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Research paper

Leveraging MES Integration for Operational Excellence in A Green Field Automotive Stamping Plant: A Digital Transformation Case Study

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Abstract

This study investigates the implementation of a Manufacturing Execution System (MES) in a newly established automotive stamping facility featuring a tandem press line. Unlike retrofit scenarios, the MES was integrated during the plant design stage, enabling deep alignment be-tween digital systems and shop floor operations. The research evaluates MES performance across seven months, focusing on changeover optimization, quality control, traceability, and Overall Equipment Effectiveness (OEE) enhancement. Real-time data collection, standardized workflows, and user adaptation contributed to early process stabilization and efficiency gains. The introduction of the MES played a pivotal role in achieving early control and standardization of key production indicators. OEE increased steadily - from 47.17% in the first month of operations (September 2024) to 72.36% by the seventh month (March 2025). The availability of real-time production data contributed to a 37.5% decline in changeover durations, while the defect rate dropped significantly - from 8.22% to just 1.93%. From the very first production cycle, the system ensured comprehensive digital traceability, covering raw materials, equipment performance, and operator activity. These outcomes serve as a reference framework for implementing MES solutions in green field environments - particularly in high-throughput sectors such as automotive stamping. By embedding MES at the foundational stage, plant commissioning transitions from a linear setup process to a feedback-driven optimization cycle. This approach accelerates efficiency gains, enforces operational consistency, and expedites digital maturity from the outset. The case demonstrates how MES, when deployed from inception, can accelerate digital maturity, ensure compliance, and support long-term operational scalability.

Keywords: *Automotive Stamping; Digital Manufacturing; Green Field Deployment; Manufacturing Execution System; MES Implementation; OEE; Smart Factory; Tandem Press Line.*

1. Introduction

Digital transformation is reshaping the global automotive manufacturing landscape [1]. In high-volume, precision-based sectors such as stamping, Manufacturing Execution Systems (MES) offer real-time visibility, control, and data-driven decision-making [2], [3]. While many plants adopt MES in response to inefficiencies, this study focuses on a proactive green field deployment, embedding MES into the core plant design.

The selected case is a new automotive stamping unit featuring a high-speed tandem press line. This project offered a unique opportunity to design MES workflows alongside physical processes, minimizing legacy system constraints. The integration aimed to achieve faster ramp-up, higher accuracy, and full traceability from Day One. Over a seven-month evaluation period, MES outcomes were studied across production, quality, and operator engagement domains. This paper presents a structured analysis of that digital journey.

The evolution of MES can be traced back to early contributions by the Manufacturing Enterprise Solutions Association (MESA) [4], which positioned MES as a central integration layer connecting enterprise planning with shop-floor execution. Foundational works [5] reinforced this perspective by emphasizing MES as a key enabler of standardized workflows, real-time visibility, and decision support across manufacturing systems. These early frameworks continue to influence contemporary approaches to MES design and provide the theoretical grounding for current Industry 4.0 implementations.

MES has gained attention as a bridge between enterprise planning and shop floor operations. Early studies focused on the evolution of MES from simple data logging tools to integrated platforms that connect production, quality, and maintenance functions. Previous research has emphasized the significance of MES in improving operational control and traceability in manufacturing. Shojaeinasab et al. [6] highlighted the role of intelligent MES systems in adapting to dynamic shop floor environments. Jaskó et al. [7] discussed the importance of aligning MES with Industry 4.0 frameworks, noting that successful integration depends on modular design and real-time data flow. Ugarte et al. [8] provided a foundational review of MES literature, identifying the functional roles of MES in synchronizing real-time manufacturing events with enterprise systems.

Another important area of research addresses the role of MES in specific industrial sectors. For instance, Dhage [9] explored MES applications in pharmaceutical manufacturing, while Henriques et al. [10] discussed the impact of technology choices on product life cycle management. In the automotive sector, Michelon [11] investigated how MES can increase productivity and shop floor visibility, highlighting that integration with Enterprise Resource Planning (ERP) and Supervisory Control and Data Acquisition (SCADA) systems improves information flow and reduces manual intervention. Gašpar et al. [12] demonstrated MES scalability in small and medium enterprises through modular retrofitting of existing systems.

User resistance is another theme commonly addressed in MES implementation studies. Jalo and Pirkkalainen [13] analyzed how training and ease of use impact adoption of digital tools like MES. Apilioğulları [14] proposed an International Society of Automation (ISA)-95-based approach for vertical integration of MES with other enterprise systems. Zhang and Li [15] focused on MES design in industrial internet environments, pointing to the importance of standard data models for cross-platform communication.

While several case studies and theoretical frameworks exist, most of them are based on brown field environments where MES is layered onto existing processes. There is limited research on green field MES implementations where system design starts from scratch. This gap motivates the current study by offering a practical and structured approach to MES deployment in a newly established automotive stamping facility.

This study contributes to the evolving conversation around MES by emphasizing early-stage integration as opposed to post-deployment retrofitting. It presents how embedding MES from the outset in a green field automotive stamping setup can support rapid production stabilization, enhance operational agility, and enabling rapid digital adoption. The findings are intended to support practitioners, system architects, and academic researchers involved in implementing smart factory solutions under the Industry 4.0 framework.

The paper is organized as follows: Section 2 outlines the methodology, detailing the structured approach used for MES planning, design, and rollout in the new facility. It includes a description of the technical architecture, data integration model, and the key performance indicators (KPIs) used for performance measurement. Section 3 discusses the outcomes of the deployment, including data-driven improvements in Overall Equipment Effectiveness (OEE), defect reduction, full traceability, and user experience. Section 4 concludes the work, summarizing its contributions, identifying limitations, and proposing directions for future study, both from academic and industrial perspectives.

2. Materials and methods

The study was conducted at a green field automotive stamping plant established in 2024. The facility includes a four-station tandem press line designed for high-volume body panel production. MES was deployed during plant setup, integrated with ERP and Programmable Logic Controller (PLC) systems.

A hybrid architecture based on International Society of Automation (ISA)-95 standards was followed. The MES platform interfaced with barcode scanners, Radio Frequency Identification (RFID) modules, press PLCs, and Human-Machine Interface (HMI) terminals. A structured approach guided platform selection, master data creation, and workflow configuration.

Figure 1 illustrates the proposed hybrid MES architecture specifically designed for a green field manufacturing environment. The architecture follows a layered model integrating Operational Technology (OT) with Information Technology (IT) through a structured ISA-95 framework. At the Level 0–1 layer, various shop floor devices such as sensors, PLCs, and HMIs interface directly with production equipment, enabling real-time data capture.

Level 2 incorporates SCADA and Historian systems, which collect and store time-series production and process data. This level ensures accurate timestamping of machine events, such as die strokes or fault alarms. The MES operates at Level 3 and acts as the central engine for production tracking, quality monitoring, and traceability functions. It is modular in design, allowing tailored deployment of features like electronic Standard Operating Procedures (e-SOPs), digital checklists, and downtime categorization.

Level 4 comprises the ERP system, which manages business planning, inventory, and order management. The MES exchanges data with the ERP layer through standardized Application Programming Interfaces (APIs), enabling seamless flow of job orders, material transactions, and production confirmations.

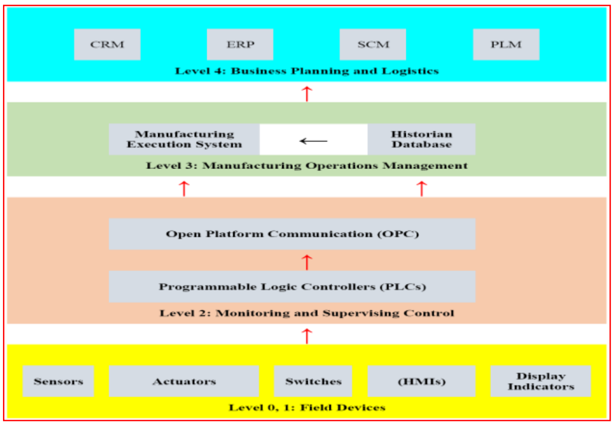

Fig. 1: Proposed Hybrid MES Architecture for Green Field Setup.

This hybrid architecture supports bi-directional communication between layers and ensures horizontal integration across departments such as production, quality, and maintenance. It enables scalability, modular deployment, and real-time responsiveness—key attributes for building a digitally mature green field facility.

Key modules implemented included production tracking, downtime logging, quality checks, traceability mapping, and shift approvals. MES workflows were configured to enforce standard operating procedures through barcode validations, tool ID checks, and digital inspection logs.
Training was conducted in phases, targeting operators, supervisors, and engineers. Adoption readiness was enhanced through simulated job orders and MES dashboards tailored to each user group.
Data was collected over seven months (Sept. 2024 to Mar. 2025) via MES logs and ERP integrations. During the seven-month evaluation period, the MES recorded production data from a tandem press line that processed blanks as the primary raw material into Class A and Class B automotive body parts, including door panels, fenders, and reinforcement components. The plant operated on an average of three shifts per day, with production volumes showing a steady increase as operations stabilized. The number of parts produced rose from 46,000 in the first month (September 2024) to 196,000 by the seventh month (March 2025). Real-time logging was conducted continuously at one-second intervals from PLCs and MES terminals, capturing stroke counts, downtime events, changeover durations, and quality inspection results. Each batch was digitally linked to coil identifiers, die IDs, and operator credentials, enabling complete traceability and ensuring reliable measurement of OEE, defect rates, and compliance metrics. Performance was measured using KPIs such as OEE, changeover time, defect rate, and traceability completeness.

3. Results and discussions

3.1. Early stabilization and SOP compliance

Figure 2 outlines representative activities contributing to compliance with MES-defined SOPs. These operations were monitored through a combination of MES interfaces, HMI entries, RFID tag scans, and signals from the PLC system. The MES-enabled plant achieved early stabilization of production parameters due to SOP-driven workflows. MES terminals recorded operator compliance against key checkpoints such as die setup, material loading, and inspection validations. A steady increase in compliance was noted, with over 90% adherence achieved within four months.
This early stabilization helped reduce process variations and ensured faster convergence toward target cycle times. The use of digital interlocks reduced errors such as incorrect die usage or missed inspections, improving repeatability.

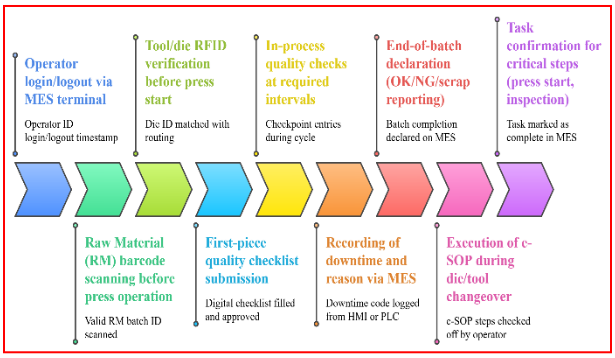

Fig. 2: Constituents Supporting MES SOP Compliance Rate.

Figure 3 illustrates the monthly trend of SOP compliance recorded through the MES over a continuous 7-month period. The graph demonstrates a consistent upward trajectory, indicating growing operator adherence to digitally enforced procedures. In the initial months, compliance levels were relatively low due to early-stage operator unfamiliarity and incomplete MES module activation. However, with progressive training, simulation-based reinforcement, and real-time feedback through MES terminals, compliance steadily improved.

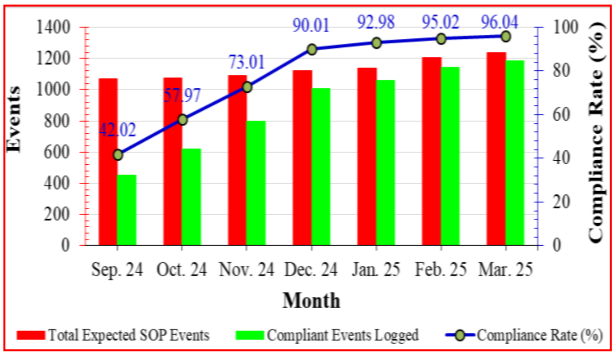

Fig. 3: MES SOP Compliance Trend Over 7 Months.

By Month 4, the compliance rate crossed 90%, showing significant behavioral alignment and system integration. This improvement reflects the effectiveness of embedded MES prompts, RFID checkpoints, and digital checklists in guiding operator actions. The final months show plateauing near full compliance, suggesting stabilization in MES usage and mature process discipline. This trend confirms that MES not only standardizes workflows but also fosters a culture of procedural accountability, especially when integrated from the beginning in green field operations.

Under stable operating conditions - defined by a fixed line configuration, consistent shift patterns, an unchanging number of stations, and a steady product mix - the number of expected SOP events should ideally remain constant. However, during the early stages of MES implementation in the current green field setup, a progressive rise in the count of expected SOP events was noted. This trend can be attributed to various factors, as outlined in Figure 4.

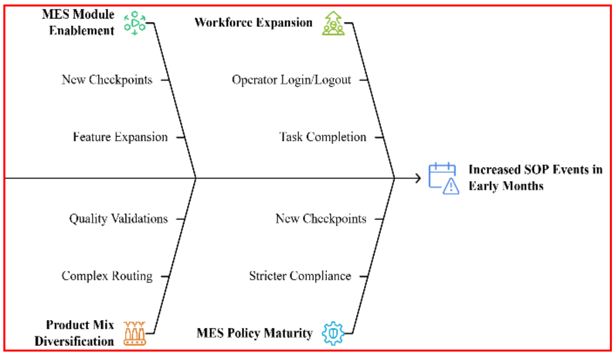

Fig. 4: Reasons for Increasing Total Expected SOP Events (in Early Months).

A phase of stabilization in these SOP events is anticipated once essential components of the manufacturing environment are fully established. This includes the complete operationalization of the tandem press line, ensuring every station is active and connected to the MES infrastructure. The rollout of all planned MES modules will bring clarity to the event landscape, spanning production, quality assurance, and traceability. As production volumes and product variety become more consistent, fewer modifications will be needed in the SOP configuration. Standardization of SOP templates and their systematic adoption across the production line will contribute to a unified event structure. Moreover, with comprehensive operator training and clear assignment of responsibilities, logging practices within MES are expected to become uniform. Together, these advancements will likely lead to a leveling-off of the total expected SOP events. Nonetheless, this plateau may still exhibit variability over time if new processes are introduced, product variations occur, or the MES system undergoes further development.

Even after reaching operational stability, the expected SOP event count is unlikely to remain fixed. It will adjust in response to changing manufacturing demands and process alterations. Launching new product families that come with distinct inspection or verification steps will necessitate corresponding updates in MES workflows, leading to an expanded SOP event set. Similarly, process optimization efforts - such as incorporating new quality checks or inspection gates - will result in additional data capture requirements. Evolving compliance standards, whether driven by regulatory bodies or customer-specific audit needs like International Automotive Task Force (IATF), may call for more granular data entry and validation. Additionally, advancements in automation, especially those involving new hardware or sensors, will introduce extra MES interaction points. As a result, even in a mature system, the Total Expected SOP Events will continue to evolve, reflecting the ongoing transformation of manufacturing systems in pursuit of operational excellence.

3.2. Changeover time reduction, downtime reduction and OEE improvement

3.2.1. Checkpoints contributing to the calculation of OEE: factors, sub-factors, and flow of information

The calculation of OEE involved a structured flow of data across four integrated layers: Manual Interaction with MES, Automation and Orchestration, MES Calculation Engine, and ERP. Each layer contributed distinct checkpoints and data points essential for deriving OEE and its sub-factors - Availability, Performance, and Quality.

At the Manual Interaction with MES layer, data got manually polled for:

- Planned Downtime (PD), which included elements like software maintenance (PD-01), lack of work (PD-02), learning and meeting (PD-03), preventive maintenance (PD-04), process-related downtime (PD-05), TPM/5S activities (PD-06), quality inspections (PD-07), and similar activities.
- Unplanned Downtime (UD) 1, comprised quality issues (UD-01), logistics delays (UD-02), process-related halts (UD-05), and material shortages (UD-07).
- Scrap Parts, used in Quality computation.

The Automation and Orchestration layer captured machine-automated events:

- Unplanned Downtime 2, involved machine/tooling issues such as die/tool changeovers (UD-04), tool failures (UD-06), or utility interruptions (UD-08).
- Minor Stoppages, which are short, non-critical disruptions.
- Actual Parts Produced, a core performance measure.

In the MES Calculation Engine, these inputs got synthesized to compute:

- Total Downtime = Planned + Unplanned + Minor Stoppage.
- Planned Production Time, derived from ERP-level inputs.
- Operating Time, Ideal Total Parts, and OEE sub-metrics:
- Availability (%) = Operating Time ÷ Planned Production Time.
  - Performance (%) = Actual Parts ÷ Ideal Parts.
  - Quality (%) = (Actual Parts – Scrap or Defective Parts) ÷ Actual Parts.
  - OEE (%) = Availability × Performance × Quality.

The ERP layer provided foundational planning parameters:

- Total Calendar Days, Shifts per Day, Hours per Shift, Parts per Stroke, and Theoretical Strokes per Minute (SPM).
- These parameters contributed to compute Planned Production Time and Ideal Parts output.

The logical integration of all layers ensured real-time and accurate OEE computation, offering insight into the production system's overall health and effectiveness.

3.2.2. Changeover time

Changeover duration, a key determinant of OEE performance, witnessed significant improvement following MES deployment. In traditional stamping operations, the changeover process - comprising die removal, installation and clamping, and adjustment of feeder or transfer systems - tends to vary depending on operator proficiency and manual procedures. A comparative summary of average changeover durations over a seven-month period, compared with pre-MES baseline values, is shown in Figure 5. Data spans seven months, with Month 3, Month 5, and Month 7 reflecting progressive improvements following the rollout of e-SOPs and MES-integrated workflows. With the implementation of MES-driven electronic SOPs and interactive guidance protocols, these changeover steps became standardized, repeatable, and subject to digital validation. As a result, variability reduced, and operator dependency declined. By Month 7 (March 2025), the overall changeover time dropped to 35 minutes from the original 56-minute benchmark - reflecting a 37.5% reduction. The incorporation of MES checklists, which mandated real-time logging and step verification, played a central role in ensuring process consistency and minimizing unnecessary delays across all shifts and operator groups.

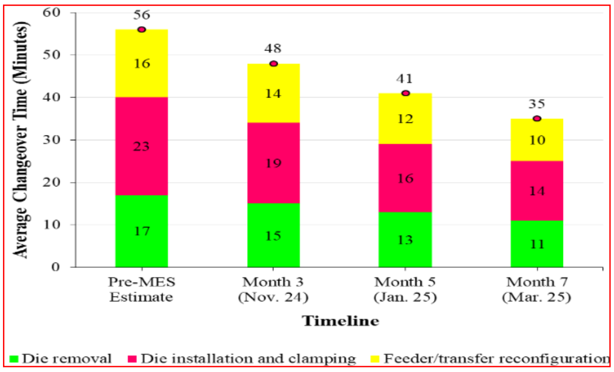

Fig. 5: Changeover Time Reduction from Sept. 2024 to Mar. 2025.

3.2.3. Downtime

Figure 6 presents the scenario of planned production time over seven months. The contributors to the planned production time [= (working days per month) × (number of shifts per day) × (number of hours per shift) × 60] are operating time and total downtime (planned downtime, unplanned downtime and minor stoppages). The implementation of MES-based preventive maintenance alerts led to timely servicing and reduced downtime, while enhanced coordination in die changeovers and part handling improved flow efficiency. MES-triggered alerts enabled proactive maintenance, reducing unplanned downtime from 21.84% to 10.41% w.r.t. the planned production time. Standardized inspection protocols reduced rejection-related losses. Total downtime reduced from 42% to 23.12%. Quality metrics also benefited from digitized inspection protocols, resulting in reduced defect rates.

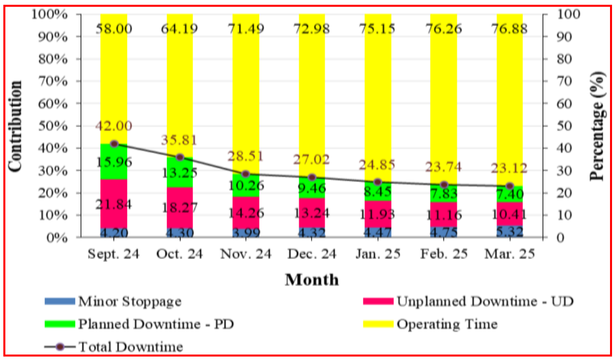

Fig. 6: Month-Wise Breakup of Planned Production Time.

3.2.4. OEE

A key metric consistently tracked throughout the MES deployment was OEE, which combines the dimensions of availability, performance, and quality. Figure 7 illustrates the month-wise trend in these three elements over the course of production between September 2024 and March 2025. Real-time visualization of OEE via MES dashboards enabled floor supervisors to act swiftly on machine utilization insights and coordinate maintenance proactively.

The input parameters contributing to the OEE calculation were detailed - including scheduled time, downtime categories, operating time, and quality-related figures. This dataset also included MES-sourced polling points from multiple checkpoints, which fed into the computation of planned and unplanned downtimes. These checkpoints, along with their hierarchical contribution lead toward OEE derivation. During the observed timeframe, OEE improved significantly - from an initial 47.17% to 72.36% - marking an overall gain of over 25 percentage points.

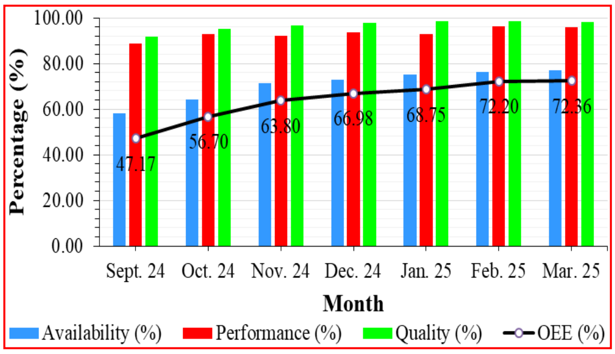

Fig. 7: Month-Wise OEE Improvement (Availability, Performance, and Quality).

The observed OEE improvement was closely linked to specific MES functionalities. Real-time production dashboards enabled immediate visibility of stroke counts and bottlenecks, allowing supervisors to intervene quickly. PLC-based downtime logging improved accuracy in capturing stoppages, ensuring corrective actions could be prioritized effectively. Additionally, digital SOP enforcement reduced variability in operator practices, improving process consistency. Together, these features directly contributed to higher equipment availability, better performance rates, and reduced quality losses, thereby driving the overall OEE gain from 47.17% to 72.36%.

The gradual month-over-month rise in OEE signifies increased production maturity, stemming from operator familiarity with MES tools, the stabilization of workflows, and more effective utilization of digital SOPs. Notably, the quality dimension showed consistent performance due to reduced scrap and better in-line control mechanisms.

Although OEE is expected to reach a relatively steady range once production routines, MES functionality, and product mix stabilize, it will continue to vary in response to changes in part complexity, process updates, tooling wear, and new automation deployments. This reflects the inherently dynamic nature of discrete manufacturing and its continuous improvement trajectory.

The MES downtime module successfully logged over 90% of known stoppages through direct communication with press-line PLCs. These were automatically grouped into categories such as die setting delays, sensor malfunctions, quality holds, and material jams. The remaining 10%, labelled as "uncategorized stoppages," comprised events that were either too short to register, involved auxiliary systems outside MES scope, or required manual confirmation. Addressing these will require better peripheral system integration, broader sensor coverage, and the application of analytics for event inference.

3.3. Quality and traceability gains

The quality management functionality within the MES was integrated with both visual inspection stations and in-line sensor networks, allowing for immediate defect identification and classification. Defect types such as wrinkles, splits, and misfeeds were automatically logged and linked with key identifiers like die set IDs, raw material batch numbers, and operator credentials. As referenced in the previous section (Figure 7, complement of Quality (%)) and shown in Table 1, a steady month-wise decline in defect rates was observed, indicating progressive quality improvements.

Table 1: Monthly Defect Rate, First Pass Yield and Key MES Quality Milestones.

Month	Defect Rate (%)	First Pass Yield (%)	Key MES Quality Milestone
Sep. 2024	8.22	91.78	Initial MES Rollout, Manual Logging
Oct. 2024	4.94	95.06	Digital Check Sheets, First Peace Inspection
Nov. 2024	3.20	96.80	Batch-wise and Shift-wise Traceability
Dec. 2024	2.11	97.89	Tool Correlation Dashboards
Jan. 2025	1.62	98.38	Defect Trend Alerts Activated
Feb. 2025	1.60	98.40	Corrective Action Tracking Added
Mar. 2025	1.93	98.07	Preventive Die Maintenance Linked to MES

By March 2025, which marked the seventh month of MES implementation, the defect rate had dropped from an initial 8.22% to 1.93%, signifying a 76.52% improvement. Each in-process inspection was recorded against a unique part serial number, making it possible to generate traceability reports for Original Equipment Manufacturers (OEMs) and to support both internal and external audits effectively.

Such granular traceability proved instrumental in recognizing recurring issues across repeat production runs and facilitated informed scheduling of maintenance tasks. Compared to traditional methods, which relied on paper-based reporting or lagging indicators, MES offered instant alerts when defect metrics exceeded pre-set thresholds, enabling quicker response.

The MES rollout had a transformative impact on quality assurance processes at the newly established stamping facility. During the initial implementation stage (September-October 2024), quality records were sparse and often unreliable, due to undocumented rejections and manual defect entry. The introduction of digital inspection sheets in September and the deployment of first-piece approval procedures in October marked a significant shift toward a structured and data-driven quality regime. These digital workflows helped eliminate inconsistencies and ensured real-time inspection logging.

By November, MES capabilities were extended to include batch-wise and shift-wise traceability, allowing quality teams to track issues back to specific production runs or material inputs. In December, the system was augmented with defect dashboards that linked recurring rejections to particular tools or dies. This correlation feature greatly accelerated root cause diagnosis and corrective action.

In January 2025, MES started issuing trend-based alerts for emerging defect patterns, which helped supervisors take early preventive action. As a result, First Pass Yield (FPY) consistently surpassed 98%, a sign of increased process stability and reliability.

February saw the inclusion of a corrective action tracking feature, which enabled structured documentation and verification of non-conformance resolutions. Despite an increase in production throughput in March 2025, the plant maintained high product quality levels. This was largely facilitated by the successful connection between MES and the preventive die maintenance module, which initiated condition-based maintenance activities based on tool usage data. This linkage significantly curbed tool-related defects and ensured sustained part quality.

The marginal uptick in defect rate in March - from 1.60% in February to 1.93% - coincided with the early operational phase of the preventive maintenance module. Although the system had gone live, it required time to gather sufficient usage data to generate actionable insights. Furthermore, while the corrective action tracking module had been deployed a month earlier, the full closure of cross-functional actions often spans multiple production cycles. The slight rise in March thus likely reflects residual quality issues from the previous month or newly surfaced challenges identified through improved detection mechanisms.

Thus, MES Quality Logs were configured to capture real-time inspection results and defect events at every critical stage. For example, during the production of a side panel reinforcement part, the MES system recorded first-piece inspection results for dimensional accuracy, surface finish, and blank alignment. Any deviations, such as minor wrinkles or burrs, were automatically tagged by the visual inspection terminal and classified under predefined defect codes. Each defect entry included the die ID in use, coil batch number, operator ID, and shift timing, enabling complete traceability. When repeated misfeeds were detected across three consecutive shifts, MES triggered a quality alert and correlated the issue to a worn-out feeder sensor. This led to a preventive maintenance action recorded under the Corrective Action Log. All quality events were timestamped and logged into the MES database, forming a digital record of compliance with inspection SOPs. These records were later used during an internal quality audit and successfully demonstrated adherence to IATF 16949 traceability requirements. Thus, MES-supported traceability linked each stamped part to its die set, press parameters, raw material batch, and inspection outcome. This digital linkage enabled faster root cause identification, reduced undocumented rejections, and simplified customer audit preparation.

3.4. Operator and supervisor perception analysis

In addition to tracking performance metrics quantitatively, qualitative insights were obtained from frontline personnel to evaluate how the MES implementation influenced user experience in a green field tandem press line environment. Feedback was collected from three primary stakeholder groups: machine operators, shift supervisors, and maintenance staff. Ten machine operators, three shift supervisors and five maintenance staff from the facility participated in this survey.

Two rounds of structured surveys were conducted - first, one month after MES go-live, and again after seven months of sustained system use. The feedback instrument assessed four essential parameters: (i) ease of interaction with the system, (ii) effectiveness of the training delivered, (iii) perceived value of real-time operational data, and (iv) confidence in the accuracy of MES-logged information versus traditional manual tracking. Participants rated each dimension on a five-point Likert scale (1 = Strongly Disagree, 5 = Strongly Agree). Average scores for each parameter at both time intervals are presented in Figure 8. The grouped bar chart presented in Figure 8 compares operator, supervisor, and maintenance personnel feedback between Month 1 (Oct. 24) and Month 7 (Apr. 25) across four MES-related metrics.

Over the course of the evaluation period, user sentiment exhibited marked improvement - especially with respect to training quality and data trust. The growing comfort with system usage reflects a successful adaptation curve, as users gained familiarity and confidence in the digital workflows. Early-stage hesitation, often encountered in green field digitization settings - particularly among teams previously reliant on paper-based methods - was mitigated through structured onboarding programs and the deployment of user-centric interface designs. The feedback confirmed that user adaptation, when supported by proper training and intuitive interfaces, enhances system adoption even in non-digitally experienced environments. The MES rollout followed a structured three-phase training program. In the initial phase, operators were introduced to basic MES functions through classroom sessions and simulation-based exercises that mimicked real production orders. The second phase emphasized on-the-job guidance, where supervisors and MES champions provided direct support during live operations. The third phase involved continuous reinforcement, including dashboard-based feedback, periodic refresher sessions, and hands-on workshops focused on troubleshooting. Initial resistance was observed among some operators accustomed to paper-based methods; however, this was addressed through step-by-step digital interlocks, peer mentoring, and simplified user interfaces. Over the seven-month period, survey feedback indicated a steady rise in user confidence and trust in MES-logged data. This progression reflects not only successful system training but also the importance of embedding a change management strategy alongside technical deployment to achieve long-term acceptance.

This evolution in user feedback underscores the importance of addressing human factors in MES rollout strategies. Technical robustness alone is insufficient; sustainable adoption hinges on proactive change management, continuous training, and clear communication.

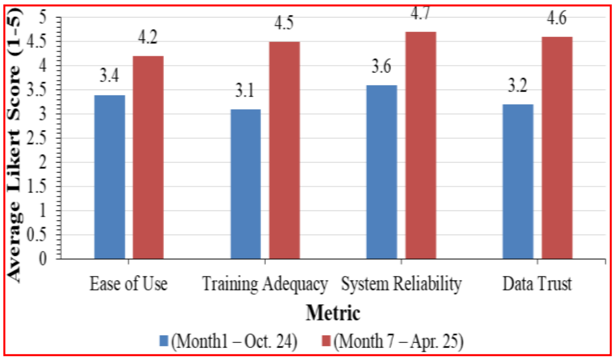

Fig. 8: Operator and Supervisor Feedback on MES System.

3.5. Advancing strategic digitalization through MES deployment

Beyond operational gains, the MES implementation created a robust foundation for future digital initiatives. Real-time data structures enabled condition-based maintenance, batch reconciliation, and paperless record keeping.

Although the immediate aim of deploying the MES was to enhance operational workflows, its broader influence has been in setting a clear trajectory toward digital transformation and aligning the stamping facility with Industry 4.0 paradigms. Figure 9 outlines the digitally enabled evolution pathway of the greenfield stamping line, showcasing key milestones and system achievements.

From the outset, core digital functionalities were embedded across the plant. The MES ensured comprehensive traceability of raw materials, equipment conditions, and operator actions - enabling enhanced process transparency and accelerated root-cause identification. Moving away from paper-based operations, the plant adopted digital tools for logging inspections, maintenance activities, and production records, which significantly improved data reliability and reduced manual intervention errors.

Bidirectional, real-time communication between MES and the ERP system facilitated automatic job dispatch, live tracking of material usage, and batch-level reconciliation - resulting in improved inventory precision and streamlined administrative workflows. Simultaneously, the MES tapped into stroke count data and machine alarm logs via PLC connections to trigger predictive maintenance actions, reducing unexpected machine stoppages and boosting asset availability.

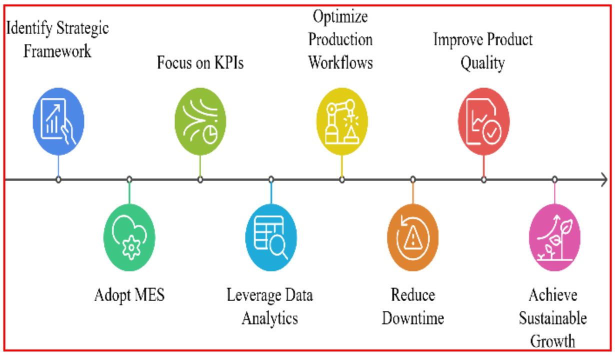

Fig. 9: Roadmap for MES Driven Digital Transformation.

These foundational steps created a robust digital infrastructure capable of scaling toward more advanced capabilities as depicted in Figure 10. With structured datasets now available, the facility is positioned to leverage analytics for identifying throughput constraints, tracking operator effectiveness, and assessing shift-level productivity. Correlating quality inspection results with equipment and workforce parameters opens up avenues for implementing AI-powered quality prediction models.

Clean, structured data captured during production can now be used for advanced analytics, predictive quality, and potential digital twin deployments. The MES architecture allows seamless integration with Industrial Internet of Things (IIoT) and energy monitoring systems in the next phases of digitalization.

Thanks to its modular design, the MES platform offers future readiness for integration with IIoT ecosystems, facilitating smart features like energy consumption analysis, real-time asset location services, and holistic factory intelligence. In the longer term, consistent data standards across the MES framework also support the eventual deployment of digital twins for simulating and refining production processes [16-18].

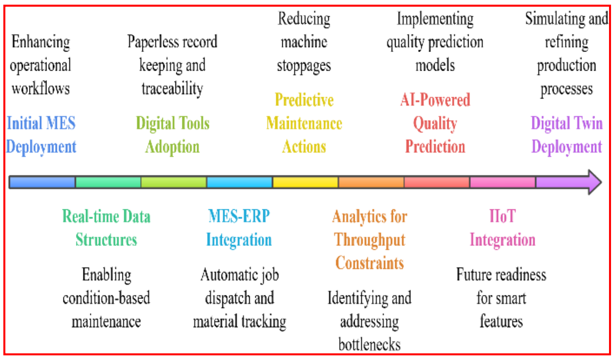

Fig. 10: Roadmap for MES Driven Digital Transformation with Advanced Capabilities.

While the MES deployment demonstrated significant operational benefits, it is important to acknowledge potential trade-offs. The implementation required substantial initial investment in IT–OT infrastructure, system integration, and user training. However, these upfront costs are offset by the long-term advantages of enhanced traceability, reduced defect rates, shorter changeovers, and improved OEE, which collectively strengthen operational stability and accelerate digital maturity. This cost–benefit balance underscores the strategic value of green field MES adoption for high-throughput industries.

By embedding digital technologies into the plant's DNA from the beginning, the organization has not only achieved efficiency improvements but also established the flexibility and preparedness needed to integrate next-generation industrial solutions. Table 2 highlights the feature-wise impact of MES implementation with future readiness.

Table 2: MES Implementation Impact

Impact / Feature	Immediate Aim	Broader Influence	Future Readiness
Enhanced Operations	Improved workflows	Digital transformation	IIoT ecosystem integration
Data Management	Comprehensive traceability	Advanced analytics	Digital Twin deployment
Communication	Real-time communication	Structured datasets available	Seamless integration
Maintenance	Predictive maintenance actions	AI-powered quality production	Consistent data standards

4. Conclusions

The deployment of a MES in a newly commissioned automotive stamping facility - centered around a tandem press line - has proven instrumental in shaping both operational excellence and long-term digital strategy. This case highlights how incorporating MES from the earliest design stages, rather than integrating it as a post-deployment upgrade, can serve as a catalyst for performance enhancement and digital evolution.

The MES implementation led to marked improvements in several core manufacturing metrics. Over the first seven months of production, OEE rose by 25 percentage points, changeover durations were shortened by 37.5%, and defect rates dropped by over 76%. Furthermore, the plant achieved complete part-level traceability from the outset, linking each component to its raw material batch, die identification, machine cycle, and responsible operator. These results demonstrate the strategic benefit of embedding MES within the foundational architecture of green field facilities.

Real-time data availability enabled prompt, informed decisions and continuous performance refinement. Rather than functioning merely as a process control tool, the MES became a central enabler of operational visibility, traceability, and standardization across roles and shifts. Feedback from operators and supervisors showed increasing confidence in the system, improvement in procedural compliance, and overall acceptance - affirming the MES's role in driving cultural change alongside technological transformation.

From a scholarly perspective, this study makes a timely contribution to the limited literature on MES applications in green field contexts. Unlike brownfield environments - where MES often retrofits into legacy systems - the green field scenario allows full alignment of digital tools with business intent, process flows, and data structures from inception. The findings presented here offer an evidence-based blueprint for deploying MES as an integral component of smart manufacturing infrastructure.

This work also proposes a replicable framework for MES rollout in discrete production environments. It outlines practical considerations spanning platform selection, system architecture, workflow definition, user training, and commissioning—all tailored to greenfield implementation. Such guidance can benefit industry professionals and consultants working in fast-paced, high-volume manufacturing domains such as electronics, white goods, and aerospace.

While this study demonstrates substantial early-stage improvements from MES implementation in a green field automotive stamping facility, the evaluation period was limited to the first seven months of operation. As such, it primarily reflects short-term stabilization and efficiency gains. Long-term scalability, system resilience under varying product mixes, and adaptation to evolving manufacturing conditions remain outside the current study's scope. Future research should extend the evaluation horizon to multiple years, incorporating data from seasonal demand fluctuations, progressive operator training, tooling lifecycle changes, and integration with adjacent processes such as blanking, welding, and assembly. Such longitudinal studies will provide deeper insights into the sustainability and robustness of MES-driven improvements.

Nonetheless, the research has its limitations. The evaluation period was restricted to the first seven months (September 2024–March 2025), which, while sufficient for assessing early outcomes, does not capture long-term scalability and resilience. Additionally, the scope was limited to stamping operations; integration with adjacent processes such as blanking, welding, or sub-assembly stages remains unexplored. Advanced features - including predictive quality analytics, AI-supported scheduling, and mobile MES access - were also beyond the scope of this phase.

Future research may extend into areas such as IIoT integration to unlock predictive maintenance and real-time energy management. Leveraging machine learning models on MES-generated datasets could further aid in cycle time optimization and anomaly detection. Moreover, expanding MES functionalities into warehousing and logistics would pave the way for full traceability and supply chain transparency. Linking MES with enterprise systems like Product Lifecycle Management (PLM) or Customer Relationship Management (CRM) could also foster enterprise-wide digital continuity.

Building on these outcomes, future directions include leveraging MES and IIoT data for AI-driven predictive maintenance, advancing cross-plant MES standardization to strengthen enterprise-wide consistency, and integrating MES with digital twin platforms to simulate and optimize production scenarios in real time.

In essence, this case reaffirms that MES, when integrated as a core element in green field manufacturing strategy, plays a pivotal role not only in achieving operational goals but also in enhancing organizational adaptability and digital readiness. It transitions MES from a supportive function to a strategic driver - unlocking quality, responsiveness, and innovation from the first day of operations. Beyond its practical relevance, this study invites further academic inquiry into how digital systems reshape the future of industrial production.

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