Case Study and Examination of Production Methods in a Steel Manufacturing Facility

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Abstract: This research represents a practical case study focusing on the technical and energy evaluation of proposed production lines within a steel manufacturing facility. It incorporates IoT-enhanced SCADA (Supervisory Control And Data Acquisition) technology into its modern control systems framework. The analysis also includes an examination of the mechanical and electrical maintenance sectors in the factory, as they significantly influence both production costs and energy usage.

The investigation was carried out in two primary stages: initially, data collection and process assessment were performed through traditional direct observation methods along with activity classification; subsequently, a proposed control methodology emphasizing architectural design was introduced. Furthermore, this study recommends implementing a maintenance planning program aimed at reducing downtime during maintenance activities to lower associated costs.

The analyzed steel plant produces various products including concrete reinforcing bars (ReBars), flat bars, square section bars such as standard flat bars and round plane bars, alongside wire mesh of different dimensions as well as steel pellets. Within the realm of steel manufacturing automation can generally be categorized into two distinct levels:

- **First Level: This pertains to device actuation at an electromechanical level within the production facility; it is prevalent across all plants.**
- **Second Level: This refers to supervisory control over the entire production process which is less frequently implemented and often only partially so.**

In practice, producing steel involves numerous complex physical processes governed by sophisticated mathematical models that rarely offer real-time guidance for effective supervision or control over these processes. Most operators rely on simpler microprocessor-based systems for support during steel manufacturing tasks.

As part of enhancements based on operational findings from this study, the factory has acquired a new melting furnace with a capacity of 60 tons to replace an older 30-ton model previously utilized prior to this research initiative. Additionally, plans are underway for budgeting towards acquiring scrap pressing equipment intended to enhance scrap quality before melting—this will aid in decreasing electrode consumption rates within furnaces.

To streamline operations further, there will be consolidation between electrical and mechanical maintenance divisions under one department managed by an assistant manager appointed specifically for overseeing these functions.

Keywords: *Steel Production Line, SCADA System, Maintenance Structure, Efficiency.*

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I. INTRODUCTION

As the effective operation of a unit becomes essential to prevent catastrophic failures in crucial equipment, particularly metallurgical machinery, there has been a noticeable evolution over time from Breakdown Maintenance—where repairs occur post-failure—to Preventive Maintenance, which involves scheduled maintenance based on planning. The subsequent development was Computerized Maintenance Management Systems (CMMS), with the latest trend encompassing comprehensive asset management and maintenance packages supported by various implementation methods for Condition Based Maintenance Systems (CBMS) alongside in-service inspection protocols.

CBMS or Predictive Maintenance techniques extend preventive practices and have demonstrated potential benefits such as reduced maintenance costs, improved operational safety, and decreased frequency as well as

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severity of equipment breakdowns during service. Condition monitoring serves as a fundamental principle indicating the deteriorating state of machine components ahead of failure occurrences, allowing for timely preventive measures.

In an integrated steel plant setting—which consists of numerous specialized units each functioning independently—various types of equipment demand focused attention tailored to their specific needs. For instance, within the Coal Chemicals unit are Gas Boosters and Exhausters that handle coke oven gas—a highly combustible substance—while Sinter Plant Blowers and Waste Gas fans operate amid air mixed with abrasive sinter dust.

Additionally, Turbo Alternators within Captive Power Plants require ongoing oversight concerning multiple parameters; seemingly minor elements like Forced Draft & Induced Draft fans associated with Reheating Furnaces also hold critical importance since their malfunction could lead to production declines at Hot Strip Mill/Plate Mill ranging between 33% - 50%.

Given today's competitive landscape for steel producers prioritizing cost-effectiveness is imperative; proficient maintenance management is acknowledged globally as foundational to corporate strategies aimed at minimizing expenses. This recognition necessitated integrating maintenance operations into broader production challenges beyond mere mechanical issues.

Consequently, organizations are adopting innovative technologies that can be easily implemented both effectively and economically to enhance financial performance while realizing that efficient maintenance management may account for up to 35%-40% of revenues—and often reach approximately 15% regarding overall production costs per unit sold. Industry projections indicate that achieving even a modest reduction in upkeep expenditures by about 10% equates roughly to augmenting profitability by around 30%.

The preceding analysis underscores an evident necessity for technology adoption within steel manufacturing processes. Advanced solutions derived from this investigation assist factories not just in enhancing product quality but also optimizing space usage along with electrical energy consumption while reducing labor resources—all leading toward lower downtime periods coupled with increased reliability standards backed by real-time data accuracy involving significant personnel numbers comprising technicians engineers plus administrative staff overseeing factory operations.

The facility utilizes a thirty-ton electric furnace designed specifically for recycling scrap metal into molten iron casted into molds yielding steel billets processed subsequently through affiliated facilities producing concrete reinforcement bars (Rebar) available across diverse dimensions via rolling extrusion methodologies including flat square configurations alongside wire mesh products originating from this newly established plant initiated back in 2008 under Saudi Arabian manufacture boasting monthly output capabilities reaching ten thousand tons worth of steel billets.

II. METHODOLOGY

This study focused on analyzing the maintenance department's structure within a factory to enhance and advance the existing maintenance processes, ultimately aiming to lower production costs related to electrical electrodes and energy consumption. The monthly electricity expenses for the factory have escalated to around 0.5 million USD, which is considered high for an establishment in a developing nation. As previously mentioned, an investigation was conducted into how the automated control system influences both electrical and mechanical upkeep during iron and steel melting operations.

Numerous machine parameters can be monitored, tracked, and analyzed to predict failures or emerging issues; some of these include machinery vibration analysis, lubrication oil assessment along with wear debris evaluation, infrared thermography, ultrasonic testing methods, motor current examination, shock pulse measurements among others. Additionally, operational characteristics such as flow rate, heat levels, pressure readings, tension metrics, and speed configurations can also contribute significantly towards systematic fault diagnosis reviews.

For example: In terms of machining tools, the quality of products at their final state—specifically regarding surface finish standards, dimensional tolerances etc.—frequently indicates underlying problems that may exist. All aforementioned techniques possess unique values but selecting a specific method hinges on its relevance and ease of implementation [1–4].

To reduce overall product costs, it is essential to implement improvements in the Electrical Arc Furnace (EAF) control systems utilized by the factory. In pursuit of this aim, data-driven analytical approaches were employed to refine the steel production process within EAF settings. The research was divided into two sequential yet interrelated phases. Firstly, a set of traditional work measurement methodologies rooted in industrial engineering practices was applied. This included defining processes, generating flowcharts, and collecting data through time-and-motion studies, to comprehensively analyze current operational procedures workflow patterns as well as to identify productivity constraints.

The second phase built upon insights gained from the initial stage. Focusing primarily on identifying opportunities for enhancing throughput especially those requiring minimal capital investment, this phase leveraged operations research project management tools as key analytical instruments aimed at pinpointing critical workflows and resource utilization discrepancies within the system.

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➢ *Improving Maintenance Management*

Here is a working definition of various maintenance actions:

- Failure Maintenance: This involves the approach of repairing or replacing a module or assembly solely after it has failed.
- Block Maintenance: This refers to the strategy of servicing all components within subsystems (blocks) at predetermined intervals.
- Preventive Maintenance: This policy focuses on repairing or replacing specific parts or subsystems when another component fails, or following a designated time period in service.

Ongoing maintenance is essential for keeping production equipment and capital assets in suitable condition to support their intended output quality and quantity levels. As reported by the IMF, typical maintenance costs range from 5% to 7% of fixed capital asset values; thus, reducing these expenses can have significant economic implications. Repair costs can be tracked along with statistics such as downtime percentages and spare inventory usage.

These metrics assist in budget formulation, historical comparisons, and general control information management. A balanced combination of failure-based and preventive maintenance approaches will help achieve these objectives effectively. Preventive measures are particularly valuable based on how equipment tends to fail—typically those that experience random failures due to unexpected overstress do not lend themselves well to preventive strategies; however, machinery subject only to wear may benefit from them.

The initial phase in planning maintenance should involve analyzing subsystem failure characteristics that contribute collectively to system performance. Predicting equipment failures probabilistically relies on past operational data trends while assuming future conditions remain constant; this leads us toward establishing statistical distributions related specifically to subsystem failures using historical data with confidence limits exceeding 90%.

Once established, statistical sampling methods become applicable for estimating failure rates during analyses—common distribution types include Exponential Distribution, Normal Distribution, Log-Normal Distribution, Gamma Distribution, and Weibull Distribution tailored towards electromechanical systems.

A Multi-Program Planning (MPP) system comprises interconnected programs contributing synergistically toward effective overall maintenance strategies across electrical/mechanical functions within steel manufacturing lines while detailing inspection protocols involving lab equipment as well.

This integrated program encapsulates multiple concepts into one cohesive framework ensuring collaborative efforts among all participants involved—it's possible each element could operate independently but together create enhanced effectiveness.

Establishing this comprehensive structure became necessary since previous singular attempts at implementing just one concept proved insufficient over time necessitating an inclusive master program accommodating every facet relevant underlined through systematic integration processes like the Maintenance Job Order System where inputs derive from crew inspectors alongside departments such as nondestructive testing groups operations divisions plus mechanical/electrical teams—all crucial for determining upcoming tasks especially during scheduled outages via review mechanisms including detailed history files reflecting prior work done aiding coordination needs accordingly.

Following this analysis comes unlocking job orders which entails either sending them directly onto respective foremen/department planners responsible overseeing execution plans linked back centrally concerning shop priorities aligning manpower resource allocation spares required fulfilling completion criteria set forth throughout assigned jobs ultimately closing out successfully once completed per outlined requirements laid down beforehand enabling smooth transitions between phases efficiently managing workflow continuously aimed enhancing productivity outcomes realized collaboratively amongst diverse skilled personnel engaged actively maintaining efficacy standards upheld consistently guaranteed delivering results expectedly aligned expectations governing organizational goals aspired regularly undertaken throughout ongoing operations!

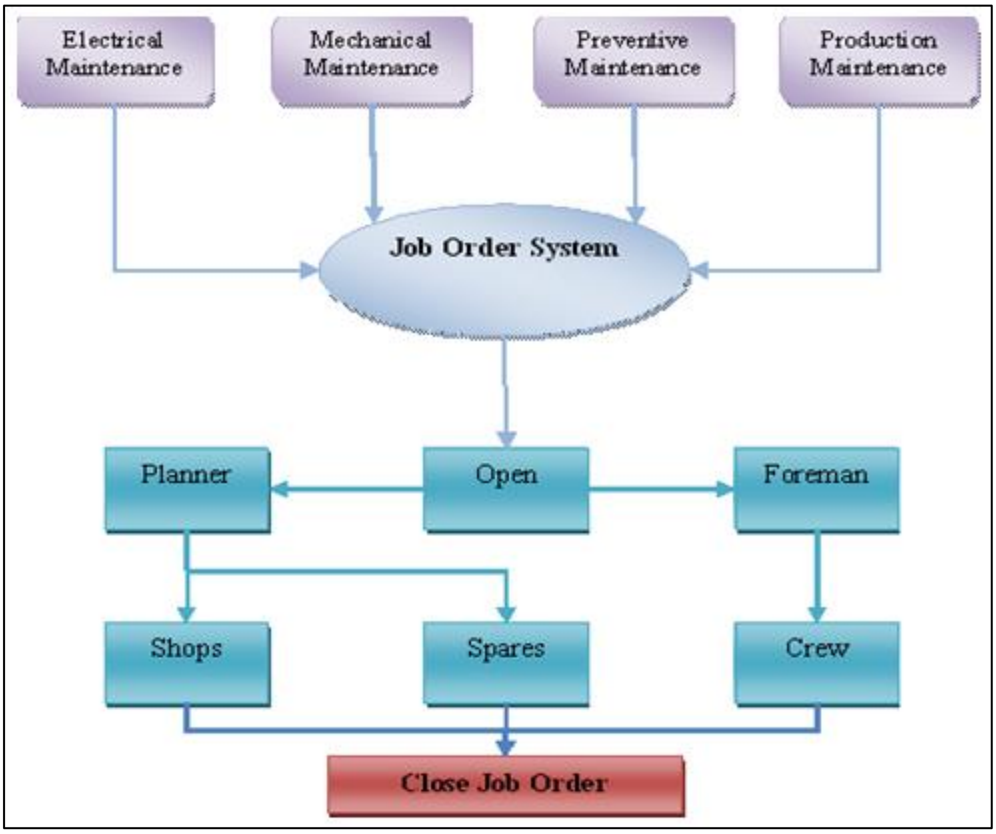

Fig 1: Maintenance Job Order System [5].

➢ *System Modelling*

Fig. 's FIGS. 2 and 3 depict both physical and electrical model representation of the existing EAF. The basic principle of this technology relies on moving three electrodes vertically up and down by using hydraulic actuators. Each of these electrodes is 1.5m long and weighs 0.4 tons. The electrodes release a massive surge of power to melt the ore. The scrap metal is less dense than the actual product and so it floats atop of the furnace, forming the matte. The slag, into which the electrode tips are dipped, floats above the matte. The intense heat is produced both by the ore itself and the electrodes, liquefying and separating the ores. More raw materials are then added to the furnace and the cycle continues.

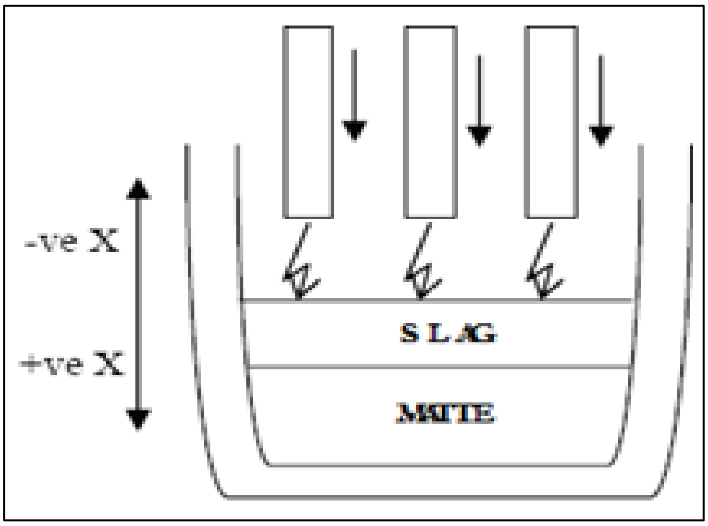

Fig. 2: Physical Model of the EAF [2].

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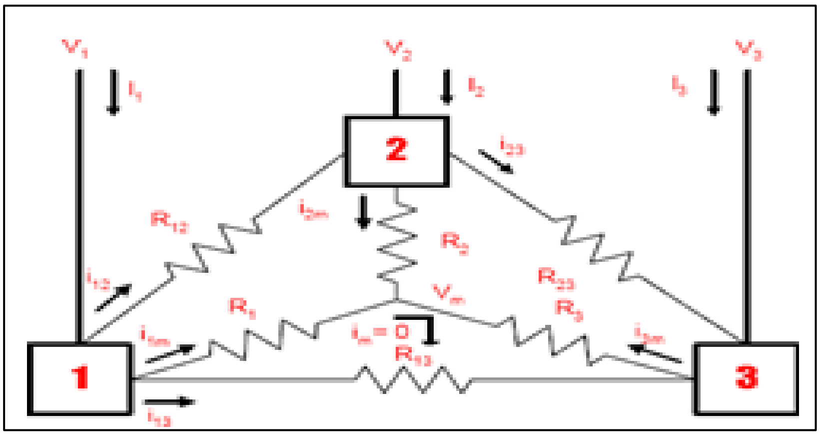

Fig. 3: Electrical Model of the EAF [2].

III. RESULTS

The Electric Arc Furnace (EAF) operates on the principle of direct arc heating. It utilizes three graphite electrodes to introduce a three-phase current into the furnace, generating an electric arc between the electrodes and metal charge that produces heat. This heat melts the charge through both direct impingement from the arc and radiation emanating from the roof and walls of the furnace. Maintaining an appropriate arc length is critical during the melting process.

Structurally, the furnace consists of a cylindrical steel shell supported by supporting rockets. It features tapping spouts for extracting molten metal as well as a slag door at its rear for removing slag. The top of this shell has a removable roof, through which all three electrodes pass via designated openings; each electrode connects to holders mounted on an electrode arm within.

Mobile hydraulic cylinders adjust a carriage over electrode posts to control their positioning, while water cooling systems are implemented where electrodes enter in order to manage temperature effectively. A separate water storage tank equipped with centrifugal pumps circulates cooling water throughout various components including shells, holder assemblies, roofs, and slag doors.

A control panel is integrated into this system allowing operators to regulate power input levels for forward or backward tilting motions alongside monitoring currents and voltages necessary for precise lifting and lowering actions involving electrodes. The Programmable Logic Controller (PLC S7 400) manages hydraulic cylinder operations related to electrode movement ensuring consistent arc impedance tailored around specific voltage requirements; charging occurs by swinging open one side of the roof.

In research surrounding three-electrode controls, maintaining uniform power consumption across all electrodes emerges as a primary goal achieved by adjusting their depth placement leading towards targeted resistance values—this results in stable power consumption metrics overall. To implement effective error correction mechanisms within closed loops necessitates minimizing generated error signals using suitable controllers—a foundational concept behind operational management principles like PID Controllers designed optimally for performance enhancement.

For such systems emphasizing current regulation yields corresponding power adjustments since these magnitudes represent scalar multiples relative solely unto individual electrode currents alone. The incorporation SCADA technology into melting/casting processes enhances product quality significantly while also reducing manpower needs plus maintenance duration & costs—increasing reliability along with real-time data accuracy provided consistently. Here's what this technology aims deliver:

- Continuous Monitoring: Instantaneous oversight regarding plant state/process conditions
- Alerts & Warnings: Displayed abstractly yet comprehensively
- Metallurgical Management Advice: Delivered based upon situational necessities
- Historical Reporting Capabilities

IV. DISCUSSION AND CONCLUSIONS

However, our investigation revealed that the SCADA system utilized in the factory is primarily focused on brief continuous monitoring of operational states within both the plant and process. Therefore, it is highly advisable to enable operation at the other three facilities of the plant. Furthermore, the SCADA systems associated with the Electric Arc Furnace (EAF), Ladle Furnace, and Continuous Casting Machine (CCM) are not interconnected, which adds extra workload and complexity to management tasks.

In light of this analysis, we propose several enhancements aimed at establishing active control and analytical processes within this facility to lower production costs as well as maintenance expenses—this includes better scrap management. Economic pressures compel industrialists and process engineers alike to pursue ongoing improvements in manufacturing workflows.

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Within a complex industrial environment such as that found in an EAF setting—characterized by varying material selection methods, facility redesigns, along with innovative energy contributions—the specific consumption patterns for energy can lead to improved metallic yields between taps.

The United States Department of Energy has conducted extensive research comparing theoretical versus actual energy requirements involved in steel production during its current operations. The primary analytical tools employed during this phase included project management techniques from operations research alongside heuristic scheduling methodologies.

Despite significant operational differences among EAFs complicating straightforward comparisons between them, there remains a noticeable gap between theoretically predicted energy use versus real-world consumption—a disparity suggesting potential efficiency gains could account for approximately 25% reduction in required energies. One pathway towards achieving enhanced yield rates involves optimizing processing sequences through Programmable Logic Controllers (PLCs). Moreover, publishing more resources detailing efficient processing avenues would aid productivity advancements across EAF operations.

A considerable effort has also been directed toward exploring alternatives to electrical power sources due largely because they contribute significantly—approximately 10-15%—to overall operating costs associated with electric arc furnaces. Additionally identified cost categories include those related directly to feed materials as well as implications arising when specific control objectives are unmet.

Variations inherent among characteristics tied specifically either directly or indirectly influence final product quality; higher-grade products typically require superior scrap substitutes while environmental impacts stemming from steel production processes hinge globally upon prevailing scrap market prices.

Another crucial aspect concerning optimization revolves around mitigating energy expenditures; however adequate models illustrating optimal furnace performance remain absent leading operators often rely heavily on empirical knowledge bases instead managing numerous variables manually based solely upon individual experience-driven decision-making regarding O2 injection levels or additions such coal/HBI/hot briquetted iron—and intervening measures dependent entirely on observed conditions like temperature checks prior halting procedures altogether—instead automating these factors may enhance operational outcomes within EAF contexts further still [7-13].

Steel scrap serves predominantly throughout electric steelmaking endeavors representing roughly 60%-80% total expenditure shares but fluctuations affecting raw material quality simultaneously constrain controllability/optimization possibilities intrinsic therein thus necessitating accurate predictive modeling surrounding diverse classifications anticipated future characterizations relevantly impacting effective governance over said processes moving ahead into subsequent stages including classification schema relying chiefly sized distributions chemistry density origins & handling methodologies established internally via some melt shops developing proprietary grading protocols subdividing broader norms distinguishing additional internal grades sourced exclusively onsite yet fundamentally remaining commercial constructs presenting high variability intergrade properties ultimately dividing broadly physicochemical attributes/process-related distinctions elucidated separately below:

- *Physicochemical Properties*

These encompass chemical composition densities surface areas melting points heat capacities content ratios effectively defined under controlled laboratory assessments contingent strictly upon designated grade definitions.

- *Process-Specific Parameters*

Yield efficiencies unique energetic demands respective roles influencing resultant chemistry slag interactions filling degrees dust emissions/off-gas compositions each reliant not only type-specific frameworks but additionally affected by composite qualities present amongst various scraps examined collectively.

When evaluating same-grade properties differing outputs emerge markedly depending establishment site variances particularly involving measurements reflecting physical aspects conductivity metallurgical contents dimensional gradings derived per isolated samples random sampling regimes although discrepancies frequently exceed acceptable thresholds precluding representational accuracy against piles assembled consequently strategic experimental designs have proposed sequencing heating cycles yielding estimative values concerning thermophysical responses might necessitate replicates owing fluctuating conditionals/material diversities encountered

Due increased volume challenges posed encompassing all distinct grades requiring heightened experimentation quantities hence preliminarily unsuitable alternative approaches advocate leveraging historical datasets collated across databases employing advanced statistical analyses comprehensively studying interplay effects existing amidst mixed inputs concurrent procedural considerations culminating desired end-state parameters—including liquid metal profile evaluations corresponding energetics output metrics [2–3][13].

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