

Performance Evaluation of Billet Handling Systems: A Review on Time, Safety, Cost, Rejection Ratio, Precision and Efficiency

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Abstract— This review explores the automation strategies and process improvements in billet handling systems, emphasizing six critical factors: time, safety, cost, rejection ratio–quality, precision, and efficiency. Automated loading mechanisms, conveyor networks, and precision forging lines have been employed to shorten handling cycles and enhance workplace safety in manufacturing operations. High-speed billet cutting machines and hot separation techniques have been utilized to increase productivity while reducing rejection rates, ensuring consistent material integrity. Furthermore, innovations such as multi-layer furnaces and automatic loading networks have been introduced to improve throughput and optimize energy consumption. Precision heating approaches using induction and resistance furnaces contribute to defect minimization and process consistency. The use of PLC and SCADA systems has facilitated real time monitoring, fault prediction, and operator friendly interfaces, thereby enhancing reliability and safety compliance. Cost analyses show that automation lowers operational expenses, maximizes equipment utilization, and improves overall process effectiveness. Nevertheless, challenges persist in integrating smart algorithms, handling variability, and ensuring system interoperability within Industry 4.0 environments. This paper lays the groundwork for systematically comparing existing methods with a PLC based automation framework. The findings aim to guide the development of safer, cost-effective, and high-performance billet handling solutions tailored to modern industrial requirements

Index Terms— Aluminium billet handling, HMI integration, Industrial optimization, PLC control, Smart manufacturing.

I. INTRODUCTION

Efficient billet handling is an essential part of industries such as forging, extrusion, and hot stamping, where productivity, cost control, and safety are primary concerns. Traditionally, handling processes have relied on manual or partially automated methods, which often resulted in longer production times, higher labour costs, and increased exposure to safety risks [1], [3], [7], [36].

To overcome these limitations, automation technologies such as conveyor systems, robotic loading stations, and precision cutting tools have been increasingly adopted to enhance throughput and reduce operational disruptions [2], [5], [7], [37].

Advances in heating and material conveying technologies have further contributed to improving billet processing. Multi-layer furnaces, erosion resistant rollers, and automated loading systems have enhanced energy efficiency and process reliability in high volume production settings [9], [10], [11], [38]. Additionally, integrating PLC and SCADA systems has allowed manufacturers to monitor processes in real time, predict failures, and schedule maintenance while ensuring seamless control through user friendly human machine interfaces [14], [15], [21], [25], [39]. These improvements have led to reductions in material waste, fewer defects, and enhanced precision, improving product quality and reducing rejection rates [12], [23], [27], [40].

Despite these advancements, significant challenges remain. Variations in raw materials, energy consumption patterns, and equipment coordination introduce complexity, affecting system performance and reliability. Industry 4.0 solutions such as artificial intelligence, machine learning algorithms, and the Internet of Things (IoT) offer promising approaches for managing these complexities by enabling smarter process controls and predictive maintenance strategies [18], [35], [41], [42].

This paper aims to present a structured review of existing billet handling systems by evaluating their performance across six key parameters: time, safety, cost, rejection ratio quality, precision, and efficiency. By compiling data from various studies and industrial practices, this review establishes a foundation for comparing current systems with a PLC-based automation approach. The objective is to support the development of safer, more cost effective, and efficient billet handling processes, aligned with modern industrial needs and technological advancements.

II. METHODOLOGY OF REVIEW

This review systematically examined 42 publications on billet handling, classifying them into manual methods, semi-automated systems, and PLC-driven automation. Literature published between 1977 and 2025 was screened through predefined inclusion criteria, focusing only on peer-reviewed and industrially relevant sources. Data extraction emphasized six performance parameters: processing time, safety compliance, cost, rejection rates, positional precision, and operational efficiency.

To enable comparison, quantitative results were normalized and analyzed using multi-criteria decision-making tools, primarily Analytical Hierarchy Process (AHP) and Grey Relational Analysis (GRA). This ensured balanced evaluation of trade-offs among speed, quality, safety, and cost. Complementing this, thematic coding captured qualitative insights on control architectures, interlocks, SCADA-based supervision, and PLC-HMI integration.

Findings were cross validated with industrial case studies in steel forging, extrusion, and stamping lines to establish robust benchmarks. The methodology thus integrates quantitative rigor with qualitative synthesis, ensuring both breadth and depth in assessment.

III. LITERATURE REVIEW

Modern billet handling systems in forging, extrusion, and casting industries are shifting towards high automation, with clear impact on time, safety, cost, rejection ratio, precision, and efficiency. Traditionally, billet separation and transfer were labour intensive, prone to variation and human error, leading to limitations in throughput, quality, and safety [1], [7], [36]. Recent studies emphasize the use of PLC (Programmable Logic Controller) and SCADA (Super-visory Control and Data Acquisition) to optimize and control the process parameters, offering considerable improvements across all benchmarking metrics [14], [15], [24], [39].

The evolution of billet handling can be categorized into three phases:

- Manual operations: Relying on labour intensive methods such as nick and break or cold shearing, which were slow, hazardous, and prone to inconsistency [1], [7].
- Semi-automated systems: Incorporating basic mechanical or electrical aids, which improved safety and reduced handling effort but remained limited in precision and throughput [8], [16].
- Fully automated PLC-SCADA systems: Which now dominate modern manufacturing due to their superior control, monitoring, and predictive capabilities [14], [15], [24], [39].

A. Time

Manual billet separation processes, such as nick-and-break or cold shearing, typically require sequential, multi-stage handling per billet, with cycle times ranging from 1–2 minutes per billet [7], [36]. Hot shearing integrated

with auto-mated handling systems reduces billet separation cycle to under 20 seconds, allowing direct forging [2], [6]. Auto-mated sawing can further decrease cycle times to 15–30 seconds per billet and ensure continuous operation [2], [4]. Automated manipulator-based systems (serial-parallel or robotic) achieve throughput rates upwards of 100 billets per hour, relying on optimized motion planning [5], [37].

B. Safety

Manual processes carry risks of worker injury due to hot metal, moving parts, and repetitive handling. Rejection due to improper handling or accidents is a documented concern [7], [36]. Automation using PLC/SCADA and sensor-based monitoring has led to near-zero workplace accidents in modern plants, with integrated interlocks and real-time alarms, dramatically improving operator safety and reducing liability [14], [15], [22], [39].

C. Cost

Traditional systems entail high labour and maintenance costs, compounded by material waste from inaccurate separation methods [7], [16]. Automated solutions, although involving higher upfront investment, deliver long term savings through reduced workforce, low rejection rates, and minimal unplanned downtime. Case studies report operating cost reductions of 20–40% compared to manual lines [2], [9], [14], [40].

D. Rejection Ratio

Manual sorting and parting often lead to high rejection ratios (5–10%) due to inconsistent sizing, irregular cuts, or contamination [7], [8]. Automated billet sorting and sawing mechanisms achieve rejection ratios as low as 0.5–1%, thanks to precision sensors, vision-based inspection, and robust quality assurance routines [8], [14], [17], [36].

E. Tolerance Level

PLC based automation systems maintain length tolerances within ± 1 mm, compared to ± 3 –5 mm when using manual methods [2], [4], [14]. Integrated measurement and sorting units ensure correct alignment and transfer, minimizing off-specification products and maintaining batch consistency [8], [19], [37].

E. Overall Equipment Effectiveness

The efficiency of billet handling is now characterized by synchronized, continuous production, with OEE (Overall Equipment Effectiveness) values regularly exceeding 85% in advanced setups [2], [26], [36]. SCADA integrated multi-layer furnace feeding and unloading, combined with hot shearing, has demonstrated up to 35% improvement in production rates, reduced energy consumption per billet, and maximized material yield [9], [10], [14], [38].

TABLE I. COMPARATIVE ANALYSIS OF TRADITIONAL VS. AUTOMATED BILLET HANDLING

Parameter	Traditional Handling	Automated Handling
Time (per billet)	60–120 seconds [7], [36]	15–30 seconds [2], [4], [5], [37]
Safety incidents	Moderate to High [7], [36]	Very Low [14], [15], [22], [39]
Cost (per billet)	High [7], [16], [40]	20–40% lower [2], [9], [14], [40]
Rejection ratio (Quality)	5–10% [7], [8], [36]	0.5–1% [8], [14], [17], [36]
Tolerance Level	± 3 –5 mm [7], [36]	± 1 mm [2], [4], [14], [37]
Overall Equipment Effectiveness	50–70% [7], [36]	85%+ [2], [14], [26], [36]

IV. CRITICAL ANALYSIS

The critical analysis underscores the transformative impact of automation on billet handling performance by improving productivity, quality, and safety while reducing operational costs.

A. Processing Time

Manual methods take 60–120 seconds per cycle, whereas PLC-based systems achieve 18–30 seconds, and robotic solutions can reduce this to 15 seconds per billet [5], [6], [9], [37].

B. Cost

Although automation requires capital investment (Rs. 14,120–486,000), the payback period is typically 6–24 months, thanks to reduced labor dependency and increased productivity [2], [4], [8], [12], [14], [15], [23], [24], [26], [33], [40].

C. Rejection Ratio

Defect rates in manual setups (15–20%) drop to 1–3% under PLC control, due to precise actuation and cycle consistency [8], [14], [22], [23], [26], [36].

D. Tolerance Level

Accuracy improves from ± 0.1 mm in manual handling to ± 0.02 mm with PLC-based automation [5], [11], [12], [23], [26], [37].

E. Overall Equipment Effectiveness (OEE)

OEE rises from 60–70% in manual operations to 85–95% with predictive maintenance and real-time monitoring enabled by SCADA [18], [22], [23], [26], [27], [28], [30], [35], [36].

TABLE II. CRITICAL EVALUATION OF BILLET HANDLING METHODS ACROSS AUTOMATION LEVELS

Parameter	Manual Systems	Semi-Automated Systems	PLC-Based Automated Systems	Sources
Time / Cycle Time	60–120 seconds per cycle	25–56 seconds per cycle	18–30 seconds per cycle; 15 seconds in robotic setups	[5], [6], [9], [37]
Safety	High risk of burns, crush injuries	Basic guards and protocols	Emergency stops, sensors, interlocks	[14], [15], [21], [22], [23], [24], [26], [27], [29], [30], [32], [34], [35]
Cost	Rs. 12,000–24,000 monthly labor costs	Rs. 8 400–16 800 per month	Rs. 14,120–486,000 initial investment; payback 6–24 months	[2], [4], [8], [12], [14], [15], [23], [24], [26], [33], [40]
Rejection Ratio (Quality)	15–20% rejection rates	5–10% rejection rates	1–3% rejection rates	[8], [14], [17], [22], [23], [26], [36]
Tolerance Level	± 0.1 mm tolerance	± 0.05 mm with basic controls	± 0.02 mm precision control	[5], [11], [12], [23], [26], [37]
Overall Equipment Effectiveness	0–70% availability	75–80% availability	85–95% OEE with predictive maintenance	[18], [22], [23], [26], [27], [28], [30], [35], [36]

V. RESEARCH GAPS AND FUTURE DIRECTIONS

Based on the reviewed studies [3], [6], [10], [11], [12], [13], [15], [16], [18], [21]–[35], several critical research gaps are evident. Despite notable progress in billet handling automation, integration of modern systems with existing industrial infrastructure remains limited, often causing implementation delays and increased costs [3], [13], [21], [22], [29], [32]. Although predictive maintenance and real time compensation techniques have been proposed [6], [10], their practical deployment is hindered by the absence of standardized approaches and insufficient validation across diverse operational environments, raising reliability concerns.

Economic evaluations, such as long-term ROI studies for high-capital technologies including multilayer furnaces, robotic manipulators, and PLC–SCADA systems, are largely lacking [11], [13], [23], [24], [30], [31], [33], [41]. Additionally, the reliability of automation platforms is often compromised by weaknesses in software stability and hardware resilience, highlighting the need for more robust system designs [26], [27], [38].

Sustainability considerations remain secondary; most research emphasizes throughput and accuracy, while energy efficiency, lifecycle assessment, and environmentally responsible automation have received limited attention [12], [25], [34]. Adoption of Industry 4.0 features such as digital twins, automated parameter configuration, and smart building integration is still in its early stages, and Industry 5.0 principles, which focus on human–machine collaboration and resilient systems, have not yet been fully realized [15], [16], [18], [33]–[35].

Future investigations should emphasize multi-objective optimization that balances cost, time, safety, precision, and sustainability. Developing standardized integration protocols, scalable architectures, and operator-centric designs, alongside AI-driven decision-making, will be essential to advance the next generation of reliable, efficient, and eco-friendly billet handling automation systems.

VI. CONCLUSION

This review highlights the transformative impact of automation on billet handling, demonstrating measurable gains in cycle time reduction, cost efficiency, safety, and process precision. Flashless forging, hot shearing, and

advanced conveying have set new benchmarks, while intelligent handling and Industry 4.0/5.0 technologies offer unprecedented flexibility. Nevertheless, the literature reveals persistent challenges in predictive maintenance, integration with existing infrastructure, energy optimization, and consistent safety documentation. By bridging these gaps through AI-enhanced control, digital twins, and sustainable practices, future billet handling systems can become not only faster and safer but also more resilient and environmentally responsible. Ultimately, the convergence of automation, digitalization, and human-machine collaboration promises a robust pathway toward next-generation, future-ready manufacturing.

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