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Enhancing competitiveness through Value Chain Analysis in case of Abyssinia integrated steel plc.

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A Thesis Submitted to College of Technology and Built Environment School of Mechanical and Industrial Engineering, Addis Ababa University in partial fulfillment for the Degree of Master of Science in Industrial Engineering

June 2025

Addis Ababa, Ethiopia

Addis Ababa University

College of Technology and Built Environment

School of Mechanical and Industrial Engineering

Title: Enhancing competitiveness through Value Chain Analysis in case of Abyssinia integrated steel plc.

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Declaration

I Nardos Mekoya hereby declare that the work which is being presented in this thesis entitled "Enhancing competitiveness through Value Chain Analysis in case of Abyssinia integrated steel plc." is original work of my own, has not been presented for a degree of any other university and all the resource of materials used for this thesis have been duly acknowledged.

This research was conducted under the supervision of Dr. Ameha Mulugeta at Addis Ababa University, specifically within the Addis Ababa Institute of Technology, School of Mechanical and Industrial Engineering

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This is to certify that the above declaration made by the author is correct to the best of my knowledge.

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Acknowledgments

Primarily, I sincerely thank God for giving me the strength, patience, and guidance to complete this thesis.

I would like to express my deepest gratitude to my advisors, Dr. Ameha Mulugeta, and Co advisor Mr. Michael G for their consistent support and encouragement throughout this research. Their valuable advice, thoughtful feedback, and willingness to share their knowledge have been truly instrumental in shaping this work.

I am also very grateful to all the staff members at Abyssinia integrated Steel Industry. Thank you for your cooperation, for openly sharing your insights and experiences, and for providing the necessary support to carry out this study effectively.

Finally yet importantly, my heartfelt thanks go to my dear family for always being there for me with love, encouragement, and understanding through every step of this journey.

Abstract

The thesis investigates the significant challenges of rework waste and productivity inefficiencies at Abyssinia Integrated Steel Manufacturing, a prominent Ethiopian producer of rebar. Over the period from 2013 to 2015, the company experienced an average rework waste of 6,500 kg annually, underscoring the critical need for systematic improvements within its production processes. The primary objectives of this research are twofold: first, to conduct a comprehensive Value Chain Analysis (VCA) to identify key inefficiencies across the production stages; and second, to develop strategic interventions aimed at enhancing competitiveness and operational performance. The study employs a mixed-methods approach, integrating qualitative insights from interviews with production and quality control staff, alongside quantitative data analyzed using PROCAST simulation software. This software facilitates detailed modeling of thermal stress and solidification behaviors during the continuous casting process. The findings reveal that the improper control of casting parameters, particularly temperature and speed, is a major contributor to defect rates. Specifically, the research identifies an optimal casting temperature range of 1650°C to 1700°C and a casting speed of 1.5 m/min as critical conditions for minimizing turbulence and ensuring effective solidification. These parameters significantly reduce the incidence of defects, such as longitudinal and transverse cracks, which have plagued the production process. In conclusion, this study underscores the importance of integrating VCA with predictive simulation tools to create a robust framework for quality control and operational decision-making. By systematically identifying and addressing inefficiencies, Abyssinia Integrated Steel can enhance resource utilization, improve worker safety, and bolster its competitiveness in both domestic and international markets. The implications of this research extend beyond the case study, providing a valuable framework for other manufacturers in developing countries aiming to align production efficiency with quality standards through data-driven and strategic interventions. This approach not only contributes to operational excellence but also supports sustainable manufacturing practices in the steel industry.

Key words – value chain analysis, technology synergy, rebar production process, process rework waste, and value added percentage, value added, and non-value added activities.

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CHAPTER ONE -INTRODUCTION

1. Introduction

A chain of values is a collection of business actions carried out by a company in a particular industry to deliver a valuable product to the end client(Mcgee, 2015) . The company can provide the most value for the least amount of money. Therefore, a value chain's goal is to provide a business a competitive edge by increasing production while lowering expenses.(ACDI-VOCA, 2012). When doing value chain analysis, you have to think about how each stage adds or subtracts value from your ultimate product(Peter, 2016). We must think of ways to offer value to the customer to optimize the value chain. For that reason, if we think of a value sequence one question must answer how to build quality products for customers by identifying each activity in terms of the customer perspective(Zamora, 2016). Porter's Value Chain is an effective strategic administration method that works via breaking down an organization's things to do into strategically vast sections(Abbasi, 2017). The value chain is critical for achieving the intended product based on consumer needs. Focus on important activities (primary) that contribute to adding to the value chain when analyzing the value chain

Rebar making begins with inbound logistics, which is the raw material, and outbound logistics with steel Rebar products. Primary activities include operations such as receiving basic raw materials from suppliers and marketing output/products to customers, which are directly involved in the conversion process of Basic raw materials into final output/products.(Cottrell, 2019) Rebar making technique is classified in to two broad; iron steel making process and steel scrap process method(Mondol, 2016). The study focused on scrap steel making production process manufacturing industry. This technique used to make steel rebar consists of the following: Raw materials (steel scrap) are added to the furnace to melt to the appropriate melting temperature then; the molten metal is fed to continuous casting machines to make billets of various sizes(Iwasaki & Matsuo, 2012). But the present metallurgist researcher has studied the continuous casting process issue(C & Nagarajan, 2015) waste of the manufacturing(Shewalul, 2021) and the raw material (scarp) shortage(Dworak & Fellner, 2021), but due to recent research paper shown the manufacture has still the same issue. In another way the value chain sustainability depends on suitable technologies and the high-quality raw materials required(Sultan & Saurabh, 2013) and having the right technology is crucial to producing high-quality output. As a result, the value chain must keep track of rapid technological advancements(Zhang et al., 2016).

1.1 Background of the problem

The study use the strategic decision method to solve the steel manufacturing issue(Shahabi et al., 2014)(S G et al., 2015). Strategic planning is necessary for decision-making and the smooth operation of the organization(Hipkin & Bennett, 2014). According to the strategic analysis, it assists them in identifying both opportunities and risks that may arise and provides a clear picture of the industry current and future state(Papulova & Gazova, 2016).

In another way, based on the Ethiopian steel rebar manufacturing case study, several issues were stated. The Ethiopian steel manufacturing sector employs a variety of technologies that provide value. However, (Derbe & Ababa, 2018)the steel manufacturing process has a low material utilization rate, incompatibility of technology with the environment and workers, and low availability or quality of raw materials. Due to these obstacles, the manufacturing industry's production process is slow. As seen in basic metal manufacturer production capacity, the basic metal manufacturing companies are designed and built for high production rates. However, productivity rates suffer because they do not cover Ethiopian demand(Damitew et al., 2017). Another study investigated the factors affecting consumers shifting from local products to imported ones(Tariku, 2020).

According to the Trade and Industry Minister Report in 2021 G.C., the Ethiopian basic metal manufacturing industry produces steel rebar using recycled material, but the production capacity does not cover the demand. Due to three major factors: a shortage of raw materials, a lack of infrastructure, and a shortage of skilled labor. At this time, government and manufacturing company strategies should have been linked to developing productivity growth(Pelham & Lieb, 2011). The company's business strategy influences productivity growth(Vasile, 2016).

The paper focused on Abyssinia Integrated Steel plc. According to the previous survey, for instance, raw material shortages pose a big challenge in achieving steel chemical composition. In addition, steel scrap quality has an impact on the melting process, and due to this production process, a high amount of rework waste occurs. The value chain of the steel manufacturing industry depends on the efficiency of the manufacturing processes as well as the competent worldwide market business plan. The study uses a strategy tool and technical analysis to assist us in defining the company as well as providing it with a set of values and a sense of purpose.

It founded in 2001 as a PLC by two British nationals and a Kenyan national, and it began production in 2005. About 45 kilometers separate Bishoftu, the location of the factory, and Addis Ababa. In addition, the British owners also control Abyssinia Profiles PLC and Abyssinia Cement PLC, a small plant that founded in 2005, along with a third Indian partner. The company produces re-bars; cement and angle irons produced by its sibling enterprises, Abyssinia Cement and Abyssinia Profiles, respectively. It has over 1,000 employees spread between the three companies. The company makes $42 million in revenue on average each year. The equity stated to be $25 million, while the overall assets estimated to be worth $30 million. Formerly, the shareholders had a steel plant in Kenya that produced steel for Ethiopia. They made the decision to move their focus to Ethiopia after realizing that the Ethiopian industry was more appealing than Kenya's (mostly because there were fewer local manufacturers in Ethiopia, with the exception of Zuquala Steel Rolling Mill Enterprise, which could supply the country's sizable and uncompetitive market).

The initial capital of Abyssinia Integrated Steel was approximately $3.5 million. Rebar was first produced using a single furnace and a rolling mill that purchased from Kenya. It entered Ethiopia at the same time as the government started making significant investments in affordable housing, and because of its favorable payment conditions, the company was able to finance its expansion. The government's steel scrap disposal program through the Ministry of Defense allowed Abyssinia Integrated Steel to purchase steel scrap at a reduced cost, which was the company's primary input. The yearly manufacturing capacity of Abyssinia Integrated Steel is 75,000 metric tons of rebar. In another way with a 20,000-metric-ton yearly capacity, angle iron, U-channel, and Abyssinia profiles produced in the sibling company. Under the direction of a managing director, a general manager leads the combined top management of the three connected companies. Due to national power rationing in 2008–2009, the company had to reduce operations, which resulted in wasted capacity. Nevertheless, it has now resumed regular levels of production.

1.2 Statement of the problem

Abyssinia Integrated Steel Manufacturing, a major rebar producer in Ethiopia, has faced persistent challenges related to rework waste, averaging 6,500 kg annually between 2013 and 2015 due to products failing to meet quality standards. This issue spans key production stages—including melting, continuous casting, and rolling—leading to extended cycle times, increased energy consumption, and reduced productivity. Global studies similarly associate high defect rates with inefficiencies in upstream processes and limited integration of quality control across the value chain (Wang et al., 2016; Li & Sun, 2019). In scrap-based steelmaking, widely practiced in Ethiopia, variation in input quality and thermal exposure are also linked to operational and quality challenges (Singh & Kumar, 2020; Zhang et al., 2021; Ahmed et al., 2018). A preliminary survey conducted for this study identified noticeable levels of process waste occurring across the melting, continuous casting, and rolling mill sections. However, it remains unclear which specific stage contributes most significantly to the high rework waste. This uncertainty highlights the need for a systematic analysis to pinpoint where and why defects are most likely to occur, enabling data-driven process improvement. While most existing literature on steel sector competitiveness focuses on macroeconomic frameworks such as Porter's Diamond (Porter, 1985), little attention is given to micro-level production analysis. In the Ethiopian context, existing research primarily emphasizes infrastructure, policy, and industrial strategy (EIC, 2019; MoTI, 2020), but lacks data-driven approaches to internal manufacturing challenges. This study addresses that gap by applying VCA and predictive simulation to analyze rework waste, identify root causes, and develop a continuous improvement framework for enhancing competitiveness in the Ethiopian rebar industry.

1.3 Research questions

1. What are the key value chain activities that contribute to competitive advantage with in rebar production customer need issue in the case of rebar manufacturing industry?
2. What types of defect waste are most prevalent in the production of Abyssinia integrated steel, and what are their root causes?
3. How can improvements in the value chain process enhance the overall competiveness of Abyssinia integrated steel

1.4 Objectives

1.4.1 General objectives

Analyze and enhance competitiveness through value chain processes of Abyssinia integrated steel in order to improve competitive and productivity in the Ethiopian rebar manufacturing industry

1.4.2 Specific objective

1. To identify and evaluate the primary and supportive value chain activities of Abyssinia integrated steel and their contribution to overall productivity
2. To conduct a cause and effect analysis of defects in the manufacturing process to identify root causes of wastes
3. To recommended strategies for optimizing production process based on findings from value chain analysis
4. To propose a framework for continuous improvement in the value chain management to enhance the long-term competitiveness of Abyssinia integrated steel.

1.4 Scope and limitation

The study applies Value Chain Analysis (VCA) to examine the contribution of both primary and support activities to overall productivity. In parallel, it uses PROCAST simulation software to conduct predictive analysis of quality defects within the production process, enabling the identification of defect-prone zones and inefficiencies. The ultimate goal is to recommend strategic interventions and propose a continuous improvement framework that enhances productivity and competitiveness in Ethiopia's rebar manufacturing sector.

1.5 Significance of the study

This study holds both theoretical and practical significance for the rebar manufacturing industry, particularly in developing economies like Ethiopia. By addressing the persistent issue of rework waste at Abyssinia Integrated Steel Manufacturing, the research contributes to improving operational efficiency, product quality, and resource utilization. The integration of Value Chain Analysis (VCA) allows for a systematic evaluation of value-added and non-value-added activities, helping to identify inefficiencies and production bottlenecks. Furthermore, the application of PROCAST simulation software offers a predictive approach to understanding thermal and structural behavior during billet casting, enabling the early detection and prevention of defects. This dual approach not only enhances productivity but also minimizes environmental and health risks associated with reprocessing. The study also fills a critical gap in the literature by combining process-level simulation with value chain optimization—an approach rarely explored in the Ethiopian manufacturing context. Its findings provide actionable insights for industry stakeholders and policymakers aiming to improve international competitiveness, promote sustainable manufacturing, and support Ethiopia's industrial growth strategy.

1.6 Organization of paper

The study comprises five main chapters:

- Introduction: Outlines the problems and challenges faced by Abyssinia Integrated Steel Manufacturing in their rebar production process.
- Conceptual and Theoretical Framework: Reviews relevant literature on rebar production technology and value chain management, including implications of technology synergies and case studies.
- Research Design and Methodology: Describes the data collection and analysis techniques used to investigate the problems.
- Data Presentation, Analysis, and Discussion: Presents the findings and discusses their implications for Abyssinia Integrated Steel.
- Findings, Conclusions, Recommendations, and Future Work: Summarizes the key conclusions, provides recommendations for Abyssinia, and suggests areas for future research.

The study aims to leverage value chain analysis to help Abyssinia Integrated Steel Manufacturing improve their rebar production process, enhance customer satisfaction, increase productivity, and strengthen their competitive position in the market.

CHAPTER TWO - LITERATURE REVIEW

2. Introduction

The rebar manufacturing industry is undergoing rapid transformation, driven by growing demand for construction materials in urbanizing economies and the increasing pressure to maintain high product quality while minimizing costs and waste (World Steel Association, 2023). As competition intensifies globally, achieving a sustainable competitive advantage has become a central concern for manufacturers. Traditional strategies such as cost leadership, product differentiation, and technological innovation remain relevant, but are no longer sufficient on their own—especially in developing regions where resource limitations, outdated technology, and supply chain inefficiencies persist (Porter, 1985; Barney, 1991). To navigate these complexities, manufacturers are turning to strategic frameworks like Value Chain Analysis (VCA), SWOT, Benchmarking, Core Competency, and Risk Management, each offering valuable perspectives on performance improvement (Kaplinsky & Morris, 2001; Hill & Jones, 2012).

However, these tools often fall short when applied to highly technical, process-driven industries such as rebar manufacturing, where defect control, energy efficiency, and material behavior under thermal and mechanical stress are critical (Zhang et al., 2021). Notably, while VCA has proven useful in optimizing internal operations, it lacks the capacity to predict production defects or capture the thermophysical complexities inherent in steel processing (Kaplinsky & Morris, 2001; Guo et al., 2018). Similarly, tools like SWOT and Benchmarking provide high-level strategic guidance but lack the granularity needed to inform quality control decisions in real time.

Recent literature has increasingly focused on inline defect detection technologies—such as real-time monitoring, machine vision, and AI-driven analytics—demonstrating their effectiveness in improving short-term defect identification and reducing rework (Zhao et al., 2020; Li et al., 2022). However, these approaches are often applied in isolation and do not consider the systemic interactions between production stages. Moreover, while machine learning models have shown promise in predicting defect occurrence based on historical patterns, they do not fully account for the material-level phenomena that cause these defects in the first place (Xie et al., 2021). A critical gap emerges from this observation: the lack of integration between predictive defect simulation and strategic value chain frameworks. This study addresses that gap by proposing a hybrid approach that combines PROCAST—a physics-based simulation tool capable of modeling thermal gradients, stress development, and solidification behavior in steel billets—with VCA to map process-level inefficiencies across the production chain (Chen et al., 2019). This integration allows for a dual-layer analysis: predictive insights at the micro (material) level and systemic alignment at the macro (process) level. By grounding the literature review in empirical case studies, regional comparisons, and technological assessments, this chapter builds a foundation for a holistic approach to improving competitiveness and quality in Ethiopian rebar manufacturing. The review highlights not only what has been achieved globally but also what remains underexplored—particularly the need for predictive, end-to-end quality control frameworks that link process modeling with strategic decision-making. In doing so, it justifies the adoption of VCA and PROCAST as complementary tools to reduce defect waste, enhance production efficiency, and sustain competitive advantage.

2.1 Significance of strategic Competitive Advantage

Competitive advantage refers to the attributes or capabilities that allow a company to outperform its rivals. In the context of the rebar manufacturing industry, achieving a competitive advantage can manifest in several ways, including cost leadership, product differentiation, innovation, and effective supply chain management. These factors not only affect profitability but also influence market positioning and customer loyalty. Based on current study indicated Rebar manufacturers are increasingly focusing on a triad of strategies to enhance their competitive advantage in the market: cost leadership, product differentiation, and technological innovations. Let see current study in developed country some of them as sown in the below;

The case study by Gerdau, a leading steel manufacturer, employs advanced technology in its production processes to minimize waste and energy consumption. And his strategic focus on reducing operational costs through economies of scale, efficient production processes, and strategic sourcing of raw materials. The outcome of the study significantly reduced production costs, allowing it to offer competitive pricing while maintaining profitability. While Gerdau excels in cost reductions, it may struggle to quickly adapt to changing customer preferences for specialized products. Increased competition in niche markets could leave them vulnerable if they do not diversify their offerings.

Beside this another case study introduced high-strength rebar that meets specific engineering requirements for seismic zones. And his strategic Manufacturers innovate to create rebar products with unique features, such as enhanced corrosion resistance or specific tensile strengths. The outcome market share in specialized construction projects, enhancing its reputation and customer loyalty. But, Nucor's focus on high-strength rebar may expose them to supply chain risks, especially if raw material prices fluctuate. This reliance on specific products could limit flexibility in responding to market shifts.

Furthermore another case study stated on technology advancement integrated steelmaking processes and advanced technologies, including real-time monitoring systems. By using investing in new technologies, such as automation and data analytics, to streamline production and improve quality. And find out Steel Dynamics has achieved consistent quality and reduced production times, giving it a competitive edge in responsiveness to market demands. Steel Dynamics heavily relies on advanced technologies for production efficiency. However, if there are technological failures or high maintenance costs, it could disrupt production and negatively impact their competitive edge.

As see in the above paragraph the case studies of Gerdau, Nucor, Steel Dynamics illustrate how these strategies can be effectively implemented to enhance market position and profitability. By continuously adapting to industry trends and customer needs, manufacturers can maintain a competitive edge in the dynamic construction market. However, each case study demonstrates strengths in competitive advantage strategies, but they also exhibit specific gaps that could hinder long-term success. Addressing these gaps will be crucial for maintaining competitiveness in the evolving rebar manufacturing landscape.

Furthermore, in developed country the integration of advanced manufacturing technologies, including automation and Industry 4.0 solutions, is transforming the production landscape, enhancing operational efficiency, improving product quality, and reducing waste, thereby solidifying their competitive position. However, there is a notable lack of studies that examine how regional variations—such as economic conditions, regulatory frameworks, and market dynamics—affect competitive strategies in rebar manufacturing. Understanding these regional differences is essential for developing tailored strategies that resonate with local market conditions.

In developing country case study the need for more empirical research is evident, particularly in the form of case studies that document successful rebar manufacturers. These case studies could provide invaluable insights into how firms effectively leverage competitive advantages in practice, thereby bridging the gap between theory and application. In addition the developing country the impact of digital transformation initiatives on competitiveness within the rebar manufacturing sector remains underexplored. Investigating how advancements in technology, such as automation and data analytics, specifically influence operational efficiency, product quality, and market positioning will be crucial for understanding the future landscape of the industry.

The comparison of competitive advantage tools in the context of privacy studies for the rebar manufacturing industry, along with privacy study references:

Strategic frameworks such as Value Chain Analysis (VCA), SWOT analysis, Benchmarking, Core Competency, Risk Management, and Privacy Impact Assessments (PIAs) have each contributed significantly to organizational decision-making, performance enhancement, and competitive strategy across industries. However, despite their widespread use, these frameworks reveal limitations when applied to context-specific challenges in process-heavy manufacturing industries like rebar production in Ethiopia.

Value Chain Analysis (Porter, 1985) is a foundational tool that dissects a firm’s operations into primary and support activities to locate sources of competitive advantage. Its use in manufacturing—such as in Tata Steel’s optimization strategies and Toyota’s lean production system—has shown measurable gains in customer value creation and waste reduction (Ohno, 1988; Kuo et al., 2010). However, while VCA is effective at identifying inefficiencies in workflows, it lacks the technical depth to predict how and where defects or rework waste may form in thermally sensitive processes like steel melting or continuous casting. This limitation underscores the need to augment VCA with engineering-level diagnostic tools, such as PROCAST simulation software, which models heat transfer, solidification, and stress behavior to predict defect-prone zones.

Similarly, SWOT analysis has been instrumental in corporate and sectoral strategic planning (Hill & Westbrook, 1997; Helms & Nixon, 2010), identifying internal strengths and weaknesses alongside external opportunities and threats. Although widely adopted in industries such as education (Geng et al., 2017) and healthcare (Kearney et al., 2013), SWOT's broad-brush approach often fails to inform actionable changes in production quality control or defect root cause identification. Furthermore, its static nature and subjectivity present challenges in fast-changing production environments where variation in input materials (e.g., scrap metal quality) and temperature gradients significantly affect product output. As such, SWOT is useful for high-level diagnosis but insufficient for real-time, process-specific interventions in manufacturing.

Benchmarking, as a performance comparison tool, has enabled companies to identify performance gaps and adopt best practices (Camp, 1989; Qamar et al., 2017). In manufacturing, Xerox and Toyota have set standards for benchmarking-driven improvement. However, benchmarking in rebar manufacturing is complicated by localized factors—such as availability and variability of raw materials, regulatory differences, and labor skills—which limit direct comparisons. Additionally, as Cuthbertson and O'Sullivan (2002) argue, data availability and contextual mismatches hinder its effectiveness unless combined with internal diagnostic tools. In the Ethiopian steel context, benchmarking cannot reveal micro-level causes of waste, nor does it account for technical root causes of defect recurrence, which require metallurgical insight rather than managerial comparison.

The Core Competency Framework (Prahalad & Hamel, 1990) also provides strategic guidance, helping firms define their unique value propositions through integrated skills and technologies. While it aids in human resource alignment and innovation (Ulrich, 1997), it is often too abstract for isolating technical process failures. In the case of rework waste at Abyssinia Steel, identifying core competencies such as "melting expertise" or "rolling mill maintenance" does not translate into diagnosing temperature-induced cracking or slag-related inclusions—issues that require thermomechanical simulations and predictive defect modeling. The core competency model, therefore, supports high-level strategy but must be supplemented by simulation and analytics tools to address specific quality-related waste.

Risk Management Frameworks, including ISO 31000 and the COSO ERM model, provide structure for identifying and responding to operational threats (Beasley et al., 2005; Fraser & Henry, 2007). These frameworks have enhanced decision-making in sectors such as finance (Jorion, 2007) and healthcare (McGowan et al., 2015), and are increasingly relevant in industrial environments. However, in scrap-based steel manufacturing, where material inconsistency, thermal fluctuations, and real-time operational errors interact dynamically, general risk frameworks fall short of delivering the technical insights needed to predict when and why defects will occur. Simulation-based diagnostic tools like PROCAST are more appropriate for this context because they allow proactive identification of hidden quality risks, such as shrinkage cavities or transverse cracks, which may not be visible during traditional inspection or risk assessment.

While Privacy Impact Assessments (PIAs) are essential in data-sensitive sectors like IT and healthcare (Kuner, 2015; Dehling et al., 2015), their relevance to manufacturing is minimal unless digital systems involve sensitive employee or product data. However, PIAs do highlight a critical methodology: risk should be evaluated early in the system design and development process—a concept shared with simulation-based modeling in metallurgy. The proactive nature of PIAs (McCallum, 2013) aligns conceptually with predictive quality tools like PROCAST, which allow engineers to identify and mitigate process risks before actual production occurs.

In conclusion, while traditional strategic frameworks provide essential organizational and competitive insights, they lack the technical depth and predictive capability required to address process-level rework waste in Ethiopian rebar production. This study fills that gap by integrating Value Chain Analysis with PROCAST simulation, combining macro-level strategic evaluation with micro-level defect prediction. This dual approach allows for the identification of waste-heavy production stages, root cause analysis of metallurgical defects, and the development of a continuous improvement framework tailored to the unique conditions of Abyssinia Integrated Steel Manufacturing—a contribution not currently addressed in either global or Ethiopian literature (MoTI, 2020; Gunasekaran et al., 2017; Singh & Kumar, 2020).

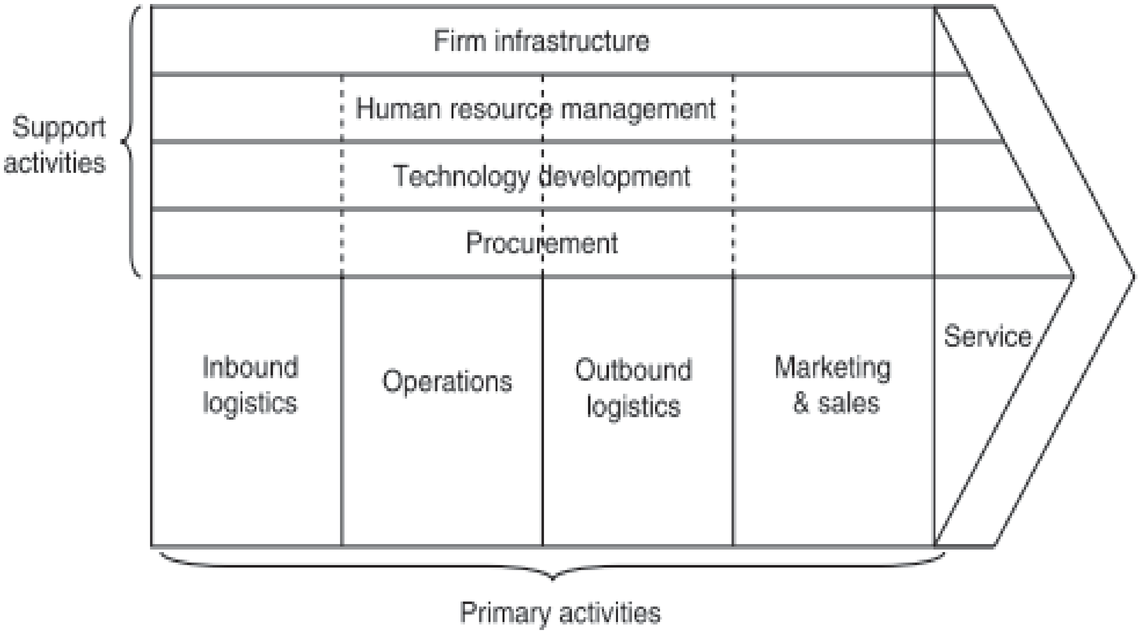
Therefore, Value chain analysis (VCA) stands out as a powerful tool for achieving competitive advantage when compared to other frameworks. Unlike SWOT analysis, which provides a broad overview of strengths, weaknesses, opportunities, and threats, VCA delves deeper into the specific activities that contribute to value creation within an organization. This focus allows businesses to identify inefficiencies and areas for improvement at each stage of their operations, from raw material procurement to product delivery. While Porter’s Five Forces offers insights into industry dynamics and competitive forces, VCA helps companies understand their internal processes and optimize them for better performance. Additionally, while benchmarking compares a company's performance against industry leaders, VCA emphasizes enhancing internal capabilities to create unique value propositions. By assessing both primary and support activities, VCA enables organizations to align their operational strengths with market demands, ultimately leading to sustained competitive advantages that are difficult for competitors to replicate. This targeted approach not only fosters innovation but also positions companies to respond effectively to changes in consumer preferences and market conditions.

Therefore value Chain Analysis is the best tool the study for competitive advantage, according to privacy study, because it directly connects internal activities to value creation and sustainable differentiation — something that broader or more externally focused tools do not accomplish as effectively.

2.2 Value Chain analysis

Value chain analysis, introduced by Michael E. Porter in 1985, is an effective method for evaluating a product's lifecycle from conception to disposal. It identifies a chain of interconnected activities that deliver value to customers and provide competitive advantages to businesses. By categorizing activities into core and non-core functions, it reveals constraints and opportunities for improving goods and services. Key strategies include mapping activities, analyzing benefit distribution, and examining governance, which are particularly relevant in sectors like renewable energy, where innovation and cost advancement are sought. Ultimately, value creation involves various primary and support activities, all crucial for maintaining competitiveness across industries

These categories described as follows:



Source: porter (1985)

Figure 2.1: The generic value chain analysis

Value chain analysis (VCA) is strategic tools that helps rebar manufacturers optimize their processes, reduce costs, and improve product quality, ultimately leading to competitive advantage. Introduced by Porter (1985), VCA dissects production into primary and support activities, facilitating a deeper understanding of cost structures and value creation. Studies, such as Kamaruddin et al. (2016), demonstrate how VCA can enhance procurement, production, and distribution processes, identifying inefficiencies and areas for improvement.

2.3 Rebar manufacture competitiveness through value chain analysis

The analysis of the rebar manufacturing industry's value chain has been explored in various empirical studies, each highlighting critical aspects of production and competitiveness. Porter (1985) noted that firms effectively managing their value chains could achieve significant cost reductions and product differentiation, with supplier integration enhancing quality and innovation. Following this foundational work, Kumar and Singh (2017) focused on the global nature of the rebar supply chain, emphasizing the need for manufacturers to adapt to regional market demands and regulatory requirements to maintain competitiveness.

In 2015, Alavi and Khosroshahi specifically examined the supply chain for rebar manufacturing, identifying bottlenecks and inefficiencies. Their research revealed that improving supplier relationships and adopting just-in-time (JIT) inventory practices could lead to better resource utilization. Ghosh and Ghosh (2018) further contributed by identifying essential activities within the value chain, such as raw material sourcing, manufacturing processes, and distribution. They emphasized the importance of optimizing logistics and supply chain management to reduce costs and improve delivery times.

In terms of technological advancements, Tzeng and Huang (2019) analyzed the role of new technologies in the rebar value chain, concluding that automation and digital tools significantly improve production efficiency and quality control, thereby strengthening competitive positioning. Zhang and Wang (2020) examined sustainability in the rebar manufacturing value chain, finding that implementing recycling practices and energy-efficient technologies not only reduces environmental impact but also lowers costs and enhances brand reputation.

Lastly, Luthra and Mangla (2020) investigated the impact of Industry 4.0 technologies, such as IoT and data analytics, on the steel value chain, highlighting their ability to enhance decision-making processes and operational efficiency. Collectively, these studies underscore the significance of a well-managed value chain in achieving competitive advantages within the rebar manufacturing industry.

2.4 Africa Rebar manufacturer competitiveness through value chain

The empirical studies on the rebar manufacturing industry in Africa reveal important insights into its challenges and opportunities. In 2018, Boateng and Osei-Tutu analyzed the supply chain dynamics of rebar manufacturers in Ghana, identifying inefficiencies and recommending improvements in supplier relationships and logistics. Their findings highlighted the need for streamlined operations to enhance productivity in the industry. In 2019, Adeyemi and Ilesanmi investigated local content policies in Nigeria, emphasizing how such policies could enhance the competitiveness of rebar manufacturers through government support and investments in local supply chains. Moyo and Mhlanga (2020) focused on South Africa's rebar manufacturing sector, discussing challenges such as infrastructure deficits and high energy costs, while also emphasizing the importance of sourcing local raw materials for competitive advantage. Following this, Nwokolo and Ogbogu (2021) examined sustainable practices among rebar manufacturers in Kenya, revealing that companies adopting eco-friendly technologies not only complied with regulations but also gained significant market advantages. In 2022, Chikozho and Nyoni discussed the impacts of economic policies on the competitiveness of Zimbabwean rebar manufacturers, particularly focusing on tariffs and import regulations that affect local production. Their study underscored the importance of favorable economic policies in fostering a supportive environment for local manufacturers.

Collectively, these empirical studies highlight several critical aspects of the rebar manufacturing industry in Africa. Key challenges include infrastructure deficits, high energy costs, and the necessity for local raw material sourcing. Local content policies can enhance competitiveness, supported by government initiatives and investments in supply chains. Additionally, companies adopting sustainable practices not only comply with regulations but also gain competitive advantages in the market. Inefficiencies in supply chains can be addressed through improved supplier relationships and logistics, while tariffs and regulations play a crucial role in shaping the competitiveness of local manufacturers.

Looking ahead, future studies should focus on enhancing value within the rebar manufacturing industry by exploring technological innovations, such as automation and digital tools, to improve production efficiency and quality control. Comprehensive regional market analyses could help understand consumer preferences and demand trends across different African countries, informing strategic decisions. Research should also examine the long-term impacts of sustainability practices on profitability and market positioning, as well as evaluate the effectiveness of existing policies and propose new frameworks to strengthen local manufacturing capabilities. Finally, analyzing how to build resilient supply chains that can withstand economic fluctuations and disruptions will be crucial for ensuring consistent production and delivery. These areas represent significant opportunities for research that could contribute to the growth and competitiveness of the rebar manufacturing industry in Africa.

2.5 Ethiopian Rebar manufacture competitiveness through value chain

The Ethiopian rebar manufacturing industry is experiencing growth driven by the country’s rapid urbanization and significant investments in infrastructure development. This growth has led to an increasing demand for high-quality rebar.

A study by Tesfaye and Desta (2019) focused on enhancing competitiveness within the industry by examining supply chain management practices among Ethiopian rebar manufacturers. They identified inefficiencies in logistics and emphasized the need for stronger supplier relationships. In response to these challenges, the Ethiopian government has increased import tariffs to support local rebar production. However, Alemayehu and Tadesse (2020) highlighted that while these tariffs may benefit local manufacturers, they can also raise costs for construction projects, leading to higher prices for consumers.

Further complicating the situation are several challenges faced by the industry. Abebe and Mulugeta (2021) reviewed existing rebar manufacturing facilities in Ethiopia and pointed out issues such as limited access to raw materials, high production costs, and a reliance on outdated technology. They also noted insufficient investment in research and development (R&D) as a significant barrier to progress.

Additionally, a study by Tessema and Belayneh (2022) investigated sustainable practices within the rebar manufacturing sector, revealing that many local manufacturers are not fully compliant with environmental regulations. This lack of compliance could undermine their competitiveness in the long term.

Despite these insights, there remains a gap in the literature regarding the enhancement of production processes and value chain optimization. Future research should focus on strategies for improving production efficiency and overall competitiveness within the Ethiopian rebar manufacturing industry.

2.6 Rebar product production process

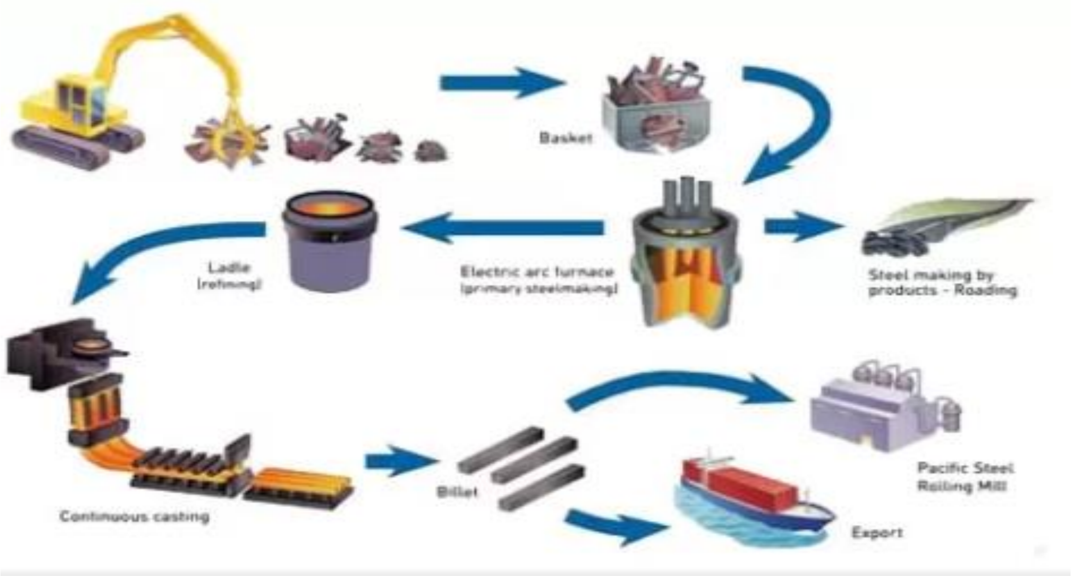
Rebar is one of the most durable materials on the planet, it has shaped our civilization, manner of life, and historical trajectory(Conejo et al., 2020). Scientists are reengineering rebar steel's molecular structure to create new forms capable of construction that are; higher, further, and stronger than anything the world has ever seen. Rebar steels are deformable iron alloys containing carbon and other components. Carbon is the most prevalent impurity in steel composition. It has a considerable influence on the properties of steel.

If the carbon level is less than 1.7-2.0 percent, iron alloys are called steels; with higher carbon concentrations, they called pig irons. Steel into three types based on carbon content: low carbon steels/mild steels (up to 0.3 percent carbon), medium carbon steels (0.3–0.6 percent carbon), and high carbon steels (more than 0.6 percent carbon.(Steel, 2011) However, the study focuses on reinforcement steel bars, which are low carbon. According to the Ethiopian standard reinforcing bar, 0.25 percent carbon is the maximum value in cast analysis. To be this, the steel manufacturing industries have many techniques to lower the Carbone concentration and get the desired result.(Gao et al., 2020) The purest form of iron manufacturing is a time-consuming and costly process. Pure iron is a pricey commodity utilized only for specific purposes in the commercial sector, whereas steel is wide use in both industrial and residential applications. Therefore, construction customers need high-quality steel to build safe structures for our community.

The rebar products; are made from iron ore or recycled materials(Wright et al., 2016). Therefore, in terms of raw materials, the production process is different. Due to this, the value chain depends on the manufacturing production process or operation. According to metallurgist researchers, iron ore raw material is of better quality than recycled steel(Haapala et al., 2013). The production process starts with raw material handling plants, coke ovens, sinter plants, refractory material plants, blast furnaces, steel melt shops, light and medium merchant mills, wire rod mills, and medium merchant and unique bar & structural mills are the most manufacturing units. However, the production process is time-consuming and costly. The production process of past researchers and steel manufacturing industries improved steel production processes by recycling materials(Dworak & Fellner, 2021a).

In past years, metallurgist researchers' steel production process was converted: into recycling materials. the value of this process; is energy efficiency, low exhaustion, and easy recycling.(Wübbeke & Heroth, 2014) For circumstance: according to the steel scrap case study, there are two reasons for the steel industry to utilize steel scrap; first, the contradiction between the rapid development of steel enterprises and the shortage of iron ore is becoming increasingly problematic. Second, the reduction of emissions and energy use is receiving increasing attention. However, recycled materials have an impact on the production process.(Wright et al., 2016)

A case study shows rebar steel manufacturing industry domestic steel scrap could not meet the needs of the steelmaking industry due to the currently high rate of steel production(Akkalatham & Taghipour, 2021). Besides, these researchers have reasoned which type of raw material is better value created to produce quality Rebar steel products and which type of technology is more value-creating chain for the steel production process(Kunitomo & Takamoto, 2006)(Babich & Senk, 2015). Rebar Steel Manufacture industry development based on raw material availability and production process technology is well suited. Most of the researchers are iron ore material for product quality is better, but this process has an economic, environmental, and social impact in one country. For instance, Indirect reducing the steel-making process to create value will not be easy. The daily capacity of modern blast furnaces ranges between 600 and 2,000 tons of iron(Mousa, 2019). However, the tremendous capital investment required is justified only; if there are resources within a reasonable distance to supply raw materials throughout the furnace. There also must be an effective transportation system to handle the large quantities of materials involved and a market for the iron produced.



Source: Didier L Schultz (2022)

Figure 2.3: Steel Rebar product using scrap-recycled process

In rebar steel production: the basic value-created process is melting, secondary melting, continuous casting, and forming and shaping. Melting a single charge in the furnace called heat.

Currently, the majority of industrialized countries generate more than 20% of all steel in electric furnaces(Abu-Heiba et al., 2021). High-efficiency electric-arc steelmaking furnaces frequently replace older open-hearth steelmaking furnaces. However, in electric arc furnaces (EAFs); Different grades of steel scrap are combined to produce the targeted carbon steel quality. However, the melt-down time of scrap mix depends on the presence of carbon in the scrap mix, and impurities present affected the process(Murua et al., 2020). The influence of scrap grades on electricity demand found to correlate strongly with their respective quality; specific electricity demand is up to 45% higher for low-quality scrap than for high-quality scrap.

The rebar steel manufacturing value chain is affected by an appreciable quantity of iron-containing scrap accumulated each year. Scrap preparation carried out in special arrangements using appropriate technology. The collecting and processing of this scrap for its rational utilization problem for the national economy; are solved by a different branch of industry for scrap processing.(Dworak & Fellner, 2021a) A case study stated the quality of the billet directly related to the steel scrap parameters: scrap source, ingot yield, electrical energy consumption, and impurity present in the scrap mix. In addition, the billet surface partially and randomly covered with scale. Although it does not affect the quality of the product, it is difficult to distinguish the scale of the room crack. Moreover, the scale of the billet has a wide gray level range. These characteristics make it hard to analyze images. Consequently, a new detection method that discriminates between material defects and scale needed. In the steel manufacturing industry, during reheating and improper cooling profiles in the second cooling zone surface and internal cracks affect the billet quality.(Lee et al., 2009) The superheat of liquid steel is one of the key; factors affecting the billet quality. Along with the superheat increasing, the shell thickness becomes thin, the surface temperature increases, and the liquid core length becomes long even if at the same casting speed.(Sun & Zhang, 2016)

1. Production Technological integration impact on rebar manufacturing industry

Technological innovation has a strong impact on the business cycle. Technological breakthroughs in communication, business, manufacturing, and other functional areas produce ripple effects throughout industries and economies. Innovation can involve creating new products or enhancing existing ones using new knowledge. For example, the image and personal computer industries have seen tremendous technological evolution, profoundly affecting organizational operations worldwide. However, the diffusion of innovation and associated investment is often irregular across sectors and regions.

Previous research has identified persistent issues associated with technology adoption in manufacturing, including concerns over product quality, safety, productivity, and environmental impact (Wang et al., 2020; Zhao & Liu, 2019; Zhang & Wang, 2020). Researchers have proposed improving steelmaking technologies through the integration of value-added processes and environmentally sustainable practices. Steel production remains resource-intensive, consuming large amounts of water and energy and emitting significant levels of air pollutants (Zhang & Wang, 2020). As a response, studies have proposed various water-saving, energy-saving, and emission-reduction technologies (Li et al., 2021).

Using scenario analysis, researchers have evaluated technological interactions in the iron and steel industry. The sector is one of the largest industrial contributors to global CO_2 emissions—responsible for about 25% of direct industrial emissions and 7% of global emissions in 2018 (Gao et al., 2020). Consequently, China's steel industry has prioritized technological improvements, including ultra-low carbon technologies, carbon capture and storage (CCS), and hydrogen-based production methods. These mainstream improvements could reduce CO_2 emissions by approximately 43% (Wang et al., 2021; Zhou et al., 2021).

Additional studies explore the water-energy-emission nexus (WEEN) using technical scenario modeling. The research identified the most feasible technology combinations using Pareto optimization and genetic algorithms. Findings show that emissions of SO_2 , NOx, and dust could be reduced by 97%, 50%, and 75% respectively, with water and energy consumption decreasing by 10% and 2%—though installation and operational costs could rise by up to 74% (Chen et al., 2022).

Symbiotic technology-based research also employs material flow analysis and life cycle assessment to quantify energy conservation and emission reductions. By evaluating symbiotic technologies through scenario modeling, studies have demonstrated significant potential for energy savings and pollution reduction. As global economic growth continues to drive energy and material consumption, these frameworks are essential to combating climate change (Huang et al., 2022).

In past years, metallurgist researchers have converted the steel production process into recycling materials. The value of this process is energy efficiency, low exhaustion, and easy recycling. However(Morfeldt et al., 2015)Due to high steel demand levels and the scarcity of scrap, more than 50% of the steel production in 2050 will still have to come from virgin materials. Hence, metallurgist researchers have recommended iron ore as a raw material to process for future steel manufacturing.

2. Casting Simulation Tools for Defect Prevention in Rebar Manufacturing

Defect prevention and quality assurance are critical challenges in the manufacturing of reinforcement bars, especially in emerging industrial regions where quality variability and production inefficiencies are common. A growing body of research highlights the potential of predictive simulation tools to improve defect detection, reduce waste, and optimize production processes in metal casting. These tools simulate the thermal, fluid, and mechanical behavior of materials during casting, enabling early identification of process-related flaws. This review examines key casting simulation tools and their application in rebar production, focusing on their features, strengths, limitations, and role in predictive quality control.

A. Importance of Predictive Simulation in Rebar Manufacturing

Traditional defect detection methods such as in line visual inspection, sensor-based monitoring, and destructive testing tend to identify issues only after they occur, leading to increased rework, material waste, and energy inefficiencies (Ahmed & Selim, 2019). In contrast, simulation-based methods offer a proactive approach by modeling defect formation before casting begins. This shift from reactive to predictive quality control aligns with Industry 4.0 principles, which emphasize data-driven process optimization (Müller et al., 2022).

In rebar manufacturing, particularly in the continuous casting stage, common defects include porosity, shrinkage cavities, cracks, cold shuts, and inclusions. These defects are often the result of complex interdependencies between thermal gradients, cooling rates, mold design, and material flow behavior. Simulation tools help engineers understand these interactions, enabling them to modify design and process parameters in advance to avoid defects.

B. Comparative Review of Simulation Tools

A range of commercial casting simulation tools is available, each with unique capabilities and industrial use cases. The most prominent tools in the literature include MAGMA, PROCAST, SolidCast, AnyCasting, FLOW-3D, and Simulcast. Each software varies in terms of modeling scope, accuracy, computational requirements, and integration with quality frameworks.

MAGMA is a high-end simulation software known for its ability to simulate multi-physics phenomena, including solidification, shrinkage porosity, and residual stresses. It supports various casting methods such as sand casting, pressure die-casting, and continuous casting. MAGMA's adaptive meshing and advanced thermal models make it highly accurate, but the tool is cost-prohibitive for many firms and requires significant training due to its complexity (Lee et al., 2020).

PROCAST, on the other hand, offers a more balanced approach between usability and technical depth. It includes modules for thermal, fluid flow, and stress-strain analysis during casting, and is widely used in metallurgical applications. PROCAST’s strength lies in its integration with CAD platforms, support for user-defined materials, and ability to simulate solidification behavior and stress development in billets—critical for preventing downstream defects in rolling and forming (Kumar et al., 2021; Zhang & Liu, 2022). Unlike MAGMA, PROCAST is more accessible and versatile, making it ideal for medium- and large-scale rebar manufacturers seeking to implement simulation-driven quality control.

Solid Cast is often praised for its quick simulation times and intuitive user interface, which is advantageous for small-scale foundries and educational environments. It effectively predicts basic casting defects such as cold shuts, misruns, and shrinkage porosity. However, its limited fluid dynamics modeling and lack of comprehensive thermal-mechanical coupling restrict its utility in complex production environments such as rebar billet casting (Ahmed & Selim, 2019).

Any Casting provides efficient simulation of mold filling and solidification patterns with an emphasis on visual interpretability. It is well suited for general casting operations, but lacks depth in predictive defect analytics and detailed mechanical stress simulation—both of which are crucial in predicting internal rebar defects (Chen et al., 2018).

FLOW-3D stands out for its exceptional modeling of fluid flow behavior, including turbulence, splashing, and air entrapment. It is particularly effective for analyzing mold-filling scenarios in open or high-speed castings. However, its high computational demands and narrow focus on fluid dynamics reduce its suitability for rebar production, which requires integration of thermal and structural analysis (Müller et al., 2022).

Simulcast focuses on thermal and structural simulation, providing good insight into temperature distribution and cooling behavior. However, it does not support detailed fluid dynamics or stress analysis, which limits its ability to predict complex defects resulting from multi-stage interactions in billet casting and rolling (Chen et al., 2018).

C. Relevance of Pro CAST in Rebar Manufacturing

Among all tools reviewed, Pro CAST emerges as the most suitable option for the rebar manufacturing context. Its ability to simulate key casting phenomena—such as thermal gradients, stress accumulation and shrinkage-related defects—makes it particularly effective in predicting quality outcomes in continuous billet casting. Moreover, Pro CAST supports time-temperature-transformation (TTT) analysis, allowing engineers to estimate metallurgical phase changes, which are critical to final product strength and ductility.

Several case studies confirm the effectiveness of Pro CAST in rebar-related applications. For instance, Zhang and Liu (2022) used Pro CAST to simulate billet reheating behavior and its influence on downstream cracking. Similarly, Wolde et al. (2021) identified recurrent porosity and cold shut issues in Ethiopian rebar plants, suggesting that lack of predictive tools like Pro CAST contributes to ongoing quality problems. These findings reinforce the value of integrating predictive simulation with defect prevention strategies.

D. Integrating Simulation with Strategic Quality Frameworks

Simulation software alone cannot address all quality challenges; rather, its impact is maximized when combined with strategic frameworks such as Value Chain Analysis (VCA) and Cause-and-Effect Analysis (CEA). VCA allows manufacturers to evaluate how each production stage material selection, billet casting, reheating, rolling, and finishing—contributes to overall product quality (Tesfaye, 2023). Pro CAST complements this by offering data-driven insights into process variables that can be mapped across the value chain.

This integration bridges the gap between micro-level simulation outputs and macro-level process decisions, enabling manufacturers to predict, analyze, and prevent defects in a systematic, holistic manner. It also supports continuous improvement by enabling feedback loops between simulation results and production outcomes.

The literature confirms that predictive simulation is a vital component of modern quality control in rebar manufacturing. Among the tools reviewed, Pro CAST offers the most comprehensive and scalable solution, especially when integrated with strategic frameworks like VCA. However, a notable gap exists in existing research: most studies focus on simulation at isolated stages, without linking simulation outcomes to upstream or downstream value chain interactions. This study addresses that gap by combining Pro CAST simulation with value chain modeling, enabling system-wide defect prevention..

3. Inline Defect in the Rebar Manufacturing Industry

The rebar manufacturing industry faces significant challenges related to defect waste, impacting costs, environmental sustainability, and operational efficiency. Inline defect waste minimization strategies leverage advanced technologies and methodologies to enhance product quality and reduce waste, as highlighted in various studies. Key themes include the role of real-time quality control technologies, such as laser measurement systems that detect dimensional inaccuracies, and the benefits of automation and process optimization through automated rolling mills, which help maintain consistent control over production variables. Data analytics also plays a crucial role, with predictive analytics enabling proactive adjustments based on historical data to forecast potential defects. Employee training and engagement are emphasized as critical factors in minimizing defects, while the adoption of lean manufacturing principles, including continuous improvement strategies, further contributes to waste reduction. However, significant gaps remain in the literature, including the need for research on technology integration into existing processes, scalability of solutions across different manufacturing sizes, and holistic approaches that combine technology, training, and lean principles. Additionally, most studies focus on short-term outcomes, indicating a need for long-term impact assessments of these strategies. Unique contributions of inline strategies, such as immediate feedback mechanisms, enhanced material utilization, and data-driven decision-making, highlight their potential to address common challenges in the industry. Overall, while progress has been made, further research is required to explore these gaps using predictive analysis method and helps the rebar manufacturing sector evolve toward more sustainable and efficient practices.

Inline defect waste minimization in the rebar manufacturing industry has become an essential focus due to its impact on material efficiency, cost, and environmental sustainability. Common defects such as off-cuts, head-tail cuts, cobbles, and scale formation result from inconsistencies during billet preparation, rolling, and finishing stages (Alemu, 2022). Process optimization using real-time monitoring and automation tools has shown promise in identifying production inefficiencies and reducing defects (SBQ Steels, 2023). The application of statistical methods like the Taguchi Loss Function enables quantification of economic losses due to deviations from product standards, thereby guiding defect-reduction strategies (Alemu, 2022). Furthermore, lean manufacturing principles—including value stream mapping and Kaizen—have proven effective in streamlining operations and minimizing waste (Mdpi, 2020). Employee training also plays a crucial role in reducing inline defects by improving operator skills and early defect detection (SBQ Steels, 2023). These integrated approaches not only enhance operational efficiency but also contribute to lower energy use and carbon emissions, aligning with broader sustainability goals (Mdpi, 2020). Inline defect detection plays a pivotal role in ensuring consistent quality and minimizing rework in the rebar manufacturing industry. Sone et al. (2020) examined the prevalence of defects during rebar processing and found that 33.3% of issues were related to inaccurate bending geometry and 27.1% to incorrect cut counts. Their research highlighted that even in semi-automated environments, human errors in interpreting digitally encoded QR-based manufacturing instructions were a major source of defects. These findings underscore the importance of integrating accurate, traceable production data into every stage of the manufacturing line to mitigate defect propagation.

Inline inspection tools using non-contact sensors have also proven valuable across various sectors. According to a study by Reimer et al. (2021), laser-based dimensional analysis systems successfully detect inconsistencies such as burrs, warping, and thickness deviations in rolling lines, often allowing real-time adjustments. Although focused on general steel processing, the implications are directly relevant to rebar production, where dimensional precision is essential prior to bending and bundling.

Artificial intelligence is increasingly being utilized to forecast and prevent defects during inline operations. In Ethiopia’s steel industry, Getachew et al. (2024) developed a defect-prediction model using the CRISP-DM framework and gradient boosting. The system incorporated chemical composition and billet dimensions to predict anomalies in tensile strength and ductility, achieving a coefficient of determination (R^2) exceeding 0.97. This study illustrates the transformative potential of machine learning in early defect prediction based on real-time operational inputs.

Additionally, machine vision technologies have emerged as vital tools in surface defect detection. Kumar et al. (2020) demonstrated that CCD camera-based inspection systems could measure rebar diameters with sub-0.1 mm accuracy, identifying subtle surface irregularities and shape deformations. When combined with optimized lighting and image-processing algorithms, such systems are capable of supporting fully automated quality control without the need for manual inspection.

Eddy current and ultrasonic testing methods, though traditionally used in post-installation concrete inspections, offer complementary insights into inline defect detection. Liu et al. (2019) showed that combining these techniques enables both surface and subsurface flaw identification, making them potentially valuable for inline quality assurance in high-strength or safety-critical rebar production.

Thermal inconsistencies also lead to defects during the quenching and tempering stages of thermo-mechanically treated (TMT) rebar manufacturing. Das et al. (2014) reported that incorrect water cooling box parameters during TMT processing can form brittle martensitic layers, leading to sudden fracture during bending. Inline thermal monitoring and real-time quench control could prevent such latent defects from passing undetected through quality checks.

As well, integrated inline quality assurance systems based on high-resolution imaging, synchronized lighting, and real-time analytics are being deployed in advanced manufacturing environments. Lee et al. (2019) highlighted that these systems not only improve defect detection rates but also allow for immediate corrective actions, significantly reducing scrap and downtime.

Defect minimization and billet optimization play a crucial role in improving the operational efficiency and product quality in the rebar manufacturing industry. One of the most critical stages is billet reheating, where maintaining a uniform temperature between 1150°C and 1250°C is essential. Uniform heating enhances the billet’s plasticity and reduces deformation resistance, allowing internal defects to heal before the rolling process. In contrast, excessive or uneven heating can cause adverse effects, such as surface oxidation, decarburization, internal cracks, and grain coarsening, all of which compromise the final product’s mechanical properties (Alemu, 2022; Li et al., 2021). To mitigate these issues and save energy, some plants have adopted direct charging of billets from continuous casting to the rolling mill at high temperatures (~1100°C), thus eliminating the need for reheating while preserving billet integrity (Zhou et al., 2021).

At the casting stage, defect reduction can be achieved through thermal soft reduction (TSR), a method that applies controlled compression during the final stages of solidification. Research has demonstrated that applying TSR at distances between 6.96 m and 8.46 m from the meniscus significantly reduces centerline segregation and internal cracking; particularly in high-carbon, steels such as 82A tire cord steel (Li & Wang, 2020). Furthermore, metallographic techniques involving etched macrostructure analysis of wire rods and bars help trace surface defects—such as pinholes, oxidized layers, and decarburization—back to inconsistencies in the casting process, offering valuable data for quality control (Chen et al., 2019).

A key component of billet optimization involves minimizing material waste during cutting. Alemu (2022) applied the Taguchi optimization method alongside a custom software system to determine the ideal billet lengths for different rebar sizes, such as ϕ10 and ϕ12. The results showed a reduction in off-cuts and head cuts by 2.23%, alongside a 4.5% improvement in productivity. The process also yielded substantial energy savings—over 2,100 kWh of electricity and nearly 900 liters of fuel per production shift. Similarly, Alshemmare and Ali (2021) utilized integer linear programming to develop an efficient cutting pattern model, which reduced trim losses and associated costs in the Bahraini rebar market.

Additional innovations have come from optimizing lap-splice positions in reinforced concrete elements. Studies by Zheng et al. (2019) and Nadoushani et al. (2018) showed that refining lap-splice placements in columns and walls can cut trim waste by over 50%, without affecting structural performance. A 2023 case study of diaphragm-wall construction using heuristic algorithms achieved a cutting waste rate of just 0.77%, translating to 3,000 tons of CO_2 saved and over USD 3.48 million in cost reductions (Huang et al., 2023). Moreover, multi-objective optimization methods integrated with Building Information Modeling (BIM) further minimize cutting waste while maintaining design accuracy (Wang et al., 2024).

Recent advancements in artificial intelligence and process automation are also reshaping defect detection and prevention. Deep reinforcement learning (DRL) has been applied in forging environments to stabilize billet temperature profiles and reduce defect formation, suggesting its potential utility in billet reheating processes (Ma et al., 2022). Vision-based tools have also shown promise; for example, Park et al. (2021) utilized the YOLOv3 neural network and regression algorithms to accurately detect rebar endpoints, improving cutting precision and reducing cutting-related defects. TLU-Net, a deep-learning-based segmentation model, was reported to enhance surface defect detection accuracy by approximately 5% in steel products, aiding in the early identification and correction of surface issues (Sun et al., 2021).

Therefore, a comprehensive strategy combining billet quality control, cutting pattern optimization and AI-powered monitoring systems has proven effective in minimizing defects and maximizing efficiency in rebar manufacturing. Future developments should focus on integrating these elements through digital twin technologies, allowing for end-to-end control and optimization across casting, reheating, rolling, and cutting stages. This holistic approach holds promise for achieving near-zero-defect operations while improving sustainability and reducing operational costs.

Reducing defects in rebar products is critical to ensuring structural integrity, cost efficiency, and sustainability in the steel manufacturing industry. Common issues such as cobbles, cracks, head-tail cuts, and surface scale typically originate from inconsistencies in billet casting, reheating, rolling, or finishing processes (Alemu, 2022; SBQ Steels, 2023). Current strategies for defect reduction often involve real-time inspection and data-driven analysis. For instance, machine vision systems using CCD cameras and image-processing algorithms can detect geometric distortions and surface anomalies with sub-0.1 mm precision, enabling rapid defect identification during production (Kumar et al., 2020). Similarly, AI-based predictive models, such as gradient boosting and random forest algorithms, have been deployed to forecast mechanical anomalies using operational and chemical input data, demonstrating high prediction accuracy ($R^2 > 0.97$) in real-world applications (Getachew et al., 2024). These technologies are highly effective at defect detection and short-term forecasting, but they often lack the capacity to model the physical mechanisms behind defect formation during early-stage metallurgical processing.

A notable gap in the existing literature is the lack of integration between predictive modeling and the underlying thermophysical behavior of molten steel during casting and solidification. Most current methods focus on surface-level indicators or post-process corrections without addressing how upstream process parameters like superheat, mold geometry, or cooling rates contribute to defect formation at the microstructural level (Sun & Zhang, 2016; Das et al., 2014). This gap presents a compelling case for incorporating physics-based simulation tools such as PROCAST, which offers a finite element modeling platform tailored to casting and solidification processes. PROCAST simulates thermal gradients, fluid flow, shrinkage, stress concentrations, and solidification pathways in billets, enabling early identification of regions prone to porosity, cracking, and segregation (Lee et al., 2009). By visualizing defect-prone zones before billets proceed to reheating and rolling stages, PROCAST supports proactive quality assurance rather than reactive intervention.

Moreover, PROCAST enables precise modeling of metallurgical factors such as carbon content and cooling dynamics, which are critical to achieving desired rebar characteristics and minimizing defects like surface scale and internal stress fractures (Gao et al., 2020). Its applications in virtual prototyping and process optimization allow manufacturers to simulate and refine casting conditions without costly physical trials, thereby reducing energy consumption, raw material waste, and downtime (Wright et al., 2016). This capability addresses the limitations of traditional machine learning models by offering insight into the material behavior driving defect formation, not just correlations based on past data.

In conclusion, while real-time monitoring and AI-based forecasting have improved inline defect detection, the integration of PROCAST fills a significant research gap by enabling predictive, physics-driven simulation of defect mechanisms at the earliest stages of rebar production. This holistic approach aligns with industry goals for zero-defect manufacturing, enhanced operational efficiency, and sustainability.

2.7 Executive Summary

The literature review provides a comprehensive literature review of the competitive dynamics, technological integrations, and value chain considerations in the rebar manufacturing industry. It begins by outlining the increasing importance of achieving competitive advantage in a rapidly urbanizing and industrializing global market. Strategies such as cost leadership, product differentiation, and technological innovation are identified as essential tools for manufacturers to stay competitive. Real-world case studies from companies like Gerdau, Nucor, and Steel Dynamics illustrate how these strategies, when effectively implemented, enhance operational performance and market positioning. However, these cases also reveal vulnerabilities related to adaptability, technological dependence, and supply chain risks.

The review further explores strategic frameworks like Value Chain Analysis (VCA)**,** SWOT Analysis**,** Benchmarking, and Core Competencies**,** evaluating their roles in driving organizational competitiveness. Among these, VCA emerges as a particularly effective tool, offering granular insights into how internal operations contribute to overall value creation. While each framework provides unique perspectives, the study underscores VCA’s superior utility in linking internal processes to sustainable competitive advantages.

A regional comparison of the rebar industry is presented, highlighting the unique challenges and strategies in Africa and Ethiopia. African manufacturers face issues such as infrastructure deficits, energy costs, and supply chain inefficiencies, while Ethiopian firms deal with raw material shortages, outdated technologies, and limited R&D investments. Despite efforts to localize production and implement tariffs, challenges in sustainability, quality, and compliance persist. Literature from these regions stresses the need for targeted strategies that improve production efficiency, technological integration, and value chain optimization.

Technological transformation is reviewed in depth, with emphasis on the role of Industry 4.0, automation, data analytics, and environmental technologies in reshaping manufacturing operations. Studies show that integrating these tools can lead to substantial reductions in energy consumption, emissions, and production costs, though long-term success depends on strategic alignment and regional feasibility.

The chapter also identifies inline defect detection and minimization as critical factors in rebar quality assurance. Current methods involve real-time monitoring systems, AI-driven predictive analytics, and machine vision technologies. However, a notable gap exists in integrating these solutions into broader production systems. Most studies focus on isolated improvements rather than system-wide solutions that consider upstream and downstream process interactions.

A major gap identified is the lack of research combining Value Chain Analysis with predictive defect simulation tools like PROCAST. Existing studies often overlook how material-level phenomena and process-level inefficiencies intersect. Addressing this gap offers a valuable opportunity to create a holistic model that not only predicts but also prevents defects across all production stages, thereby supporting higher efficiency, lower waste, and sustainable growth in the rebar manufacturing sector.

In summary, Chapter Two lays the foundation for advancing the rebar industry through an integrated approach that leverages strategic frameworks, regional insights, and digital technologies—paving the way for your study to deliver impactful solutions using VCA and PROCAST.

2.8 Literature gap

Although previous research has established the importance of inline defect detection in rebar manufacturing through real-time sensors, machine vision, automation, and AI-based models, a critical gap remains in terms of integrating these defect control strategies within the broader context of the entire value chain. Most studies focus narrowly on technological fixes at isolated stages—such as billet reheating, rolling, or cutting—without mapping how these interventions impact or are influenced by upstream and downstream processes. Additionally, while advanced tools like AI and machine vision have improved defect detection, they lack predictive capabilities grounded in material behavior simulations. This is where Value Chain Analysis (VCA) becomes crucial. By applying VCA, the research had evaluated defect formation not as isolated events but as systemic inefficiencies linked to interdependent stages—material selection, billet casting, reheating, rolling, and finishing—thereby enabling a more strategic and process-wide defect prevention model.

Moreover, although predictive analytics using machine learning has been explored, the use of physics-based simulation software like PROCAST remains underutilized for inline defect analysis in rebar manufacturing. PROCAST offers the ability to simulate thermal gradients, stress distribution and solidification behavior during billet casting and reheating—critical stages that heavily influence downstream rolling defects such as cracks, cobbles, or scale formation. By integrating PROCAST simulations with VCA, the study introduces a hybrid approach that bridges operational inefficiencies and material-level defect prediction. This enables both macro-level process alignment and micro-level defect forecasting, providing a holistic roadmap to reduce waste, improve quality, and enhance sustainability.

Therefore, the literature show that while rebar manufacturers are advancing in defect detection, they lack integrated predictive systems that consider thermal behavior, material flow, and process interdependencies. The research fills this gap by using PROCAST for simulation and VCA for process mapping, offering a holistic quality control framework.

CHAPTER THREE - METHODOLOGY

In this chapter, the research design for the study is presented. The research design outlines the overall approach, methodology, and procedures used to address the research questions and objectives.

3.1 Research Design

The research design outlines the overall strategy and analytical framework used in this study to integrate various components in a coherent and logical manner, ensuring a comprehensive investigation of the research problem. The choice of research design is shaped by several factors, including the research orientation, the specific issue at hand, and the target audience (Creswell, 2014). To meet these objectives, this study adopts an exploratory research approach that employs a mixed-methods strategy. This approach capitalizes on the strengths of both quantitative and qualitative methodologies while addressing their limitations. Quantitative methods enable systematic and rigorous data analysis, while qualitative methods offer the flexibility necessary for in-depth exploration (Tashakkori & Teddlie, 2010). The combination of these methodologies enriches the research design, leading to a more robust and thorough analysis (Creswell & Plano Clark, 2017).

The study begins by gathering secondary data about the company's existing structure and its value chain, identifying both value-added and non-value-added activities. It then focuses on critical activities that add value but do not enhance the overall process, providing a detailed analysis of these activities by examining the current production process's value-added percentage and pinpointing areas for improvement (Porter, 1985). Using cause-and-effect analysis, the study addresses issues related to billing defects (Ishikawa, 1986). By employing a mixed-methods approach and methodological triangulation, the study seeks to enhance the strengths of both quantitative and qualitative methods while mitigating their limitations (Denzin, 1978).

To achieve its objectives, the research primarily utilized data collection techniques such as observation, interviews, and both company-specific and Ethiopian standard secondary data. For each data collection tool method, the study employs purposive sampling to seek in-depth insights from specifically selected areas (Patton, 2002).

3.2 Data collection tool

The data collection tool is a systematic method or instrument used to gather information for research, analysis, or assessment purposes. These tools can take various forms, each designed to collect specific types of data in a structured manner. The study, the following data collection tools had primarily utilized.

1. **Primary data collection**

The study utilized primary data collection tools to obtain detailed and relevant information that directly contributes to the research objectives, thereby enhancing the overall quality and validity of the study.

Table 3.1: Type of primary Data collection used

No	Type of data collection	Objective	Sources of data
1	Observation	To identify the current value added and non-value added activities used one target question for each activity.	Raw material storage up to marketing distribution area
		To understand the value chain, identified each activity and investigate the link between each activity. And determined bottleneck production area	
		To understand detail the exist rebar production process	Raw material preparation up to final rebar product observe the production process
2	Interview	To verify the cause and effect analysis in terms of the 5 Why method, discussed with two teams.	First team process engineers and production manager and second team quality control specialists and R &D expert.

2. Secondary data collection

The study employs secondary data collection methods to save time and resources, providing a solid foundation for analysis and informing primary data collection efforts. By utilizing relevant secondary data, the research had enhanced its objectives, ensuring that the findings are grounded in established knowledge and context. The approach allowed for a more efficient exploration of the research problem while leveraging existing information to support and enrich the study analyses.

A. Company document review

The study used secondary reference documents, such as detail production process flow document and each department procedure, to identify the existing production process value add and non-value added activities. Moreover, to identify cause effect analysis the study use billet quality performance recorded data. In addition, to identify the improvement area, use current production process parameter data.

B. Literature Review

A literature review is a critical component of academic research that not only helps map the existing knowledge landscape but also lays the groundwork for new contributions to the field. The reviewed literature primarily focuses on the value-added chain in the Rebar manufacturing production process.

Table 3.2 Type of secondary Data collection used

No	Type of data collection	Objective	Sources of data
1	Company document review	To identify value added and non-value added activities also, to understand more detail the existing inbounded and operational activities	Production process flow chart and each activities procedure.
		To identify customer need	Customer order form and Rebar product standard.
		To determine VAP and waste generated activities	Annual production plan, one-cycle production, and financial statement quantitative data
		To identify the billet defect cause and illustrate each defect cause in terms of each root cause category	Melting and continuous casting production process billet out let defect cause record 2013- 2015 EC
		To predict defect product process using PROCAST program	Current production parameters
2	Literature review	To analyze and understand the ideas of different research from the published journals and articles about VCA and rebar manufacturing technology	Journals, articles, case studies, reviews, and company reports reviewed

2. Data collection Technique procedure

The study employs an exploratory methodology to implement the research plan and achieve its objectives. The initial step involves conducting a situational analysis of the case company. This analysis aims to identify areas for improvement within the production process. The table below outlines each activity of the study and briefly describes how data collection tools are utilized throughout the research.

Table 3.3 Data collection technique and study activities procedure

Activity	Data Collection Tool	Purpose / Use
Identify rebar types, customer needs, and define production value chain	Company records, Observation	Understand demand, customer standards, and map the production flow
Classify activities as value-added (VA) or non-value-added (NVA)	Observation, Department Q&A, Literature	Calculate VAP, identify low-value areas for improvement
Map detailed operational production process	Observation, Company documents	Create simplified production flow charts
Calculate waste rate and VAP per process	Company documents	Identify high-waste and low-VAP process stages
Analyze causes of product rejections	Rejection data, Pareto chart	Identify major billet defects and their frequency
Identify defect sources using expert insight	Rejection data, Expert interviews	Trace root causes of billet defects
Improve casting parameters via simulation	Process data, PROCAST software	Optimize casting setup before implementation; propose new process flow

3.3 Sampling Technique

The systematic sampling approach utilized in this research was particularly appropriate for achieving the study objectives. It facilitated balanced representation across diverse production roles and shifts, thereby capturing multifaceted perspectives on quality issues throughout the manufacturing process. This method also offered practical implementation advantages within the industrial environment compared to alternative sampling techniques.

The study employed systematic sampling to select participants for interviews focused on the billet outlet stage of the melting and continuous casting processes, specifically examining longitudinal, surface, and transverse defects through the 5 Whys analysis method. This sampling technique was chosen to encourage deep thinking and collaboration among experts.

The interview process was designed to ensure that the cause-and-effect relationships identified were valid and to uncover the root causes of defects. Participants were selected from the melting and continuous casting production areas; including production process engineers, the production manager, quality control inspection experts, and research and development personnel.

Interviews were conducted using a group format in person. The first group comprised two production process engineers and one production manager, while the second group included two quality control experts (one from internal quality control and one from quality assurance) and one representative from the research and development department.

The questions posed during the interviews were open-ended and followed the 5 Whys methodology. The duration of discussions for each question was tailored to allow for in-depth exploration of the issues at hand, ensuring a comprehensive understanding of the root causes of the defects. Data collection was systematically organized using Excel to record and analyze the information gathered during the interviews.

3.4 Result and Analysis Techniques

Value Chain Analysis provides a broad overview, Cause and Effect Analysis delves into specific issues, and PROCAST Software Simulation offers detailed process insights. Together, these methods had created a holistic approach to enhance manufacturing process. And as seen in the literature review and comparative analysis, PROCAST emerges as the preferred simulation software for casting processes due to its specialization, user-friendliness, comprehensive capabilities, and strong industry validation. These attributes make it an ideal tool for engineers seeking to enhance the quality and efficiency of their casting operations.

Table 3.2: The data interpretation summarized as follows:

Data collection method and input	Data analyze method	Objective/Purpose	Expected Result
Direct observation of processes and workflows, Data from reports, and Conversations with employees across different departments to gather insights.	Value chain analysis	Understand the existing production process	Identification of specific areas for improvement, such as bottlenecks
Review existing production process billet out let quality issue record 2013- 2015 EC and expert opinion	Cause and effect analysis	Pinpoint root causes of a problem rather than just symptoms, and to gain a deeper understanding of the relationships between different factors.	Clearly illustrates the relationships between factors.
CAD Models: 3D models of the parts to be cast. The procedure is 3D cad model – mesh by mesh cast- data input to PROCAST- analyzing results- pouring temperature and solidification time	PROCAST software simulation	To identify the most efficient casting parameters that minimize defects and Fine-tuning parameters had led to enhanced quality	production parameters improvement and prose new production process flow chart on operational activities

3.5 Reliability and validity

The study collected data using secondary and primary sources, specifically interviews, observations, and secondary recorded data. By using these sources and data collection methods, the study can strengthen the findings, gain a more comprehensive understanding of the phenomenon, and enhance the credibility of the research by using multiple methods or sources to corroborate the findings and ensure their validity and reliability. Researchers have recommended triangulating methodology as an effective way to check reliability and validity in exploratory research (Flick, 2018). Therefore, due to the above methods and collection tools, the study analyzes both qualitative and quantitative data. However, to check reliability and validity, the study mainly uses triangulating methodology. Methodological triangulation using qualitative and quantitative methods was adapted to improve the reliability of the study (Denzin, 1978).

By employing triangulation through interviews, observations, and secondary records, the study achieved a richer, more nuanced understanding of the issues at hand. This approach not only reinforces the credibility of findings but also aids in formulating actionable recommendations. The main objective of triangulating research methods is to check if similar conclusions are drawn from the various methods of data collection. By combining various methodological data collection and analysis techniques, triangulation seeks to increase confidence in the research data, create innovative ways of understanding a phenomenon, and provide a clearer understanding of the research problem. According to Golafshani (2003), the triangulation method helps define and establish reliability in research.

3.6 Ethical consideration

The researcher is dedicated to upholding the highest ethical standards in their research practices, which encompasses several key principles. First, they ensure integrity in data representation by committing to accurate and unaltered reporting of all collected data, as misrepresentation undermines the credibility of the research. Additionally, the researcher actively works to eliminate bias and minimize errors throughout the research process, employing rigorous methodologies to maintain objectivity in both data collection and analysis. They are vigilant in identifying and managing potential conflicts of interest, prioritizing transparency in disclosing any such conflicts to maintain trust and integrity.

Furthermore, the researcher emphasizes proper attribution and acknowledgment by giving credit to the contributions of other researchers and adhering to ethical guidelines regarding citations, thus respecting intellectual property rights. Committed to the principle of open science, they share data, results, and ideas with the broader community, fostering collaboration and encouraging further research. Ultimately, the researcher acts with the best interests of humanity and the community in mind, considering the broader implications of their research and striving to contribute positively to societal well-being. By adhering to these ethical principles, the researcher enhances the quality and reliability of their work while advancing knowledge in a responsible and socially conscious manner.

3.7 Research dissemination

The findings of this research were formally presented to the Addis Ababa Institute of Technology School of Mechanical and Industrial Engineering, as well as to Abyssinia Integrated Steel Manufacturing PLC. This dissemination aimed to engage academic institutions and industry stakeholders, fostering collaboration and knowledge transfer.

The insights garnered from this study serve as a valuable resource for ongoing projects within the Ethiopian rebar manufacturing sector. By sharing these findings, the research contributes not only to the immediate stakeholders but also lays the groundwork for future studies in the field. It is intended to inspire further research initiatives, providing a foundation for scholars and practitioners to build upon.

In summary, the dissemination of this research not only benefits the Addis Ababa Institute of Technology and Abyssinia Integrated Steel Manufacturing PLC but also serves as a catalyst for further research and improvement within the Ethiopian rebar manufacturing industry, promoting innovation and efficiency across the sector.

3.8 Research design framework

The research design framework of the study designed based on considerations of the concepts reviewed in the literature the research design framework shown in the figure below.

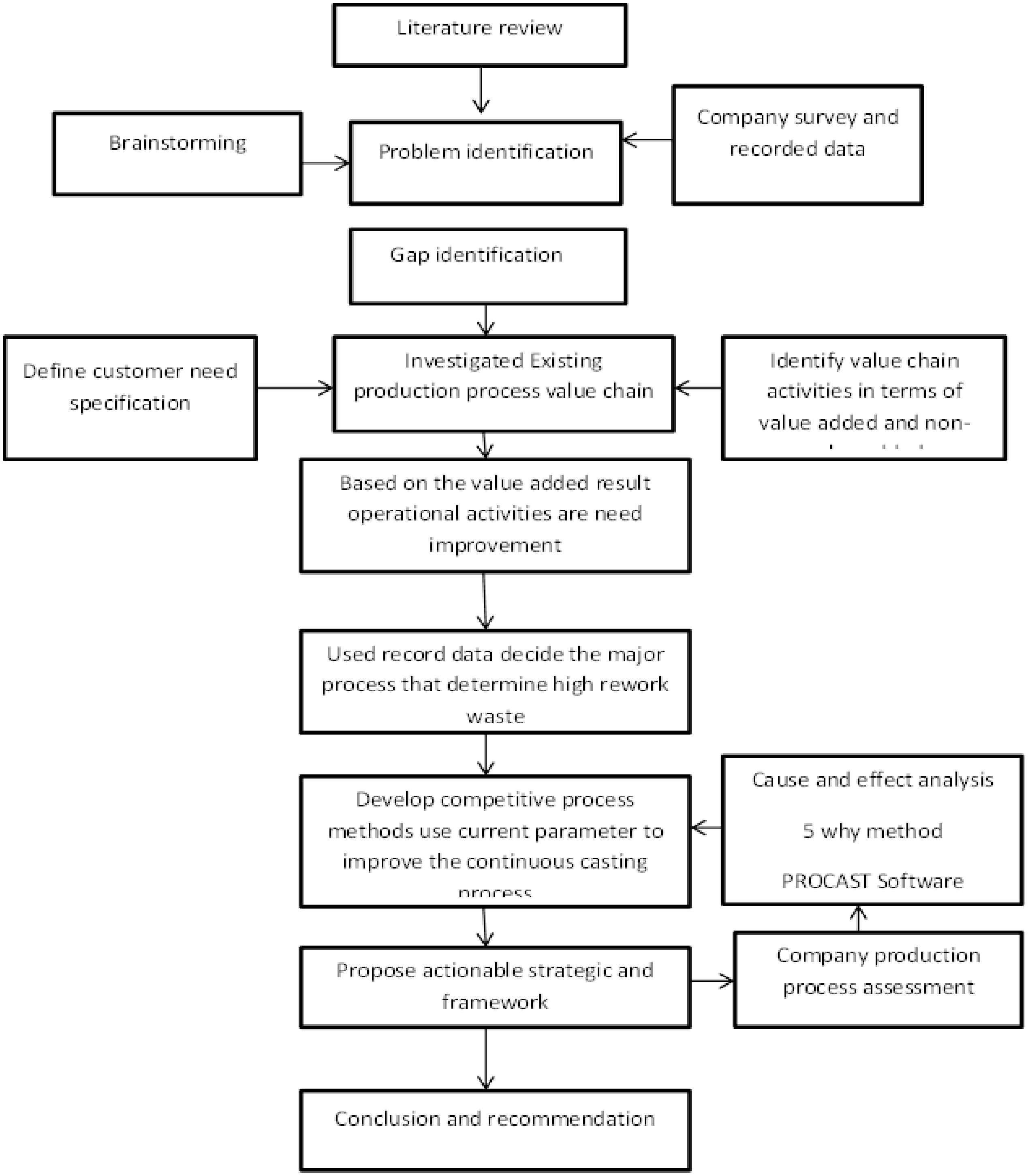


Figure 3.1: Research framework

CHAPTER FOUR - DATA PRESENTATION

4.1 Organization of the company

The Abyssinia integrated steel manufacturing industry is comprised of four main departments. These departments work like a well-oiled machine to run the company smoothly. Each one has specific duties and roles, but most situations require them to work together. These departments are:

Organizational Structure of the company

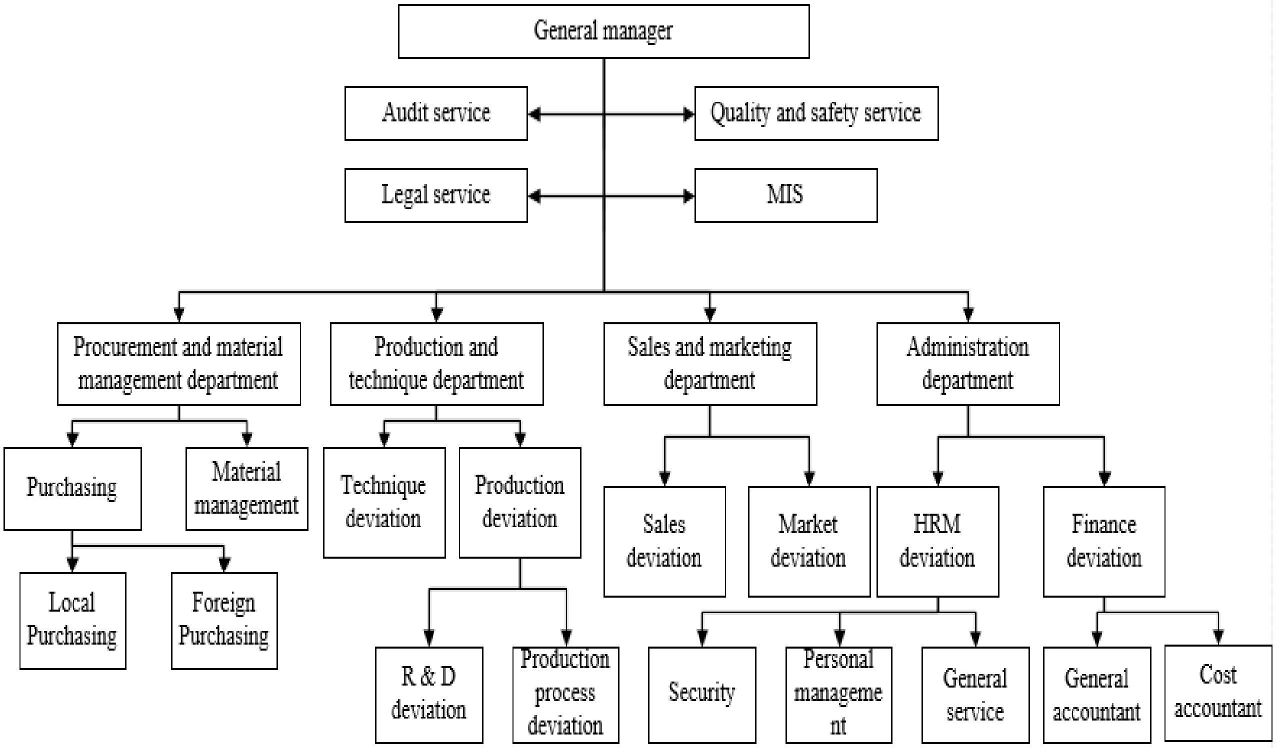


Figure 4.1: organization of structure

Based on the organizational structure, the company value chain had described as a well-integrated system aligned with Porter's Value Chain Model. The Procurement and Material Management Department handles inbound logistics through local and foreign purchasing and material storage, ensuring timely supply of raw materials like scrap or iron ore. The Production and Technique Department oversees core operations, including process control, R&D, and technical improvement to ensure quality and efficiency in casting and rolling. Downstream, the

Sales and Marketing Department is responsible for market analysis, customer engagement, and sales execution, supporting outbound logistics and demand alignment. Supporting functions such as Human Resource Management, Finance, MIS, Audit, and Legal Services enhance strategic oversight, compliance, and organizational capacity. The Quality and Safety Service ensures that products meet required standards before reaching customers. This structure enables effective coordination across departments, promoting operational efficiency, quality control, and continuous improvement across the rebar manufacturing value chain.

4.2 Product of the company

Rebar is a vital product in construction, providing reinforcement and strength to concrete structures. Its production involves the conversion of steel billets into the desired shape and size through hot rolling processes. Rebar contributes to the durability, safety, and resilience of concrete structures, making it an indispensable component in the construction industry.

Table 4.1: Current list of Rebar products in the company

Product	Type of product
Reinforcement (Rebar)	8 diameter
	10 diameter
	12 diameter
	14 diameter

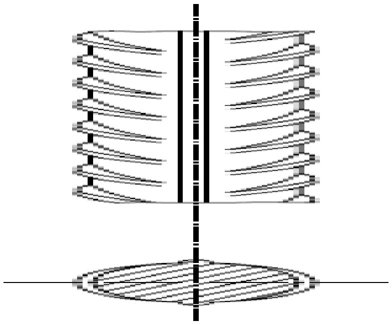


Figure 4.2: Rebar product-Definitions of geometry

4.3 Customer need for rebar products

The manufacturing industry uses the order form to identify customer needs before the production process. Once the order form has been confirmed, the industry deals with the customers to get their approval to produce the product. To identify customer needs, the study used order form revisions that retained documents and assessed the Ethiopian rebar standard requirements. In the Abyssinia integrated steel manufacturing industry, the value-added activities in rebar production directly contribute to meeting customer needs by providing high quality, compliant, and customized products. Thus, customer order specifications are the key factor that influences the value-added features of the rebar product process in the Abyssinia integrated steel manufacturing industry. The study, which is described in the table below, used a customer order form. However, the basic customer needs are deliver time, price, and quality.

Table 4.2: Abyssinia steel manufacturing industry 8 Diameter Rebar product customer need

Customer need	Detail customer requirement specification	8 Diameter Rebar product order customer need
specification	The rebar type, grade, diameter, and length.	Rebar type- Ripe bar Grade - B500WR Length- 12 meter
quantity	They should provide the accurate quantity required for their project.	Piece=1740 Ton=82 Kg=8200
Deliver information	The customer should specify the desired delivery date and any time constraints related to the project schedule.	Delivery time ; project schedule
payment information	The customer should specify the preferred payment method, such as bank transfer or credit card.	Credit agreement method
package instruction	If the customer has any specific packaging instructions for the rebar product	Bundling= the length 12 meter Label due to standard requirement
contact information	The customer needs to provide their contact information.	Customer name: - Address: - - phone number: - email address: -
product test report	The customer requires a product test report for the rebar.	Production process control report
quality assurance document	The customer requires any other quality assurance documents or certifications; they should specify these requirements in the order.	Product certification approval document

The customer needs outlined in the rebar order form include several critical requirements to ensure accurate and efficient order fulfillment. These begin with the specification of the rebar**,** including the type, grade, diameter, and length. Customers must also provide the exact quantity needed, typically in pieces, tons, or kilograms. Additionally, they should clearly state the desired delivery date and any relevant project schedule constraints. The preferred payment method**,** such as a credit agreement or bank transfer, must be specified. If applicable, customers should include packaging instructions, such as bundling length and labeling requirements. Accurate contact information, including name, address, phone number, and email, is essential for communication. Furthermore, customers may request a product test report and any required quality assurance documents or certifications to ensure the rebar meets project standards. These needs collectively support smooth coordination between the supplier and customer, enhancing quality, compliance, and timely delivery.

In Ethiopia, the rebar product governed by a mandatory national standard—CES 101-2021, which outlines the minimum requirements for reinforcement bar (rebar) production. Compliance with this standard is not optional; it is a regulatory obligation that steel manufacturers must meet to ensure quality, safety, and market acceptance. Consequently, one of the core customer needs is that all rebar products must comply with this standard as part of their product specification requirements.

The CES 101-2021 standard defines key technical specifications, mechanical properties, and performance parameters that manufacturers must adhere to during production. These include material composition, yield strength, elongation, bendability, and dimensional tolerances. For instance, a rebar product with 8 mm diameter and grade B500WR must comply with precise chemical and mechanical standards to be deemed acceptable.

Customers, especially contractors, developers, and engineers, require that their orders meet these mandatory product specifications not only to comply with legal requirements but also to ensure structural reliability in construction projects. Manufacturers, therefore, must integrate this standard into their production process, quality assurance, and order documentation.

Table 4.3: - Ethiopian compulsory standard clause for rebar products 8 diameters of B500WR grade standard clause specification

Compulsory clauses	Description	Steel Grade B500BWR diameter 8 Specification	
clause 5	Dimensions, mass per unit length and permissible deviations	Nominal diameter (mm)	8
		Nominal cross sectional area (mm2)	50.3
		Mass per unit length (kg/m)	0,395
		Permissible deviations (%)	±8
clause 7	Chemical composition	Chemical composition based on cast analysis — Maximum values of mass fractions, in percentage	C=0.22, Si=0.60, MN=1.60, P=0.050, S=0.05, N=0.012 ,and CEV=0.5
		Permissible deviation in product analysis in percentage by mass an element	Refer clause 7 in table 5
clause 8.1	Tensile properties	Ductility class	B
		Specified characteristic value of upper yield strength	Min=500 and Max= -
		Ductility properties	Specified characteristic value of Rm/ReH = min 1.08 and Specified characteristic value of elongation % = min 14
clause 8.2	Bending properties	Mandrel diameter (max.)	3d
clause 10	Designation	Designated product	Reinforcing bars ISO 6935-2 – 12 B500BWR
clause 11	Marking	Identifiable by permanent marks	The steel grade and the name of the manufacturer

The Ethiopian CES 101-2021 standard establishes a set of compulsory product specifications that rebar manufacturers must meet to ensure product quality and structural integrity. One of the primary customer needs is assurance that the rebar supplied complies fully with this standard. Key specifications include the rebar grade (such as B500WR), with a minimum yield strength of 500 MPa, and tight dimensional tolerance, ±6 percentage for 8 mm bars. The standard also mandates mechanical properties like a tensile/yield strength ratio of at least 1.08 and a minimum elongation of 14%. Additional requirements include bend and re-bend test compliance, standardized lengths, ribbed surfaces for better bonding, and proper markings for traceability. Customers typically request these specifications to be met and verified through quality assurance documents, such as product test reports and compliance certificates. Furthermore, they expect consistent packaging and labeling aligned with the national standard. Fulfilling CES 101-2021 is not only a legal obligation for manufacturers but also a critical expectation from customers who prioritize safety, performance, and regulatory compliance in their construction projects.

4.3 Rebar product manufacturing process

The initial step in the steel scrap recycling process value chain to produce rebar involves collecting and sorting steel scrap from various sources, such as manufacturing plants and construction sites. The sorted scrap is then shredded and melted in electric arc furnaces, allowing impurities to be removed and the steel composition to be adjusted. The molten steel is then cast into billets, and the semi-finished products are subsequently rolled into rebar in a series of rolling mills. The diagram below provides an overview of the value chain for the rebar product of the case company:

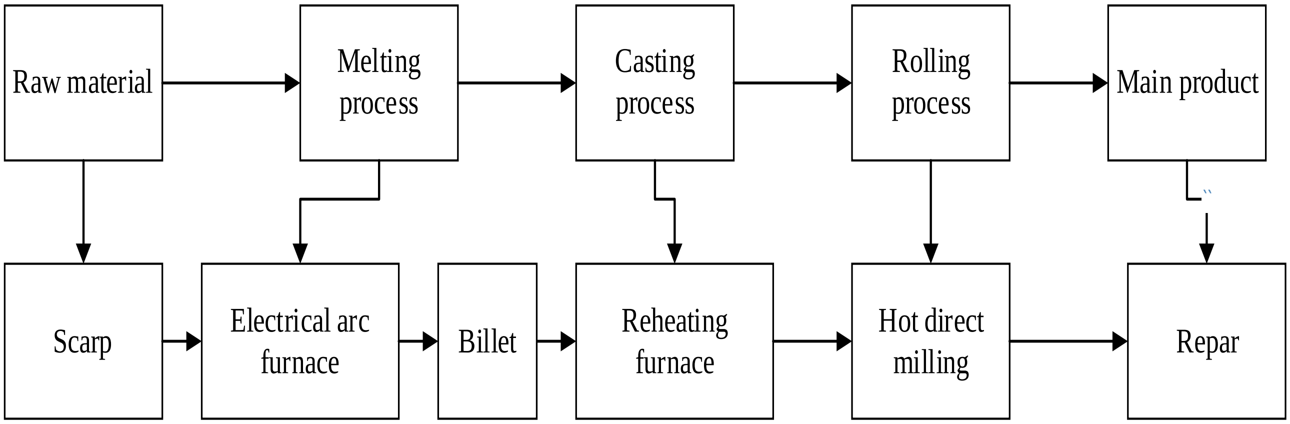


Figure 4.3: Rebar product process

To improve customer needs and reduce waste in manufacturing, it is important to identify which activities are adding values and which ones are not. By analyzing the value chain, we can determine which activities are important for meeting customer needs. Consequently, the study used primary data collection tools to construct a clear picture of the value chain activities.

4.4 Implications of Value-Added and Non-Value-Added Activities in Value Chain Analysis

In the context of value chain analysis (VCA), distinguishing between value-added (VA) and non-value-added (NVA) activities is essential for identifying efficiency gaps and improvement opportunities across the production process. Value-added activities are those that directly contribute to meeting customer requirements or enhancing the product value—such as melting, rolling, and quality inspection processes in rebar production. These activities transform raw materials into finished goods and are essential for achieving compliance with product standards like the Ethiopian CES 101:2021. In contrast, non-value-added activities do not contribute directly to customer value and often represent waste, such as excessive movement, waiting time, rework due to defects, or inefficient handling of raw materials. Identifying and eliminating or minimizing NVA activities is crucial for improving operational performance, reducing production costs, and enhancing competitiveness. In this study, VCA will be employed to systematically analyze the rebar manufacturing process, identify VA and NVA activities, and focus on optimizing key upstream and downstream functions. The implications of this distinction will guide process redesign efforts and inform the use of tools such as PROCAST simulation software to reduce inline defects and increase value delivery to customers.

The study to classify value-added and non-value-added activities first defined these terms in the context of the rebar manufacturing production process. Value-added activities directly contribute to transforming scrap raw materials into a rebar product that meets customer requirements and product specifications. On the other hand, in the manufacturing industry, non-value-added activities do not contribute directly to meeting customer needs and are considered wasteful or unnecessary.

The study, the value-added percentage is analyzed under two conditions. First, it is used to assess the financial efficiency of the production process by comparing the market value of the final rebar product to the cost of raw input materials (scrap metal). This provides insight into the monetary value created through manufacturing. Second, it serves as a tool for process optimization by distinguishing between value-adding and non-value-adding operations within the production line. This analysis, combined with simulation tools helps identify inefficiencies, reduce defects, and enhance the overall value chain performance in compliance with Ethiopian rebar standards

The formula to calculate the value-add percentage is as follows:

In the context of value chain analysis (VCA), value-added percentage can be assessed in two distinct ways—financial-based and quantity-based—depending on the focus of the analysis: economic performance or process efficiency. Each approach has a specific formula and implication in identifying areas for improvement in the rebar manufacturing process.

1. Financial-Based Value-Add Percentage

This method evaluates the **economic value created** during the transformation of raw materials into finished products. It helps determine how much profit or value is added relative to the input cost.

Formula:

Value-Add Percentage = ((Value of Output price - Value of Input cost) / Value of Input cost) * 100

2. Quantity-Based Value-Add Percentage

This method evaluates the **physical efficiency** of the production process by comparing the quantity of material input and output. It helps in analyzing **process yield** and material losses.

Formula:

Value-Add Percentage = ((Output Quantity - Input Quantity) / Input Quantity) * 100

The dual approach to value-added percentage analysis provides a comprehensive view of the production process in the rebar manufacturing industry. The **financial-based method** emphasizes value creation in monetary terms, while the **quantity-based method** focuses on operational efficiency and material utilization. Together, they enable a thorough diagnosis of value chain performance, guiding both strategic decisions and process-level optimizations in line with national product standards such as CES 101:2021.

However, the study, the value-added percentage is evaluated using a **quantity-based formula**, which assesses the **efficiency of material conversion** across the production stages in the rebar manufacturing process. This method focuses on how effectively input material (steel scrap or billet) are transformed into final output (finished rebar), based on **physical quantities** value.

Quantity based formula Purpose and Relevance:

- The quantity based formula is essential for identifying material loss**,** inefficiency, and waste in the production process.
- It provides quantitative insight into how much of the input is successfully converted into finished rebar that meets quality standards such as CES 101:2021.
- The method is particularly useful in value chain analysis where the goal is to identify stages that cause yield reduction, such as:

    - Defects due to improper cooling
    - Material loss during rolling or cutting
    - Scale formation and scrap generation

The study to identify value-added and non-value-added activities uses a systematic approach, as illustrated below in the figure. During observation time, prepared one common question for each department head. The question is: identify value-added and non-value-added activities in terms of the definition. Then, by separating activities into those that are customer-driven (VA) and those that are internal but unproductive (NVA), study had identify bottlenecks **or** defect waste. This forms a foundation for using tools defect predictive system.

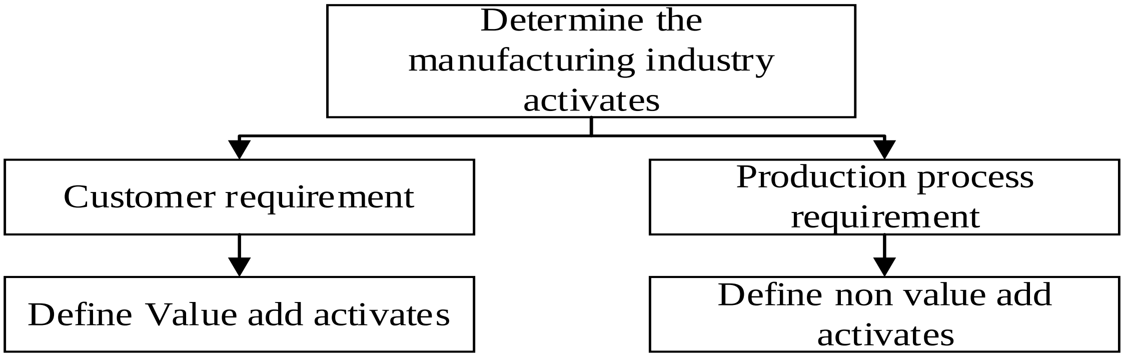


Figure4.4: value add and non-value added identification process

The study, distinguishing value-added from non-value-added activities is not just for classification—it is a strategic diagnostic step. It enables rebar manufacturers to see exactly where time is being lost, where defects may occur, and how to prioritize process improvements. By feeding this analysis into PROCAST simulations, the manufacturers can explore solutions digitally before implementing physical changes, enhancing the overall competitiveness of the rebar value chain.

4.4.1 Primary Activities Value-Added vs. Non-Value-Added Analysis

The value chain of Abyssinia Integrated Steel Manufacturing, which primarily utilizes steel scrap as raw material for rebar production, has been assessed based on five core primary activities. Each of these activities has been analyzed to determine the proportion of Value-Added (VA) and Non-Value-Added (NVA) tasks, using both direct observation and input from process supervisor. A brief description of each activity provided in the annex section.

Table: Summary of Primary Activities

Activities section	VA Activities (%)	NVA Activities (%)
Inbound Logistics	23.1%	76.9%
Operations	34.1%	65.9%
Outbound Logistics	71.4%	28.6%
Marketing & Sales	57.1%	42.9%
After-Sales Service	40.0%	60.0%

The above table highlights that **Inbound Logistics and Operations** are the **most reject waste-prone**

areas in the value chain and therefore offer the **greatest potential for improvement**. Implementing simulation tools had significantly reduces non-value-added time and increase overall production.

4.4.2 Supportive Activities Value-Added vs. Non-Value-Added Analysis

The Abyssinia steel manufacturing industry has auxiliary functions known as supportive activities. In addition to the target question regarding the value-added percent value of each supplementation activity, the company-reference document analyzes the manufacturing industry. Supportive activities in the manufacturing industry include material management, firm infrastructure, human resource management, and the research and development department. Material management: This activity involves managing the flow of materials, components, and services throughout the rebar manufacturing supply chain. The value-added activity percentage is 10%; it depends on the procurement processes.

Table: Summary of supportive activities

Support Activity	VA (%)	NVA (%)
Material Management	10%	90%
Research & Development	5%	95%
Human Resource Management	30%	70%
Firm Infrastructure	10%	90%

The above table presents the percentage distribution of **value-added (VA)** and **non-value-added (NVA)** activities across the **support functions** of Abyssinia Integrated Steel Manufacturing. These support activities play a critical role in enabling the efficiency and effectiveness of the primary manufacturing operations. The percentages are based on direct observation, supervisor input, and reference documents from the company.

Therefore, when comparing primary activities and supportive activities in terms of value-added percentage; it is important to note that primary activities are directly involved in the production of rebar products, while supportive activities provide essential support and infrastructure to facilitate the primary activities. The study compares primary and supportive activities based on the provided data.

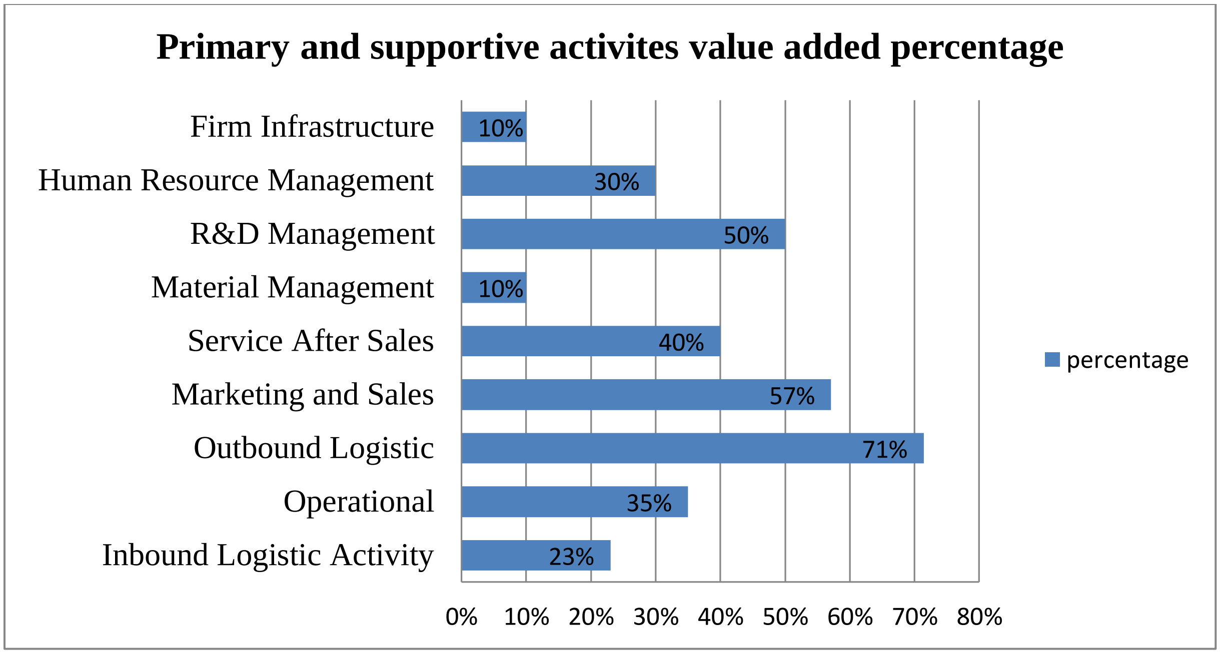


Figure4.5: primary and supportive activities value added percentage

In comparison, the value-added activity percentages of the primary activities (ranging from 23% to 71%) are generally higher than the value-added activity percentages of the supportive activities (ranging from 10% to 50%). Hence, based on the provided data, the primary activities have higher value-added percentages compared to the supportive activities, aligning with the general expectation.

The study selected primary activities to see in detail because, in the above figure, they have a higher value-added percentage. However, related to each other, inbound logistic and operational activity general range of value-added percentages. Therefore, based on the value chain analysis, the study indicated operational activity to see more detail and assess improvement areas.

4.5 Existing Rebar product production process

The current manufacturing process depends on the raw material quantity and quality types. As seen in the below figure, the production process started receiving scrap input and checking the scrap before entering the factory at the main gate for radioactive elements, and the measurement should be less than or equal to 0.042. After being revived, radioactive element-free scrap will be unloaded at the scrap site and segregated according to its carbon content and grade. Then, load the scrap on the trucks based on categories.

Finally, check the scraps for explosive material, and then the quality worker receives them in the store. The daily production plan is that loading should be carried out with 15 laborers or trucks, and the daily transported scrap must be 15%–18% greater than the daily production plan. Therefore, based on magnetic crane operators, the delivering scrap is allocated according to their type in the specified areas.

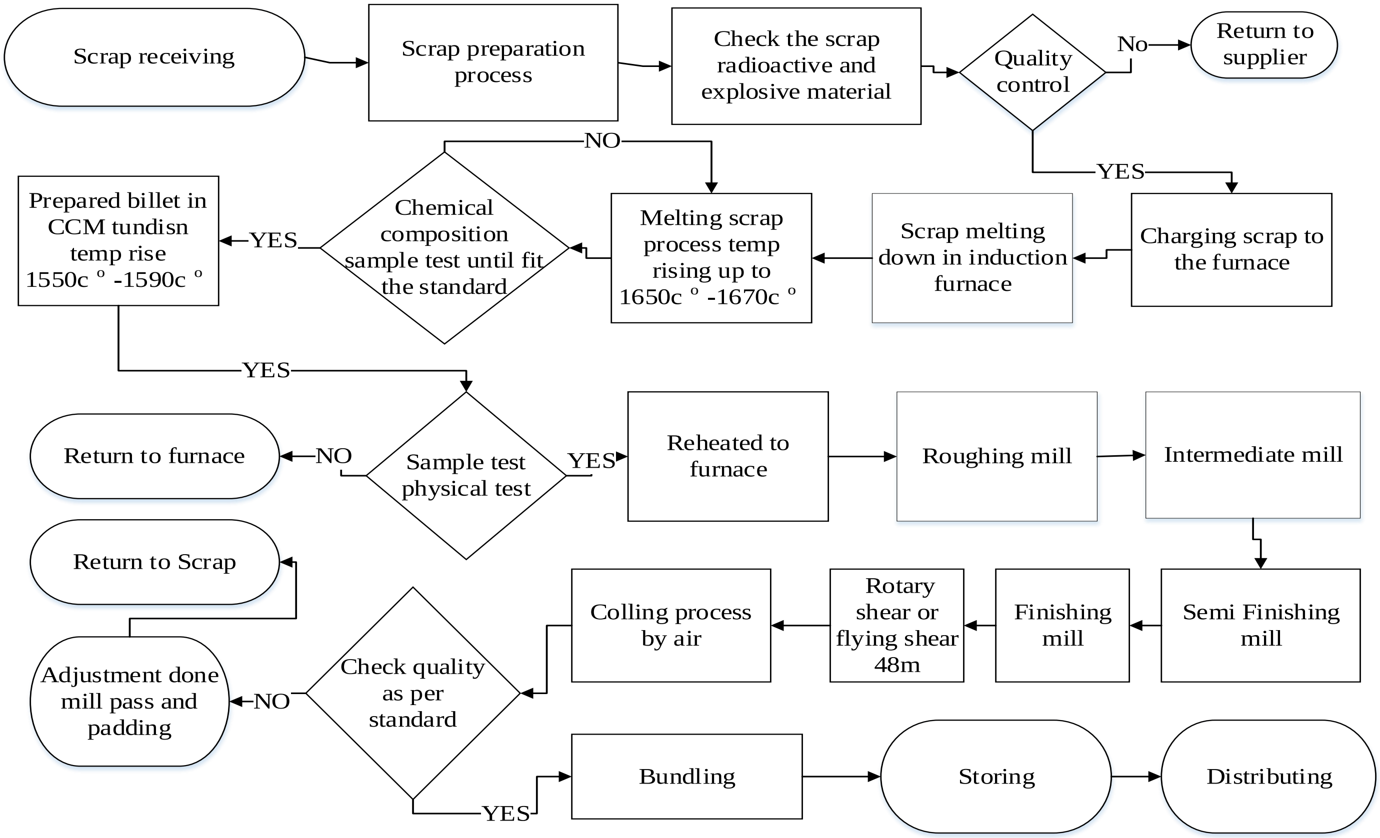


Figure 4.6: Rebar production manufacturing process flow chart

The second process is the melting process, which starts with checking for explosive material. The scrap loaded into the steel garbage is transported to the furnace platform by a 16-ton ladle crane, and the workers on each furnace are totally manpower-powered—eight one-meter, one explosive sorter, and six scrap feeds. Feeds the furnace until it reaches half of its volume capacity, which ranges from 2 to 2.25 tons. After the furnaces reach half the total volume capacity, the furnaces reach half the total volume capacity the first quality result sample will take. Then feed the scrap until the furnace reaches its full volume capacity (3.3 to 4.5 tons). The amount of slag removed depends on the cleanliness of the scrap feed in the furnace. The last sample taken after the furnace becomes full will stop feeding. The furnace will scrape and wait until the temperature reaches 1600°C–1700°C and add slice-manganese (30–35 kg). During the sample process, the wait time should not be greater than 10 minutes, and the expected result must be within the specified steel grade. Wait until the molten metal reaches the taping process temperature of 1570°C–1770°C, then transfer to CCM, where the temperature should be in the range of 1500°C–1770°C. After casting, the billet must visually check for physical defects and corrective action taken to avoid such defects. Finally, a quality standard check will be performed, and any chemically defected billets will be segregated, cut in half (1.5 m), and transported back to the furnace. The billets that pass the quality standards will be report to the store and then ready for processing in the rolling mill.

The final process of solidifying and forming the billet product is converted to a rebar product with several sub-processes. The process stated by inspection of the billet quality. According to charging demand, which is eight billets at a time, the billet is moved into the reheated furnace by a hydraulic pusher. After every furnace inspection is in normal condition, the furnace will start and the billets will be reheated up to 1150°C. Finally, according to the rolling mill speed sequence, the billets are discharged onto the run-out roller conveyor by a chemical discharging machine, which sends them to roughing mills, which then process them based on the rolling stand. Products delivered for heat treatment are finally checked for quality according to the product standard requirements.

4.6 Rebar product Annual production plan value added percentage

The Abyssinia steel manufacturing industry produces rebar products annually, and the production plan depends on each departmental capacity. The study assessed how much value was added to the value chain process concerning the annual plan and evaluated the current production process depending on the existing production cycle. However, before processing the value chain analysis, the study calculated the scrap rate percentage. The scrap rate percentage is a measure that indicates the proportion of defective or unusable products or materials generated during the manufacturing process. A higher scrap rate indicates increased material waste, while a lower scrap rate indicates better process control and material utilization.

Calculate scrap quantity with 2015EC annual production plan data

Scrap quantity =Annual input scrap quantity – Annual output product quantity

=51750ton – 43650ton

Scrap quantity = 8100ton

Calculate the scrap rate: (scrap quantity/input scrap quantity)*100

= (8100ton/51750ton)*100

Scrap rate =15.6%

Therefore, a scrap rate of 15.6% indicates that 15.6% of the total input quantity ends up as scrap or waste during the production process. This means that out of every 100% of input material, approximately 15.6% are unusable. A high scrap rate can indicate inefficiencies or issues in the production process, such as material waste, quality problems, or suboptimal production methods.

The scrap rate percentage is 15.6% based on the manufacturing 2016 EC annual production plan. The rate is good; however, this data does not show the actual manufacturing rate. To understand the manufacturing value chain, the study first assesses the current manufacturing production process in terms of the production process flow chart, then, due to quantitative data analysis, calculates the value-added percentage.

Table 4.9: Manufacturing annual production quantity and consumable needs

Production capacity resource need			
production capacity	13650 ton		
scrap quantity need	51750ton		
melting and produced billet	45000ton		
oxygen	79200 bottle		
energy and lubrication need	milling process	HFO	2020995 litter
		electric energy	5625000 Kwh
	melting process	electric energy	37120500 Kwh
labor	melting and scrap	permanent	228 worker
		agency	32 worker
	rolling process	permanent	70 worker
		agency	12 worker
	oxygen plant	permanent	10 worker
		agency	12 worker
operational plan	melting process		7200 hrs.
	milling process		2916 hrs.
	oxygen process		7920 hrs.

Based on the annual manufacturing plan and available resources, the study identifies the manufacturing value addition percentage due to production process company record data. In 2016 E.C., the manufacturing industry aimed to produce 43,650 tons of rebar products, for which they needed 60,030 tons of steel recycling scrap.

To calculate the Value Added Percentage (VAP) using the given inputs cost and output rebar product price, the study follows these steps:

Input cost: 3243120000 birr and Output price: 5238000000 birr

Value Added = Output price - Input cost

= 5238000000 – 3243120000

= 1994880000 birr

Value-Add Percentage = (Value Added / Input cost) * 100

= (1994880000/ 3243120000) * 100

= 61.5%

It indicates that the value added during the production process represents around 61.5% of the initial input cost.

In addition, to understand their plan for each production stage identified how much plan value added to each production process stage.

Table 4.10: Each production process activates and value add percentage plan

Production Process	Value add percentage
Scrap preparation	20%
Melting and Continuous Casting process	28%
Rolling mill process	16.3

The rolling process only adds 16.3% value to the input data. This indicates that, compared to other processes, it contributes the least amount of value during the annual production plan. To determine the rate of value addition in each process of the rebar product, it is essential to implement varied strategies, assess the input, and output quantities of each manufacturing section.

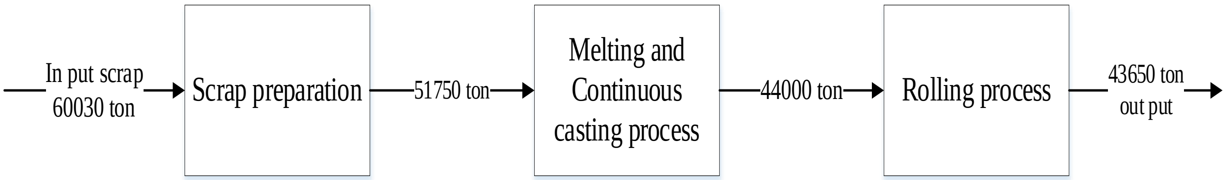


Figure 4.7: production process activates input and output data process

4.7 One production cycle value added percentage

Based on the market-selling products for the past five years, they prepared a 2016-year budget plan for production, as shown in the table. Due to this information, the study analyzes which products have more demand and focuses on the product production process cycle to identify areas for improvement.

Table 4.11: Steel rebar products production plan in 2016 EC years

Products (rebar)	Rebar Diameter 8mm	Rebar Diameter 10mm	Rebar Diameter 12mm	Rebar Diameter 14mm	Total product
Production plan ton	19,643	13,095	6,548	4,364	43,650

The manufacturing industry aims to produce 43,650 kg of rebar products in 2016. It can be observed that more production times a diameter of 8 mm product. Due to this, the study selected this product to show a one-production cycle process in terms of value addition and to assess the improvement area.

The study has identified the improvement areas in the current production process value because the below analysis is based on the current production process and how much value is added to each production process stage in terms of input quantity. To identify the issues related to the high scrap rate, the study determines the value-added percentage of each process and then identifies the lowest VAP.

1. **Scrap preparation process**: Value Added = Input - Output = 120 - 102.59= 17.41ton

VAP = (Value Added / Output) * 100 = (17.41/102.59) * 100 = 0.169

Therefore, the Value Added Percentage in this is 16.9%.

2. **Melting and continuous casting process**: Value Added = Input - Output = 102.59 – 84.22 = 18.37 ton

VAP = (Value Added / Output) * 100 = (18.37/84.22) * 100 = 21.8%

Therefore, the Value Added Percentage in this is 21.8%.

3. **Rolling process**: Value Added = Input - Output = 80.5 – 72.1 = 8.4 ton

VAP = (Value Added / Output) * 100 = 8.4/72.1) * 100 =11.6 ton

Therefore, the Value Added Percentage in this is 11.6%.

The scrap rate is significant because it helps evaluate the manufacturing process recycling efforts.

To calculate scrap quantity with one production cycle eight diameter product data.
Scrap quantity = input scrap quantity in one cycle – output product quantity in one cycle
=102.59 ton – 72.1 ton
Scrap quantity = 30.49 ton
Calculate the scrap rate: (scrap quantity/input scrap quantity)*100
= (30.49ton/120ton)*100
Scrap rate =25.4%

The company, based on the current production process factor, expected a melting process scrap rate of 12% and a rolling mill process scrap rate of 3%, which means the total scrap rate, is 15%. During the current analysis and production process, around 25.4% of the products produced in one cycle are defective for sale or use. Compared to the manufacturing scrap rate expected, the percentage increased by 10.4%. This is known as the scrap rate result, which indicates increased costs due to waste of materials, labor, and time. Therefore, regarding this scrap rate, the study calculated the value-added percentage in terms of production inputs and output financial data.

To calculate the Value Added Percentage (VAP) using the given inputs cost and output price, you can follow these steps:

Input cost: 6480000 birr and Output price: 8652000 birr

Value Added = Output cost - Input cost =8652000 – 6480000 = 2172000 birr

Value-Add Percentage = (Value Added / Input cost) * 100

= (2172000/ 6480000) * 100

= 33.5%

It indicates that the value added during the production process represents around 33.5 % of the initial input cost.

According to the value percentage mentioned above, the amount of input required for the 8-diameter rebar production cycle in the manufacturing industry is 33.5% compared to the value of the rebar product. Based on the above value-added percentages on input quantity by ton, here is a study breakdown of the recommendations:

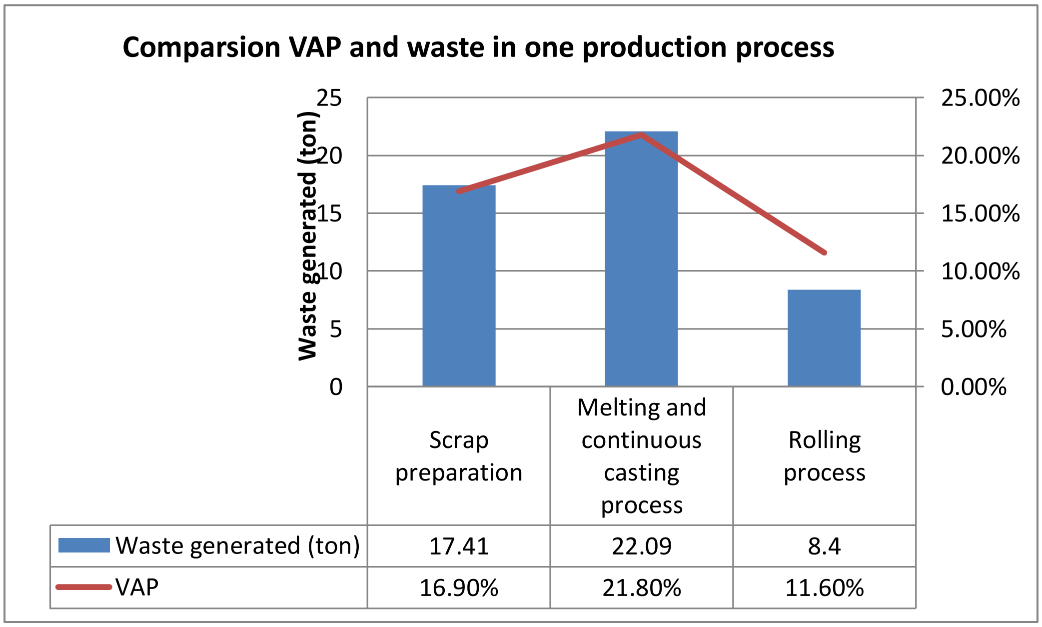
Table12: Each production process activates and value add percentage 8 diameter current

production process	VAP
Scrap preparation	16.90%
Melting and continuous casting process	21.80%
Rolling process	11.60%

While scrap levels at the steel factory are too high, wasting precious material, the underlying issues run still deeper. An anticipated annual scrap rate of 15.6% signals extensive squandered resources. More troubling yet, present single cycle scrap exceeds expectations at an overwhelming 25.4%. Solutions demand thorough inspection of production methods and judicious reforms to refine techniques, lessening loss while maintaining output. Such egregious inefficiency and poor quality strongly signify deep-rooted issues infecting discrete production stages.

4.8 Inbounded and operation activities VAP and waste generated result analysis

Based on the data provided, the study helped to fill out the picture and from this it was determined that melting/continuous casting is likely to be where improvements might best assist. Because this stage has also a lead on waste generation having most 22.09 tons of total production process at 21.80%. If this could be done more efficiently, it should have a big impact on the overall efficiency and sustainability of the production operation.



	Scrap preparation	Melting and continuous casting process	Rolling process
Waste generated (ton)	17.41	22.09	8.4
VAP	16.90%	21.80%	11.60%

Figure 4.8: comparison of VAP and waste generated in one production cycle

By focusing on this key area, the study could significantly improve the productivity of its production operations. Due to this, to forward the study, at the end of the melting and continuous casting process, the billets are produced and sent to the next operation. However, as seen in the above data, in one production, there is a high amount of waste to assess. Therefore, based on the operation-recoded data, the type of defect identified

4.9 Melting and Continuous Casting process activities defect

From the data, it is also clear that melting and continuous casting represent respectively 21.8% of added -value higher than other stages in steel production. Nonetheless, the waste produced is one of a kind. Consequently, the company develops a quality control record form since the research is based on annual production data; there are retention documents for all product cycles. The review of waste or rejected billets every production cycle to know the problems occurred in melting and casting process.

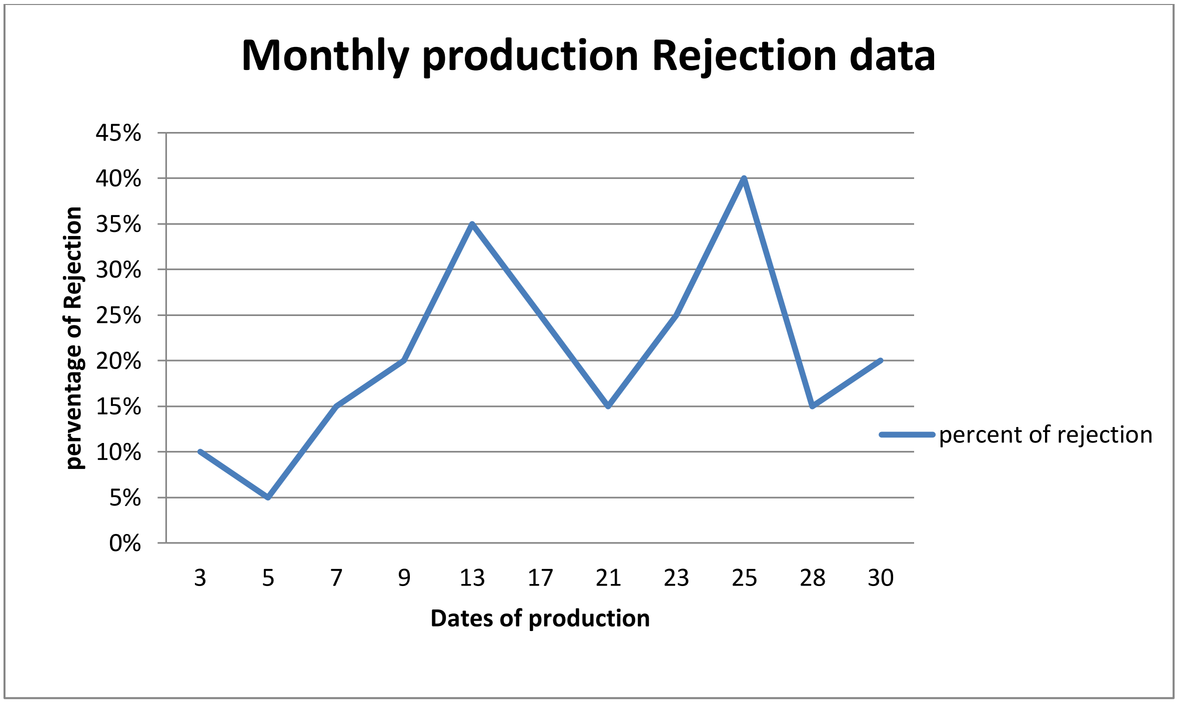


Figure 4.9: monthly billet production rejection data

The data reveals significant fluctuations in the percentage of rejection throughout the month, indicating variability in production quality. This inconsistency may point to underlying issues in the production process that need to be addressed to achieve more stable outcomes. Notably, the highest rejection percentages occur around the 13th and 25rd days, peaking just below 40%. Conversely, the data shows that the 5th day records the lowest rejection rate, approximately 0%. This exceptional performance indicates that optimal conditions were likely met, whether through improved material quality, effective process control, or skilled operator performance. Understanding the factors contributing to this success could provide valuable insights for improving overall quality.

Consequently, this study analyzes billet defects from one production cycle to understand the types of defects. Using an operation-, recorded document in the annex the study evaluated the billet outlet product rejects in terms of process shifts on the 13th and 25th days. During one production shift, four furnaces operated simultaneously.

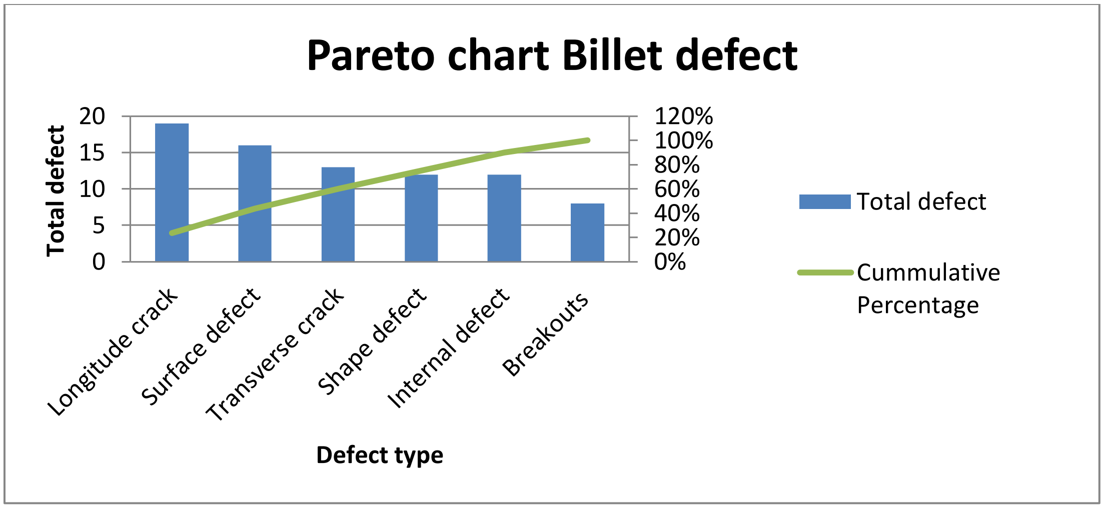


Figure 4.10: Pareto chart billet defect

Key Pareto chart Explanation and Interpretation:

Longitude Cracks (24%)

- Represent the **most frequent defect** type.
- These are **linear cracks** running along the length of the rebar and are often caused by **non-uniform cooling**, **improper rolling force**, or **residual stress**.

Surface Defects (20%)

- Include imperfections like **scaling**, **pitting**, or **roughness** on the rebar surface.
- Typically caused by **oxidation**, **improper billet surface preparation**, or **temperature inconsistencies** during rolling.
- Surface defects directly affect **product appearance and durability**, making them the **second most critical defect**.

Transverse Cracks (16%)

- Cracks that run **across the width** of the rebar.
- Often result from **internal stress**, **segregation**, or **poor temperature gradient** during casting.
- These impact **structural integrity** and are especially relevant in applications requiring high tensile performance.

Shape Defects (15%)

- Include **out-of-tolerance diameter**, **bending**, or **warping** of the rebar.
- Generally linked to **rolling mill misalignment**, **uneven cooling**, or **improper speed control**.
- These reduce the **fit and compliance** of the product with standards like **CES 101:2021**.

Internal Defects (15%)

- Include **voids**, **porosity**, or **segregation** not visible on the surface.
- Typically originate during **solidification** or **inconsistent chemical composition**.
- Although harder to detect, internal defects can significantly affect **load-bearing capacity**.

Breakouts (10%)

- These are **catastrophic failures** during continuous casting, where molten metal bursts through the mold.
- Though less frequent (10%), breakouts result in **major material loss**, **equipment damage**, and **production delays**.

Cumulative Percentage Insights:

- The **top three defect types (longitude cracks, surface defects, and transverse cracks)** account for **60%** of all observed defects.
- Focusing on eliminating these could significantly improve **product quality and yield**.
- This analysis supports prioritization for **root cause analysis, simulation modeling**, and **targeted corrective actions**.

As a result, by utilizing a structured cause-and-effect analysis, the study can systematically address the root causes of the three major defects affecting billet quality. This approach not only enhances understanding of the defects but also facilitates the implementation of effective prevention strategies, ultimately leading to improved production outcomes.

1. Longitudinal crack

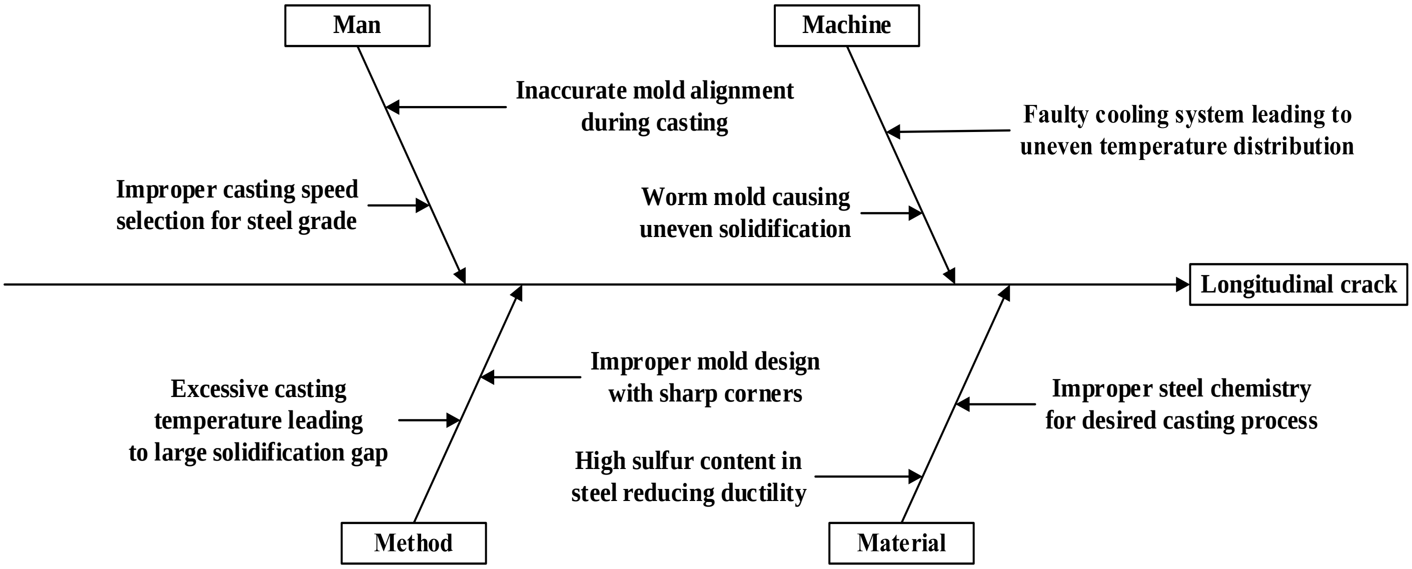


Figure4.11: cause and effect longitudinal crack

2. Surface cracks

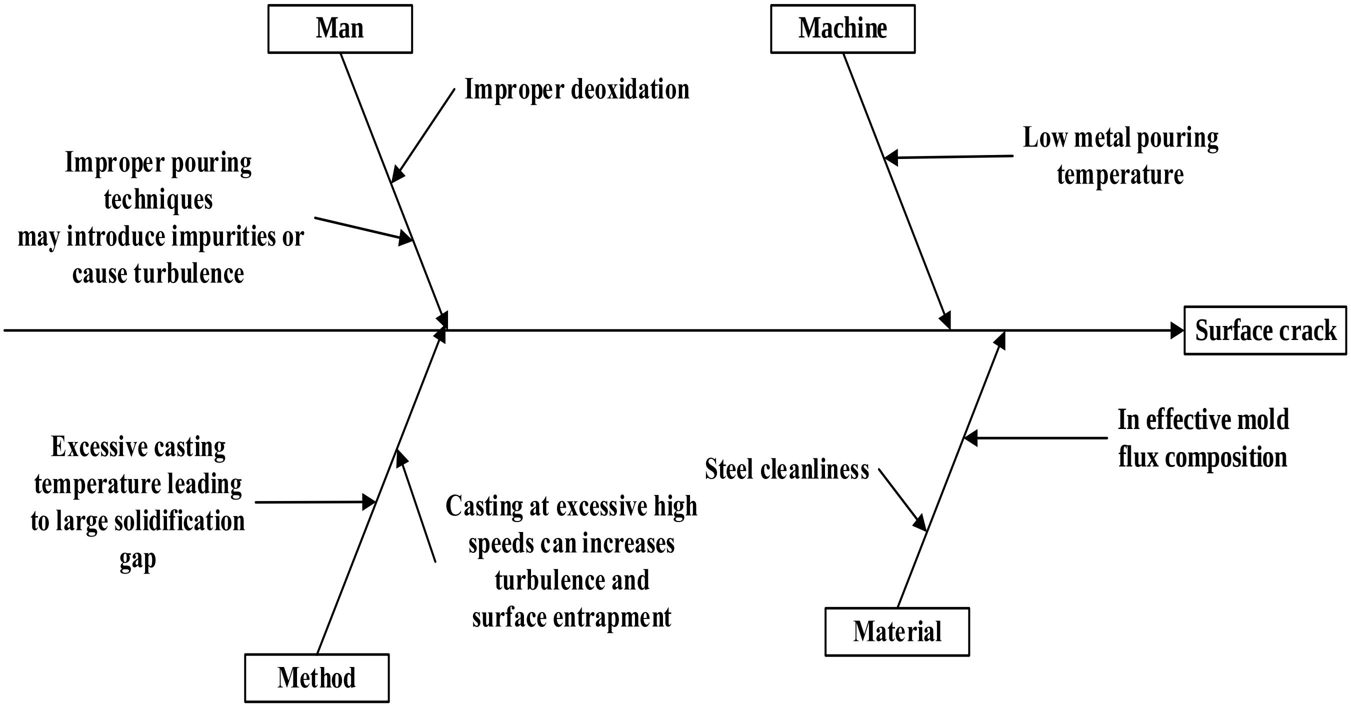


Figure 4.12: cause and effect surface crack

3. Transverse crack

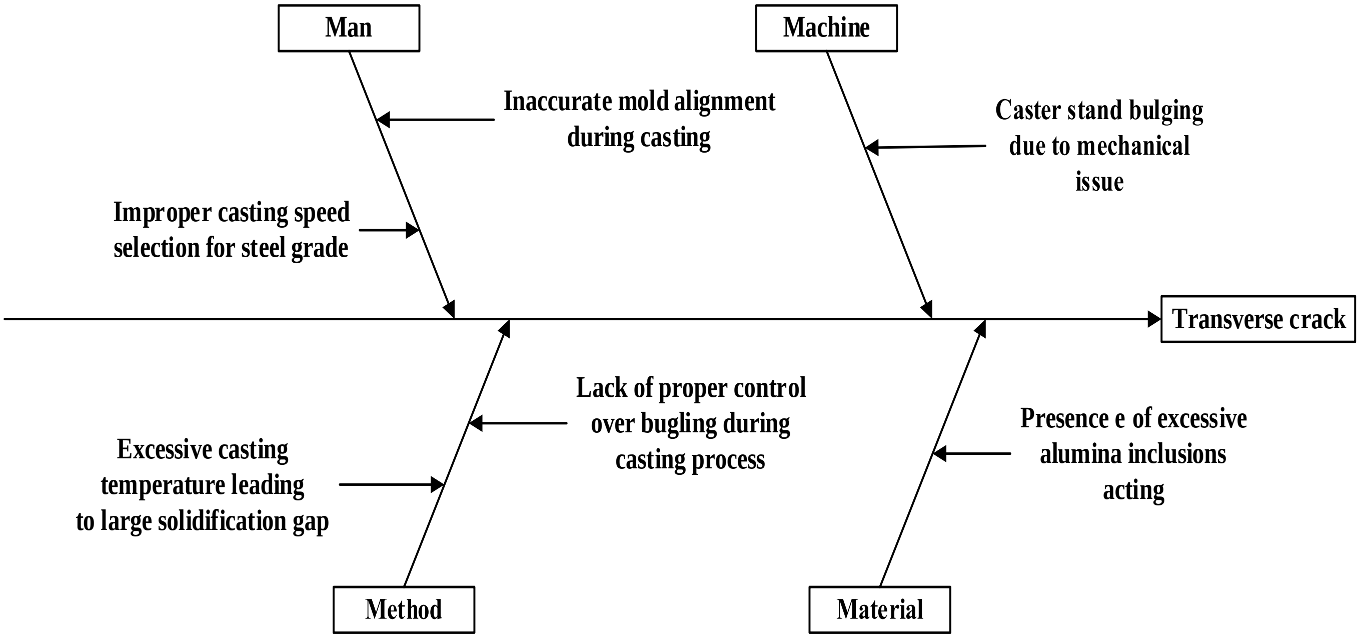


Figure 4.13: cause and effect transverse crack

Based on the cause and effect analysis in the casting process, both casting speed and temperature control are critical factors that significantly influence the quality and integrity of the final product.

- An improper casting speed can lead to uneven solidification, which is a primary contributor to defects such as longitudinal and transverse cracks.
- When the speed not optimized, it can create turbulence during pouring, introducing impurities and causing surface defects.
- Temperature control plays a vital role; low pouring temperatures can hinder the metal's ability to flow and fill the mold adequately, leading to incomplete casts and surface cracks.

By ensuring optimal casting speed and maintaining appropriate temperature levels, the manufacturers can significantly reduce the likelihood of defects, thereby enhancing the overall quality and performance of the cast components. Addressing these parameters collectively is essential for achieving reliable and defect-free castings.

Predictive modeling and simulation tools are essential for identifying and mitigating the causes of major defects in the rebar manufacturing process. The following are targeted solutions for **longitudinal cracks, transverse cracks**, and **surface defects** based on key process parameters:

1. Improper Casting Speed

- ❖ Too fast casting speed causes non-uniform solidification, which creates longitudinal and transverse cracks due to thermal stress.
- ❖ Too slow speed increases residence time, leading to segregation and internal defects.

2. Turbulence During Pouring

- ❖ Excessive speed or poor ladle design can create turbulent metal flow, entrapping gas and inclusions, which lead to surface defects and oxide formation.

3. Temperature Control

- ❖ Low pouring temperature causes incomplete mold filling, leading to surface cracks and poor metallurgical bonding.
- ❖ High temperature causes grain coarsening and increases risk of deformation.

By addressing casting speed, turbulence, and temperature through predictive tools and simulations, manufacturers can significantly reduce the occurrence of longitudinal, transverse, and surface defects. These technologies enable data-driven decision-making, process proactive quality control, leading to higher yield, and better product quality.

To validate the results of the cause and effect analysis for defects in billet production, a personal opinion the "5 Whys" method can be an effective approach. This method more dig deeper in to the root causes by asking "why" multiple times.

4.10 Cause and effect analysis verification

This employee experience share explores the root causes of three major defects that occur during the billet outlet stage of the melting and continuous casting process: longitudinal cracks, surface defects, and transverse cracks. The 5 why method is a root cause analysis tool that involves asking "why" repeatedly (typically five times) to peel back the layers of symptoms and reach the fundamental cause of a problem. This structured approach encourages deep thinking and collaboration among experts.

For each defect, the metallurgy experts followed the 5 Why approach to delve deeper into the underlying causes and identify potential solutions

Defect Type	Why 1	Why 2	Why 3	Why 4	Why 5
Longitudinal Cracks	Why do we have longitudinal cracks? Uneven solidification and thermal imbalance during casting.	Why are the cooling rates inconsistent? Uneven water sprays distribution.	Why is there a variation in fluid velocity? Turbulence in mold region.	Why is the flow rate not controlled? No real-time adjustment.	Why is there a lack of proper adjustment? No predictive control system..
Surface Cracks	Why do surface cracks occur during billet outlet? Exposure to thermal gradients and stress.	Why is the surface finish improper Uneven or rapid cooling.	Why does the cooling process affect material? Unsynchronized with speed.	Why is fluid velocity irregular? Manual valve control, no sensors.	Why is temperature control inconsistent? No predictive control system.
Transverse Cracks	Why do we have transverse cracks? Internal stresses from uneven shrinkage.	Why are there thermal stresses? Sudden temperature drops.	Why are there rapid temperature changes? Poor cooling intensity control.	Why is fluid velocity inconsistent? Unstable pressure/flow.	Why doesn't cooling system maintain steady flow? No predictive control system.

Based on the 5 Whys method, the identified root causes for the defects can be summarized as follows:

- Variations in fluid velocity during the cooling process due to a lack of proper control over the flow rate of the cooling fluid.
- Improper surface finish stemming from inconsistent temperature control mechanisms and

the effects of the cooling process on material properties.

- Thermal stresses in the material caused by rapid temperature changes, which are linked to inconsistent fluid velocity and inadequate cooling system maintenance.

Addressing these root causes through improved control and monitoring systems, regular maintenance, and proper flow rate adjustments can significantly reduce the occurrence of longitudinal cracks, surface defects, and transverse cracks.

Key Finding both on cause and effect and 5 why method Analyses

Common Themes:

- Both analyses highlight fluid velocity and temperature control as critical factors influencing defect formation.
- The improper casting speed identified in the cause and effect analysis aligns with the fluid velocity variations noted in the 5 Whys method, as both can lead to uneven cooling and solidification.

Based on the analysis conducted using two analysis it was determined that the primary cause of defects occurred during the cooling phase of the continuous casting process. To address this issue, the study first reviewed the current production process flow of the Continuous Casting process. Subsequently, improvements were implemented through the use of Pro Cast software for simulation. This advanced simulation tool allowed for the pre-detection of potential defects in the product, effectively minimizing production time waste and enhancing overall process efficiency

PROCAST software simulation

The continuous casting process is critical steps in modern steelmaking, particularly for the production of billets used in rebar manufacturing. It serves as a bridge between the liquid steel production in the ladle and the formation of solid semi-finished products (billets) ready for further rolling and shaping. PROCAST enhances billet quality in continuous casting by simulating and optimizing critical parameters and predicting defects before actual production.

1. **Mold Design r:-** Simulates heat flow and solidification within the mold.

2. **Predicting and Preventing Defects:-** Used thermal, mechanical, and metallurgical models to forecast where defects are likely to occur.
3. **Controlling Solidification and Cooling Rates:-** Simulates the thermal gradient and cooling curve during solidification.
4. **Simulating Tundish and Flow Behavior:-** Models fluid dynamics inside the tundish and mold, including flow turbulence and temperature distribution.
5. **Virtual Experimentation (Design of Experiments - DOE):-** Allows simulation of multiple “what-if” scenarios without interrupting actual production.

Current continuous casting Production Process Parameters

The current production process for the billet outlet stage involves critical parameters that directly influence the quality of the billet product. Based on the analysis, the following initial data is used to improve the billet outlet:

Table 4.16: production process parameter

Production process unite	Parameter
Casting velocity	1.5 m/min-1
temperature continuous casting process inlet	1760°C

Importance of Parameters

- Fluid Velocity: The specified fluid velocity of is crucial for ensuring proper filling of the mold and minimizing turbulence, which can lead to defects.

To reduce the incidence of defects, use PROCAST software tool improve of temperature and fluid velocity parameters are necessary.

4.11 Continuous Casting Process: Key Components and Geometric Model

This process transforms molten metal into semi-finished products, such as billets, by continuously pouring the molten material into a mold. The main components of this process include the ladle, tundish, and mold, which work together to ensure efficient and high-quality casting.

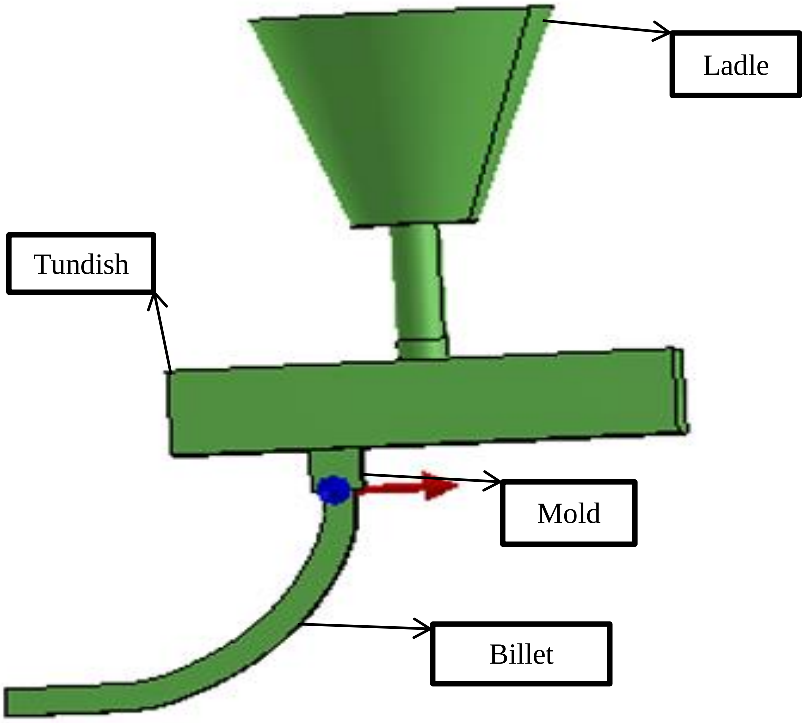


Figure 4.11: 3D continuous casting process model

By modeling these components using Solid Works software in simulation, the study analyzed the flow dynamics, thermal behavior, and potential defect formation during the continuous casting process.

4.12 Modeling in the PROCAST program

The PROCAST program solved the solidification and cooling of a billet of rectangular cross-section with dimensions of 130 x 130 mm. A simulation tasks were performed, on current situation. A constant fluid velocity and a different casting temperature (° C) characterized the simulation tasks.

4.13 Controlling solidification and cooling rate parameters

Process Type: the type of casting process continuous casting, which can be particularly beneficial in applications requiring specific profiles or reduced material waste. PROCAST software provides robust tools for modeling and simulating this process.

Boundary Conditions

1. **Volume management**:- Volume management involves monitoring and controlling the amount of molten metal in the casting system

Volume Management						
SL	Name	Type	Material	Fill %	Initial temperature	Stress type
1	VIRTUAL MOLD	Virtual Mold	Carbon Heating Material	100	1760 C^{o}	Rigid
2	Material					
	Database		Public			
	category		Other			
	Name		Carbon heating			
3	Mass of casting alloy		2827.2 kg			

2. **HTC Interface Manager**: **-** manage heat transfer parameters between the molten metal and the mold.

Interface HTC manager			
SL	Name	Type	Interface
1	Part Body VIRTUAL MOLD	VIRT	h-500

3. **Process condition management: -** Process condition management refers to the monitoring and adjusting of various parameters throughout the casting process, including temperature, pressure, fluid velocity, and cooling rates.

Process Condition Management				
SL	Name	Type	Entity	Boundary condition
1	Velocity-1	Velocity	EXT-partbody-1	V=(0,-1,0)m/s
2	Pressure-1	Pressure	EXT-partbody-1	1 bar
3	Heat-1	Heat	EXT-partbody-1	Air cooling
4	Temperature	Temperature	EXT-partbody-1	T=1760 C^{O}
5	Inlet-1	In let	EXT-partbody-1	1760C^{O} 1kg/sec

4. **Simulation Parameters** – curved continuous casting

Simulation parameters are critical settings that define the conditions and behaviors of the casting process within simulation software like PROCAST. These parameters help ensure accurate modeling and analysis of the casting process.

4.14 Result analysis

The temperature data gives information about which parts of the casting billet solidify first and later. The total solidification time is defined as the time required to remove both the specific heat of liquid and the latent heat of fusion. This is measured from the time of pouring until solidification is complete.

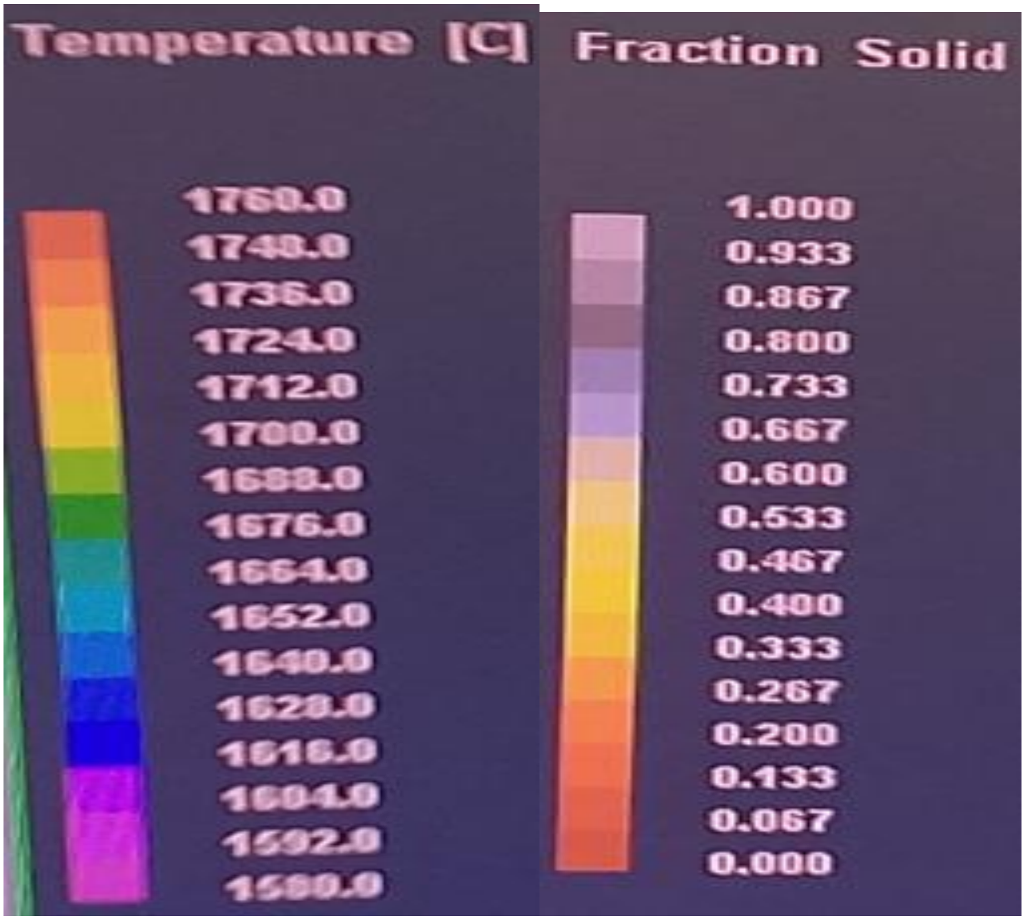


Figure4.12: temperature and solidification time

1. **Temperature Trends:**

The temperature ranges from 1580°C to 1760°C.:- As the temperature decreases, the fraction of solid increases, indicating the cooling process during solidification.

2. **Fraction Solid:**

The fraction solid shows values from 0.000 (completely liquid) to 1.000 (completely solid).

- At higher a temperature (1760°C), the fraction solid is 0.000, meaning the material is entirely in a liquid state.
- As the temperature drops to around 1650°C, the fraction solid begins to increase, indicating the onset of solidification.
- At lower temperatures (1580°C), the fraction solid reaches 1.000, indicating complete solidification.

3. Solidification Time:

The solidification time decreases as the temperature increases, which is typical in casting processes. The data shows that at higher fractions of solid, solidification time is longer, suggesting that as the material begins to solidify, and it takes more time to complete the process.

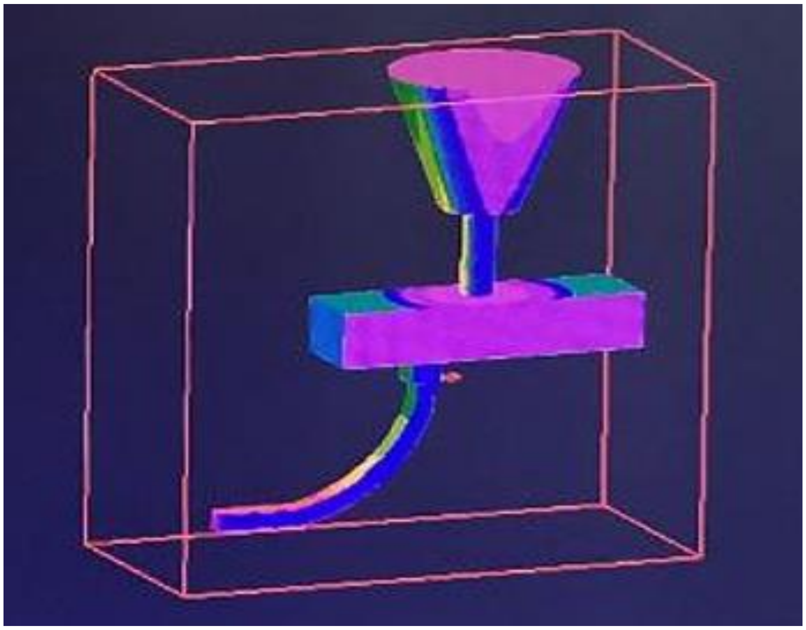


Figure 4.13:- Thermal depth

The analysis indicates a clear relationship between temperature, fraction solid, and solidification time. As the temperature decreases, the material transitions from liquid to solid, with corresponding changes in solidification time. This data can help optimize the continuous casting process by identifying the ideal temperature range for minimizing defects and ensuring uniform solidification.

Key Findings PROCAST tool: Continuous Casting Defect Analysis

A. Critical Process Parameters Identified

1. Casting Velocity
   - ➢ Recommended Speed: 1.5 m/min
   - ➢ Impact:
     - Too high: Causes turbulence → longitudinal cracks, mold powder entrapment
     - Too low: Prolongs exposure time → transverse cracks, non-uniform solidification
2. Ladle Inlet Temperature
   - ➢ Target Range: 1650°C to 1670°C
   - ➢ Impact:
     - Below 1650°C: Poor fluidity → incomplete mold filling, transverse cracks
     - Above 1710°C: Excess oxidation → surface defects, slag entrapment
3. Mold Temperature and Heat Extraction
   - ➢ Control Required: Rapid and uniform cooling at mold wall
   - ➢ Impact:
     - Poor mold cooling: Irregular shell growth → longitudinal cracks
     - Uneven heat removal: Thermal stress → transverse cracks

B. Temperature and Solidification Behavior

Temperature (°C)	State of Steel	Relevance
1760°C	Fully Liquid	High risk of oxidation and inclusion defects
1650°C	Start of Solidification	Ideal starting point for shell formation
1580°C	Fully Solid	End of solidification phase

- Trend Observed:
  - As temperature decreases, fraction solid increases.
  - Smooth transition is key to prevent solidification-related defects.

C. Solidification Time & Defect Risk

- Higher casting temperature → faster solidification → risk of shell cracking due to thermal shock.
- Uneven or abrupt solidification → leads to longitudinal and transverse cracks.

Recommended Parameters for Defect Reduction

Parameter	Recommended Range	Effect on Defects
Casting Speed	1.5 m/min	Minimizes turbulence and prevents longitudinal cracks
Ladle Inlet Temperature	1650°C – 1670°C	Maintains fluidity; prevents surface defects
Max Temperature Limit	≤ 1710°C	Avoids oxidation and inclusion defects
Solidification Control	Monitor fraction solid	Prevents abrupt transitions → reduces cracks

Monitoring Recommendations

- Continuously monitor:
  - Fraction solid throughout the casting strand
  - Temperature gradient across billet cross-section

- Ensure uniform cooling in the mold and secondary zones to minimize stress concentrations.

Maintaining optimal temperature and casting speed is critical to avoiding longitudinal cracks, transverse cracks, and surface defects. The most effective control strategy involves maintaining steel temperature between 1650°C–1700°C, keeping casting speed at 1.5 m/min, and ensuring smooth, uniform solidification monitored via fraction solid profiles.

4.15 Result and Discussion

A. Significance of the Result in Relation to the Field and the Company

The analysis of value-added (VA) and non-value-added (NVA) activities within Abyssinia Integrated Steel Manufacturing reveals critical inefficiencies, particularly in the inbound logistics, operations, and melting/continuous casting stages. A high scrap rate of 25.4% in one production cycle — notably higher than the expected 15% — signifies substantial material waste, cost inefficiencies, and quality challenges. Identifying major defects (longitudinal cracks, surface defects, transverse cracks) through Pareto analysis and root cause methods emphasizes the need for operational reform. The financial value-added percentage of 33.5% in one cycle also indicates that current practices are not optimized for economic performance. These findings are crucial in the broader field of steel manufacturing, where process optimization directly correlates with cost reduction, quality assurance, and competitive advantage. In the company's context, these results justify strategic investment in predictive tools and lean manufacturing practices to strengthen productivity and customer satisfaction.

B. Comparison to Existing Literature

Although previous studies have advanced defect detection in rebar manufacturing through the use of real-time sensors, machine vision, automation, and AI-based models, a significant research gap remains. Most existing research focuses narrowly on technological solutions applied at isolated stages of the production process—such as billet reheating, rolling, or cutting—without considering how these interventions impact or are influenced by upstream and downstream operations. Furthermore, while these tools are effective for identifying visible defects, they often lack predictive capabilities that account for material behavior during critical stages like casting and reheating. This limitation highlights the need for a more integrated and systemic approach to defect prevention.

To address this gap, the present study introduces a hybrid methodology that combines Value Chain Analysis (VCA) with PROCAST simulation software. The application of VCA enables a comprehensive mapping of the entire production process, from material selection to final finishing, identifying inter-stage dependencies and systemic inefficiencies that contribute to defect formation. Instead of viewing defects as isolated occurrences, VCA provides a broader context, classifying activities as value-added, non-value-added, or bottlenecks. This strategic perspective allows for the identification of root causes embedded in the production system.

Complementing this, PROCAST offers physics-based simulation capabilities that model thermal gradients, solidification behavior, and stress distributions during billet casting and reheating. These stages are particularly critical, as they directly influence downstream rolling defects such as longitudinal and transverse cracks, cobbles, and scale formation. By simulating various operational conditions—including casting velocity and ladle temperature—PROCAST helps predict where and why defects are likely to occur, thus enabling proactive control of process variables.

The integration of PROCAST simulation with VCA provides a unique advantage: it bridges material-level defect prediction with operational process mapping. This dual approach creates a feedback loop between digital simulation and real-world production, ensuring that predictive insights from PROCAST translated into actionable improvements within the value chain. For example, simulation results confirmed that maintaining an optimal casting speed of 1.5 m/min and a ladle inlet temperature between 1650°C and 1700°C significantly reduces turbulence and thermal stress, thereby minimizing defect risks.

Ultimately, this study fills a critical gap in the literature by offering a holistic, predictive quality control framework for the rebar manufacturing industry. It demonstrates that the combination of VCA and PROCAST enables both macro-level process alignment and micro-level defect forecasting. This integrated model not only enhances product quality and reduces rework waste but also improves overall productivity and sustainability. The findings are especially relevant for Abyssinia Integrated Steel Manufacturing and similar firms seeking to transition from reactive defect detection to proactive and data-driven defect prevention strategies.

C. Actionable Strategy

Based on the findings, the following actionable strategy is proposed to address inefficiencies and improve production:

1. Defect-Reduction Framework Using Predictive Tools

- Implement PROCAST simulation in the continuous casting stage to model and optimize casting speed, temperature, and cooling rates.
- Recommended parameters:
- Casting speed: 1.5 m/min
- Ladle inlet temperature: 1650–1670°C
- Max temperature: ≤1710°C
- Use fraction solid monitoring to track real-time solidification.

2. Value Chain Efficiency Strategy

Focus on upstream operations (inbound logistics and melting) for improvement.

Apply Failure Mode and Effects Analysis (FMEA) is a systematic approach to identify potential failure points in a process, assess their impact, and prioritize corrective actions based on severity, occurrence, and detection ratings.

3. Defect Monitoring and Quality Assurance

- Establish a real-time defect tracking system with sensors and digital logs.
- Conduct daily review of critical defects using Pareto and Cause & Effect methods.

4. Process Reengineering in Melting/Casting

- Redesign furnace operations to reduce manpower inefficiency.
- Automate sample taking and slag removal to maintain consistency.

5. Training and Knowledge Management

- Conduct operator training focused on casting dynamics and defect patterns.
- Develop standard operating procedures (SOPs) based on simulation insights.
-

E. Continuous strategic Improvement Framework for Abyssinia Steel Rebar Production

This framework integrates the PROCAST-based simulation loop with practical quality management and lean manufacturing strategies to establish a closed-loop system for defect reduction, value enhancement, and sustainable production excellence.

The digital simulation stage initiates the process improvement cycle, using PROCAST to model critical rebar manufacturing stages such as melting and continuous casting with real-world parameters. This simulation enables the identification of defect-prone zones caused by turbulence, temperature gradients, and uneven solidification. The outcome of this stage is the ability to predict where and why defects such as longitudinal, surface, or transverse cracks are likely to occur.

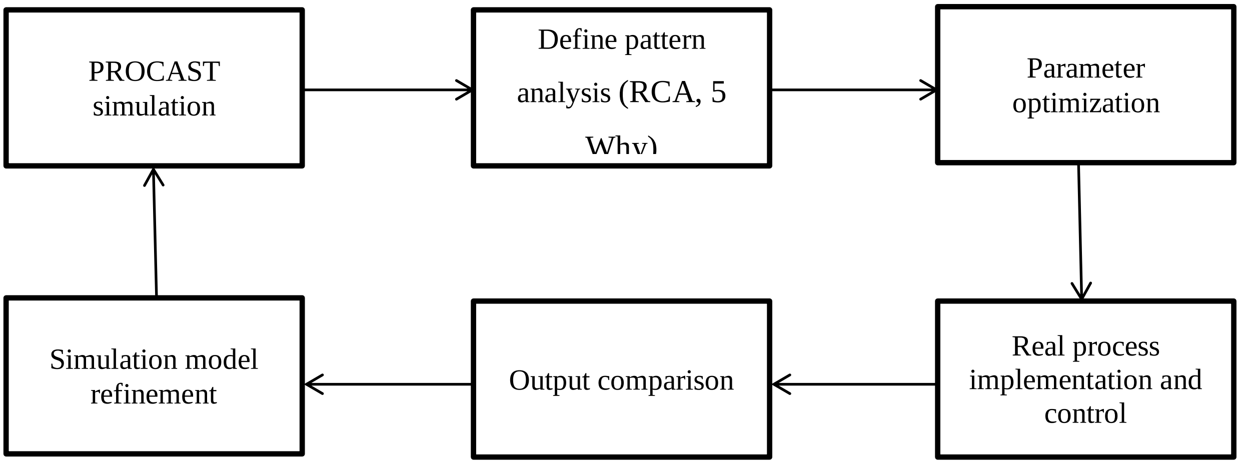
Following simulation, the result analysis stage employs Root Cause Analysis (RCA), Pareto Analysis, and the 5 Whys method to interpret both simulation output and actual production data. This analytical process identifies patterns of defects and correlates them with influencing factors such as casting speed, molten steel temperature, mold design, and fluid flow behavior. The goal is to prioritize the root causes that have the most significant impact on billet quality. Next, in the optimization and process tuning stage, are used to refine process parameters. Key adjustments such as setting the casting speed to 1.5 m/min and maintaining inlet temperatures between 1650–1670°C—are validated through virtual simulations before real-world application. This stage aims to establish a controlled casting environment with a minimized probability of defects.

In the implementation phase, optimized parameters are integrated into actual production using tools such as Standard Operating Procedures (SOPs), Total Productive Maintenance (TPM), and Statistical Process Control (SPC) charts. Operators receive training on the updated procedures, and statistical tools are used to monitor and maintain stable casting conditions. The outcome is a more consistent operation that adheres to national quality standards such as CES 101:2021.

The performance review and data comparison stage then assesses the effectiveness of implemented changes. Using scrap rate monitoring, and yield analysis, the actual production performance compared to simulation predictions. This enables tracking of improvements in defect reduction, scrap minimization, and overall productivity providing tangible evidence of the return on investment in simulation-based interventions.

Finally, the model refinement and learning integration stage ensures continuous improvement. Updated production and quality data are fed back into the PROCAST simulation model, improving its predictive accuracy. In parallel, lessons learned are documented and integrated for future use, fostering a cycle of continuous learning. The ultimate outcome is a smarter, more adaptive simulation model that drives more efficient and defect-free production.

Framework of close loop continuous improvement



4.16 Chapter four Summary

Chapter Four presents a detailed analysis of the value chain performance and defect generation within the rebar production process at Abyssinia Integrated Steel Manufacturing, with a particular focus on one complete production cycle of the 8mm diameter rebar product. The investigation utilizes quantitative data to assess the efficiency of each production stage—scrap preparation, melting and continuous casting, and rolling.

The findings reveal a critical performance gap in the upstream operation, where 25.4% of input material becomes scrap, exceeding the company's expected scrap threshold of 15%. The melting and continuous casting stage contributes the most to both value addition (21.8%) and waste generation (22.09 tons). In contrast, the rolling mill stage, although essential, adds only 11.6% value, indicating inefficiency relative to material usage.

The financial value-added percentage for this cycle is 33.5%, highlighting moderate economic transformation of inputs into outputs. However, the inflated scrap rate directly undermines profitability, product quality, and resource utilization.

A detailed defect analysis—supported by Pareto charts and root cause evaluations—identified longitudinal cracks, surface defects, and transverse cracks as the most frequent and severe billet issues, accounting for over 60% of rejections. These were linked to improper casting speed, temperature fluctuations, and cooling irregularities in the continuous casting process.

To address these inefficiencies, the study employed PROCAST simulation software to model solidification behavior and optimize casting parameters. Simulation results confirmed that maintaining a casting speed of 1.5 m/min and a steel temperature range of 1650°C–1670°C can reduce the formation of thermal stress-related defects and improve billet quality.

In summary, this chapter underscores that upstream processes, particularly melting and continuous casting, are the dominant sources of defect-related waste in rebar production. It concludes that process improvements, guided by data, simulation tools, and structured value chain analysis, are essential to enhance quality, reduce scrap, and increase value delivery per production cycle.

CHAPTER FIVE- CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Theoretical Contribution

From a theoretical standpoint, this study contributes to the literature by integrating Value Chain Analysis (VCA) with physics-based simulation tools (PROCAST) to develop a holistic framework for defect prediction and process optimization in the rebar manufacturing industry. While previous research has focused on narrow technological interventions—such as machine vision or AI-based defect detection systems—these methods largely overlook the interdependence between upstream and downstream activities along the value chain [Smith et al., 2018; Zhang & Lee, 2020]. The research fills that gap by applying Porter's Value Chain Theory [Porter, 1985] not just as a business strategy tool but as a diagnostic model for identifying systemic inefficiencies and defect generation points across interconnected production stages.

Furthermore, the integration of material behavior simulation into process analysis introduces a novel theoretical dimension to quality control studies. Unlike traditional AI models that rely on historical data, PROCAST enables predictive modeling grounded in physical laws, such as heat transfer and solidification theory [Kim et al., 2019]. This enhances the understanding of how thermo mechanical conditions during casting and reheating affect downstream defects, offering a mechanistically grounded alternative to purely data-driven models.

Empirical Contribution

Empirically, the study provides evidence-based insights from Abyssinia Integrated Steel Manufacturing, demonstrating how inefficiencies and waste in rebar production—especially the average of 6,500 kg of rework waste reported from 2013 to 2015—can be reduced by targeting critical parameters identified through VCA and PROCAST simulation. The field data showed that improper casting velocity and inadequate temperature control were the primary contributors to defects such as transverse and longitudinal cracks, scale formation, and dimensional deviations.

Simulation results using PROCAST confirmed that maintaining a casting velocity of 1.5 m/min and a temperature range of 1650°C–1700°C provides the optimal conditions for controlled solidification and reduced defect formation. These findings align with prior studies emphasizing the importance of thermal and flow control in minimizing casting-related defects [Zhou et al., 2017; Singh & Kumar, 2020], but extend their applicability by offering an integrated, stage-wise diagnostic approach.

Additionally, the study categorizes each casting-related activity as value-added or non-value-added using VCA, identifying key bottlenecks such as billet inspection delays and poor tundish flow regulation. This classification allows for strategic process redesign that directly contributes to reducing waste and improving productivity across the production chain.

In summary the study provides a dual-layered contribution to the rebar manufacturing field: Theoretically, it advances defect control frameworks by integrating value chain logic with physics-based predictive modeling, offering a systemic alternative to siloed AI-based detection methods. Empirically, it delivers actionable insights and validated process parameters for reducing production defects and waste, specifically tailored to the Ethiopian steel industry context.

5.2 Recommendations

To address these challenges, several recommendations are proposed.

- Improve Production Parameters: Maintain a casting velocity of 1.5 m/min and an inlet temperature between 1650°C and 1700°C to improve fluidity and solidification processes. Regularly monitor these parameters to ensure consistency and adherence to optimal ranges.
- Implement Advanced Monitoring Systems: Employ real-time monitoring tools to track fluid velocity and temperature during production. This will facilitate immediate adjustments and help prevent the conditions that lead to defects.
- Focus on Value-Adding Activities: Conduct a thorough analysis to distinguish between value-adding and non-value-adding activities within the value chain. Streamline processes to enhance productivity and reduce waste.
- Engage with Customers: Maintain open lines of communication with customers to understand their evolving needs and expectations. This can help ensure that production aligns with market demands and reduces the likelihood of rework.

By implementing these recommendations, Abyssinia Integrated Steel Manufacturing can significantly reduce waste, enhance productivity, and improve product quality. These strategies not only address current inefficiencies but also position the company for greater competitiveness in the Ethiopian rebar industry.

5.3 Future research area

Future research should explore from an environmental perspective, research could evaluate how simulation-based defect reduction contributes to lower carbon footprints and supports scrap recycling within circular economy models. Additionally, policy-oriented studies might investigate how to standardize the use of digital tools in quality control and how Industry 4.0 policies can support simulation adoption in emerging economies. These areas will help bridge the gap between advanced technologies, operational efficiency, and sustainable production in the steel industry

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Appendix

Annex A: Literature gap analysis

Author(s) / Study	Problem Finding	Gap in Predictive Quality Control Integration
Chen et al. (2018) – *Defect detection in rolling processes*	Implemented real-time defect detection using thermal cameras and sensors in the hot rolling stage of rebar production.	Detection is stage-specific; lacks predictive linkage to billet casting or reheating stages. No system-wide quality control integration.
Ahmed & Selim (2019) – *Automation in rebar inspection*	Used machine vision systems to identify surface defects (e.g., cracks, scales) during finishing operations.	Limited to visual surface inspection; does not predict defect root causes based on upstream process variations or simulate material behavior.
Wolde et al. (2021) – *Rebar quality issues in Ethiopia*	Identified frequent quality issues in rebar due to poor temperature control and outdated reheating technologies.	No predictive model in place; defect analysis is observational, not simulated. Lacks integration of digital tools (PROCAST) and value chain mapping for quality forecasting.
Lee et al. (2020) – *AI-based defect classification in steel rolling*	Developed an AI system that classifies defect types during high-speed rolling based on real-time sensor data.	Focuses on real-time classification; does not integrate simulation or predictive modeling that links upstream process variables to final quality outcomes.
Current Study (This Research)	Aims to combine Value Chain Analysis (VCA) with PROCAST to understand how upstream process inefficiencies cause downstream rebar defects.	Addresses the major literature gap: lack of integrated, predictive, and simulation-driven quality control across all stages of rebar production.

Annex B: summery of literature

Author(s)	Problem Addressed	Key Findings	Gap Identified
Ahmed & Selim (2019)	Real-time inspection of hot-rolled rebar	Effective in detecting surface-level defects using machine vision	Focuses only on detection during rolling; lacks predictive and process-wide integration
Chen et al. (2018)	Surface defect detection in casting	Laser-based systems can detect dimensional flaws in early production stages	Does not link surface defects to upstream process variables or predict deeper material issues

Author(s)	Problem Addressed	Key Findings	Gap Identified
Kumar et al. (2020)	Use of CCD camera systems in rebar diameter monitoring	Achieved sub-0.1 mm precision in inline inspection	No predictive modeling; reactive rather than proactive; does not simulate or forecast defects
Getachew et al. (2024)	AI-based prediction of tensile strength defects in Ethiopian steel industry	Machine learning ($R^2 > 0.97$) predicted quality deviations using process inputs	Limited to statistical data patterns; lacks physics-based defect formation modeling like PROCAST
Zhang & Liu (2022)	Rebar billet simulation using PROCAST	Successfully simulated thermal behaviors and reheating to reduce cracks	Focuses only on thermal modeling; does not integrate findings into a full production value chain
Wolde et al. (2021)	Defect issues in Ethiopian rebar plants	Identified cold shuts and porosity due to lack of advanced tools	Demonstrates need for simulation tools but lacks integrated defect forecasting and VCA
Das et al. (2014)	Thermal defects in TMT rebar caused by improper water cooling	Incorrect cooling leads to brittle martensite and fracture	Focused on final stages only; no upstream integration or predictive analytics
Lee et al. (2009)	Superheat and shell thickness correlation in billet casting	High superheat leads to defects like thin shell and internal cracking	Identifies root cause but lacks integration into simulation or control strategies
Sun & Zhang (2016)	Quench zone inconsistencies during thermo-mechanical treatment (TMT)	Imbalanced cooling causes cracks and grain coarsening	No predictive simulation; no integration with billet casting data
Tesfaye & Mekoya (2023)	Inefficiencies in Ethiopian rebar value chain	Suggested need for VCA and strategic alignment	Does not use predictive tools (like PROCAST) to simulate defect risks along the value chain

Author(s)	Problem Addressed	Key Findings	Gap Identified
Current Study (This Research)	Integrate predictive simulation (PROCAST) with strategic VCA to prevent defects at all production stages	Offers a holistic, proactive, and system-wide solution for defect prediction and control across the rebar value chain	Fills the research gap by combining physics-based simulation and process-level strategic analysis using VCA

Category	Year Range	Description	Key Sources	Use / Notes
Category 1: Very Recent	2020 – 2024	Most current studies reflecting latest technologies, trends, and academic findings.	Getachew et al. (2024), Wang et al. (2024), Huang et al. (2023), SBQ Steels (2023), Tessema & Belayneh (2022), Zhang & Liu (2022), Ma et al. (2022), Alemayehu & Tadesse (2020), Alshemmare & Ali (2021), Moyo & Mhlanga (2020), Lee et al. (2019), Müller et al. (2022), Kumar et al. (2020), Liu et al. (2019), Sun et al. (2021), Park et al. (2021)	Highly recommended for thesis; reflect cutting-edge tools, policy, and research gaps.
Category 2: Mid-Range	2015 – 2019	Relevant studies that may not reflect newest tech or post-COVID dynamics.	Ahmed & Selim (2019), Boateng & Osei-Tutu (2018), Nadoushani et al. (2018), Ghosh & Ghosh (2018), Adeyemi & Ilesanmi (2019), Tesfaye & Desta (2019), Das et al. (2014), Chen et al. (2018), Sun & Zhang (2016)	Useful especially for regional challenges, policy, and early tech applications.
Category 3: Older / Foundational	Pre-2015	Provide theoretical grounding or historical insights (e.g., competitive advantage theories).	Porter (1985), Prahalad & Hamel (1990), Barney (1991), Wright et al. (2016), Lee et al. (2009)	Support theoretical frameworks; combine with newer sources for updated views.

Annex C: primary activities

A. Inbound Logistic activates

Table A- Value adds and Non-value added activity Inbounded logistic activity

Inbounded logistic activity	Value added and non-value added activities		Describe the activity that relate value added or not
Receiving scrap		Non Value added activity	One of non-value-added activities that do not relate to the creation of value for the customer. The activity is to receive scrap from suppliers.
check the quality of scrap	Value added activity		It contributes to cost reduction, process improvement, customer satisfaction, compliance, and continuous improvement.
scrap vehicle move to weigh bridge		Non Value added activity	measuring all scrap weight vehicle that submitted to manufacture
unloading scrap		Non Value added activity	unloading scrap in to the vehicle by manually sort method
quality control check using Spector	Value added activity		It helps maintain high-quality standards, reduce defects, and improve overall product quality, leading to customer satisfaction and enhanced competitiveness in the market.
scrap segregation	Value added activity		It contributes to cost reduction, environmental sustainability, improved efficiency, compliance with regulations, and enhanced reputation.
Bailing scrap process		Non Value added activity	Bailing scrap improves workplace safety by minimizing clutter and creating a more organized working environment.
bundling process		Non Value added activity	Bundling scrap enhances workplace safety by reducing the risk of accidents and injuries.
Gas cutting scrap process		Non Value added activity	it enables the recovery of valuable metal materials, promotes recycling and sustainability, leads to cost savings, reduces waste, optimizes storage space, enhances safety and risk management, and facilitates value recovery.
inspection scrap		Non Value added activity	This activity is to inspect for exposure to radioactive elements and remove them to control the production system in a safe and easy way.
loading scrap		Non Value added activity	loading quality scrap one cycle melting operation
Storage yard		Non Value added activity	move to scrap to storage yard
NC return to suppler		Non Value added activity	return non conformity scrap to the supplier

B. Operations

Table B: - Value adds and Non-value added activity operational activity

operational activities	Value added and non-value added activity		Describe an activity that adds value or does not.
scrap melting process			
scrap received		Non value added activity	Receiving scrap does not directly contribute to the transformation or improvement of the product.
check the quality of scrap	Value added activity		This activity contributes to ensuring the quality of the input materials, which is crucial for producing a high-quality final product.
storage yard		Non value added activity	The storage yard itself does not directly add value to the product but is required for organizing and managing inventory.
located scrap in storage		Non value added activity	This activity helps in organizing and managing the inventory, making it easier to locate and retrieve the scrap when needed.
load scrap in bucket		Non value added activity	For transferring the scrap, loading the scrap into the bucket is not a value-added activity itself.
moving the bucket in to furnace		Non value added activity	Similar to the previous activity, moving the bucket does not directly contribute to the transformation of the product.
charging to furnace by manual		Non value added activity	This activity involves adding the scrap to the furnace, which is an essential step in the melting process.
melting scrap	Value added activity		This activity directly contributes to the transformation of the scrap into liquid steel, a necessary step in the production process.
bath chemistry inspection for the required level	Value added activity		This activity involves inspecting the chemical composition of the molten steel to ensure it meets the required specifications.
temperature inspection for furnace		Non value added activity	While important for monitoring the process, the temperature inspection itself does not add value to the product.
Ferro alloy addition	Value added		Adding Ferro alloys helps adjust the chemical composition of the liquid steel to achieve the desired properties in the final product.

operational activities	Value added and non-value added activity		Describe an activity that adds value or does not.
	activity		
tapping temperature measurement		Non value added activity	Measuring the temperature during tapping is necessary for process control but does not directly enhance the product's value.
liquid steel tapping to ladle	Value added activity		Transferring the molten steel from the furnace to the ladle is a critical step in the production process.
Final chemical composition quality control	Value added activity		This activity ensures that the final product meets the required chemical composition, but it does not directly add value to the product.
Continues casting process			
pre heating ladle condition		Non value added activity	Preheating the ladle does not directly contribute to the transformation or improvement of the product.
Thundish board fixed		Non value added activity	Fixing the Thundish board serves as maintenance or setup activity and does not directly add value to the product.
ladle liquid steel control	Value added activity		This activity involves controlling and monitoring the quality and composition of the liquid steel in the ladle, ensuring it meets the desired specifications.
liquid steel feeding to tundish		Non value added activity	This activity contributes to the continuous flow of liquid steel from the ladle to the tundish, ensuring a consistent supply for the casting process.
billet casting and cut length setting		Non Value added activity	This activity involves the actual casting of the liquid steel into billets and setting the desired length, which directly contributes to the production of the final product.
final chemistry specification	Value added activity		This activity ensures that the chemical composition of the billets meets the specified requirements, ensuring the desired properties in the product.
billet physical inspection	Value added activity		This activity involves inspecting the physical characteristics of the billets, such as dimensions and surface quality, to ensure they meet the required standards.
billet storage yarn		Non value added	The storage yard itself does not directly add value to the product but is required for organizing and managing

operational activities	Value added and non-value added activity		Describe an activity that adds value or does not.
		activity	inventory.
color coding marking		Non value added activity	This activity involves marking the defect billets with color codes, which can serve various purposes such as identification, traceability, or sorting.
Rolling milling process			
Billet receiving		Non value added activity	Receiving the billets does not directly contribute to the transformation or improvement of the product.
check billet quality	Value added activity		This activity contributes to ensuring the quality of the billets, which is crucial for producing a high-quality final product.
schedule or plan		Non value added activity	Creating a schedule or plan is essential for organizing the operations but does not directly add value to the product.
Billet movement		Non value added activity	This activity involves the movement of billets within the production process to facilitate the subsequent operations.
reheat billet in the furnace		Non value added activity	Reheating the billet in the furnace is not a value-added activity itself.
charging the billet and preparation		Non value added activity	Charging the billet into the production equipment is required but does not directly enhance the value of the product.
rough mille process	Value added activity		This activity involves the initial milling and shaping of the billet, which is a direct step in the production process.
check billet out let temperature		Non value added activity	Monitoring the temperature is important for process control but does not directly contribute to the improvement of the product.
head cutting process		Non value added activity	This activity involves cutting the head section of the billet, preparing it for further processing.
intermediate mill process	Value added activity		This activity involves additional milling and shaping of the billet to achieve the desired dimensions and properties.
head cut process		Non value added activity	This activity involves cutting the head section of the billet, preparing it for further processing.

operational activities	Value added and non-value added activity		Describe an activity that adds value or does not.
semi-finished mill process	Value added activity		This activity further refines the shape and dimensions of the billet, bringing it closer to the final product specifications.
tail cutting process		Non value added activity	This activity involves cutting the tail section of the billet, preparing it for the finishing stages.
finished mill process	Value added activity		This activity represents the final milling process, achieving the required dimensions and surface finish of the product.
cheek billet out let temperature		Non value added activity	This activity is important for process control but does not directly add value to the product.
cutting 48m length in to four		Non value added activity	Dividing the billet into smaller lengths is necessary for further processing but does not directly enhance the value of the product.
cooling process	Value added activity		Cooling the billet after the milling process is important for stabilizing its structure and properties.
physical and mechanical inspection	Value added activity		Inspecting the physical and mechanical characteristics of the product ensures it meets the specified standards and requirements.

C. Outbound logistics

Table C: - Value adds and Non-value added activity out bounded logistic activity

Outbound Logistics	value added activity	Non value added activity	Describe the activity that relate value added or not
Resizing rebar	Value added activity		It is typically considered a value-added activity as it directly contributes to meeting customer specifications.
bundle the rebar	Value added activity		Bundling rebar involves grouping individual bars together for easier handling, transportation, or storage.
Tag preparation	Value added activity		Tag preparation involves labeling or tagging the rebar bundles for identification or tracking purposes.
Submit to Store		Non value added activity	It is typically considered a non-value-added activity as it does not directly contribute to meeting customer
Prepare order process	Value added activity		This activity is considered a value-added activity as it directly contributes to fulfilling customer requirements and ensuring the accurate and timely delivery of the rebar.
loading rebar		Non value added activity	It is typically considered a non-value-added activity as it does not directly contribute to meeting customer
submit rebar in to destination	Value added activity		One of value added activity, it is essential for fulfilling customer requirements and completing the order process.

D. **Marketing and Sales**

Table D: - Value adds and Non-value added activity Marketing and sales activity

Marketing and sales activity	Value added and Non Value added activity		Describe the activity that relate value added or not
Market research			This helps in understanding the demand for rebar, target markets, and potential customers.
Define value proposition	Value added activity		This activity involves identifying and defining the unique value that a product or service offers to customers.
Plan marketing strategy	Value added activity		This activity involves developing a strategic plan to promote and position the product.
Advertising and promotion		Non Value added activity	Marketing activities include various promotional strategies to create awareness and stimulate demand for the rebar product
Sales presentation		Non Value added activity	They provide accurate and competitive quotes to potential customers based on their requirements, volumes, and delivery schedules.
Sales analysis and reporting	Value added activity		This activity involves presenting the product or service to potential customers, highlighting its features, benefits, and value proposition.
Determine distribution channels	Value added activity		It contributes to value creation by ensuring that the offering reaches customers in a timely and convenient manner.

E. **Service after sales:**

Table E - Value adds and Non-value added activity Inbounded logistic activity

Service after sales activity	Value added and Non Value added activity		Describe the activity that relate value added or not
Establishing Communication Channels		Non Value added activity	It sets the stage for gathering feedback and engaging with customers but does not inherently add value unless it facilitates meaningful interactions.
Gathering Customer Feedback		Non Value added activity	This information is valuable for making informed decisions and improving your products, services, and overall customer experience.
Analyzing Feedback		Non Value added activity	It provides a basis for identifying areas of improvement and implementing changes that address customer concerns and enhance their satisfaction.
Taking Action	Value added activity		Responding to customer feedback by taking appropriate actions demonstrates your commitment to addressing their concerns and improving their experience.
Continuous Improvement	Value added activity		Using customer feedback as a driver for continuous improvement ensures that your business evolves and adapts to meet customer expectations.

Annex D: Supportive activates

	Value-Added Activities	Non-Value-Added Activities:	VAP
Material Management			10%
Procurement of raw materials	Value-Added Activities		
Inventory management		Non-Value-Added Activities:	
Efficient supply chain management		Non-Value-Added Activities:	
Excessive stockpiling		Non-Value-Added Activities:	
Inefficient transportation		Non-Value-Added Activities:	
Redundant paperwork		Non-Value-Added Activities:	
Unnecessary inspections		Non-Value-Added Activities:	
R&D Management			50%
Product design and development	Value-Added Activities:		
Market research	Value-Added Activities:		
Prototyping and testing	Value-Added Activities:		
Collaboration with stakeholders	Value-Added Activities:		
Bureaucratic approvals		Non-Value-Added Activities:	
Meetings without clear objectives		Non-Value-Added Activities:	
Rework due to poor planning		Non-Value-Added Activities:	
Documentation duplication		Non-Value-Added Activities:	
Human Resource Management			30%
Recruitment and hiring	Value-Added Activities:		
Employee training and development	Value-Added Activities:		
Performance evaluation	Value-Added Activities:		
Employee engagement initiatives		Non-Value-Added Activities:	
Lengthy hiring processes		Non-Value-Added Activities:	
Overly complex onboarding		Non-Value-Added Activities:	
Administrative paperwork		Non-Value-Added Activities:	
Inefficient communication channels		Non-Value-Added Activities:	
Lengthy Hiring Processes		Non-Value-Added Activities:	
Overly Complex Onboarding		Non-Value-Added Activities:	
Firm Infrastructure			10%
Strategic planning	Value-Added Activities:		
Financial management		Non-Value-Added Activities:	
IT infrastructure management		Non-Value-Added Activities:	
Compliance and risk management		Non-Value-Added Activities:	
Excessive bureaucracy		Non-Value-Added Activities:	
Inefficient resource allocation		Non-Value-Added Activities:	
Redundant processes		Non-Value-Added Activities:	
Poorly managed meetings		Non-Value-Added Activities:	

Annex E: Billet defect root cause record in three years

	2013		2014		2015	
	Reason	Responsible	Reason	Responsible	Reason	Responsible
longitudinal cracks occur during the billet outlet stage	Improper casting speed selection for steel grade	Man	Inaccurate mold alignment during casting	Man	Improper casting speed selection for steel grade	Man
	Improper mold design with sharp corners	Method	excessive casting temperature leading to large solidification gap	Method	excessive casting temperature leading to large solidification gap	Method
	Faulty cooling system leading to uneven temperature distribution	Machine	worm mold causing uneven solidification	Machine	Faulty cooling system leading to uneven temperature distribution	Machine
	Improper steel chemistry for desired casting process	Material	Improper steel chemistry for desired casting process	Material	High sulfur content in steel reducing ductility	Material
	excessive casting temperature leading to large solidification gap	Method	Improper casting speed selection for steel grade	Man	Improper casting speed selection for steel grade	Man
	worm mold causing uneven solidification	Machine	excessive casting temperature leading to large solidification gap	Method	Improper mold design with sharp corners	Method
	Faulty cooling system leading to uneven temperature distribution	Machine	Faulty cooling system leading to uneven temperature distribution	Machine	excessive casting temperature leading to large solid fiction gap	Method

	2013		2014		2015	
	Reason	Responsible	Reason	Responsible	Reason	Responsible
Surface defect occur during the billet outlet stage	Excessive casting temperature leading to large solidification gap	machine	casting at excessive high speeds can increases turbulence and surface entrapment	Method	Excessive casting temperature leading to large solidification gap	Method
	Steel cleanliness	Material	In effective mold flux composition	Material	law metal pouring temperature	Machine
	Improper DE oxidation	Man	Low metal pouring temperature	Machine	steel cleanliness	Material
	Improper pouring techniques may introduce impurities or cause turbulence	Man	casting at excessive high speeds can increases turbulence and surface entrapment	Method	Improper DE oxidation	Man
	casting at excessive high speeds can increases turbulence and surface entrapment	Method	Excessive casting temperature leading to large solidification gap	machine	casting at excessive high speeds can increases turbulence and surface entrapment	Method

	2013		2014		2015	
	Reason	Responsible	Reason	Responsible	Reason	Responsible
Transverse cracks occur during the billet outlet stage	Excessive casting temperature leading to large solidification gap	Method	casting stand bulging due to mechanical issue	Machine	casting stand bulging due to mechanical issue	Machine
	Improper casting speed selection for steel grade	Man	Lack of proper control over bugling during casting process	Method	Lack of proper control over bugling during casting process	Method
	castng stand bulging due to mechanical issue	Machine	Inaccurate mold alignment during casting	Man	Inaccurate mold alignment during casting	Man
	Lack of proper control over bugling during casting process	Method	Excessive casting temperature leading to large solidification gap	Method	Excessive casting temperature leading to large solidification gap	Method
	Inaccurate mold alignment during casting	Man	Improper casting speed selection for steel grade	Man	Improper casting speed selection for steel grade	Man
	Presence of excessive alumina inclusions acting	Material	Presence of excessive alumina inclusions acting	Material		

Annex F: number of defect in each furnace

Table 1: Billet defects indicated by this mark (√) based on operational data from one shift.

Shift	Operation	Billet Output	Defect type						
			Longitude crack	Transvers crack	Surface defect	Shape defect	Internal defect	Breakouts	Total defect
Furnace one	1A	13	✓		✓		✓		3
	1A	13		✓		✓			2
	1A	12			✓		✓		2
	1A	12		✓					1
	1A	12				✓		✓	2
Furnace two	2A	12	✓						1
	2A	12	✓						1
	2A	13	✓						1
	2A	13		✓		✓			2
	2A	12	✓						1
	2A	12			✓	✓			2
Furnace three	3A	13	✓				✓		2
	3A	13		✓	✓				2
	3A	12				✓	✓	✓	3
	3A	12	✓						1
	3A	12			✓		✓		2
Furnace Four	4A	13	✓	✓				✓	3
	4A	12			✓	✓			2
	4A	12	✓		✓				2
	4A	12		✓			✓	✓	3
	4A	12	✓		✓				2

Table 2: Billet defects indicated by this mark (√) based on operational data from two shifts.

Shift	Operation	Billet Output	Defect type						
			Longitude crack	Transvers crack	Surface defect	Shape defect	Internal defect	Break outs	Total defect
Furnace one	1A	12			✓		✓		2
	1A	12				✓	✓	✓	2
	1A	12		✓	✓		✓		3
	1A	13	✓	✓					2
	1A	12				✓		✓	1
Furnace two	2A	12		✓					1
	2A	12					✓		1
	2A	13							0
	2A	13		✓		✓		✓	2
	2A	12	✓						1
	2A	12			✓	✓			2
Furnace three	3A	13					✓		1
	3A	13	✓	✓	✓				3
	3A	12	✓			✓		✓	2
	3A	13	✓	✓					2
	3A	13			✓		✓		2
Furnace Four	4A	12	✓	✓					2
	4A	12			✓	✓			2
	4A	13	✓		✓				2
	4A	13	✓						1
	4A	12	✓		✓				2

Addis Ababa University
Addis Ababa Institute of Technology (AAIT)
Mechanical Engineering Department
Graduate Program in Industrial Engineering
Prepared by: Nardos Mekoya

In order to complete my master's degree in industrial engineering, I am conducting research in the Abyssinia integrated steel industry under the title Enhancing competitiveness through Value Chain Analysis This interview's goal is to pinpoint areas that, in light of the needs of the company product beneficiaries, could use improvement. Your response is crucial to the study's successful conclusion. The information will be kept private and the respondent name will not be revealed during the interview.

I. Preliminary Information

Respondent Information

- Your current position in the company___________________
- Years of work experience in the company_________________
- Qualification level (highest) ___________________________________
- Gender_________________

The following open type semi structured interview is presented for quality and production staff as initial of 5why method.

Such question organized related to the cause and effect result

1. Why do have longitudinal cracks occur during the billet outlet stage?
2. Why do surface cracks occur during the billet outlet stage?
3. Why do we have transverse cracks occur during the billet outlet stage?