Experimental Analysis of Billet Manufacturing Losses and Development of Downtime Reduction Strategies for Productivity Enhancement in a Continuous Casting Plant

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Abstract — Continuous casting is a key process in steel manufacturing, where billet quality, productivity, and equipment reliability significantly influence overall plant performance. This study presents an experimental investigation of billet manufacturing losses and downtime factors in a continuous casting plant using actual production and maintenance data. Major losses such as downtime, billet rejection, breakout incidents, yield reduction, and process scrap were identified and quantified. Statistical analysis, Pareto analysis, and root cause analysis were employed to determine the critical factors affecting productivity. Based on the findings, suitable downtime reduction strategies were developed and implemented. The results demonstrated a reduction in production interruptions and manufacturing losses, along with improvements in productivity, yield, and Overall Equipment Effectiveness (OEE). The proposed approach provides an effective framework for enhancing operational efficiency and profitability in continuous casting operations.

Keywords: Continuous Casting, Billet Manufacturing, Downtime Analysis, Productivity Improvement, Overall Equipment Effectiveness (OEE)

I. Introduction

A. Continuous Casting Process

Continuous casting is the most widely used steel manufacturing process for producing billets directly from molten steel. In this process, molten steel is poured into a water-cooled mold where partial solidification occurs, followed by secondary cooling and cutting into required billet lengths. Continuous casting improves productivity, reduces energy consumption, and enhances product quality compared to conventional ingot casting methods [1], [3], [10]. Billet quality plays a critical role in downstream rolling operations, while higher casting productivity directly influences plant profitability and operational efficiency [2], [20].

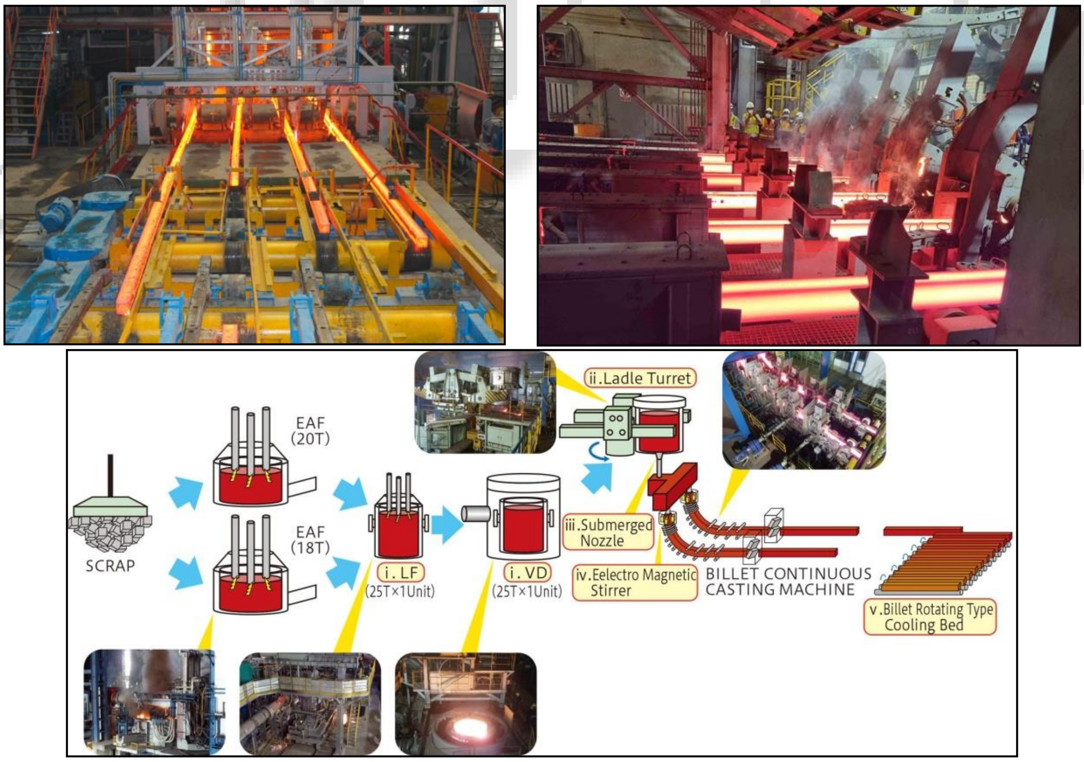


Fig. 1.1: Continuous Casting Process for Billet Production

The figure illustrates the continuous casting process starting from molten steel transfer to the tundish, mold solidification, secondary cooling zone, withdrawal system, and billet cutting operation. Continuous casting enables high-volume billet production with improved yield and reduced manufacturing losses.

B. Billet Manufacturing in Steel Plants

Billets are semi-finished steel products having square or rectangular cross-sections, typically ranging from 100 mm × 100 mm to 200 mm × 200 mm. They are used as raw materials for rolling mills to manufacture bars, rods, structural sections, and wire products. The billet manufacturing process includes molten steel preparation, tundish flow control, mold casting, secondary cooling, straightening, and billet cutting operations [7], [19]. Efficient billet production is essential for maintaining product quality, minimizing production losses, and achieving higher throughput in steel plants [11], [21].

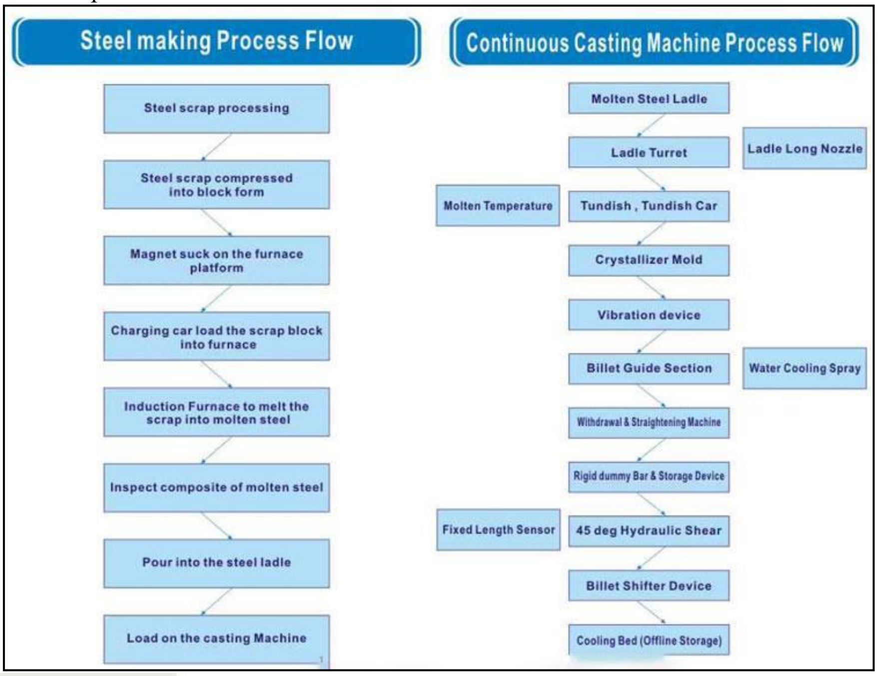


Fig. 1.2: Billet Manufacturing Flow in Steel Plants

The figure shows the billet manufacturing sequence from steelmaking to billet dispatch. The production flow highlights major process stages and their importance in maintaining billet quality and production efficiency.

C. *Manufacturing Losses in Continuous Casting*

Manufacturing losses significantly affect productivity, yield, and operational cost in continuous casting plants. These losses may arise from process inefficiencies, equipment failures, quality defects, and production interruptions. Yield losses occur due to crop ends and process scrap, while rejection losses result from surface cracks, inclusions, and dimensional defects. Breakout losses occur when liquid steel leaks through the solidified shell, causing severe production interruptions. Downtime losses reduce equipment availability and throughput, whereas energy losses increase operational costs [11], [23], [27].

D. *Problem Statement*

Continuous casting plants frequently experience production interruptions caused by equipment breakdowns, mold-related issues, hydraulic failures, electrical faults, and operational delays. These downtime events reduce billet production rates, increase manufacturing losses, and lower equipment utilization. Furthermore, excessive downtime adversely affects production planning, delivery schedules, and overall plant profitability. Therefore, there is a need to systematically analyze billet manufacturing losses and develop effective downtime reduction strategies for productivity enhancement.

E. *Objectives of the Study*

- To identify major billet manufacturing losses in a continuous casting plant.
- To analyze downtime causes affecting billet production.
- To quantify production losses using actual industrial data.
- To develop effective downtime reduction strategies.
- To improve productivity and equipment utilization through process improvements.

F. *Scope of the Study*

The present work focuses on:

- Billet continuous casting machine operations.
- Production and maintenance departments.
- Downtime analysis and loss quantification.
- Productivity and OEE evaluation.
- Development of practical downtime reduction strategies.
- Industrial implementation and validation of improvements.

II. LITERATURE REVIEW

A. *Continuous Casting Technology*

Continuous casting technology has evolved significantly with advancements in mold design, cooling systems, process automation, and casting control systems. Modern continuous casting machines achieve higher productivity, better surface quality, and reduced production losses. Research has focused on improving heat transfer, fluid flow behavior, steel cleanliness, and solidification characteristics to enhance billet quality and casting performance [5], [6], [10], [19].

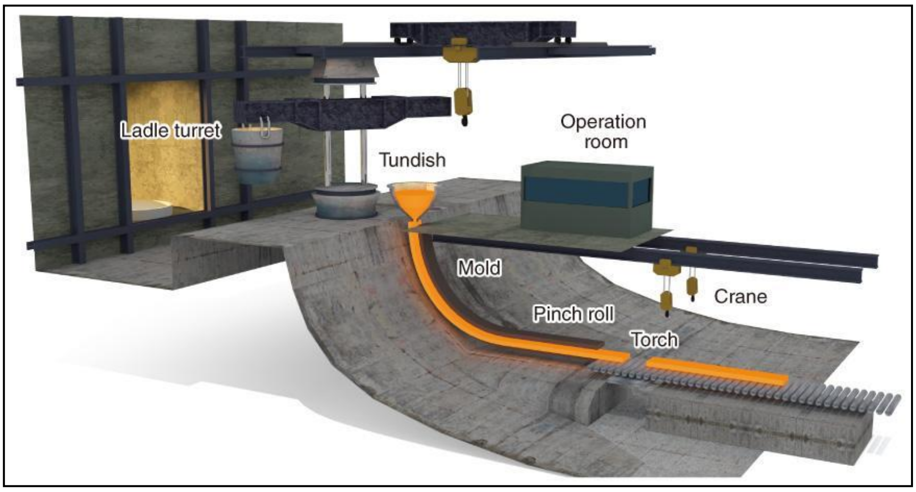


Fig. 2.1: Evolution of Continuous Casting Technology

B. Billet Manufacturing Losses

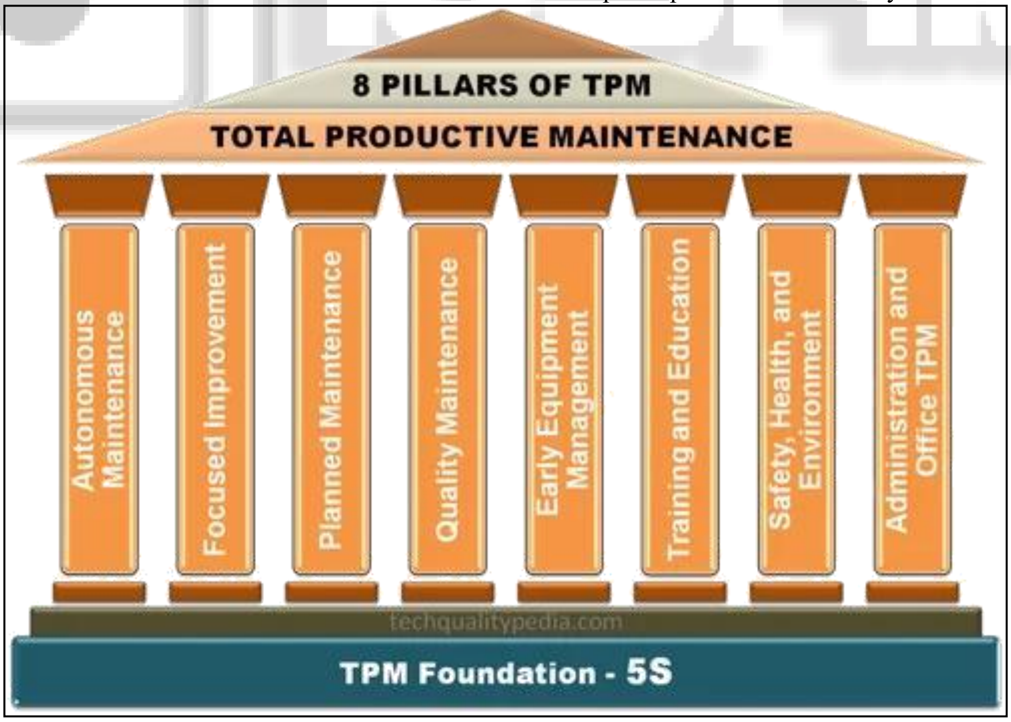
Billet manufacturing losses represent a major challenge in steel industries. Common losses include process scrap, breakout losses, crop-end losses, billet rejection, and production interruptions. Several researchers have reported that manufacturing losses significantly reduce production yield and increase operational costs. Effective monitoring and process optimization can substantially reduce these losses and improve plant productivity.

C. Downtime Analysis Techniques

Downtime analysis is widely used to identify production interruptions and equipment inefficiencies. Techniques such as breakdown analysis, root cause analysis, reliability assessment, Pareto analysis, and Total Productive Maintenance (TPM) are commonly employed for downtime reduction. These approaches assist industries in improving equipment availability and minimizing production losses.

D. Productivity Improvement Methods

Several productivity improvement techniques have been implemented in steel manufacturing industries. Lean manufacturing minimizes waste and non-value-added activities, while TPM improves equipment reliability and availability. Overall Equipment Effectiveness (OEE) is widely used for measuring productivity by combining availability, performance, and quality metrics. Preventive maintenance programs further reduce breakdown frequency and improve production continuity.



E. Research Gap

Existing studies mainly focus on casting process optimization, billet quality improvement, and maintenance management. However, limited research has been conducted on integrated analysis of billet manufacturing losses and plant-specific downtime reduction strategies in continuous casting operations. Moreover, there is a lack of comprehensive experimental studies combining production loss quantification, downtime analysis, root cause identification, and productivity enhancement using actual industrial data. Therefore, the present work aims to address this gap through systematic experimental investigation and implementation of practical improvement measures.

III. EXPERIMENTAL METHODOLOGY

A. Plant Description

The experimental study was conducted in a billet continuous casting plant equipped with a multi-strand continuous casting machine. The plant is designed for the production of steel billets used in rolling mills and forging applications. The casting machine operates with controlled cooling and automated billet cutting systems to achieve consistent product quality and higher productivity. Continuous monitoring of process parameters is essential for minimizing manufacturing losses and downtime events [3], [5], [19].

B. Data Collection Method

Production and maintenance data were collected from various operational records maintained in the plant. Daily production reports provided information on billet output, while shift reports recorded process performance and production interruptions. Maintenance logs and downtime records were used to identify equipment failures and downtime causes. Quality inspection reports supplied information related to billet defects, rejection rates, and yield performance [21], [23], [24].

Data Sources

- Daily production reports
- Shift reports
- Maintenance logs
- Downtime records
- Quality inspection reports

C. Research Methodology Flowchart

The research methodology follows a systematic approach beginning with production data collection and ending with performance evaluation. Downtime events are classified and quantified to identify major production losses. Statistical analysis and root cause identification are then performed to develop corrective actions. The effectiveness of improvement measures is finally evaluated through productivity and performance indicators.

Methodology Sequence

Production Data Collection
↓
Downtime Classification
↓
Loss Quantification
↓
Statistical Analysis
↓
Root Cause Identification
↓
Corrective Action Development
↓
Implementation
↓
Performance Evaluation

IV. EXPERIMENTAL PARAMETERS

The performance of the continuous casting process is influenced by several process and operational parameters. Input parameters are selected based on their impact on billet quality, productivity, and equipment performance. Output parameters are used to evaluate overall manufacturing efficiency and the effectiveness of downtime reduction strategies.

1) Input Parameters

Parameter	Unit	Description
Casting Speed	m/min	Speed of billet casting process
Molten Steel Temperature	°C	Temperature of liquid steel entering the mold
Tundish Temperature	°C	Steel temperature inside tundish
Mold Cooling Water Flow Rate	L/min	Cooling intensity during solidification
Machine Availability	%	Percentage of machine operating time
Downtime Duration	min	Total production interruption time

2) Output Parameters

Parameter	Unit	Description
Billet Production	tons/day	Daily billet output
Productivity	%	Production efficiency
Yield	%	Conversion efficiency of steel into billets
OEE	%	Overall equipment effectiveness
Rejection Rate	%	Percentage of defective billets
Downtime Percentage	%	Percentage of production loss due to downtime

A. Production Data Analysis

Production data analysis is carried out to evaluate the actual performance of the continuous casting plant and identify deviations from planned production targets. Monthly production records are analyzed to quantify production losses and assess overall manufacturing efficiency. Variations between planned and actual production indicate the influence of downtime, process interruptions, equipment failures, and operational inefficiencies. Production trend analysis helps identify periods of reduced productivity and supports the development of corrective actions for performance improvement [11], [23].

B. Downtime Analysis

Downtime analysis is performed to identify the major causes of production interruptions in the continuous casting plant. Downtime events are classified into mechanical, electrical, hydraulic, mold change, tundish change, breakout incidents, and material handling delays. The frequency and duration of each downtime category are evaluated to determine their impact on billet production. Downtime analysis assists in prioritizing improvement activities and reducing productivity losses [23], [24], [27].

C. Billet Manufacturing Loss Analysis

Billet manufacturing losses directly affect plant profitability and yield. Major losses include end crop losses, surface defect rejection, internal defect rejection, breakout losses, and process scrap generation. Quantification of these losses helps identify process weaknesses and improvement opportunities. Loss contribution analysis provides a basis for implementing targeted corrective actions and enhancing billet quality.

D. Productivity Analysis

Productivity analysis evaluates the effectiveness of converting available production resources into finished billet output. Productivity is calculated as the ratio of actual production to planned production. Higher productivity values indicate efficient utilization of resources and reduced downtime.

E. Yield Analysis

Yield analysis determines the efficiency of converting molten steel into acceptable billets. Higher yield values indicate lower process losses and better manufacturing performance. Yield improvement contributes directly to cost reduction and productivity enhancement.

V. Statistical Analysis

A. Descriptive Statistics

Descriptive statistical analysis is used to summarize production, downtime, yield, and rejection data. Parameters such as mean, standard deviation, minimum value, and maximum value provide an understanding of process variability and operational consistency.

B. Pareto Analysis

Pareto analysis is conducted to identify the most significant downtime causes responsible for the majority of production losses. This method helps prioritize corrective actions by focusing on the critical few causes contributing to most downtime events.

C. ANOVA Analysis

Analysis of Variance (ANOVA) is used to determine the significance of process variables such as casting speed, temperature, downtime duration, and cooling rate on productivity and yield. Statistical significance is evaluated using F-values and P-values.

D. Regression Modelling

Regression modelling establishes mathematical relationships between productivity and influencing process variables. The developed model helps predict productivity under varying operating conditions and supports process optimization.

Regression Model

$$P = \beta_0 + \beta_1(DT) + \beta_2(CS) + \beta_3(T) + \beta_4(Y)$$

Where:
P = Productivity
DT = Downtime
CS = Casting Speed
T = Temperature
Y = Yield

VI. Root Cause Analysis

A. Fishbone Diagram

Root cause analysis is conducted to systematically identify the factors responsible for downtime and manufacturing losses. Major causes are categorized under machine, material, method, manpower, and environment to facilitate structured problem solving.

B. Failure Analysis

Failure analysis investigates recurring equipment and process failures affecting plant performance. The analysis assists in identifying critical failure modes and determining their severity and impact on productivity.

VII. Development of Downtime Reduction Strategies

A. Technical Improvements

Technical improvements focus on enhancing equipment reliability and process stability. Major initiatives include:

- Preventive maintenance scheduling
- Mold condition monitoring
- Improved cooling system control
- Equipment health monitoring

B. Operational Improvements

Operational improvements aim to minimize process-related interruptions through:

- Operator skill enhancement
- Standard operating procedures
- Shift-wise performance monitoring
- Improved communication systems

C. Management Improvements

Management strategies support continuous productivity improvement through:

- Daily KPI monitoring
- Downtime review meetings
- Production planning optimization
- Maintenance planning and coordination

VIII. Validation of Improvement Strategies

A. Before and After Comparison

The proposed downtime reduction strategies were validated through a comparative analysis of production performance before and after implementation. The comparison indicated a reduction in downtime and rejection losses, along with improvements in productivity, yield, and Overall Equipment Effectiveness (OEE). These improvements demonstrate the effectiveness of maintenance and operational control measures in enhancing billet manufacturing performance [23], [24], [28].

Parameter	Before	After	Improvement (%)
Downtime (%)	12.5	8.1	35.20
Productivity (%)	78.6	88.4	12.47

Yield (%)	92.1	95.4	3.58
OEE (%)	69.8	82.6	18.34
Rejection Rate (%)	5.6	3.1	44.64

Table 8.1: Before and After Performance Comparison

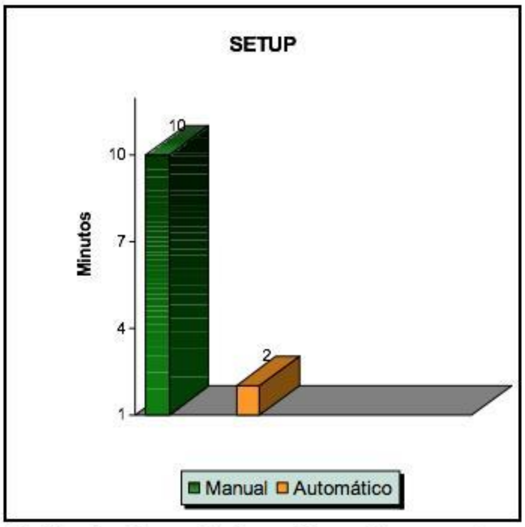


Gráfico 2 – Tempo de *Setup*. Fonte: *(Os autores)*

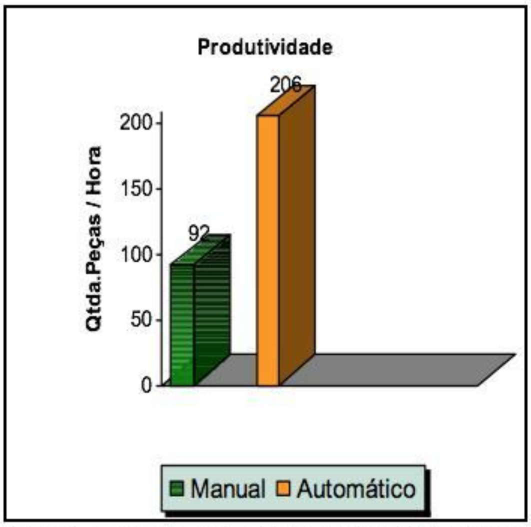


Gráfico 3 – Produtividade por processo. Fonte: *(Os autores)*

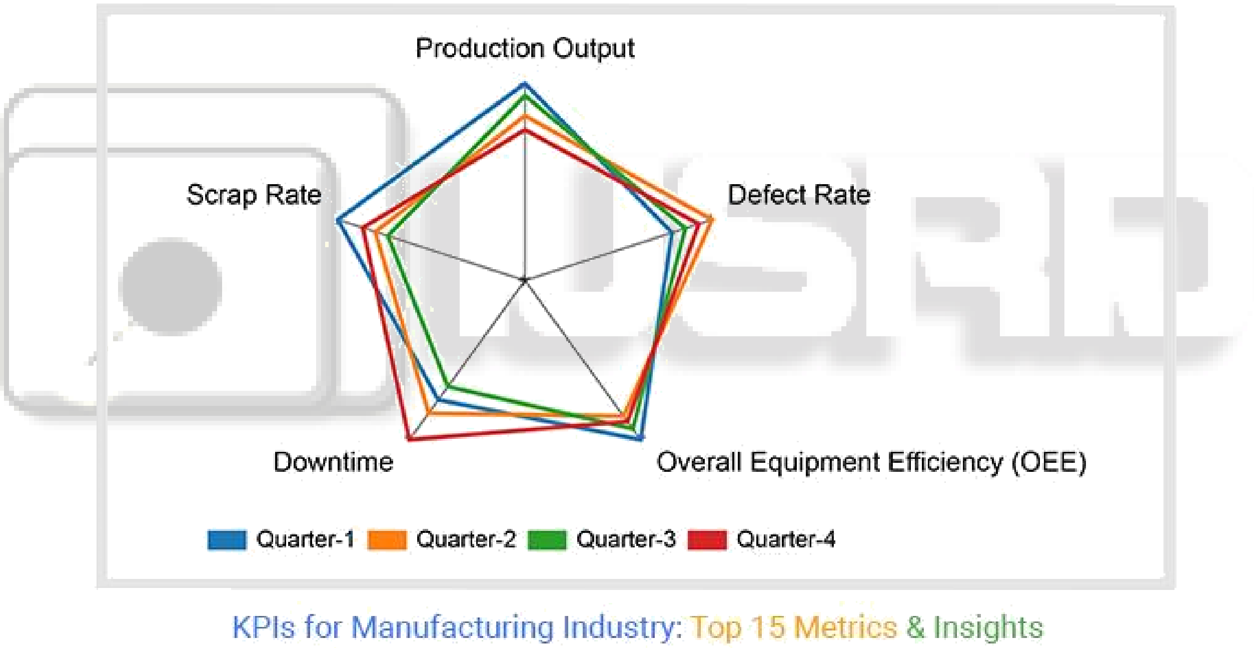


Fig. 8.1: Before and After Performance Comparison

B. *OEE Analysis*

OEE is a comprehensive performance metric used to evaluate manufacturing efficiency. It combines equipment availability, production performance, and product quality into a single indicator. Improvement in OEE reflects better utilization of production resources and reduced operational losses.

1) Availability

Availability measures the percentage of scheduled production time during which the equipment remains operational.

2) Performance

Performance evaluates the actual production rate achieved compared to the designed production rate.

3) Quality

Quality indicates the percentage of acceptable billets produced without defects or rejection.

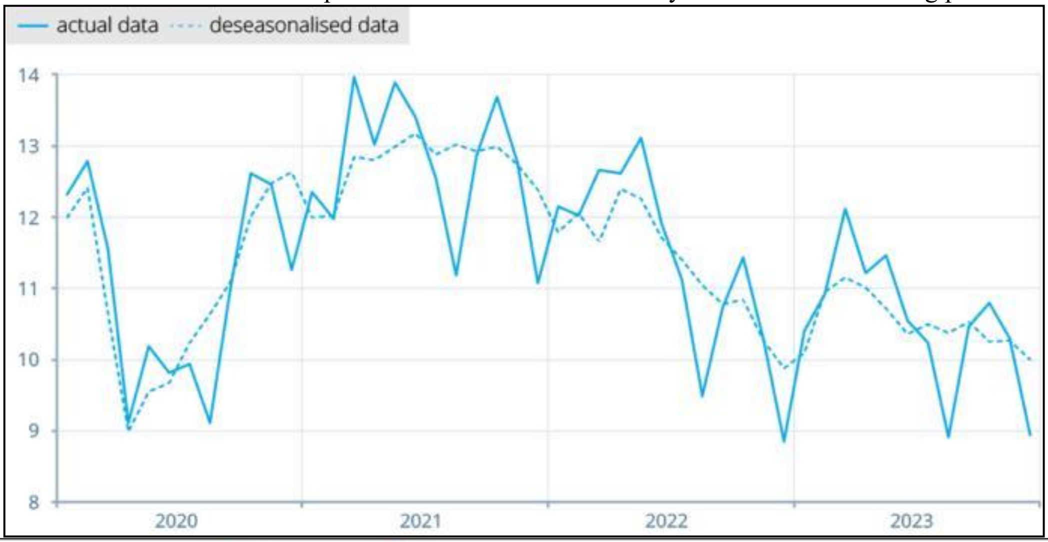
4) OEE

OEE combines availability, performance, and quality to assess overall manufacturing effectiveness.

IX. RESULTS AND DISCUSSION

The experimental study successfully identified major manufacturing losses and downtime contributors in the billet continuous casting plant. Downtime analysis revealed that mechanical failures, mold change delays, and maintenance-related interruptions were the dominant causes of production loss. Billet manufacturing losses were quantified through production records and rejection analysis.

The implementation of downtime reduction strategies resulted in measurable improvements in productivity, yield, and OEE. Billet rejection rates decreased while equipment availability improved significantly. These results confirm that systematic downtime management can substantially enhance manufacturing performance.



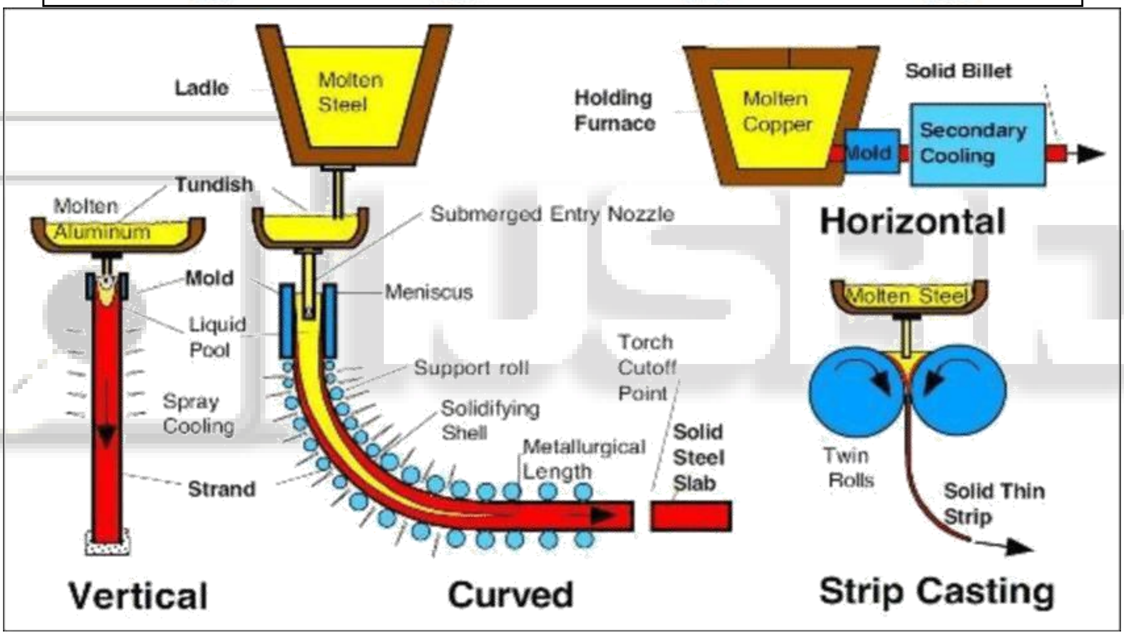
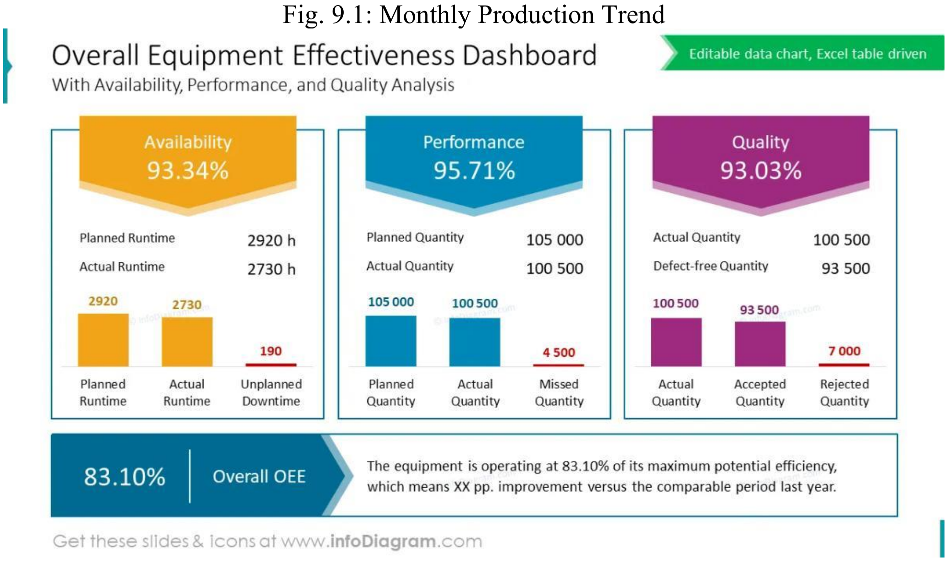
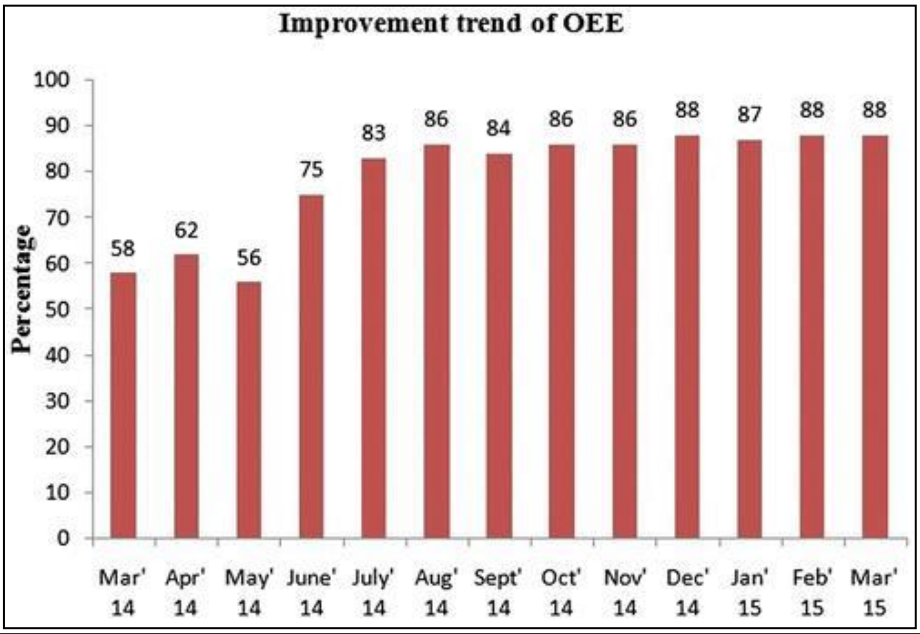


Fig. 9.1: Monthly Production Trend





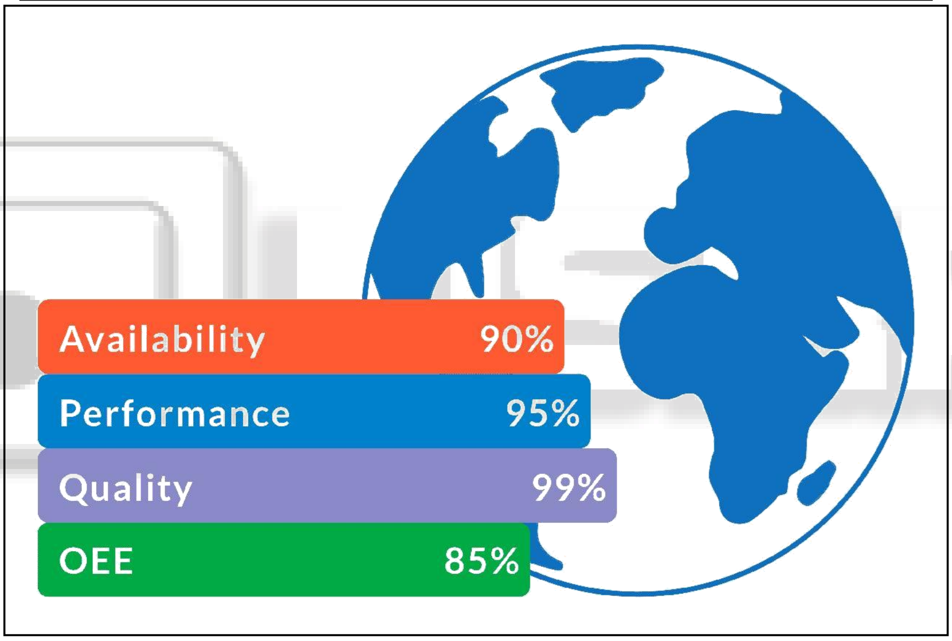


Fig. 9.2: Billet Loss Reduction Graph

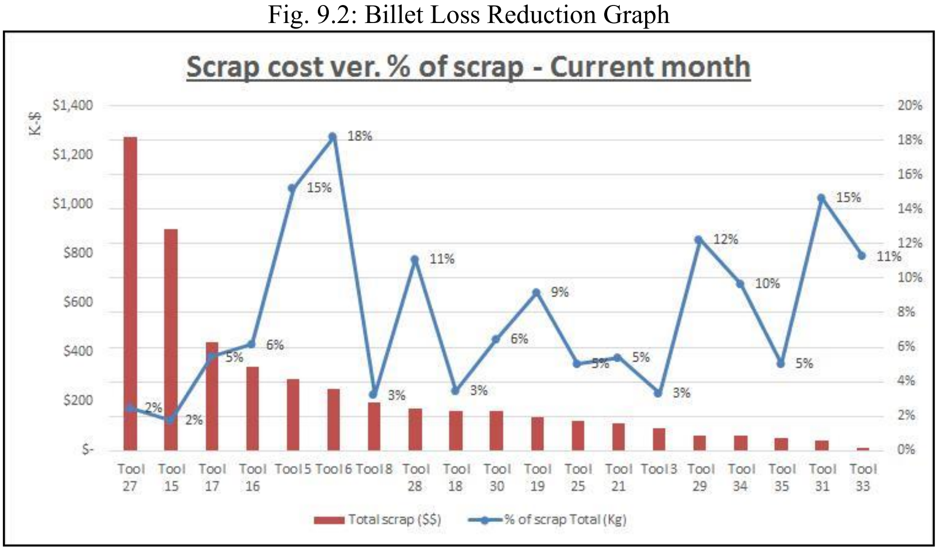


Fig. 9.3: Before–After Performance Comparison Chart

X. CONCLUSIONS

The study successfully identified the major manufacturing losses affecting billet production in a continuous casting plant. Detailed downtime analysis enabled the identification of critical failure areas responsible for productivity reduction. The implementation of targeted downtime reduction strategies significantly improved production performance, yield, and equipment utilization.

A. Major Findings

- Major manufacturing losses were successfully quantified.
- Critical downtime contributors were identified.
- Effective downtime reduction strategies were developed.
- Productivity and yield improved after implementation.
- OEE increased through enhanced equipment availability.
- Billet rejection and process losses were reduced.
- Overall plant profitability and operational efficiency improved.

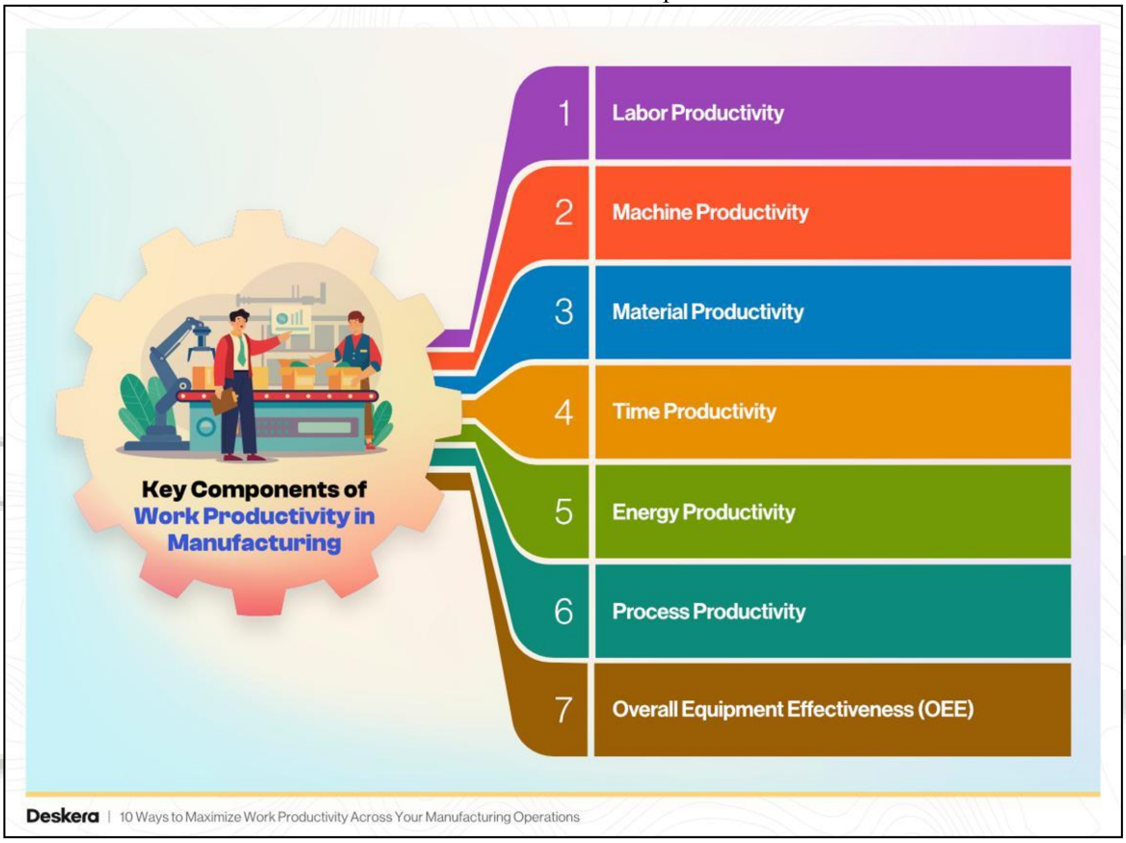


Fig. 10.1: Summary of Productivity Improvement Achieved

XI. FUTURE SCOPE

Future research can focus on advanced digital technologies for real-time monitoring and intelligent decision-making in billet manufacturing operations.

A. Future Research Directions

1) IoT-based downtime monitoring system.
2) AI-driven predictive maintenance implementation.
3) Digital twin development for continuous casting processes.
4) Real-time productivity optimization frameworks.
5) Machine learning-based failure prediction systems.
6) Smart steel plant implementation.
7) Industry 4.0 integration for billet manufacturing operations.

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