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Enhancing Operational Efficiency in Steel Plants

M. Ravi[1]; Dr. Manoj Bhatia[2]; Dr. V K Jain[3]

[1]Research Scholar, Sanjeev Agrawal Global Educational University, Bhopal.
[2]Professor and Dean of Management, SAGE University, Bhopal.
[3]Vice Chancellor, Teerthanker Mahaveer University, Moradabad.

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Abstract: Operational efficiency focuses on refining process parameters, eliminating non-value-adding bottlenecks, and reducing unnecessary time and costs. In the manufacturing industry, operational efficiency refers to the capacity of a company to produce goods and services using minimal resources while maximizing output. The operational efficiency of steel plants is crucial to the overall efficiency of the steel industry, as it reflects the performance of every interconnected unit within the plant's operations. Steel producers face significant challenges, including fluctuating demand, capital and labour intensity, raw material supply disruptions, tightening environmental regulations, downtime, and the need for optimal use of equipment and resources. Key performance indicators (KPIs) for evaluating the operational efficiency of integrated steel plants include raw material utilization, equipment availability and utilization, quality control, productivity metrics, and financial efficiency. This study analyses these KPIs using data from five integrated steel plants under the Steel Authority of India Limited (SAIL), sourced from SAIL's annual reports over the last five fiscal years. The findings suggest that fostering strong relationships with suppliers and customers creates a collaborative environment conducive to continuous improvement. Emphasis should shift from volume-based approaches to strategies centered on product quality and customer satisfaction. Regular data monitoring and predictive maintenance offer critical insights into equipment performance, production trends, and maintenance needs, enabling process optimization. Implementing cost control measures in the raw material and iron zones where 60% of production costs are concentrated can significantly impact overall efficiency. Sharing best practices, joint research, and collaborative product development further contribute to mutual benefits.

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I. INTRODUCTION

➢ *Operational Efficiency*

Operational efficiency relates to how effectively an organization manages its operations to achieve high productivity. It involves the efficient use of resources such as labor, equipment, raw materials, and time to produce high-quality goods and services. Achieving operational efficiency can enhance a company's competitive edge, adaptability to market changes, and growth potential. Benefits of operational efficiency include increased productivity, reduced operating costs, improved product or service quality, enhanced customer satisfaction, and greater competitiveness in the market. The concept emphasizes the need to identify and optimize process parameters, eliminate non-value-adding bottlenecks, and reduce unnecessary time and expenses.

➢ *Operational Efficiency in Manufacturing Units*

In the manufacturing sector, operational efficiency is the ability of a company to produce goods and services with minimal resources and maximum output. This efficiency is vital for maintaining the industry's competitiveness, profitability, and sustainability. Key factors related to operational efficiency in manufacturing include:

- Production Process Optimization: This systematic approach seeks to improve the efficiency, effectiveness, and flexibility of production processes, enabling high-quality products at lower costs, in less time, and with minimal waste. Strategies for optimizing production processes in manufacturing units are crucial to achieving these outcomes.
- Downtime Tracking**:** Monitor production stoppages to pinpoint their causes and minimize interruptions.
- Maintenance and Predictive Analysis**:** Transition from reactive to proactive maintenance to extend machinery lifespan. Real-time data analysis can enhance machine performance.
- Bottleneck Analysis**:** A vital tool for manufacturers, bottleneck analysis helps streamline production processes for optimal efficiency.
- Production Optimization**:** This involves a series of systematic activities aimed at boosting productivity.

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- Resource Utilization**:** Effective and efficient use of resources, such as raw materials and energy, is crucial for minimizing costs in manufacturing units. Ensuring the security of raw materials is particularly important, as it directly impacts production stability and overall operational performance. Optimizing resource utilization can lead to increased efficiency, productivity, and competitiveness, along with improved customer satisfaction and cost reduction.
- Inventory Management**:** Efficient inventory management is key to ensuring smooth production, cost reduction, and improved customer satisfaction.

➢ *Operational Efficiency in Steel Plants:*

The operational efficiency of steel plants is fundamental to the overall efficiency of the steel industry. It depends on the performance of every interconnected unit within the steel plant's value chain. Several critical issues must be addressed to enhance operational efficiency in steel plants:

- Energy Consumption**:** Steel production is energy-intensive, leading to high operational costs and environmental concerns.
- Raw Material Availability**:** Securing access to high-quality iron ore, coking coal, and other essential raw materials is a significant challenge for steelmakers.
- Environmental Regulations**:** Steel plants must comply with stringent emissions and waste management regulations.
- Technological Advancements**:** Keeping pace with the latest technologies and equipment is necessary to maintain competitiveness, despite the associated costs.
- Workforce Management**:** Managing labor costs and maintaining a skilled workforce is challenging, especially as automation becomes increasingly prevalent in the steel industry.
- Market Fluctuations**:** Steel prices are influenced by global market dynamics, making it difficult for steel plants to predict demand and optimize production sustainably.
- Competitiveness**:** With growing global competition, steel plants must continuously improve efficiency, reduce costs, and innovate to remain competitive in the market

II. LITERATURE REVIEW

➢ *Swati Deshpande (2023) – "8 Major Challenges in the Steel Industry in India":*

India ranks as the world's second-largest steel producer, but it faces significant challenges, including the slow adoption of new technologies, price instability, and issues related to supply chain management, logistics, and transportation. The article highlights several key problems:

- Capital and Labor Intensity**:** Establishing a steel plant with a capacity of 1 MT requires substantial capital, around ₹7,000 crores, according to a PwC report. Securing such financing is challenging, making it difficult to obtain business loans for setting up steel plants.
- Demand Forecasting**:** The steel industry struggles with fluctuating demand, making it challenging to accurately predict demand and align production, leading to delayed returns on investment.
- Logistical Challenges**:** Logistics and supply chain management are critical issues for the steel industry, particularly given the bulk nature of raw materials like iron ore and coking coal, as well as the bulk nature of finished steel. Handling and transporting these materials pose unique challenges.
- Raw Material Disruptions**:** The availability of key raw materials like iron ore (domestically sourced) and coking coal (imported, mainly from Australia) is inconsistent, leading to supply chain disruptions and fluctuating prices, which affect production costs and competitiveness.
- Low Per Capita Consumption**:** Despite being the second-largest steel producer, India's per capita steel consumption was only about 75 kg in 2020. This low domestic demand limits the industry's growth potential, especially compared to China's per capita consumption of 590 kg. The National Steel Policy 2017 aims to increase per capita consumption to 160 kg by 2030-31.
- Technological Lag**:** While some industry leaders have embraced digital technologies for supply chain management, this is not the case across the board. Many steel producers lack access to real-time data, hindering their ability to forecast demand and capitalize on short-term opportunities, potentially leading to financial losses.
- Downtime and Capacity Utilization**:** The aforementioned challenges contribute to low-capacity utilization, with Indian steel plants rarely achieving 80% capacity due to issues like raw material shortages and logistics-related problems.
- Environmental Concerns**:** The steel industry is highly energy-intensive, ranking just behind the chemical sector in energy consumption. It also has a significant carbon footprint. Implementing modern energy management systems and advanced technologies can help the industry become more environmentally friendly and competitive.
- Beyond these challenges, the steel industry faces additional issues, such as taxes and duties specific to the sector. While some challenges are external and beyond the industry's control, adopting the latest production technologies, energy management systems, and efficient resource utilization could attract more foreign direct investment (FDI), driving industry growth.

➢ *Steel Outlook 2023-24 Report:*

The report emphasizes that the availability of raw materials will be a critical issue for the steel industry. Indian steelmakers face significant logistical challenges due to the bulk nature of raw materials like iron ore and coal and the bulk nature of finished steel. These factors complicate the transportation of materials to demand centres. Although railways are the preferred mode of transport for steelmakers, infrastructure limitations exacerbate the logistical challenges. India's reliance on the blast furnace method, which requires coking coal, further complicates matters, as the country depends on imports from Australia. This dependency is vulnerable to supply and price fluctuations, often driven by unpredictable weather patterns.

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- International Energy Agency Journal (2020) – "Iron and Steel Technology Roadmap (Towards More Sustainable Steelmaking)": Steel is one of the most recycled materials globally, with iron ore providing about 70% of the metallic raw materials for steelmaking, and recycled steel scrap supplying the remainder. Producing steel from scrap requires significantly less energy—about one-eighth of what is needed to produce steel from iron ore, primarily using electricity instead of coal. The significant benefit of this approach is that it enables a remarkably high rate of recycling, with global averages reaching approximately 80-90 %. However, recycling alone cannot meet the sector's raw material needs, as current steel production exceeds the amount of steel produced in the past that is now being recycled. Thus, recycling alone cannot achieve the emission reductions needed to meet climate goals. New steelmaking processes, including those involving hydrogen, carbon capture, utilization, and storage (CCUS), bioenergy, and direct electrification, are essential for reducing emissions.
- Diogo Jose Horst et al. (2023) – "Sustainability of the Steel Industry: A Systematic Review":The increasing focus on environmental sustainability and decarbonization in the steel and iron industries is critical, as these sectors contribute to emissions of harmful gases such as ammonia, benzene, carbon monoxide, hydrogen chloride, hydrogen sulphide, nitrogen dioxide, and Sulphur dioxide. Addressing these emissions and adopting eco-friendly production methods are vital for environmental protection. Techniques like carbon sequestration can effectively reduce carbon dioxide emissions from the steel sector. Additionally, steel by-products can be repurposed into raw materials for products like paints, cement, and fertilizers. Analyzing the energy efficiency of a typical iron and steel manufacturing process (ISMP) reveals that the energy efficiency of such processes can be significantly improved by adjusting the steel ratio, recovering waste heat, and developing interface technologies.

III. DISCUSSION

Drawing from the literature review and the examination of issues related to the operational efficiency of manufacturing units and integrated steel plants, this discussion focuses on key parameters that offer a comprehensive view of integrated steel plant operations with a focus on sustainability. The current approach to assessing the operational efficiency of integrated steel plants considers the following parameters:

- BF Productivity: Measured by the tons of hot metal produced per cubic meter of blast furnace working volume per day (T/cubic meter/day).
- Coke Rate: Calculated in kilograms of blast furnace coke consumed per ton of hot metal produced in the blast furnace (Kg/THM), typically excluding nut/pearl coke mixed with sinter.
- Pulverized Coal Injection/Coal Dust Injection (PCI/CDI) Rate: Relevant for minimizing overall coking coal consumption and production costs, expressed in kilograms of non-coking coal consumed per ton of hot metal produced in the blast furnace (Kg/THM).
- BOF/LD Productivity: Assessed by the number of heats taken per converter per year.
- Specific Energy Consumption (Energy Intensity): This metric tracks the total energy consumption across the entire plant, expressed in Giga Calories per ton of crude steel produced (GCal/TCS).
- Specific CO2 Emission (GHG Emission): Measured in tons of CO2 released per ton of crude steel produced (T/TCS).
- Crude Steel Capacity Utilization: This measures the actual crude steel production relative to the capacity of the steel melting shop.

In the context of operational management, the efficiency of a steel plant is defined by how effectively the integrated steel plant operates its units to achieve its goals. For this study, the key performance indicators used to measure the process efficiency of integrated steel plants include:

- Raw Material Utilization: Consistency in production depends heavily on the continuous flow and effective use of raw materials. In the blast furnace route of steelmaking, raw material consumption accounts for more than 85% of manufacturing costs in the iron-making zone. Thus, meticulous utilization and a focused approach to cost, availability, and metallurgical properties are essential. Key issues related to raw material utilization in steel plants include iron ore quality and availability, coking coal and coke quality, scrap availability and recycling, raw material price volatility, alternative iron-making technologies, and technological innovation. Effective management of these challenges can enhance competitiveness, reduce environmental impact, and contribute to the steel industry's sustainability. The study analyses raw material consumption patterns over the last five years in five integrated steel plants, focusing on materials like iron ore, sinter, dry coke, CDI, nut coke, total metallic input, hot metal, steel scrap, and lime and calcined dolomite.
- Equipment Availability and Utilization: In the steel industry, equipment availability refers to the percentage of time machinery is operational and ready for production. It is calculated by dividing total operating time by total planned time, expressed as a percentage. High availability indicates minimal downtime and maximizes productivity. Utilization measures the extent to which equipment is used during its available time, calculated by dividing actual production output by maximum potential output, also expressed as a percentage. High utilization reflects efficient equipment use, contributing to overall production capacity. Monitoring these schedules and identifying bottlenecks, optimizing maintenance schedules, and improving productivity. The study examines equipment availability and utilization in sintering plants, blast furnaces, converters, casters, and rolling mills over the past five years.
- Quality Control: Ensuring quality throughout the value chain is critical for meeting the specifications required by

subsequent units and maintaining market competitiveness. The study assesses various quality control parameters, including coal blend proportions (indigenous and imported), coke properties (M40 and M10), coal-to-hot metal ratio, coke rate, fuel rate, coal dust injection, sinter burden, and slag rate in blast furnaces.

- Productivity**:** Productivity in steel plant operations refers to how effectively the plant produces steel products by utilizing resources like raw materials, equipment, and labor. The study evaluates productivity through parameters such as BF coke yield from dry coal, sinter productivity and yields from charge mix, blast furnace productivity, crude steel yield from a total metallic charge in BOF, continuous casting yield, and the yield of various operating mills across different plants.

➢ *Financial Efficiency*

Financial efficiency in steel plants involves optimizing financial resources to maximize profitability, minimize costs, and support sustainable growth. Key aspects include cost control, revenue optimization, asset utilization, working capital management, and performance monitoring. Financial efficiency is essential for navigating the challenges of a competitive and cyclical industry. The parameters such as Return on Investment (ROI), Return on Equity (ROE), Return on Assets (ROA), Debt-to-Equity Ratio, Interest Coverage Ratio, Operating Margin, Net Profit Margin, and Cash Conversion Cycle are used to measure the financial efficiency of integrated steel plants. Achieving financial efficiency can enhance profitability and competitiveness.

IV. DATA ANALYSIS

Based on the considered parameters, key performance indicators are compiled from 5 Integrated steel plants under the umbrella of Steel Authority of India Limited. The secondary data is collected from SAIL annual reports of the last 5 financial years (2018-19,2019-20,2020-21,2021-22,2022-23) Sustainability reports of SAIL, Annual operation statistical reports of 5 integrated steel plants (BSP, BSL, RSP, DSP, and ISP) journals, and magazines. Statistical and qualitative analysis has been done considering the focused parameters for each performance indicator of the operational efficiency of SAIL plants.

➢ *Raw Material Utilization*

Table-1 RMU of BSP and BSL

Bhilai Steel Plant						
Parameters	**2022-23**	**2021-22**	**2020-21**	**2019-20**	**2018-19**	**Average**
Iron Ore	571	608	588	556	539	572.4
Sinter	1080	1091	1102	1122	1133	1105.6
Coke Dry	447.6	448.6	447.1	462.7	493.3	459.86
Cdi	119.7	83	75.9	61.1	37.1	75.36
Nut Coke	17.1	26.5	33.9	20.2	33.9	26.32
Tmi Kg/T	1131.05	1129.8	1135.4	1147.35	1142.8	1137.28
Hm	1032.9	1033.8	1027.95	1003.55	1009	1021.44
Steel Scrap	95.15	96	106.9	142.9	108	109.79
Lime+Calcined Dolo	99.7	95.75	93.55	93.3	80.7	92.6
Bokaro Steel Plant	**2022-23**	**2021-22**	**2020-21**	**2019-20**	**2018-19**	**Average**
Iron Ore	570	592	574	553	557	569.2
Sinter	1132	1192	1137	1133	1138	1146.4
Coke Dry	487	482	477	496	468	482
Cdi	56	62	57	49	59	56.6
Nut Coke	17	13	30	37	40	27.4
Tmi Kg/T	1139.2	1139.4	1139.4	1139.5	1139.5	1139.4
Hm	1021	1020	1024	1023.9	1021.9	1022.16
Steel Scrap	105	106	104	102.7		104.425
Lime+Calcined Dolo	81	82	79	77	79	79.6

Table-2 – RMU of RSP, DSP and ISP

Rourkela Steel Plant	**2022-23**	**2021-22**	**2020-21**	**2019-20**	**2018-19**	**Average**
Iron Ore	437	478	415	464	434	445.6
Sinter	1229	1247	1281	1271	1281	1261.8
Coke Dry	415	424	415	440	418	422.4
Cdi	117	110	114	116	126	116.6
Nut Coke	37	25	30	30	32	30.8
Tmi Kg/T	1124	1127	1176.5	1137	1139	1140.7
Hm	1047	1045.5	1095.5	1042.5	1030.5	1052.2
Steel Scrap	77	81.5	81	94.5	108.5	85.5
Lime+Calcined Dolo	92.36	112.9	116.75	126.8	121.3	114.02

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Durgapur Steel Plant	**2022-23**	**2021-22**	**2020-21**	**2019-20**	**2018-19**	**Average**
Iron Ore	516	551	512	504	518	520.2
Sinter	1145	1104	1119	1102	1097	1113.4
Coke Dry	457	461	482	478	459	467.4
Cdi	58	53	44	43	57	51
Nut Coke	23	24	17	18	20	20.4
Tmi Kg/T	1113	1114	1114	1118.34	1122	1116.27
Hm	1064	1056	1048	1039	1052	1051.8
Steel Scrap	49	59	66	80	72	65.2
Lime+Calcined Dolo	113.3	112	92.3	99.4	105.88	104.58
Iisco Steel Plant	**2022-23**	**2021-22**	**2020-21**	**2019-20**	**2018-19**	**Average**
Iron Ore	328	411	376	362.77	384.48	372.45
Sinter	1334	1328.5	1272.36	1251	1254	1287.972
Coke Dry	400	397	424	382	388	398.2
Cdi	123	118	89	119	29	95.6
Nut Coke	37	37	41	45	143	60.6
Tmi Kg/T	1101	1108	1112	1119	1119	1111.8
Hm	1063	1062	1071	1094	1078	1073.6
Steel Scrap	39	46	41	25.5	41	38.5
Lime+Calcined Dolo	83.9	87.2	92.7	91.8	95.51	90.132

➢ *Raw Material Utilization*

To test the significant differences in the variables of RMU across the five deifferent Steel Plants ANOVA is used.

➢ *Anova*

Table 3 ANOVA of RMU Variables

		Sum of Squares	df	Mean Square	F
IRON ORE	Between Groups	147927.990	4	36981.998	64.887
	Within Groups	11398.931	20	569.947	
	Total	159326.921	24		
SINTER	Between Groups	147015.174	4	36753.794	50.052
	Within Groups	14686.256	20	734.313	
	Total	161701.430	24		
COKE DRY	Between Groups	23939.278	4	5984.820	29.691
	Within Groups	4031.412	20	201.571	
	Total	27970.690	24		
CDI	Between Groups	14941.622	4	3735.406	7.180
	Within Groups	10405.472	20	520.274	
	Total	25347.094	24		
NUT COKE	Between Groups	5006.442	4	1251.610	2.648
	Within Groups	9453.808	20	472.690	
	Total	14460.250	24		
TMI	Between Groups	3857.560	4	964.390	8.430
	Within Groups	2287.949	20	114.397	
	Total	6145.510	24		
HM	Between Groups	9949.456	4	2487.364	11.411
	Within Groups	4359.579	20	217.979	
	Total	14309.035	24		
STEEL SCRAP	Between Groups	17427.030	4	4356.757	29.077
	Within Groups	2996.734	20	149.837	
	Total	20423.764	24		
LIME+CALCINED DOLO	Between Groups	3560.187	4	890.047	13.601
	Within Groups	1308.834	20	65.442	
	Total	4869.021	24		

ANOVA results indicate significant differences in the utilization of various raw materials across the five steel plants for most materials, with p-values less than 0.05, except for nut coke ($p = 0.064$). The highest F-value (64.887) for iron ore suggests substantial variability between plants. Significant differences were also found in sinter, coke dry, CDI, TMI, HM, steel scrap,and lime + calcined dolomite usage. Nut coke shows marginal significance, implying less variation among plants. These results highlight differing raw material usage efficiencies across.

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- BSP Coke Rate Average is on the higher side because of less Furnace Availability (Average-65.5%) and Utilization (Average-88.38%) is also less except for 22-23 Utilization was 96.8%
- BSL, Despite the consistency in production performance in the last 5 years, the Coke rate is high focus needs to be on upgradation for more CDI Nut Coke to reduce the Coke rate.
- RSP-An increase in production volume continuously from 20-21 to 22-23 reduced the coke rate to 482,461,457. Strategically more usage of sinter and less usage of iron ore resulted in good and efficient working of blast furnaces at RSP. Best CDI figures when compared to other plants
- ISP-Consistent working of single Bigger Blast Furnace operation improved coke rate and less TMI consumption. Single bigger Furnace operation with consistent input feed gave full advantage to BF operation (19-20 to 22-23) However 18-19 CDI was low (29Kg/T) for less Furnace Utilization (81%) for the year 18-19. Average scrap usage is only 3.5 % because of consistent and quality HM from single and bigger Blast Furnace.

The Figures for the last five financial years indicate that the performance of ISP (IISCO STEEL PLANT) is best around Raw Material utilization.

➢ *Equipment Availability & Utilization*

Table 4 EAU of BSP and RSP

Bhilai Steel Plant	**Equipment Availability & Utilization**							**Rourkela Steel Plant**	**Equipment Availability & Utilization**					
Parameters	**2022-23**	**2021-22**	**2020-21**	**2019-20**	**2018-19**	**Average**		**Parameters**	**2022-23**	**2021-22**	**2020-21**	**2019-20**	**2018-19**	**Average**
Sp-2 Availability	95.95	91.75	94.05	95.45	95.05	94.45		Sp M/C Availability	95.22	93.11	90.37	91.36	90.31	92.1
Bf Availability	71.3	76	58.6	51.7	69.9	65.5		Bf Availability	81.22	79.87	78.45	80.21	76.43	79.24
Convertor Availability	86.8	86.8	82	90	90.4	87.2		Convertor Availability	61.16	58.65	41.18	44.23	51.43	51.33
Urm	85	84	85	84	69	81.4		Pm Mill	74.98	91.11	91.23	87.52	87.25	86.418
Rsm	97.6	92.8	96.7	97.6	94.6	95.86		New Plate Mill	91.44	94.52	89.67	91.95	89.91	91.498
Pm	89.4	88.3	86.3	93.9	87.2	89.02		Hot Strip Mill-1	91.87	90	91.88	89.94	87.69	90.276
Brm	90.5	92.7	91.9	0	0	91.7		Erw Pipe Plant	57.17	57.78	56.99	57.19	56.76	57.178
Utilization								Sw Pipe Plant	85.75	75.56	85.48	85.79	85.75	83.666
Sp-2 Utilization	84.2	87.9	72.6	80.3	80.3	81.06		**Utilization**						
Sp-3 Utilization	86	80.8	74.1	77.6	69.9	77.68		Cob Utilization						
B F Utilization	96.8	91.8	89.2	83	81.1	88.38		Sp Utilization (2/3)	96.25	93.3	85.3	91.55	91.2	91.52
Convertor Utilization	73.1	73.1	74.9	80	77.6	75.74		B F Utilization	91.8	92.1	92.6	90.2	82.9	89.92
Urm	71.6	59.2	62.2	62.1	70.9	65.2		Convertor Utilization	96.83	98.02	94.57	78.6	92.06	92.016
Rsm	68.9	65.1	51.2	70	62.7	63.58		Mill Utilization						
Pm	88.9	77.1	65.4	73.8	72.9	75.62		Plate Mill	81.6	89.3	83.5	86.9	85.8	85.42
Brm	82.3	75.3	59.5	0	0	72.37		New Plate Mill	91.44	94.52	89.67	91.96	89.91	91.5
								Hot Strip Mill-1	60.88	78.74	69.12	78.67	79.37	73.356
								Erw Pipe Plant	39.35	41.75	40.43	46.78	43.46	42.354
								Sw Pipe Plant	72.97	71.22	58.19	58.01	68.23	65.724

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Table 5 Eau of Bsl and Dsp

Bokaro Steel Plant	**Equipment Availability & Utilization**							**Durgapur Steel Plant**	**Equipment Availability & Utilization**					
Sintering Plant M/C Availability	94.99	94.82	81.39	87.4	92.79	90.278		Parameters	2022-23	2021-22	2020-21	2019-20	2018-19	Average
Bf Availability	79.1	77.8	64.7	70.4	77.2	73.84		Sintering Plant M/C Availability	86	85	84	90	89	86.8
Sms	71.5	60.5	60.25	64.45	62.2	63.78		Bf Availability	95.61	96.74	89.39	94.99	97.95	91.45
Caster Availability	95.2	95.2	95.6	94.7	91.5	94.44		Convertor Availability	76.6	72.1	69.2	71.3	73.2	66.7
Hot Strip Mill	95.3	95.5	92.3	94	94.5	94.32		Caster Availability	97.26	99.57	98.65	97.14	96.36	97.8
Hrcf	86.58	84.52	85.75	85.38	85.75	85.6		Mill Availability	Na	Na	Na	Na	Na	
Tandem Mill	91.7	85.1	95.1	90.4	90.8	90.62		Merchant Mill						
Crm Skin Pass Mill	88.4	93.1	99.5	98.7	98.5	95.64		Wheel Plant	Na	Na	Na	Na	Na	
Crm (Crcf)	97.4	97.6	99.8	96.8	96.8	97.68		Axle Plant						
Crm (Slitting Line)	98.1	97.4	100	95.2	95.2	97.18		Section Mill	Na	Na	Na	Na	Na	
Crm (Hdgl &Ecl)				100	99.2	99.6		Msm						
Crm 3 (Spm)	97.17	94.72	93	96.22	0	76.22		Sp Utilization	87.03	84.51	76.96	80.08	81.85	75.41
Utilization								B F Utilization	96.34	95.23	91.76	95.45	94	94.56
Sp Utilization	86.78	85.37	85.52	87.54	86.84	86.41		Sms Utilization	70.4	63.8	57.3	63.1	65.7	57.3
B F Utilization	94.1	93.4	94.2	95.8	96.4	94.78		Caster Utilization (Billet)	69.58	61.87	60.6	65.99	66.28	64.864
Sms	70.4	71.35	58	57.2	60.45	63.48		Merchant Mill	71.8	72.4	55.5	65.4	65.2	63.3
Caster Utilization	83.7	79.4	77.1	84.7	86.1	82.2		Wheel Plant	49.9	53.3	45.5	46.3	50.2	49.7
Hot Strip Mill	73.1	74.4	72	69.4	73.4	72.46		Axle Plant	1	7.3	0.8	27.7	30.1	20.2
Hrcf	73.29	67.62	65.39	69.53	79.39	71.04		Section Mill	52.3	50.1	40.1	55.3	54	56
Tandem Mill	22.4	44.7	31	49.5	63.9	42.3		Msm	59	60	43	0	0	54
Crm Skin Pass Mill	37.9	51.8	36.1	50.4	59.8	47.2								
Crm (Crcf)	4.1	3.3	0	1.9	6.1	3.08								
Crm(Slitting Line)	1.6	4.7	0	6.1	7.4	3.96								
Crm 3 (Spm)	73.04	81.61	76.65	74.31	0	76.4								

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Table 6 EAU of ISP

Iisco Steel Plant	Equipment Availability & Utilization					
Parameters	2022-23	2021-22	2020-21	2019-20	2018-19	Average
Coke Ovens						
Sp M/C Availability	94	94	92	95.1	97	94.42
Bf Availability	94	90	85	92	85	89.2
Convertor Availability	92	93	92	94	91	92.4
Caster Availability						
Mill Availability						
Wrm	83.9	84.7	70.6	79.1	69.6	77.58
Bar Mill	85.5	84.8	69.9	75.95	73	77.83
Usm	83.7	91.7	65.3	29	54	64.74
Cob Utilization	93	95	91	94	91.5	92.9
Sp Utilization	99	97	92	89.3	77	90.86
B F Utilization	96	89	78	93	81	87.4
Sms Utilization	55	56.73	68.36	62.7	68	62.158
Caster Utilization	74.73	69.3	67.76	75.16	72.56	71.902
Wrm	83.9	79.6	77	80.2	76.8	79.5
Bm	80.1	70.6	58.7	72.7	71	70.62
Usm	68.2	35.4	45.2	71.7	64.8	57.06
Mill Utilization						69.06

➢ *Eau – Analysis*

- BSP: SP Availability for 2018 to 2023 was 94% but the Utilization was low (average of both SPs-81.06%) because of low BF availability of 65.5%. BF availability was low right from 2016-17 to 2020-21 because of more shutdowns, breakdowns, and unscheduled maintenance jobs in older Furnaces (BF-1 to BF-7). However, after blowing in BF-8 in February 2018 improvement could be seen in the overall performance figures of BFs of BSP. CONVERTOR utilization was less (Average-75.74%) due to less BF utilization. MILL Utilization was less for URM & RSM (average-64%) due to lower Utilization of URM during the period 2019-20, 2020-21, and 2021-22. Since the demand for rails is more and competitors like JSPL have already started supplying RAILWAYS it is very important to focus on a competitive edge by providing Head Hardened Rails and other fast-track movement rails. BRM is the most sophisticated mill and started in full swing in 2020-21 and since then its utilization is picking up. PM has tough competition from BSL and RSP who are performing well.

- BSL: BF Average Availability was 73.84%. It was good when compared to the BSP Average of 65.5 %. BF Utilization was as high as 94.78 % compared to BSP which was 88,38% SMS-1 was under the revamping and modernization stage of a few units during this period. So, the Availability was 45.36%. However, SMS-2 Availability was good at 82.2%. The utilization figures for SMS-1 and SMS-2 were 46.24% & 80.74%. Focus on operational efficiency and good quality products resulted in high NSR and good profitability and an average of 32.275 contributions to the overall profit of SAIL The average mill availability was as high as 92.11%. Utilization of HSM (72%), HRCF (71%), and CRM-3 (76.41%) are good figures. However, Tandem mill (42.3%) and CRM(CRCF) 47.6 % Are low. The focus should be more on these mills based on market demand.

- RSP: Better utilization of sintering plants (92%), Blast Furnaces (93%), and Steel Melting shops (92%) resulted in good techno-economic parameters and a good profit margin of 23.3% compared to BSP profit margin of 23%. However, the production figures of BSP are higher than those of RSP. (HM-27%, CS-27%, SS-26%) and RSP (HM-22%, CS-22%, SS-21%).However, for sustainability and due to intense competition from sister concern BSL more focus should be on mill utilization particularly ERW pipe (42%) and SW pipes (65%), and more focus should be on silicon steel

- DSP: The average BF utilization of considered 5 years is high (94%). Still, SMS utilization is less (57%) because mill utilization of all mills is less (MM-63%, WHEEL PLANT -49%, AXLE PLANT-21%, SECTION MILL AND MSM is AROUND 55%).DSP needs to focus on these areas with a good marketing strategy for better utilization of small plant resources.
- ISP: Coke ovens (92.9%), SP (90.86%), and BF (87.4%) Utilization figures are the best for this plant compared to other higher-capacity plants like BSP, BSL, and RSP. However, SMS utilization was less (62.16%) as MILL's average utilization was 69.06% only. More focus should be on USM (Average-57.06%) product sales as these are special and higher sections suitable for infrastructures like Airports and overbridges.

➢ *Quality Control*

To test the significant differences in the variables of Quality Control across the five different Steel Plants, ANOVA is used.

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Table 7 ANOVA of EAU Variables

Anova						
		Sum Of Squares	**Df**	**Mean Square**	**F**	**Sig.**
Indigenous	Between Groups	375.655	4	93.914	27.047	.000
	Within Groups	69.444	20	3.472		
	Total	445.100	24			
Imported	Between Groups	375.747	4	93.937	27.054	.000
	Within Groups	69.443	20	3.472		
	Total	445.191	24			
M40	Between Groups	26651.679	4	6662.920	9997.629	.000
	Within Groups	13.329	20	.666		
	Total	26665.008	24			
M10	Between Groups	276.367	4	69.092	947.553	.000
	Within Groups	1.458	20	.073		
	Total	277.825	24			
Coal To Hm Ratio	Between Groups	.007	4	.002	2.914	.047
	Within Groups	.012	20	.001		
	Total	.019	24			
Coke Rate	Between Groups	23958.800	4	5989.700	29.969	.000
	Within Groups	3997.200	20	199.860		
	Total	27956.000	24			
Fuel Rate	Between Groups	1465576.445	4	366394.111	918.106	.000
	Within Groups	7981.525	20	399.076		
	Total	1473557.970	24			
Cdi	Between Groups	1288825.278	4	322206.320	1567.833	.000
	Within Groups	4110.212	20	205.511		
	Total	1292935.490	24			
Sinter In Burden	Between Groups	478.007	4	119.502	69.337	.000
	Within Groups	34.470	20	1.723		
	Total	512.476	24			

The ANOVA results indicate significant differences in quality control variables across the five steel plants. Indigenous and imported materials, M40 and M10 indices, coke rate, fuel rate, CDI, and sinter in burden all show p-values less than 0.05, highlighting substantial variability among plants. The coal-to-HM ratio is marginally significant (p = 0.047). High F-values for M40 and M10 indicate especially large differences. Overall, quality control practices vary significantly across the plants.

Table 8 Quality Control Analysis of SAIL PLANTS - 1

Quality Control Analysis							
		BSP	**BSL**	**RSP**	**DSP**	**ISP**	
Parameters	**Units Of Measurements**	**Average**	**Average**	**Average**	**Average**	**Average**	
Coal Blend							
Indigenous	%	9.22	15.95	10.732	16.31	6.34	More Usage In Bsl And Dsp Which Gives A Cost-Benefit Compared To Other Plants.
Imported	%	90.78	84.05	89.27	83.69	93.66	More In Isp, Rsp, And Bsp
M40	%	85.82	78.136	79.34	82.14	86.36	Is Good For Bsp & Isp For Usage Of More Imported Coke.
M10	%	6.8	9.224	8.632	7.5	6.3	M10 Is Minimum For Isp & Bsp For More Of Imported Coal In The Blend
Coal To Hm Ratio	Ratio	0.9058	0.937	0.95	0.9462	0.939	This Ratio Is Minimum For Bsp
Coke Rate	Kg/T Of HOT METAL	460	482	422.4	467	398.2	This Is Minimal For ISP For Better Working With Single And Larger Furnace Operation Efficiently.

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Fuel Rate	Kg/T Of Hot Metal	563.72	566.2	570	538.8	550.4	This Is Minimal For Dsp.
Cdi	Kg/T Of Hot Metal	75.46	56.6	116.6	50.938	95.6	The Best For Rsp And Better In The Case Of Isp
Sinter In Burden	%	65.88	66.286	73.59	68.15	76.978	More Sinter Usage With Minimum Iron Ore And Usage Of Pallets In 2022-23 In Rsp And Isp
Slag Rate(Kg/T)	Kg/T Of Hot Metal	452.2	400	383	348	356.5	Minimum For Dsp And Good In Case Of I And Rspsp

Table 9 Quality Control Analysis of SAIL PLANTS - 2

AVERAGE OF 5 FINANCIAL YEARS 2018-19 TO 2022-23							
PARAMETERS	**UNITS OF MEASUREMENTS**	**BSP**	**BSL**	**RSP**	**DSP**	**ISP**	**REMARKS**
COAL BLEND							
INDIGENOUS	%	9.22	15.95	10.732	16.31	6.34	More usage in BSL and DSP which gives a cost-benefit compared to other plants.
IMPORTED	%	90.78	84.05	89.27	83.69	93.66	More in ISP, RSP, and BSP
M40	%	85.82	78.136	79.34	82.14	86.36	Is good for BSP & ISP for usage of more imported coke.
M10	%	6.8	9.224	8.632	7.5	6.3	M10 is the minimum for ISP & BSP for more imported coal in the blend
COAL TO HM RATIO	RATIO	0.9058	0.937	0.95	0.9462	0.939	This ratio is minimum for BSP
Coke rate	Kg/T of HOT METAL	460	482	422.4	467	398.2	This is minimal for ISP for better working with single and larger furnace operation efficiently.
Fuel Rate	Kg/T of HOT METAL	563.72	566.2	570	538.8	550.4	This is minimal for DSP.
CDI	Kg/T of HOT METAL	75.46	56.6	116.6	50.938	95.6	The best for RSP and better in the case of ISP
SINTER In Burden	%	65.88	66.286	73.59	68.15	76.978	More sinter usage with minimum iron ore and usage of pallets in 2022-23 in RSP and ISP
SLAG RATE(Kg/T)	kg/T of HOT METAL	452.2	400	383	448	356.5	Minimum for ISP and good in case of RSP

Overall QC parameters give a clear picture that ISP had an edge over other steel plants in Iron Zone which contributes to 60 % of the cost of production in a steel plant operation

- *Productivity*

Table 10 Productivity figures of SAIL Plants

Average Of 5 Years	**Bsp**	**Bsl**	**Rsp**	**Dsp**	**Isp**
Bf Coke From Dry Coal	76.1	69.28	69.2	68.77	69.16
Sinter Productivity (2&3)	1.106	1.109	1.297	1.028	1.26
SP (Yield From Charge Mix) %	73.32	72.16	69.12	68.77	77.54
Bf Productivity	1.72	1.679	1.873	1.656	1.92

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Crude Steel From Metallic Charge	86.56	88.78	88.32	88.16	91
Mill Yield	93.99	91.64	87.17	92.8	95.31

- Conversion of Coal to Coke Is Good in Bsp
- Sinter Productivity Is Good in Rsp
- Bf Productivity, Metallic Yield, And Mill Yield Are Very Good in Isp.

Table 11 Financial Figures of SAIL Plants

Financial Efficiency					
(Rs. In Crores)	**Fy 2022-23**	**Fy 2021-22**	**Fy 2020-21**	**Fy 2019-20**	**Fy 2018-19**
Sail Profit After Tax	1,903.00	12,015.00	3,850.02	2,021.54	2,179.00
Bsp	376.16	2,240.34	1,095.81	1,799.03	509.37
Dsp	638.88	1,004.37	733.07	-442	278.62
Rsp	521.07	5,610.26	2,106.40	-409.2	1,472.21
Bsl	840.84	6,052.86	2,251.50	48.44	1,916.49
Isp	339.77	661.82	66.51	-1,091.69	-402.05
Sail (Rs. In Crores)	**Fy 2022-23**	**Fy 2021-22**	**Fy 2020-21**	**Fy 2019-20**	**Fy 2018-19**
Sales Turn Over (Gross Sales)	1,03,768	1,02,805	68,452	61,025	66,267
Net Sales	1,03,768	1,02,805	68,452	61,025	66,267
Ebitda	9,379	22,364	13,740	11,199	10,283
Depreciation	4,963	4,274	4,102	3,755	3,385

Table 12 Financial Figures of BSP

Bsp (Rs. In Crores)	**Fy 2022-23**	**Fy 2021-22**	**Fy 2020-21**	**Fy 2019-20**	**Fy 2018-19**	**Average**
Sales Turn Over	28,822	26,494	19,153	19,055	16,715	22,048
Total Income	30,516	27,993	20,015	19,487	17,018	23,006
Ebitda (Back Calculation)	2,197	4,031	3,450	4,367	2,301	3,269
Depreciation	1,242	1,177	1,148	968	692	1,046
Financial Cost (Interest)	578	581	1,175	1,312	1,042	937
PBT (Before Exceptional Items)	376	2,273	1,127	2,087	567	1,286
Exceptional Items	0	0	31	288	58	75
PBT (After Exceptional Items)	376	2,273	1,096	1,799	509	1,211
TAX (Not At Plant Level)	NA	NA	NA	NA	NA	
Pbt	376	2,240	1,096	1,799	509	1,204

Table 13 Financial Figures of BSL and RSP

Bsl (Rs. In Crores)	**Fy 2022-23**	**Fy 2021-22**	**Fy 2020-21**	**Fy 2019-20**	**Fy 2018-19**	**Average**
Sales Turn Over	23,406	25,924	16,223	13,371	16,365	4485.76
Total Income	26,344	28,532	16,501	13,412	16,456	5750.982
Ebitda	2,142	7,275	3,259	1,111	2,902	1574.822
Depreciation	924	888	771	643	611	112.316
Financial Cost (Interest)	378	323	235	383	338	331
Pbt (Before Exceptional Items)	841	6,064	2,252	85	1,953	1535.192
Exceptional Items	0	0	0.51	37	37	17.5848
Pbt (After Exceptional Items)	841	6,064	2,252	48	1,916	1546.847
Tax (Not At Plant Level)	Na	Na	Na	Na	Na	#Num!
Pbt	841	6,053	2,252	48	1,916	1544.123
Rsp (Rs. In Crores)	**Fy 2022-23**	**Fy 2021-22**	**Fy 2020-21**	**Fy 2019-20**	**Fy 2018-19**	**Average**
Sales Turn Over	24,220	24,239	14,010	11,986	14,606	17,812
Total Income	25,600	26,831	15,311	12,538	15,605	19,177
Ebitda	2,720	7,283	3,437	1,137	2,864	3,488
Depreciation	1,528	935	838	816	755	974
Financial Cost (Interest)	627	385	469	671	597	550
Pbt (Before Exceptional Items)	564	5,963	2,129	-350	1,513	1,964

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Exceptional Items	43	353	23	59	41	104
Pbt (After Exceptional Items)	521	5,609	2,106	-409	1,472	1,860
Tax (Not At Plant Level)	Na	Na	Na	Na	Na	#Div/0!
Pbt	521	5,610	2,106	-409	1,472	1,860

Table 14 Financial Figures of ISP

Isp (Rs. In Crores)	**Fy 2022-23**	**Fy 2021-22**	**Fy 2020-21**	**Fy 2019-20**	**Fy 2018-19**	**Average**
Sales Turn Over	13,027	11,513	7,919	7,571	7,779	9,562
Total Income	13,521	12,201	8,356	7,752	7,948	9,956
Ebitda	1,369	1,625	1,269	327	1,050	1,128
Depreciation	811	798	756	760	747	774
Financial Cost (Interest)	218	191	389	622	685	421
Pbt (Before Exceptional Items)	340	636	124	-1,055	-382	-67
Exceptional Items	0	0	57	37	20	23
Pbt (After Exceptional Items)	340	636	67	-1,092	-402	-90
Tax (Not At Plant Level)	Na	Na	Na	Na	Na	#Div/0!
Pbt	340	662	67	-1,092	-402	-85

Table 15 Financial Figures of DSP

Dsp (Rs. In Crores)	**Fy 2022-23**	**Fy 2021-22**	**Fy 2020-21**	**Fy 2019-20**	**Fy 2018-19**	**Average**
Sales Turn Over	12,188	11,194	8,419	7,379	8,836	9,603
Total Income	13,250	11,853	8,967	7,727	9,099	10,179
Ebitda	795	1,436	1,238	121	787	875
Depreciation	293	279	265	228	200	253
Financial Cost (Interest)	162	86	175	295	289	202
Pbt (Before Exceptional Items)	340	1,071	798	-403	298	421
Exceptional Items	-298	0	65	39	19	-35
Pbt (After Exceptional Items)	639	1,071	733	-442	279	456
Tax (Not At Plant Level)	Na	Na	Na	Na	Na	#Div/0!
Pbt	639	1,004	733	-442	279	443

Table 16 AVERAGE OF 5 YEARS of SAIL Plants

Average of 5 Years (Rs. In Crores)	**Bsp**	**Bsl**	**Rsp**	**Dsp**	**Isp**
Sales Turn Over	22048	4485.76	17182	9603	9562
Total Income	23006	5751	19177	10179	9956
Ebitda (Back Calculation)	3,269	1574.82	3488	875	1128
Depreciation	1046	112.316	974	253	774
Financial Cost (Interest)	937	331	550	202	421
Pbt (Before Exceptional Items)	1286	1535.2	1964	421	-67
Exceptional Items	75	17.6	164	-35	23
Pbt (After Exceptional Items)	1211	1546.85	1860	456	-90
Depreciation, Fin Cost	1983	443.32	1524	455	1195
Pbt	1204	1544.13	1860	443	-85

➢ *Finance*

To test the significant differences in the variables of Finance across the five different Steel Plants, ANOVA is used.

Table 17 ANOVA of Financial Variables

Anova						
		Sum Of Squares	**Df**	**Mean Square**	**F**	**Sig.**
Sales Turn Over	Between Groups	654222164.160	4	163555541.040	8.018	.001
	Within Groups	407962238.000	20	20398111.900		
	Total	1062184402.160	24			
Total Income	Between Groups	731637802.640	4	182909450.660	6.761	.001
	Within Groups	541091890.800	20	27054594.540		
	Total	1272729693.440	24			
Ebitda	Between Groups	33798007.440	4	8449501.860	3.456	.027

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	Within Groups	48904299.600	20	2445214.980		
	Total	82702307.040	24			
Depreciation	Between Groups	1923445.040	4	480861.260	14.034	.000
	Within Groups	685300.800	20	34265.040		
	Total	2608745.840	24			
Financial Cost (Interest)	Between Groups	1585556.160	4	396389.040	10.270	.000
	Within Groups	771946.400	20	38597.320		
	Total	2357502.560	24			
Pbt (Before Exceptional Items)	Between Groups	19393913.360	4	4848478.340	1.906	.149
	Within Groups	50867046.800	20	2543352.340		
	Total	70260960.160	24			
Exceptional Items	Between Groups	59044.210	4	14761.053	1.284	.310
	Within Groups	229952.712	20	11497.636		
	Total	288996.922	24			
Pbt (After Exceptional Items)	Between Groups	18397602.240	4	4599400.560	1.895	.151
	Within Groups	48537245.600	20	2426862.280		
	Total	66934847.840	24			
Pbt	Between Groups	18397877.840	4	4599469.460	1.903	.149
	Within Groups	48350603.200	20	2417530.160		
	Total	66748481.040	24			

ANOVA results for financial variables across the five steel plants indicate significant differences in Sales Turnover ($F = 8.018$, $p = .001$), Total Income ($F = 6.761$, $p = .001$), EBITDA ($F = 3.456$, $p = .027$), Depreciation ($F = 14.034$, $p < .000$), and Financial Cost (Interest) ($F = 10.270$, $p < .000$). No significant differences were found for PBT (Before and After Exceptional items) and Exceptional items. These results highlight financial variability among the plants for most metrics. shareholder value while supporting sustainable growth.

➢ *Final Analysis*

Bsp's Contribution In Hot Metal, Crude Steel, And Saleable Steel Production Was 27%, 28%,26% Respectively, Whereas Bsl' Contribution Was 23%, 22% 22% Respectively And Rsp Contributed 22%, And 22%, 21% Respectively But The Profit Figures Show A Remarkable Show By Bsl With 32%Share And Rsp Stood Second With 23.30% And Bsp In Spite Of High Volume In All Three Production Areas Stood 3 Rd With 23.26% Contribution.
Even With Less Volume Of Hm, Cs, Ss Production Of 13%, 12%, 10%, Of Total Sail Figures For Both Dsp And Isp Made Profit For Last Consequtive 3 Years Which Were Otherwise Loss-Making Units For Years Togather
Isp Performed Very Well In Raw Material Utilization And Equipment Utilization, Quality Control And Productivity Areas In The Overall Process Performance
Profit Figures For 2019-20 Were Due To The Low-Grade Iron Ore Fines Taken Into Books Of Account As Inventory (3178* Crores) And Same Is The Case For Bsp *

V. CONCLUSION

- Equipment Performance: The availability and utilization of equipment in the IISCO Steel Plants (ISP) were found to be superior in areas such as coke ovens, sintering plants, and blast furnaces compared to other integrated steel plants within SAIL. However, the mills demonstrated lower utilization, suggesting the need for a more targeted marketing strategy. This strategy should focus on producing specialized and larger sections that meet the demands of infrastructural development both in India and internationally.
- Rail Product Competition: There is increasing competition from private companies and imports in the rail product segment. To address this, utilization and availability of the Universal Rail Mill (URM) and Rail Mill should be improved, particularly with an emphasis on producing high-quality rails for high-speed tracks. This is particularly relevant for BSP's wheel and axle production at DSP. Overall, mill utilization across all of SAIL's integrated plants needs to be enhanced.
- Quality Control: The quality control (QC) parameters indicate that ISP has a competitive edge over other steel plants in the iron zone, which is responsible for 60% of production costs in steel plant operations.
- Production Contribution: BSP contributes significantly to the production of hot metal, crude steel, and saleable steel compared to other SAIL plants. However, despite BSP’s

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advantage in economies of scale, BSL and RSP have consistently delivered higher profitability. This suggests that BSL and RSP benefit from better overall process efficiency, which offsets their smaller scale of production.

- Process Efficiency Improvements: Despite lower volumes of hot metal, crude steel, and saleable steel production at the Durgapur and Burnpur plants, improvements in process efficiency have enabled these plants to turn a profit over the past three fiscal years, reversing years of losses.
- Operational Efficiency at ISP: ISP's consistent operation of a single large furnace has led to the lowest coke rate, optimal CDI figures, and minimal iron ore consumption. Consequently, ISP has performed exceptionally well in terms of raw material utilization, equipment availability and utilization, quality control, and overall productivity based on the process efficiency indicators studied. Looking forward, the steel demand is projected to continue growing, with global production expected to reach 2.2 billion metric tons by 2026. Factors driving this growth include rising demand in emerging markets and technological advancements that improve production efficiency. Strategic cost control measures, particularly in the raw material and iron zones where 60% of production costs are concentrated, are crucial. Building strong relationships with suppliers and customers fosters a collaborative ecosystem that supports continuous improvement through the sharing of best practices, joint research, and collaborative product development. The focus should shift from a volume-based strategy to product quality and customer satisfaction. Additionally, leveraging data for regular monitoring and predictive maintenance can provide valuable insights into equipment performance, production trends, and maintenance needs, leading to more informed decision-making and optimized operations.

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