foundational data work. For Pakistan's dates-packaging SMEs, the literature supports a staged roadmap anchored in TOE/RBV: (1) baseline OEE and loss model with connected data capture; (2) PdM pilots on critical assets and inline vision for pack integrity; (3) progression to DT-supported changeover and line-balancing once data quality and skills mature. The main evidence gap is domain-specific, causal studies within dates packaging (vs. adjacent food/packaging cases), suggesting an SLR contribution in codifying effect sizes and readiness prerequisites for developing-country SMEs.

Method

This review followed a prespecified protocol aligned with PRISMA 2020, detailing databases, Boolean search strings, screening instruments, a structured data-extraction schema, and risk-of-bias criteria; preregistration on OSF/PROSPERO was planned to enhance transparency. Eligibility encompassed studies published from 2015 to October 2025 (with emphasis on 2021–2025), including empirical designs (case studies, quasi-experiments, before–after evaluations, surveys) and systematic reviews, as well as select high-quality grey literature with explicit methods. The substantive scope covered food/agri-food/packaging and comparable discrete-manufacturing lines, with Pakistan policy/industry sources retained for contextualization. Outcomes of interest were Overall Equipment Effectiveness (OEE) and/or its pillars (Availability, Performance, Quality), downtime/MTBF/MTTR, defects/FTQ, throughput, changeover time, readiness constructs grounded in TOE/RBV, and Industry 4.0 (I4.0) enablers (IoT/IIoT, OPC-UA/MQTT, CMMS, machine vision/AI, predictive maintenance/TPM 4.0, and digital twins).

Information sources included Scopus, Web of Science Core Collection, IEEE Xplore, and ScienceDirect (2015–present) using field tags and database-specific filters; Pakistan-specific context was triangulated through PHDEC, the Ministry of Commerce, and Trade.gov. A canonical query pattern was: (“overall equipment effectiveness” OR OEE) AND (packing* OR “food industry” OR “agri-food”) AND (“industry 4.0” OR IoT/IIoT OR “digital twin” OR “predictive maintenance” OR CMMS OR OPC-UA OR MQTT OR “machine vision”) AND (SME OR factory OR plant OR line). Two independent reviewers screened titles/abstracts and full texts, documenting exclusion reasons for the PRISMA flow. For included records, extraction captured bibliometrics, context (sector, line type, firm size), interventions/exposures (IR4.0 enablers; Lean/TPM/RCM/SMED), primary and secondary KPIs (OEE; A-P-Q; downtime; defects; throughput; changeover), readiness factors (technology, organization, workforce), and analytic details. Study quality was appraised using a mixed-methods/JBI-informed checklist; sensitivity analyses were preplanned to assess robustness by excluding lower-quality evidence.

Across recent food and packaging literature, digitally enabled improvement programs, combining Lean/TPM routines with CMMS, in-line vision, and basic connectivity consistently deliver measurable OEE uplifts: higher Availability via downtime reduction, improved Performance through fewer micro-stoppages and speed losses, and stronger Quality through higher first-time-through. Maintenance 4.0 syntheses attribute these gains to sensorization and predictive analytics that shorten MTTR and extend MTBF (Sathler et al., 2023; Gomaa et al., 2025; Peres et al., 2025). In parallel, digital-twin applications compress changeovers, stabilize throughput under SKU variability, and de-bottleneck line balances-effects that translate directly into OEE improvements (Abdurrahman et al., 2025).

Mechanistically, the OEE × IR4.0 bundle acts on A/P/Q through complementary levers. Industrial connectivity (e.g., OPC-UA/MQTT) and standardized tag architectures transform downtime, micro-stops, speed losses, and defect events into machine-interpretable signals, enabling rapid loss localization and faster detection-to-response cycles that lift Availability and Performance (Sathler et al., 2023). TPM 4.0 and predictive maintenance shift maintenance regimes from reactive to condition-based or prognostic, increasing MTBF, reducing MTTR, and smoothing cadence (Gomaa et al., 2025). In-line vision addresses Quality head-on by preventing or rapidly isolating seal, label, and contamination defects, thereby reducing rework and scrap and strengthening export-grade conformance (Peres et al., 2025). Digital twins amplify these effects by enabling safe "what-if" experimentation on SKU mix, buffer sizing, staffing, and changeover strategies, which raises Performance and dampens variability typical of seasonal product-mix shifts (Abdurrahman et al., 2025).

Within Pakistan's dates-packaging context, macro enablers are visible: a sizable packaging market, policy emphasis on post-harvest upgrading, and PHDEC programs that prioritize packaging modernization and export readiness (PHDEC, 2023a, 2023b; Ministry of Commerce, 2024; U.S. Department of Commerce, 2024a, 2024b; VIS Credit Rating Company, 2025). Yet plant-level maturity remains early-to-mid: "islands of automation," underused CMMS, sparse sensors, legacy PLCs without interoperable exposure, limited integrated OEE dashboards, and a near-absence of digital twins. Through TOE/RBV lenses, recurring readiness gaps emerge-technological (connectivity, sensors, CMMS utilization, twins), organizational (OEE data dictionary, KPI governance, TPM/RCM cadence), and workforce (data literacy, condition-monitoring skills). Notably, the very enablers that are missing-connectivity, CMMS, vision, and PdM/TPM 4.0 are repeatedly associated with statistically meaningful OEE uplifts once deployed (Peres et al., 2025; Gomaa et al., 2025; Abdurrahman et al., 2025; Sathler et al., 2023; Angreani et al., 2024; Techanamurthy et al., 2025).

The binding constraint is seldom algorithmic sophistication; it is the absence of a managed operating system that links front-line routines to OEE movement. Governance gaps (no shared OEE dictionary, unclear KPI ownership, ad-hoc escalation), capability gaps (limited operator data literacy, thin reliability engineering, weak CMMS discipline), and integration gaps (non-interoperable PLCs, fragmented vendor stacks, paper-based QC) collectively impede time-to-value and dilute ROI well-documented in developing-country SMEs (Angreani et al., 2024; Techanamurthy et al., 2025).

Given these constraints, the adoption calculus should follow a connectivity-first, cadence-led sequence that front-loads quick wins and builds the case for deeper CapEx. A phased roadmap for Pakistan's dates packaging sector is therefore warranted: 0–6 months—define OEE (A×P×Q), publish the loss tree, connect bottlenecks to a live OEE dashboard, activate CMMS, and institute TPM foundations with weekly OEE huddles; 6–18 months layer condition monitoring and predictive alerts, integrate vision for seal/label/defect checks feeding OEE-Q, and institutionalize SMED to stabilize changeovers; 18–36 months pilot a digital twin for SKU sequencing, line balancing, and staffing "what-ifs," and integrate MES/ERP for closed-loop planning and traceability aligned to export standards. Cross-cutting enablers include continuous skills programs, formal data governance (OEE dictionary, cybersecurity), robust vendor SLAs with open-protocol commitments, and blended finance tied to national export priorities (Abdurrahman et al., 2025; Peres et al., 2025; Gomaa et al., 2025; Ministry of Commerce, 2024; U.S. Department of Commerce, 2024a).

Managerial implications follow directly: (1) define OEE precisely and codify the loss taxonomy; (2) treat capability building (operator data literacy, reliability basics, structured problem-solving) as core CapEx, not "training extras"; (3) contract modularly with open-protocol requirements and performance-based SLAs to avoid technical debt; (4) align financing with staged, evidenced milestones—connectivity/TPM gains should unlock PdM/vision, which in turn funds twin/MES integration; and (5) exploit seasonal troughs to run SMED bursts and twin-guided changeover pilots, maximizing learning at minimal opportunity cost (Sathler et al., 2023; Gomaa et al., 2025; Peres et al., 2025). For policy and ecosystem actors, targeted instruments can crowd-in private investment: matching grants for connectivity and CMMS, shared systems-integrator pools to lower SME transaction costs, and procurement/standards that reward traceability and OEE-Quality improvements (Ministry of Commerce, 2024). University-industry attachments that embed reliability/data-engineering interns can accelerate capability formation, while sector associations can publish reference architectures (OPC-UA tag sets, OEE data schemas, cybersecurity baselines) to reduce reinvention.

Finally, research implications center on comparability and causal identification. Reporting should converge on common OEE definitions and disclose A/P/Q along with changeover time, downtime, MTBF/MTTR, and defect ppm to enable meta-analysis. Causal designs (stepped-wedge, interrupted time series) are needed to isolate the effects of TPM 4.0, PdM, vision, and twins, singly and in combination. TOE/RBV-grounded readiness indices, validated in Pakistani SMEs, can quantify capability gaps and predict OEE responsiveness, guiding plant investments and policy targeting (Angreani et al., 2024; Techanamurthy et al., 2025). In sum, durable OEE gains in Pakistan's dates-packaging sector depend less on "more technology" and more on sequenced capability building—governance, skills, and interoperable data, upon which advanced analytics and simulation can reliably compound value.

Limitations

This review faces several constraints. First, dates-packaging-specific empirical studies reporting complete OEE (and A/P/Q) remain scarce; much of the evidence is proximate (food/packaging or discrete manufacturing) and may not fully capture sector idiosyncrasies. Second, heterogeneity in OEE definitions, KPI granularity, and reporting intervals limits comparability and precludes robust pooled effect sizes. Third, many included studies are observational or before–after designs without strong counterfactuals, raising risks of confounding and overestimation of effects. Fourth, contextual variability (plant size, SKU mix, seasonality, equipment vintages) constrains external validity to Pakistan's dates packaging SMEs. Fifth, we restricted to English-language, 2015–Oct 2025 literature; relevant local or earlier work may have been missed. Sixth, selective availability of cost and implementation data (CapEx/Opex, payback, change-management burden) limits economic generalization. Finally, despite quality appraisal and sensitivity checks, publication and reporting biases cannot be ruled out.

Conclusion

The core contribution of this study lies in presenting an empirically supported framework for integrating OEE and Industry 4.0 principles into Pakistan's dates packaging SMEs. By linking the Technology–Organization–Environment (TOE) and Resource-Based View (RBV) perspectives, the study highlights how digital transformation can be strategically sequenced to build long-term operational excellence and export competitiveness.

Pakistan's dates packaging industry has strong potential but is not yet fully ready for OEE-aligned Industry 4.0. A sequenced roadmap (1) foundation, OEE standardization, connectivity (OPC-UA/MQTT), TPM/CMMS; (2) performance, condition monitoring/PdM, in-line vision, SMED; (3) optimization: calibrated digital twins with MES/ERP converts intent into measurable OEE gains. The TOE–RBV framework clarifies readiness gaps (technology, organization, workforce) and links capability building to outcomes. Execution requires clear KPI ownership, data governance, vendor SLAs, and milestone-based financing to de-risk adoption. Implemented this way, the sector can achieve export-grade performance and durable competitive advantage.. The proposed roadmap and readiness constructs (TOE+RBV) provide a practical path for managers and policymakers.

Figures and Tables for OEE Readiness

The following visuals and decision tables are inserted inline before the References to support the narrative. Replace placeholder values with your plant's baseline data during diagnostics.

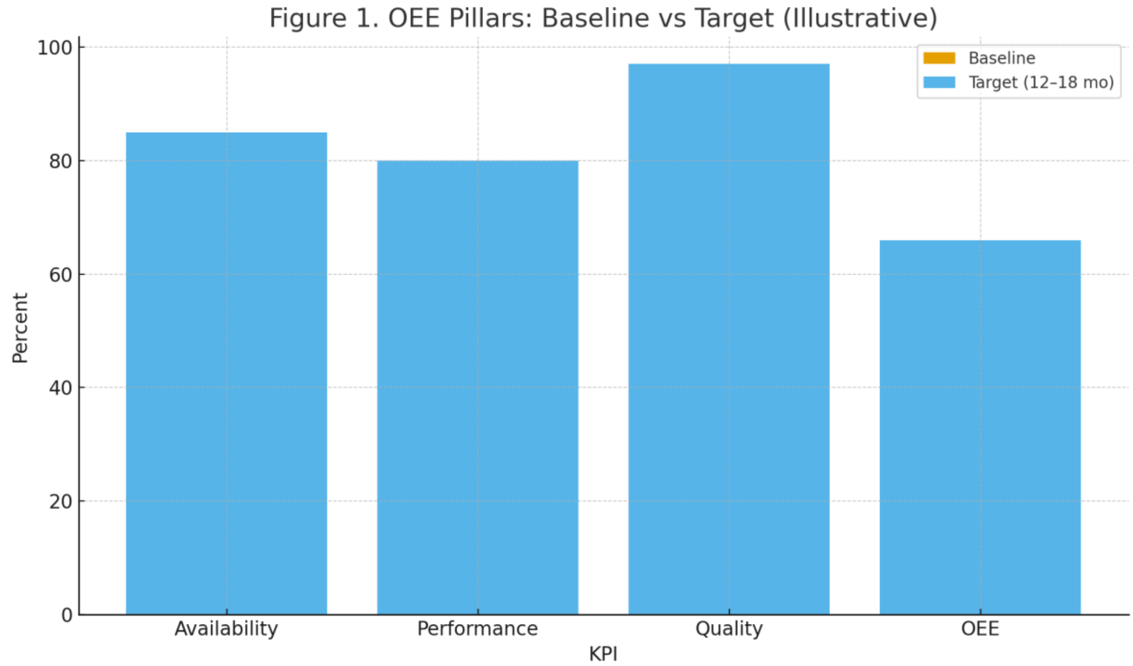

Figure 1. OEE pillars and composite OEE: illustrative baseline vs 12–18 month target.

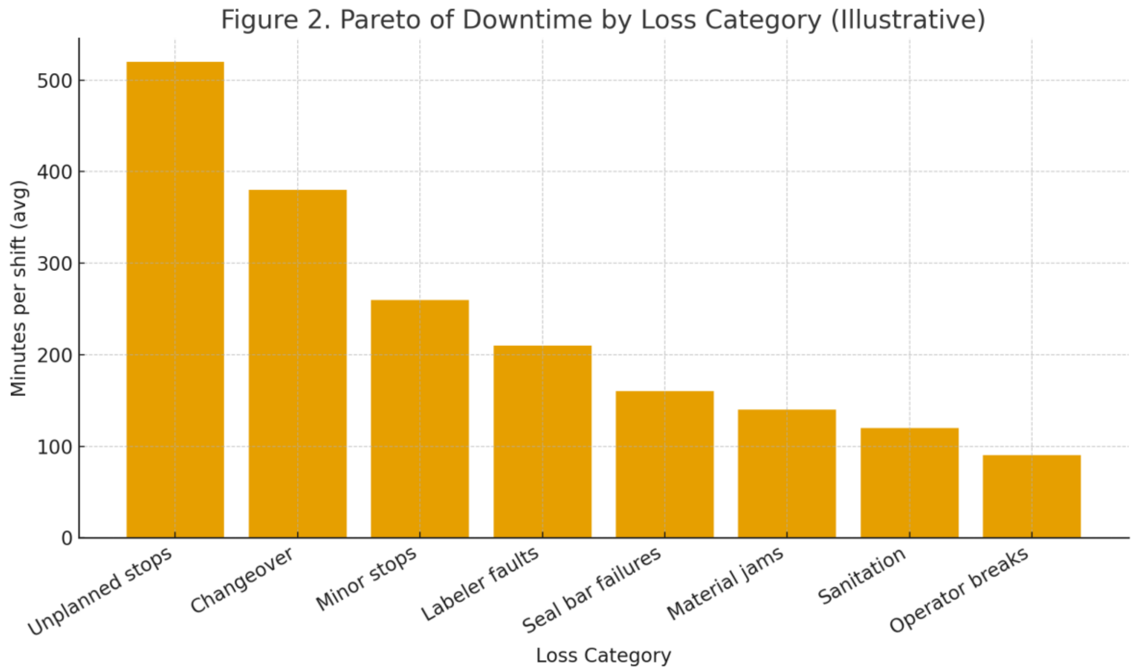

Figure 2. Downtime Pareto showing major loss contributors to guide TPM 4.0 and SMED focus.

Table 1
OEE KPI definitions, formulas, and primary levers.

KPI	Definition	Primary Levers
Availability	Run Time / Planned Production Time	PdM, CMMS discipline, MTTR↓, MTBF↑
Performance	Ideal Cycle Time × Total Count / Run Time	Micro-stop elimination, line balancing, speed loss control
Quality	Good Count / Total Count	Inline vision, process capability, first-time-through
OEE	Availability × Performance × Quality	Composite of A×P×Q with strict, shared data dictionary

Table 2
Staged adoption roadmap for OEE-aligned IR4.0 (illustrative targets).

Phase	Focus	Key Actions	Expected KPI Movement
0–6 months	Connectivity & Governance	OPC-UA/MQTT gateways; live OEE dashboard; CMMS go-live; weekly OEE huddles; SMED baseline	Availability +8–12 pts; visibility of micro-stops
6–18 months	PdM/TPM 4.0 + Vision	Critical-asset sensors; predictive alerts; seal/label vision; SMED institutionalized	Performance +8–12 pts; Quality +2–4 pts; changeover time −20–30%
18–36 months	Digital Twin + MES/ERP	Twin for SKU sequencing & line balancing; MES integration; closed-loop planning & traceability	OEE +6–10 pts via optimization; stable throughput under SKU variability

Table 3
TOE–RBV readiness checklist (to be tailored per plant).

Domain	Readiness Items	Baseline (Y/N/Partially)	Owner
Technology	Interoperability (OPC-UA/MQTT); sensor coverage; CMMS usage; inline vision; cybersecurity	Partially	Engineering/IT
Organization	Leadership cadence; OEE data dictionary; KPI ownership; TPM/RCM routines; vendor SLAs	Partially	Plant Manager
Workforce	Operator data literacy; basic reliability skills; cross-functional problem solving; analytics exposure	N	HR + Ops

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