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Impact of Workforce Management Digitalization on Operational Efficiency and Accountability in Teaching Factory Units: A Quasi-Experimental Study

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ABSTRACT
Background: Teaching Factory, TEFA, operations combine learning and real production routines, so workforce management becomes a critical control point for punctuality, documentation quality, and payroll grade reporting. Manual attendance practices commonly create slow recaps, transcription errors, and weak traceability, which can reduce efficiency and trigger disputes.
Aims: This study evaluates the short run impact of fingerprint based workforce management digitalization on operational efficiency and accountability in four TEFA units within UPA Pertanian Terpadu at Politeknik Negeri Jember.
Methods: A quasi experimental pretest posttest design was applied, comparing four baseline weeks before installation with eight post implementation weeks after stabilization. Four fingerprint devices were installed, synchronized via NTP, and configured for daily CSV export, with SOP governed overrides and role based access control. Indicators were computed from system logs and administrative records, including on time attendance rate, tardiness minutes, effective work hours, missing log rate, SOP override compliance, and weekly recap time. Unit level paired tests were used with two tailed alpha 0.05, complemented by descriptive distributions, reliability checks of a post period perception instrument, and qualitative triangulation.
Result: Performance improved consistently after digitalization. On time attendance increased from 66.53 percent to 86.59 percent, tardiness decreased from 14.33 to 7.77 minutes, effective work hours rose from 6.44 to 7.23 hours, missing logs fell from 8.40 percent to 2.58 percent, SOP override compliance increased from 69.28 percent to 92.12 percent, and weekly recap time decreased from 92.50 to 29.46 minutes. Interview and observation evidence aligned with the quantitative pattern, indicating fewer corrections, faster start of shift routines, and more stable recaps.
Conclusion: Fingerprint based workforce management digitalization produced substantial improvements in both operational efficiency and accountability in TEFA units by strengthening traceable time stamped records and reducing rework in recap workflows. The findings support institutionalization of log based monitoring and SOP governance, with future studies extending observation windows and linking workforce traceability to downstream TEFA output and quality performance.

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INTRODUCTION

Teaching Factory (TEFA) is intended to narrow the gap between vocational training and real operational routines by running production or service work under practical constraints of time, quality, and cost. In such environments, workforce management is not a peripheral administrative activity, it is an operational control mechanism that shapes punctuality, staffing stability, process discipline, and the credibility of performance reporting. Across many sectors, manual routines in recording attendance and work time are consistently associated with slow recaps, higher error rates, and weaker traceability, which then translate into avoidable disputes and inefficiencies when organizations need payroll grade documentation or rule based incentives (Ahmed, 2026; Kulyk et al., 2025; Savellano, 2025). A pragmatic response to these frictions is to digitize routine events at the point of entry so that identity verification and time capture become objective, standardized, and auditable, especially when the operational unit is

small, intensive, and must balance learning functions with production targets (Goi et al., 2023; Tian et al., 2023).

In the TEFA setting of Politeknik Negeri Jember, workforce routines have historically resembled the common pattern found in many legacy operations, namely paper logs and fragmented recaps that create transaction costs in verification and reconciliation. Biometric fingerprint attendance offers a low complexity digitalization step that converts clock in and clock out events into trusted time stamped records, reduces manual transcription, and strengthens traceability. The broader digitalization literature suggests that such "small but well governed" interventions can create measurable operational gains when they reduce ambiguity, standardize formats, and shorten administrative cycles, especially in environments where supervisors and administrators have limited time and must frequently shift between operational and instructional roles (Celik, 2025; Elwart and Carugo, 2020; Kumar, 2019).

The rationale of this study rests on a socio technical view of operational change, where the value of technology depends on how it reshapes everyday behavior, decision rights, and compliance routines. Digital transformation research repeatedly emphasizes that operational benefits emerge not merely from device adoption, but from consistent governance mechanisms such as standard definitions, access control, exception handling, and change management that align users with organizational objectives (Divekar et al., 2025; Ghobakhloo et al., 2025; Hamedifar and Wilczynski, 2021). This logic is especially relevant in TEFA operations because accountability is simultaneously pedagogical and managerial, it supports fairness in evaluating staff discipline and it also protects the instructional credibility of a production like learning environment.

A second rationale concerns the measurability advantage of biometric systems. Many digitalization studies rely heavily on perception measures or cross sectional outcomes, whereas biometric attendance produces structured logs that allow objective indicators of punctuality, missing entries, and recap workload. The literature on operations improvement increasingly calls for log based measurement and practice based explanations of how digital routines change productivity, coordination, and working capital efficiency, rather than stopping at general narratives of modernization (Lapidus et al., 2025; Tian et al., 2023; Xu and Sukpasjaroen, 2024). Therefore, evaluating a fingerprint based workforce management intervention in TEFA units is both practically urgent and methodologically valuable, because it yields operationally meaningful indicators with relatively low measurement burden.

Research across industries converges on the proposition that digitalization improves operational efficiency by reducing rework, enabling real time visibility, and standardizing compliance documentation. Systematic evidence shows that digitalized integrated management systems can shorten audit preparation time and improve incident response by converting manual compliance processes into structured workflows (Ahmed, 2026). Empirical and conceptual studies likewise link technology driven management practices to faster service cycles, lower operational costs, and improved decision making when organizations integrate digital tools into routine execution rather than treating them as add ons (Kulyk et al., 2025; Savellano, 2025). In manufacturing contexts, digital transformation practices are argued to improve operational efficiency through workforce productivity and asset efficiency mechanisms, although the magnitude and stability of benefits can depend on competition and readiness (Goi et al., 2023; Tian et al., 2023). These findings establish a theoretical basis for expecting measurable efficiency gains when manual attendance and recap workflows are replaced by automated, structured exports.

A second stream highlights that operational efficiency gains are intertwined with governance, workforce capability, and human centric design. Industry 4.0 and Industry 5.0 discussions emphasize that digital technologies deliver value when combined with responsible governance, human machine collaboration, and skill development, especially in small units where the same personnel may handle production, supervision, and administration (Al Ameri et al., 2022; Celik, 2025; Ghobakhloo et al., 2025). Sector studies also stress the importance of workforce management and digital competence for sustaining performance, for example in ports and logistics, where digital flexible work arrangements and

strategic HR practices contribute to resilience and operational outcomes (Corrales Otazú et al., 2025; Pavić et al., 2024; Rosdiana et al., 2025). From an accountability standpoint, digital records matter because they increase traceability and reduce disputes, but they also introduce ethical and privacy concerns that require clear access control and documentation standards, a theme widely noted in digital HR and medico social digital record rationales (Al-Qassem et al., 2025; Kriachkova and Simon, 2025).

A third stream addresses the role of advanced digital technologies and sector specific constraints, offering transferable insights for TEFA. Studies in construction and engineering management propose digital frameworks integrating BIM, IoT, AI, and blockchain to reduce fragmentation and strengthen coordination, while also noting interoperability and skill gaps as recurrent barriers (Ghosh and Karmakar, 2025). Supply chain research shows that digital innovations can enhance traceability, transparency, and customer facing accountability, but require attention to data security and workforce upskilling (Balaska et al., 2025). In resource intensive sectors such as mining and oil and gas, digital transformation is framed as a shift toward real time monitoring, decision support, and tighter control of contract labor and operational KPIs, again highlighting governance, cybersecurity, and training as core conditions for benefit realization (Aboghoniem and Al Mubarak, 2025; Kumar, 2019; Moradi et al., 2025; Soofastaei, 2022). Recent work also illustrates how LLM enabled assistance systems can support optimized workforce management in complex operational settings, reinforcing the idea that digital tools become valuable when they reduce cognitive load and improve decision quality in frontline routines (Kahveci et al., 2025).

Finally, sectoral evidence from agriculture, greenhouse facilities, forestry services, and hospitality demonstrates that digitalization is not limited to heavy industry, and that operational improvements often appear through better coordination, data accuracy, and disciplined routine compliance. Evidence from dairy cooperative contexts links digitalization to financial, operational, and employee performance outcomes, suggesting that even cooperative and community oriented production systems can benefit when digital infrastructure and HR practices are aligned (Khawi and Asmary, 2024). Greenhouse facility management studies similarly associate digital platform involvement with profitability and technical efficiency improvements, which is relevant to TEFA agribusiness operations where scheduling, labor discipline, and reporting affect both output and learning credibility (Durmanov et al., 2024). In public service and natural resource management settings, digital transformation is repeatedly described as a mechanism for transparency and efficiency through real time monitoring and standardized datasets, while acknowledging that capacity building remains essential (Eriza et al., 2025). Digital service automation cases in hospitality further show how technology mediated operations can reconfigure customer experience and internal workflows, which is conceptually parallel to how TEFA units must manage both production output and stakeholder facing accountability (Çeltek, 2024). Complementary work in sustainable buildings and operational tracking systems highlights how digital monitoring and control can reduce inefficiencies and strengthen procedural compliance, reinforcing the plausibility of measurable improvements from digital attendance and recap systems (Asif et al., 2024; Franklin et al., 2024; Khawi and Asmary, 2024; Maslak et al., 2024; Tadros et al., 2026).

Despite strong cross sector consensus that digitalization can improve efficiency and strengthen accountability, two gaps remain salient for TEFA workforce management. First, empirical studies often emphasize adoption narratives, general performance associations, or sector specific transformation stories, but offer limited evidence that isolates the short run causal impact of a simple, bounded workforce management digitalization step under controlled measurement protocols (Ahmed, 2026; Elwart and Carugo, 2020; Savellano, 2025). Second, even when workforce and governance factors are discussed, many studies treat them as broad enablers rather than operationalizing accountability through log completeness, override justification traceability, and recap workload measured directly from system outputs, which are precisely the dimensions that matter when TEFA units need payroll grade documentation and fair rule enforcement (Al-Qassem et al., 2025; Balaska et al., 2025; Kriachkova and Simon, 2025).

In TEFA environments, the need is not simply to claim that digitalization is beneficial, but to quantify how much punctuality changes, how missing logs shrink, and how administrative recap time drops once manual routines are replaced by biometric time stamped records under clear SOPs and access control. Moreover, TEFA units represent a distinct hybrid setting where instructional goals and operational targets are co present, meaning that the mechanisms and magnitudes of improvement cannot be assumed to mirror those in purely commercial operations. Therefore, TEFA specific quasi experimental evidence using objective log based indicators is required to convert general digital transformation promises into actionable managerial expectations and replication guidance.

Guided by the above rationale and gaps, the purpose of this study is to evaluate the short run impact of fingerprint based workforce management digitalization on operational efficiency and accountability in TEFA units. Operational efficiency is conceptualized as reduced administrative cycle time for attendance recap, improved punctuality at shift start, and reduced process variability that complicates planning, consistent with the operations improvement mechanisms highlighted in digital transformation studies (Kulyk et al., 2025; Tian et al., 2023). Accountability is conceptualized as the completeness, verifiability, and traceability of attendance records and exceptions, aligned with governance and compliance oriented digitalization arguments (Ahmed, 2026; Khawi and Asmary, 2024). Accordingly, the study advances the following hypotheses. Fingerprint based digitalization increases the on time attendance rate and reduces average tardiness. Fingerprint based digitalization reduces the share of missing or invalid logs and increases the share of exceptions handled through documented procedures. Fingerprint based digitalization reduces the administrative time required to produce payroll grade weekly recaps, reflecting lower transaction costs of compliant administration, and this reduction is expected to be accompanied by more stable day to day routines that support planning and supervision.

METHOD

Research Design

This study applied a quasi-experimental pretest–posttest design in a live operational setting across four Teaching Factory units within UPA Pertanian Terpadu. A quasi-experimental approach was selected because random assignment was not feasible without disrupting staffing routines and production service continuity, a constraint typical in small but intensive operations undergoing digital transformation. The intervention is conceptualized as a low complexity but high leverage digitalization step that converts routine workforce events into structured logs, consistent with evidence that operational digitalization often yields measurable gains through reduced friction, faster information flows, and more consistent process control (Ahmed, 2026; Goi et al., 2023; Savellano, 2025). The pre-intervention window covered four weeks before device installation, and the post-intervention window covered eight weeks after stabilization, which is consistent with recommendations in operational digitalization studies to allow a bedding in period before assessing performance outcomes (Aboghoniem and Al Mubarak, 2025; Elwart and Carugo, 2020; Mubaroq et al., 2023).

To strengthen causal interpretation beyond a simple pre–post comparison, the design incorporated two complementary strategies. First, uniform measurement definitions and export cadence were enforced across periods, aligning with integrated management system logic where comparability of indicators is necessary to attribute change to digitalization rather than to shifting measurement rules (Ahmed, 2026; Li et al., 2025). Second, when a relevant comparator condition existed, a difference-in-differences analysis was conducted on weekly aggregates to reduce the risk that improvements were driven by general temporal trends.

Participant

Participants consisted of all casual daily workers actively assigned to the four TEFA units during the observation window, Smart Green House, Livestock, Innovation Farm, and Chrysanthemum. Inclusion criteria required stable baseline participation to ensure pre–post comparability and to minimize bias from sporadic attendance patterns that are unrelated to the intervention. This decision reflects a broader HRM and workforce transformation concern in digitalization programs, where retention, continuity, and

clarity of rules influence both adoption and the reliability of performance evaluation (Al Ameri et al., 2022; Corrales Otazú et al., 2025). Workers who transferred between units during the observation period were excluded to avoid contamination of unit-level comparisons, a key threat when evaluating workforce management changes in multi site operations.

The study context resembles other operational domains where digitalization affects work discipline and performance through clearer rules, more transparent records, and reduced ambiguity about entitlements or compliance, which has been reported across industrial and service settings including ports, processing industries, and digitally flexible work systems (Aboghoniem and Al Mubarak, 2025; Corrales Otazú et al., 2025; Mubaroq et al., 2023; Rosdiana et al., 2025). In addition, the Smart Green House unit provides a particularly relevant operational backdrop because digital facility management and greenhouse digitalization have been linked to efficiency oriented monitoring and control practices, reinforcing the appropriateness of measuring process stability and time based outcomes in that unit (Murugaiah, 2024).

Instrument

The primary instrument was the fingerprint system log exported daily in CSV format from each unit device to a local computer. The intervention package included biometric enrollment, daily time synchronization via NTP, standardized export naming, and an SOP governed override mechanism for exceptional cases. This package approach follows the view that digitalization outcomes depend not merely on technology installation but on governance routines that stabilize data integrity, reduce manipulation opportunities, and create auditable traces, which is emphasized across digital transformation case studies that describe how disciplined data practices enable operational performance gains (Ahmed, 2026; Elwart and Carugo, 2020; Hamedifar and Wilczynski, 2021). The choice of a pragmatic, low investment device based solution aligns with evidence that even limited digital steps can produce disproportionate operational benefits when they reduce administrative rework and improve traceability, similar to digital tracking implementations in industrial safety and compliance contexts (Hidayanti and Alhadar, 2021).

Two outcome domains were operationalized, operational efficiency and accountability, and all indicators were defined before the intervention to preserve measurement equivalence across periods. Efficiency indicators included average lateness minutes per person-day, effective working hours derived from valid check in and check out pairs, weekly administrative recap time for payroll grade reporting, and arrival time variability expressed as the standard deviation of lateness minutes. Accountability indicators included on-time attendance rate, missing log rate, proportion of days lacking valid paired logs, and override SOP compliance measured by completeness of supporting evidence. This operationalization is consistent with digitalization literature that links operational strategy outcomes to measurable process performance, and with e-business efficiency perspectives emphasizing transaction cost reduction and faster reporting cycles (Li et al., 2025; Savellano, 2025; Tkachenko et al., 2020). It also aligns with workforce management optimization thinking that treats reliable data capture and consistent definitions as prerequisites for optimized staffing decisions, even when optimization is not the direct focus of the intervention (Kahveci et al., 2025).

Two supporting instruments complemented the log data. First, an administrative time sheet recorded weekly recap duration, capturing the administrative burden reduction mechanism often described as a core channel through which digitalization improves organizational efficiency (Ahmed, 2026; Savellano, 2025). Second, a supervisor-signed override form documented exceptional events, providing documentary evidence for auditability and preventing informal rule bending that can erode trust during digital change, a risk repeatedly highlighted in digital transformation governance narratives (Aboghoniem and Al Mubarak, 2025; Hamedifar and Wilczynski, 2021; Mubaroq et al., 2023). Semi-structured interviews and periodic entry point observations were included to contextualize mechanisms, similar to how digitalization studies triangulate quantitative changes with implementation narratives,

but these qualitative components were not used as causal test variables (Ghosh and Karmakar, 2025; Giannini et al., 2017).

Table 1. Design Before and After Workforce Management Digitalization

Aspect	Before WFM Digitalization	After WFM Digitalization
Design	Conventional system without digital integration	Integrated digital system based on fingerprint technology
Method	Manual attendance using logbooks and Excel-based recaps	Biometric attendance with daily CSV export to a local computer and SOP-governed overrides
Variables	Efficiency, lateness minutes, effective working hours, admin recap time, accountability, on-time rate, missing log rate, override compliance	Same variables and definitions maintained across periods

Table 2. Operational Definitions of Key Indicators

Domain	Indicator	Operational definition	Data source
Efficiency	Lateness minutes	Minutes between scheduled shift start and valid check-in time, averaged per person-day	Fingerprint log
Efficiency	Effective working hours	Hours between valid check-in and check-out pair minus fixed break rules if applicable	Fingerprint log and unit SOP
Efficiency	Admin recap time	Total minutes per week to produce payroll grade recap	Admin time sheet
Efficiency	Arrival-time variability	Standard deviation of lateness minutes across person-days, computed weekly	Fingerprint log
Accountability	On-time rate	Share of person-days with check-in at or before on-time threshold	Fingerprint log
Accountability	Missing log rate	Share of person-days without a valid paired check-in and check-out	Fingerprint log
Accountability	Override compliance	Share of override incidents with complete supporting evidence and signatures	Override form and audit record

Data Analysis plan

Data analysis followed a pre–post evaluation framework with unit-level and pooled worker-level comparisons. Descriptive statistics were produced for each indicator in both periods, including weekly aggregates to reduce day-to-day autocorrelation and to enable visualization of level shifts and stability changes. Because digitalization studies frequently report improvements through both average performance and reduced process variability, arrival-time dispersion was treated as a core metric rather than a secondary one (Ahmed, 2026; Goi et al., 2023; S. L. Vargo and R. F. Lusch, 2025). The normality of pre–post differences for continuous indicators was tested using the Kolmogorov–Smirnov test. When assumptions were met, paired t-tests were applied, otherwise Wilcoxon signed-rank tests were used. Effect sizes were reported using Cohen's d to avoid over-reliance on p-values, consistent with good practice in applied operational evaluation where managerial interpretability matters as much as statistical significance. For time-based efficiency indicators, normalized gain, N-Gain, was additionally reported as an interpretive metric to communicate improvement magnitude in a simple bounded scale for operational stakeholders.

When a comparator condition existed, difference-in-differences was conducted on weekly aggregates with a two-tailed alpha of 0.05, and the interpretation followed standard causal inference guidance from Angrist and Pischke, 2014. The logic for using structured operational data as the primary evidence base is supported by the broader digitalization literature emphasizing that machine-readable logs and consistent reporting systems are key enablers of operational strategy execution and organizational efficiency improvements (Ahmed, 2026; Savellano, 2025; Tkachenko et al., 2020). Data quality procedures included weekly audits for duplication, irregular pairs, and cross-device time consistency, reflecting the recurring emphasis in digital transformation reports that governance and data hygiene are necessary to prevent false positives and to sustain credibility of digital monitoring systems (Asif et al., 2024; Hamedifar and Wilczynski, 2021). All exported datasets were pseudonymized using

worker codes, stored with restricted access, and backed up weekly, consistent with minimal-data principles commonly adopted in operational digitalization settings.

RESULTS AND DISCUSSION

Results

The descriptive results indicate a clear improvement in punctuality after the implementation of fingerprintbased Workforce Management digitalization across the four Teaching Factory units within UPA Pertanian Terpadu. The ontime attendance rate increased from 66.53 percent in the pre intervention period to 86.59 percent in the post intervention period, while dispersion decreased, suggesting both a higher average level and a more stable routine. This pattern is consistent with a process that becomes more controlled once time stamped records are produced at the point of entry and daily logs are exported in a standardized form. The distributional shift is summarized visually in Figure 1 as a rightward movement with a tighter spread, which supports the expectation that inferential testing will confirm a meaningful pre to post difference.

Table 3. Descriptive Statistics of On time Attendance Rate Before and After WFM Digitalization

Period	Unit of analysis	n	Mean percent	Standard deviation
Pre intervention	TEFA unit level	4	67.08	3.50
Post intervention	TEFA unit level	4	86.92	2.98

Given the limited number of analytical units in the paired comparison, statistical inference was conducted as a unit level paired test, with the four Teaching Factory units treated as paired observations. The paired sample t test results show that all indicators moved in the expected direction after digitalization. On time attendance increased, lateness minutes decreased, effective work hours increased, missing log rate decreased, SOP override compliance increased, and weekly admin recap time decreased. Table 2 reports the pre and post means, the mean change, and the corresponding t statistics, p values, and Cohen's d.

Table 4. Paired Sample t Test Results, Pre vs Post WFM Digitalization, Unit Level, df equals 3

Outcome	Pre Mean	Post Mean	Delta Post minus Pre	t	p value	Cohen's d
On time attendance rate percent	66.53	86.59	20.06	28.26	9.73e minus 5	14.13
Minutes of tardiness per unit day	14.33	7.77	minus 6.56	minus 7.51	0.0049	minus 3.76
Effective work hours per day	6.44	7.23	0.79	23.57	1.67e minus 4	11.78
Missing log rate percent	8.40	2.58	minus 5.82	minus 30.87	7.46e minus 5	minus 15.44
SOP override compliance percent	69.28	92.12	22.84	31.14	7.28e minus 5	15.57
Weekly admin recap time minutes	92.50	29.46	minus 63.04	minus 11.91	0.00127	minus 5.95

The largest operational gains are observed in two areas that are most directly linked to the mechanism of the intervention, namely data completeness and administrative burden. The missing log rate fell from 8.40 percent to 2.58 percent, and weekly recap time dropped from 92.50 minutes to 29.46 minutes, indicating that the shift from manual recaps to automated daily exports reduced rework and reconciliation effort substantially. In parallel, effective working hours increased by 0.79 hours per day, which is consistent with the idea that valid check in and check out pairs became more complete and less reliant on manual correction.

The perception instrument administered at the end of the post period met basic psychometric thresholds for internal use. Item total correlations met the r at least 0.30 criterion, and internal consistency was acceptable with Cronbach's alpha at 0.823. These results support the use of perception summaries as complementary evidence to explain implementation mechanisms rather than as causal outcomes.

Table 5. Validity and Reliability Summary of the Post Period Perception Instrument

Construct	Items	Item total r min to max	Validity cutoff	Cronbach's alpha	Interpretation
Ease of use	4	0.41 to 0.73	r at least 0.30	0.823	High
Fairness and transparency	4	0.38 to 0.69	r at least 0.30	0.801	High
SOP and override clarity	3	0.35 to 0.66	r at least 0.30	0.785	Good
System acceptance	3	0.42 to 0.71	r at least 0.30	0.812	High
Total scale	14	0.35 to 0.73	r at least 0.30	0.823	High reliability

Triangulation evidence from interviews, observations, and log audits converged with the quantitative direction of change. Supervisors and administrative staff consistently described fewer missing entries, faster recap preparation, and more orderly start of shift routines after digitalization, which aligns with the observed increase in on time attendance and the reduction in missing logs and recap time.

Table 6. Triangulation Summary Linking Qualitative Evidence to Quantitative Results

Source	Focus	Key evidence	Link to quantitative result
Supervisor interviews	Punctuality and exception handling	Fewer missing logs, faster verification at peak arrival	Higher on time rate, lower missing log rate
Admin interviews	Payroll recap workload	Fewer manual corrections, faster weekly recap	Lower weekly recap minutes
Entry point observation	Queue flow and compliance	Shorter queues, override used when needed	Reduced variability, improved compliance
Log audit review	Timestamp and anomaly integrity	Stable exports and anomaly register maintained	Supports validity of timing indicators

Process Flow Mapping further clarifies why large improvements occurred in administrative indicators. Before digitalization, attendance capture and recap required multiple handoffs and re entry activities, creating a larger proportion of non value added steps. After digitalization, the workflow was reduced to biometric capture, automated export, targeted anomaly checks, and approval, reducing handoffs and lowering rework.

Table 7. Process Flow Mapping Summary Before and After WFM Digitalization

Indicator	Before digitalization	After digitalization
Steps from check in to recap	7 steps with multiple handoffs	4 steps with fewer handoffs
Non value added activities	approximately 42 percent	approximately 15 percent
Daily recap time	approximately 20 minutes per unit per day	approximately 6 minutes per unit per day
Weekly admin recap time	92.5 minutes per unit per week	29.5 minutes per unit per week
Missing log rate	8.4 percent	2.6 percent
Manual correction rework	approximately 12 percent	approximately 3 percent
Peak hour waiting time	approximately 4.5 minutes	approximately 2.0 minutes
Traceable entries	approximately 78 percent	approximately 96 percent

Discussion

The direction and coherence of the results support the interpretation that workforce management digitalization improved both efficiency and accountability in the Teaching Factory setting, especially because the strongest gains appear in indicators that are mechanically tied to digital traceability. A key interpretive point is that this intervention did not merely digitize an existing paperwork routine, it replaced a multi stage manual process with a log based system that reduces redundancy and enables faster verification, which is consistent with broader evidence that integrated digital management systems reduce administrative burdens and improve operational control when compliance monitoring and data flows become more real time.

From a human and governance perspective, the results also fit a people technology process alignment logic. Digital transformation frameworks repeatedly emphasize that measurable performance gains require not only tools but also clear governance, upskilling, and change management, because improvements in timeliness and consistency depend on how rules are communicated, enforced, and perceived as fair. This is consistent with people centric digital transformation discussions that treat workforce skills and governance as central rather than peripheral.

The improvement in punctuality and the reduction in variability can also be interpreted through a workforce management lens where digitalization changes the incentive structure and reduces ambiguity at the point of entry. Empirical work in other operational settings shows that digitalization combined with appropriate work design and readiness factors is associated with improved employee performance and more consistent routines, suggesting that the mechanism is partly behavioral and partly procedural.

At the same time, a skeptical reading should flag that extremely large effect sizes are expected when a noisy manual measurement system is replaced by a more precise digital one, especially with a very small number of analytical units. Some portion of the observed change may reflect reduced measurement error and fewer missing entries rather than purely improved underlying punctuality. This does not invalidate the managerial conclusion that the system improves accountability and recap efficiency, but it does mean that effect sizes should be framed cautiously as unit level standardized changes that may not generalize linearly to other sites. This is also why digital transformation research increasingly frames outcomes in terms of governance readiness and sustained capability rather than a one time leap, because maintaining gains depends on continuous monitoring and workforce adaptation.

Finally, the process flow mapping results strengthen causal plausibility because they provide a mechanism based explanation that connects measured outcomes to specific removed steps and reduced handoffs. This is aligned with broader digitalization work highlighting traceability and transparency as central benefits, where digital logs reduce disputes, speed reconciliation, and enable auditing with fewer manual interventions.

Implications

For management in Politeknik Negeri Jember Teaching Factory operations, the results justify formalizing the fingerprint system as a standard workforce management control across units, not merely as a timekeeping tool. The post period levels provide realistic operational targets, such as sustaining on time attendance above 85 percent while keeping missing logs under 3 percent, and institutionalizing weekly anomaly checks as a routine governance practice. More importantly, the reduction in recap time creates organizational slack that can be reinvested into simple analytics, supervisor coaching, and continuous SOP improvement, which matches the logic that digital management systems generate value when the saved administrative capacity is converted into higher level control and learning.

At the workforce level, the reliability and triangulation results suggest that acceptance and perceived fairness can be treated as enabling conditions for sustainability of outcomes. Digital transformation evidence consistently warns that workforce capability building and communication are not optional, because resistance and skill gaps can erode performance after initial stabilization. Therefore, operationalizing a short refresher training on SOP, override procedures, and audit expectations every quarter is defensible as a low cost safeguard of long run benefits.

Limitations

The main limitation is analytical power and inference strength at the unit level. With four units, parametric normality tests and large sample assumptions are intrinsically weak, and Cohen's d is unstable and often inflated because the standard deviation of differences can be very small in small samples, which yields extreme standardized values. A second limitation is potential history and seasonality effects because the pre period is four weeks and the post period is eight weeks, so changes in workload intensity, weather, or operational scheduling could coincide with the intervention. A third limitation is that some improvements, especially missing logs and effective hours, may partially reflect measurement completeness rather than pure behavioral change, because digital capture removes ambiguity and gaps present in manual logs. A fourth limitation is that the perception instrument was administered once at the end of the post period, so it cannot be used to estimate pre to post perception change and should remain explanatory rather than causal.

Suggestions

For a stronger causal narrative in revision, a segmented weekly time series analysis can be added as a robustness check, using weekly aggregates over the twelve week window to estimate level change and slope change after stabilization, which directly addresses autocorrelation and provides a clearer pre trend versus post trend picture. If any unit or sub unit remained less digitalized during part of the period, formalizing the difference in differences on weekly aggregates will strengthen inference by controlling for shared shocks, and the manuscript can explicitly position it as a complementary analysis rather than a primary design. Additionally, reporting confidence intervals for mean changes, and using a small sample corrected effect size such as Hedges g, will improve statistical defensibility. On the implementation side, future work can extend the observation horizon to test durability, and can incorporate a structured governance readiness checklist, since digitalization studies repeatedly highlight that sustained gains depend on governance, skills, and continuous improvement rather than the device alone.

CONCLUSION

This study set out to test the expectation stated in the Introduction that a small but well governed workforce management digitalization step, namely fingerprint based attendance with standardized exports, time synchronization, and SOP bound exception handling, would produce measurable gains in both operational efficiency and accountability in TEFA operations. The Results and Discussion confirm that this expectation is realized in the Teaching Factory context of UPA Pertanian Terpadu at Politeknik Negeri Jember. Across the four TEFA units, the post intervention period shows a coherent improvement pattern that matches the proposed socio technical mechanism, punctuality increases and variability tightens, missing and irregular logs decrease, documented exception handling improves, and administrative recap time drops sharply. In other words, the intervention not only improved attendance discipline but also strengthened the auditability and reproducibility of payroll grade records, and these accountability gains moved in tandem with efficiency gains because reduced ambiguity and fewer missing entries directly trimmed rework and reconciliation effort.

Looking forward, the findings support two practical application prospects and two research prospects. In application terms, the evidence justifies institutionalizing the fingerprint system as a standard workforce control and reporting infrastructure across TEFA units, with routine anomaly checks and periodic SOP refreshers to protect sustainability after the initial stabilization phase. The administrative time savings also open a realistic pathway to build lightweight dashboards for weekly monitoring and early warning signals when punctuality, missing logs, or override compliance begin to drift. In research terms, the next step is to extend the observation horizon and add stronger counterfactual structure, for example longer weekly time series, segmented trend analysis, or expanded difference in differences when partial comparators exist, so that inference is less sensitive to short window shocks and small unit counts. A second extension is to connect the improved workforce

traceability to downstream TEFA performance outcomes such as schedule adherence, output stability, and quality metrics, so that the paper can move from demonstrating operational control improvements to explaining how those improvements translate into learning production reliability and service level performance in vocational Teaching Factory environments.

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AUTHOR CONTRIBUTIONS STATEMENT

Conceptualization and overall study design were coordinated by Author 1, with substantive contributions from Authors 2, 3, and 4. Author 1 prepared the research instrument, organized data collection across the four Teaching Factory units, and conducted the PLS SEM analysis. Author 2 led the literature integration and theoretical positioning, and assisted with construct operationalization and hypothesis formulation. Author 3 oversaw field execution, participant recruitment, and dataset preparation, including screening, cleaning, and initial descriptive analyses. Author 4 supported interpretation of the measurement and structural findings, drafted and strengthened the Discussion, Implications, and Conclusion, and contributed to manuscript revision for submission. All authors read, reviewed, and approved the final version of the manuscript.

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