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PERFORMANCE EVALUATION AND LOSS ANALYSIS OF A SEMI-AUTOMATIC HOT PRESS MACHINE USING OVERALL EQUIPMENT EFFECTIVENESS IN THE FIBERBOARD INDUSTRY

Kamal Hussain Laghari[1], Abdul Salam Soomro[2], Muhammad Ali Khan[3], Kazim Raza Burdi*[4]

[1]*Post-Graduate Student, Department of Industrial Engineering and Management, Mehran University of Engineering & Technology, Jamshoro-76062, Sindh, Pakistan.*
[2]*Professor, Department of Industrial Engineering and Management, Mehran University of Engineering & Technology, Jamshoro-76062, Sindh, Pakistan.*
[3]*Assistant Professor, Department of Industrial Engineering and Management, Mehran University of Engineering & Technology, Jamshoro-76062, Sindh, Pakistan.*
[*4]*Lab Supervisor, Department of Industrial Engineering and Management, Mehran University of Engineering & Technology, Jamshoro-76062, Sindh, Pakistan.*

[*4]kazimrazapk340@gmail

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Corresponding Author: *
Kazim Raza Burdi

Abstract

Overall Equipment Effectiveness (OEE) is an important performance measurement tool for identifying equipment-related losses and evaluating manufacturing productivity through Availability, Performance, and Quality. This study evaluates the operational effectiveness of a semi-automatic hot press machine used in the lamination sector of Al-Noor MDF, Shahpurjahania, Pakistan. A case study approach was adopted using quantitative production and downtime records supported by direct observation, time and motion analysis, and discussions with operators and maintenance personnel. Data were collected over a 60-day study period and analyzed using OEE, Pareto analysis, and the Six Big Losses framework. The results indicate that the machine produced 23,765 boards against an ideal production capacity of 72,000 boards, while 300 boards were classified as rejected/B-grade. The calculated Availability, Performance, and Quality were 40.08%, 70.17%, and 98.74%, respectively, resulting in an overall OEE of 27.79%. Pareto analysis identified production stoppages (45.42%), preventive maintenance (18.35%), and unavailability of labor (14.13%) as the major downtime contributors, collectively accounting for 77.90% of the identified causes. The Six Big Losses analysis recorded 49,670 minutes of classified losses, with planned stops representing the largest contribution (39.94%), followed by production rejects (23.49%) and startup rejects (17.32%). Comparison with world-class benchmarks revealed substantial gaps in Availability (49.92 percentage points), Performance (24.83 percentage points), and overall OEE (57.21 percentage points), while Quality was close to the benchmark with a gap of only 0.26 percentage points. The findings demonstrate that machine availability and operating performance are the primary areas requiring improvement. The study recommends strengthening preventive maintenance, reducing production stoppages, improving labor availability and operator

practices, optimizing setup activities, and applying continuous improvement techniques to enhance the OEE of the hot press machine.

I. INTRODUCTION

Globalization has significantly transformed economies by expanding international trade, finance, communication, and business operations [1]. Customer demands have become a key driver of manufacturing strategies and operational performance [2]. Organizations operate in highly competitive and dynamic environments that require continuous adaptation to sustain success [3]. Global competition has compelled manufacturers to adopt innovative, quality-oriented, and customer-focused strategies to remain competitive [4]. Consequently, organizations emphasize reducing production costs, increasing profitability, and improving productivity through effective process management and standardized techniques [5]. Productivity improvement is essential for increasing output while reducing the consumption of labor, time, and capital resources [6]. Effective maintenance has become a strategic requirement due to increasing technological complexity, globalization, and changing market demands [7] [8] [9]. Poor maintenance practices reduce productivity, increase production costs, and maintenance expenses typically account for 25–30% of total production costs, directly affecting organizational profitability [10]. Therefore, maintenance is now regarded as a strategic function that significantly influences manufacturing performance [11]. Total Productive Maintenance (TPM) was developed in Japan and introduced in 1971 to address maintenance challenges and improve equipment reliability and organizational efficiency [12]. TPM focuses on maximizing equipment performance because production equipment directly influences quality, productivity, cost, inventory, safety, and production output [13]. Overall Equipment Effectiveness (OEE) was introduced by Nakajima under the TPM framework, as a key performance indicator for evaluating equipment utilization and supporting continuous improvement [12]. OEE is widely applied in Lean Manufacturing to assess equipment effectiveness and identify improvement opportunities [14]. It evaluates equipment performance using three components: availability, performance efficiency, and quality rate [15]. Overall Equipment Effectiveness (OEE) is a key performance indicator that measures equipment efficiency by evaluating losses caused by downtime, minor stoppages, and speed reductions, which directly affect productivity, quality, and delivery performance [16]. Manufacturing industries increasingly adopt lean philosophy to enhance productivity and operational performance [17]. The Toyota Production System (TPS) focuses on waste elimination, efficiency improvement, and customer value creation [18], [19]. Similarly, Lean Manufacturing (LM) provides a systematic approach to eliminate waste, optimize resources, and improve operational efficiency [20], [21]. Consequently, LM has become a widely recognized methodology for improving manufacturing productivity and economic performance [22].

This research was conducted at Al-Noor MDF, Shahpur Jahania, Pakistan, a leading manufacturer of Medium Density Fiberboard (MDF) that produces high-quality boards for the furniture, construction, and interior design industries using advanced manufacturing technologies and sustainable production practices. The fiberboard industry faces significant productivity challenges due to equipment inefficiencies, including frequent minor stoppages, speed losses, and unplanned downtime, which reduce Overall Equipment Effectiveness (OEE) and adversely affect production efficiency, product quality, and on-time delivery. The lack of effective productivity measurement and benchmarking further contributes to operational inefficiencies, increased waste, and higher production costs. The aim of this research is to evaluate the productivity and operational effectiveness of the semi-automatic hot press machine at Al-Noor MDF fiberboard industry using Overall Equipment Effectiveness (OEE). To achieve this aim, the study establishes the

following objectives: **(1)** to identify and analyze the Six Big Losses affecting the performance and productivity of the semi-automatic hot press machine; **(2)** to evaluate the Overall Equipment Effectiveness (OEE) of the semi-automatic hot press machine by determining its key components, namely Availability, Performance, and Quality; **(3)** to compare the existing OEE performance with world-class OEE benchmarks and identify performance gaps in Availability, Performance, Quality, and overall OEE, using benchmark values of 90% Availability, 95% Performance, 99% Quality, and 85% overall OEE; **(4)** to identify the major causes of downtime and production losses contributing to the low effectiveness of the semi-automatic hot press machine through downtime and Pareto analysis, with particular emphasis on ranking production stoppages, preventive maintenance, labor unavailability, and other recorded causes to prioritize the major sources of loss; and **(5)** to propose practical improvement measures for reducing the identified losses and improving the existing OEE and productivity of the semi-automatic hot press machine.

II. LITERATURE REVIEW

Globalization has created opportunities for economic growth and innovation while increasing the need for sustainable and equitable development [1]. Customer demands drive manufacturing strategies, requiring organizations to deliver high-quality products at the right cost, time, and quantity to remain competitive [2]. Modern organizations operate in increasingly dynamic and uncertain business environments, making innovation, adaptability, and customer focus essential for long-term success [3]. Global competition provides equal market opportunities but requires manufacturers to emphasize quality, innovation, and customer satisfaction to sustain a competitive advantage [4]. Consequently, organizations are increasingly adopting productivity assessment tools and continuous improvement practices to optimize manufacturing performance and maintain competitiveness [5]. Productivity improvement is essential for enhancing manufacturing efficiency, competitiveness, and long-term organizational growth [6]. Industrial engineering improves productivity by optimizing processes and resource utilization while supporting continuous improvement with minimal capital investment [16]. The case studies demonstrated that lean manufacturing techniques such as line balancing, time and motion study, takt time, SMED, SAM analysis, method study, and work measurement can significantly improve productivity and assembly-line performance in textile and automobile manufacturing [23]–[26]. Kalwar et. al. (2022) demonstrated the application of linear programming, mathematical modelling, simulation, ERP implementation, and VBA-based automation to optimize product mix, maximize profit, and improving manufacturing performance [27]–[29]. Khan (2024): The study highlights the integration of Lean Manufacturing, Industry 4.0, and sustainable manufacturing, demonstrating how IoT, AI, JIT, VSM, 5S, TPM, and Kaizen can improve process efficiency and resource utilization. These practices also contribute to waste reduction and environmental sustainability. However, high investment costs, infrastructure limitations, inadequate regulatory support, and workforce skill shortages remain major barriers to successful implementation [30]–[32]. TPM considers production equipment as the foundation of manufacturing performance and focuses on improving its reliability and effectiveness. Effective TPM implementation enhances productivity, supports continuous improvement, and increases organizational competitiveness and customer satisfaction [13]. There are total eight pillars of TPM on which it sustains which include 1) focused improvement, 2) Autonomous maintenance, 3) Planned maintenance, 4) Early Equipment management, 5) Quality maintenance, 6) Education and training, 7) Administrative & office maintenance and 8) Safety health and environment.



Figure 1: Pillars of TPM Source: [13]

Lean manufacturing improves productivity by eliminating waste, increasing efficiency, and creating customer value through continuous improvement and employee involvement [18], [19]. Manufacturing organizations widely adopt LM to enhance operational performance and maintain competitiveness in dynamic markets [20], [21]. LM also supports cost reduction, productivity improvement, and sustainable organizational growth [22]. Lean manufacturing is defined as a systematic management approach that delivers customer value while minimizing unnecessary waste [33]. Khan (2018) investigated the applications the lean manufacturing wastes in the textile and garment industry and highlighted the use of Lean Six Sigma, 5S, TPM, SMED, Kanban, Kaizen, VSM, and TQM to eliminate waste and improve productivity [34], [35]. Khan et al. (2020) examined the lean manufacturing implementation in Pakistan and highlighted the key benefits and barriers for lean implementation [36]. Zaidi et al. (2020) highlighted the use of 5S, Kaizen, JIT, VSM, and TPM across manufacturing industries to reduce waste and improve productivity, quality, and operational efficiency [37]. The recent studies across the automobile, textile, and pharmaceutical industries highlighted the applications of lean manufacturing practices to improve overall operational performance [38]–[41]. Khan et al. (2020) The studies in the textile spinning industry of Sindh, Pakistan identify process defects and interrelationships among the seven Lean wastes using WRM, while highlighting practices such as 5S, Kaizen, Poka-Yoke, Jidoka, standardized work, and root cause analysis for reducing defects and improving quality. The findings support systematic Lean implementation for waste reduction, quality improvement, and process efficiency [42], [43]. The practitioners demonstrated the effectiveness of Lean, Six Sigma, and Lean Six Sigma (LSS) tools, including DMAIC, Gemba, VSM, and WRM, in identifying and eliminating wastes and defects across pharmaceutical, textile, food, and SME industries [44]–[48]. Keegan classified Overall Equipment Effectiveness (OEE) into three components: availability, performance, and quality, providing a comprehensive framework for evaluating equipment effectiveness. Availability measures equipment operating time, performance evaluates production speed against the ideal rate, and quality measures the proportion of defect-free

products. Together, these components help identify production losses and support targeted improvements to enhance productivity and operational efficiency [49].

Figure 2: Elements of OEE Source: [49]

Effective maintenance has become a strategic requirement due to increasing technological complexity, globalization, and the need for continuous production [7] [8] [9]. High-quality maintenance improves equipment reliability, production efficiency, and profitability through preventive, predictive, and data-driven maintenance practices [10]. Consequently, maintenance is recognized as a key driver of operational efficiency, cost control, customer satisfaction, and long-term sustainability in manufacturing industries [11]. TPM is a comprehensive maintenance system that goes beyond traditional approaches. Total Productive Maintenance (TPM) is a comprehensive maintenance approach that involves all employees to improve equipment performance, reduce downtime, and support continuous improvement

The concept of the "Six Big Losses" is an important aspect of OEE analysis. The Six Big Losses classify the major sources of production inefficiencies affecting Overall Equipment Effectiveness (OEE) and help organizations identify targeted improvement opportunities to enhance equipment performance and productivity [12] [51]. The Six Big Losses of Overall Equipment Effectiveness (OEE) are equipment breakdowns, setup and changeover losses, minor stops and idling, reduced speed losses, defects and rework, and startup and yield losses. Equipment breakdowns are unplanned failures that cause production downtime, reduce equipment availability, and lower Overall Equipment Effectiveness (OEE). Setup and changeover losses occur when equipment is adjusted for a new production run, reducing available production time. Minor stops and idling are short production interruptions that reduce equipment performance and overall efficiency. Reduced speed losses occur when equipment operates below its designed capacity, decreasing production output and performance efficiency. Defects and rework reduce product quality and OEE by increasing scrap, rework, and material waste. Startup and yield losses occur during machine start-up when production has not yet reached stable operating conditions or required quality standards [12] [51]. Addressing the Six Big Losses through preventive maintenance, optimized changeovers, operator training, and continuous improvement helps organizations improve Overall Equipment Effectiveness (OEE), enhance equipment performance, and increase productivity. OEE analysis also supports prioritizing improvement efforts and efficient resource allocation to achieve higher manufacturing efficiency and competitiveness.



Figure 5: Six Big Losses in Production Source: [12] [51]

Previous studies have established Overall Equipment Effectiveness (OEE) as an effective tool for measuring equipment performance through Availability, Performance, and Quality and for identifying major sources of production loss. Its integration with Lean Manufacturing, DMAIC, FMEA, and other improvement techniques has produced substantial performance gains, with reported OEE improvements from 49% to 64%, 68% to 87%, and achievement of 81.73% in different manufacturing applications [15], [53], [54]. Few studies demonstrated that systematic identification and elimination of bottlenecks, downtime, and process inefficiencies can significantly improve equipment effectiveness and productivity [55], [56]. TPM-based

investigations consistently identify equipment breakdowns, downtime, idle time, and maintenance-related losses as major causes of low OEE. TPM implementation has increased OEE to 68.04%, while other applications have demonstrated improvements in equipment reliability, availability, product quality, and maintenance performance [57]–[61]. Preventive maintenance, autonomous maintenance, operator training, and systematic failure analysis have therefore been widely recommended for reducing equipment failures and sustaining OEE improvement. Reliability measures such as MTBF and MTTR, together with the Six Big Losses framework, have also been used to identify maintenance-related performance gaps [58], [60]. Studies focusing on the Six Big Losses show that production stoppages, equipment breakdowns, setup and adjustment time, speed losses, and quality losses are recurring constraints on productivity. For example, OEE was reported at only 31.55% in a motorcycle assembly plant, mainly due to severe performance and downtime losses, while a heavy engineering study reported 44.5% OEE against the 85% world-class benchmark [62], [63]. In another application, OEE increased from 60% to 71% after Pareto and Fishbone analyses were used to identify and address the major losses [64]. Similarly, targeted process improvements increased OEE from 49.8% to 77.6% by eliminating setup and material-handling losses [14]. These findings highlight the importance of prioritizing the most significant losses rather than addressing all sources of downtime equally. Root-cause and Lean improvement techniques, including Pareto analysis, Fishbone diagrams, Why-Why analysis, FMEA, 5-Why analysis, VSM, 5S, Kaizen, SMED, Kanban, and standardized work, have been widely applied alongside OEE and TPM to reduce waste, improve machine utilization, and enhance productivity [35], [41], [57], [62], [65]–[68]. Recent studies further confirm the applicability of OEE across automotive, pharmaceutical, injection molding, plastic, and textile manufacturing. Notably, preventive maintenance reduced downtime from 23,540 to 2,064 minutes in an injection-molding application, while the combined use of OEE, 5S, and Kanban increased OEE substantially across stitching, checking, and packing operations in a textile company [69], [70]. Overall, the reviewed literature confirms that OEE is an effective tool for measuring and diagnosing equipment performance, while TPM, Lean Manufacturing, DMAIC, Pareto Analysis, FMEA, root-cause analysis, and preventive maintenance provide effective approaches for reducing equipment-related losses and improving productivity. However, existing studies have primarily focused on pharmaceutical, fertilizer, food, automotive, heavy engineering, injection molding, and machining industries, with limited attention given to semi-automatic hot press machines in the fiberboard industry. Moreover, limited research has combined OEE measurement with detailed downtime analysis and Six Big Loss classification in this specific production environment. Therefore, the present study addresses this research gap by evaluating the Availability, Performance, and Quality of a semi-automatic hot press machine, identifying and prioritizing its major downtime sources and Six Big Losses, comparing its OEE with world-class benchmarks, and proposing targeted improvement measures to enhance machine effectiveness and productivity.

III. METHODOLOGY & METHODS

This study adopted a **case study research design** to investigate the operational performance of a semi-automatic hot press machine in the lamination sector of Al-Noor MDF, Shahpurjahania, near Moro, District Shaheed Benazirabad, Sindh, Pakistan. Established in 1987 as a division of Al-Noor Sugar Mills, the lamination sector employs approximately 95 personnel and operates six hot press machines, including one semi-automatic, four manual, and one short-cycle machine. The study specifically focused on the semi-automatic hot press machine used to laminate MDF boards with decorative impregnated sheets under controlled temperature, pressure, and pressing time. The study was conducted over a 60-day period to examine machine performance within its actual manufacturing environment and identify

equipment, process, and operational factors contributing to productivity losses.



Figure 6: Research Methodology Source: [Authors]

Both quantitative and qualitative data were collected from machine logs, production records, direct observations, time and motion studies, and discussions with operators, maintenance personnel, and managers. The quantitative data included operating time, downtime, production quantity, rejection quantity, production rates, and changeover information, while historical performance records and industry benchmarks were used as secondary information. The recorded stoppages were initially categorized into unplanned downtime, planned downtime, and miscellaneous losses. Pareto analysis was subsequently used to rank downtime causes and identify the major contributors to production losses. The identified losses were further classified according to the Six Big Losses framework into unplanned stops, planned stops, small stops, slow cycles, production rejects, and startup rejects, and their effects on Availability, Performance, and Quality were examined. Finally, the machine's OEE was determined and compared with world-class benchmarks to identify performance gaps and prioritize improvement areas. A distinction was maintained between total recorded downtime and the subset of losses classified under the Six Big Losses framework; losses that could not be assigned to these categories were retained separately to avoid double counting and ensure consistency in the analysis.

Overall Equipment Effectiveness (OEE) was evaluated using its three standard components: Availability, Performance, and Quality. Production records, operating-time data, downtime records, and quality information were used as inputs for the OEE assessment.

Availability was determined by comparing the actual operating time of the machine with the applicable scheduled production time. This measure was used to assess losses resulting from machine stoppages and downtime.

Ideal Cycle Time was determined from the planned production time and target production quantity per shift. This value represented the theoretical time required to produce one board under ideal operating conditions.

Performance was evaluated by comparing the production achieved during actual operating time with the production that could theoretically be achieved at the ideal cycle time.

Quality was determined by comparing the quantity of good boards with total production. Rejected and B-grade boards were considered when determining the number of good products.

Finally, Overall Equipment Effectiveness was calculated by multiplying the three OEE components:

The calculated Availability, Performance, Quality, and overall OEE values were subsequently presented and interpreted in the Results & Discussion section. The measured OEE components were compared with the adopted world-class benchmarks of 90% Availability, 95% Performance, 99% Quality, and 85% overall OEE. This comparison was used to quantify the performance gaps and determine the major areas requiring improvement.

IV. DATA ANALYSIS & RESULTS

The study was conducted in the lamination sector of a Medium Density Fiberboard (MDF) manufacturing industry. The sector produces laminated MDF boards using different decorative surface materials, including High-Pressure Laminate (HPL), Low-Pressure Laminate (LPL), and melamine laminate. The lamination operation comprises several hot-pressing machines, including a semi-automatic hot press machine, manual hot press machines, and a short-cycle hot press machine. The present study focuses specifically on the semi-automatic hot press machine because of its significant production role and the need to identify and quantify its major sources of productivity loss. The semi-automatic hot press machine is used in the lamination process to bond MDF boards with impregnated decorative sheets under controlled temperature, pressure, and pressing time. The machine consists of a supporting frame, chain-driven sliders, heated pressing plates, a hydraulic system, a control panel, and an automatic unloading mechanism. The sliders transport MDF boards toward the loading and impregnation area, while the heated plates apply the required temperature and pressure during the lamination cycle. The control panel regulates the principal operating parameters, whereas the automatic unloading mechanism transfers the laminated boards to the unloading section.



Figure 7: Semi-automatic hot press machine (L) & Control Panel (R)

The manufacturing process begins with the feeding of raw MDF boards through the automatic slider and chain mechanism. The required impregnated decorative sheet is then placed on the board before the prepared board is positioned between the heated plates. The pressing cycle is performed under controlled temperature

and hydraulic pressure to achieve proper bonding and the required surface finish. Following completion of the pressing cycle, the automatic clamper and suction mechanism transfer the laminated board onto the unloading belt. The finished boards are subsequently moved to the storage area, where quality inspection is performed and the products are classified according to their quality grade. The process flow is presented in Figure 8.



Figure 8: Process flow of the semi-automatic hot press lamination process

4.1 Identification, Classification and Contribution of Downtime in Production Losses

To evaluate machine effectiveness, downtime and production losses were collected and classified into unplanned downtime, planned downtime, and miscellaneous losses. During the study period, total recorded downtime and losses amounted to 60,155 min (1,002.58 h). Planned downtime represented the largest proportion of the recorded losses at 51.16%, followed by miscellaneous losses at 34.78% and unplanned downtime at 14.06% which is mentioned in table.

Table 1. Classification of Recorded Downtime and Production Losses

S. No.	Downtime Category	Downtime (min)	Downtime (h)	Contribution (%)
1	Unplanned downtime	8,460	141	14.06
2	Planned downtime	30,775	512.92	51.16
3	Miscellaneous losses	20,920	348.67	34.78
Total recorded losses		60,155	1,002.58	100

The contribution of major downtime categories is represented in the figure by using bar diagram chart,

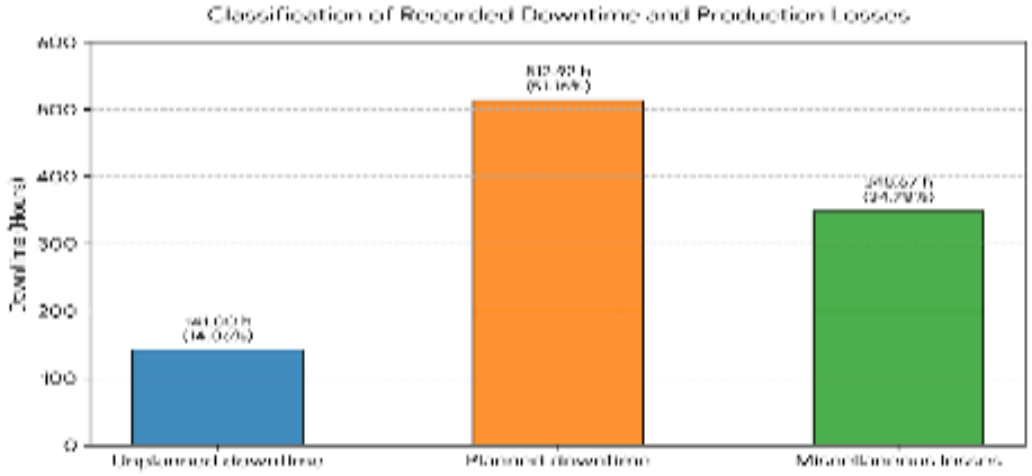


Figure 9. Contribution of major downtime categories

4.2 Pareto Analysis of Major Downtime Causes

A Pareto analysis was performed to identify the most significant individual causes of downtime. The results indicate that production stoppages, preventive maintenance, and unavailability of labor were the three major contributors, accounting for a cumulative 77.90% of the identified downtime. When miscellaneous stoppages are included, the cumulative contribution increases to 92.00%. These findings indicate that improvement efforts should initially focus on the highest-contributing causes rather than distributing resources equally among all downtime categories.

Table 2. Pareto Analysis of Major Downtime Causes

Rank	Downtime Cause	Contribution (%)	Cumulative (%)
1	Production stoppages	45.42	45.42
2	Preventive maintenance	18.35	63.77
3	Unavailability of labor	14.13	77.9
4	Miscellaneous stoppages	14.1	92
5	Thermal oil supply	4	96
6	Lunch break	2.5	98.5
7	Cleaning and daily inspection	1.5	100

The Pareto analysis demonstrates that production stoppages were the dominant source of downtime, contributing 45.42% of the total identified downtime, followed by preventive maintenance (18.35%) and unavailability of labor (14.13%). Together, these three causes accounted for 77.90% of the total contribution, indicating that they should receive priority in improvement initiatives. The addition of miscellaneous stoppages increased the cumulative contribution to 92.00%, further confirming that a relatively small number of causes were responsible for the majority of downtime losses.

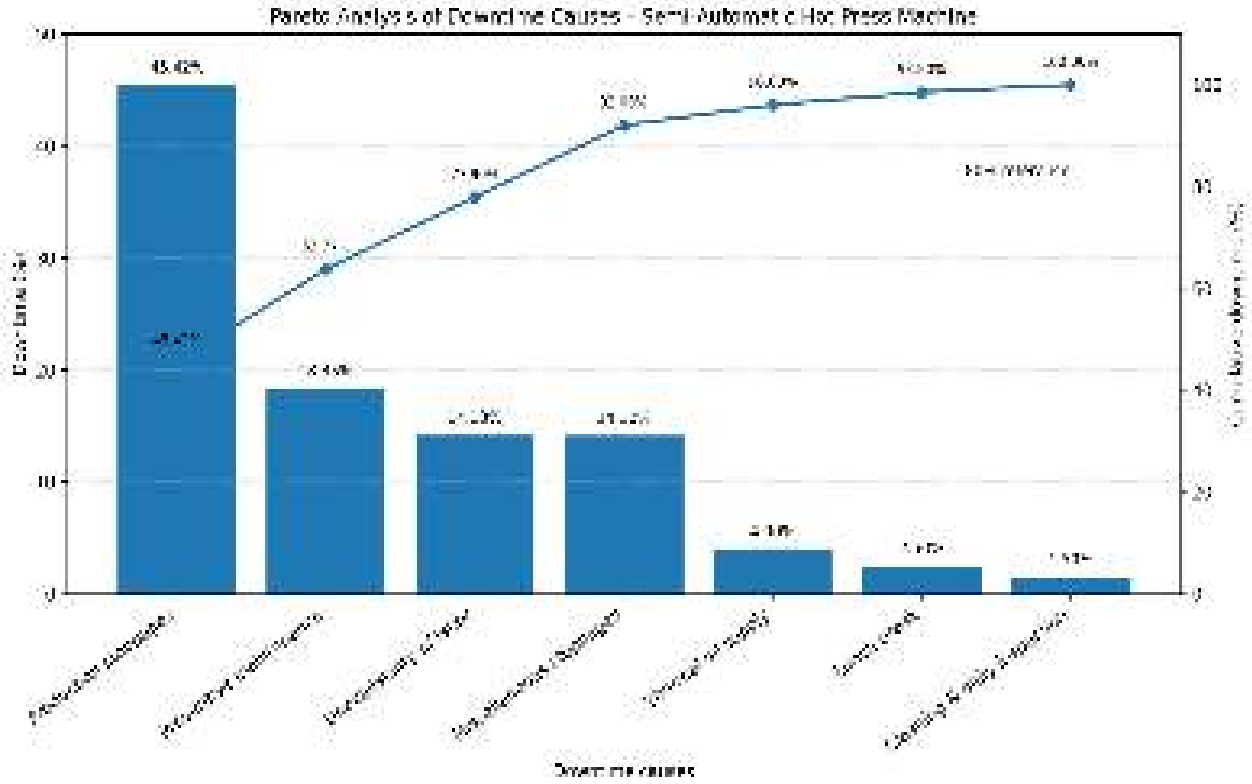


Figure 10. Pareto analysis of major downtime causes

4.3 Analysis of Six Big Losses

The identified production losses were further classified according to the Six Big Losses framework, which provides a structured basis for linking operational losses with the Availability, Performance, and Quality dimensions of OEE. The recorded Six Big Losses amounted to 49,670 min (approximately 827.8 h). Planned stops were the largest contributors at 39.94%, followed by production rejects at 23.49% and startup rejects at 17.32%.

Table 3. Six Big Losses and Their Contribution to Total Time Loss

S. No.	Six Big Loss	Time Loss (min)	Contribution (%)	OEE Dimension
1	Unplanned stops	6,142	12.36	Availability
2	Planned stops	19,845	39.94	Availability
3	Small stops	1,890	3.81	Performance
4	Slow cycles	1,520	3.06	Performance
5	Production rejects	11,670	23.49	Quality
6	Startup rejects	8,603	17.32	Quality
Total		49,670	100	

4.4 Evaluation of Overall Equipment Effectiveness

The OEE of the semi-automatic hot press machine was evaluated using the three conventional components: Availability, Performance, and Quality. The study covered a period of 60 days. The recorded actual production was 23,765 boards, of which 300 were classified as rejected/B-grade, resulting in 23,465 good boards. The time

parameters used for the calculation are presented in Table 4.

Table 4. Production and Time Parameters Used for OEE Calculation

S/No.	Parameter	Value	Unit
1	Case Study period	60	days
2	Ideal production capacity	72,000	boards
3	Actual production	23,765	boards
4	Rejected/B-grade boards	300	boards
5	Calendar time	86,400	min
6	Miscellaneous downtime/losses	20,920	min
7	Net scheduled production time	65,480	min
8	Planned downtime	30,775	min
9	Planned production time	34,705	min
10	Unplanned downtime	8,460	min
11	Actual operating time	26,245	min
12	Good boards produced	23,465	boards

4.5 Calculation of OEE Components

The Availability, Performance, and Quality components were calculated using the production and time data presented in Table 4. The original manuscript contains duplicate OEE tables with slightly different rounded results; these have been consolidated into a single calculation table below.

4.5.1 Availability

Availability was calculated as the ratio of actual operating time to net scheduled production time:

The resulting Availability of **40.08%** indicates substantial time losses before productive operation was achieved. The major contributors identified in the downtime analysis include planned stoppages, miscellaneous losses, and unplanned downtime.

4.5.2 Ideal Cycle Time

The ideal cycle time was determined from the target production rate of 400 boards per shift and an effective production time of 310 min per shift:

Thus, the machine's ideal cycle time was **0.775** min per board.

4.5.3 Performance

Performance was calculated by comparing the theoretical output during actual operating time with the actual production achieved:

The Performance rate of **70.17**% indicates that the machine operated below its ideal production rate during its available operating time.

4.5.4 Quality

The Quality rate was calculated using the number of good boards relative to total production:

The Quality rate of **98.74**% indicates that only a relatively small proportion of total production was classified as rejected/B-grade.

4.5.5 Overall Equipment Effectiveness

OEE was calculated as:

Therefore, the semi-automatic hot press machine achieved an overall OEE of approximately **27.8**% during the study period.

Table 5. Summary of OEE Results

OEE Metric	Calculated Value
Availability	40.08%
Performance	70.17%
Quality	98.74%
Overall OEE	27.79%

V. DISCUSSION

The results reveal a substantial gap between the theoretical production capacity and actual output of the semi-automatic hot press machine during the 60-day study period. Against an ideal capacity of 72,000 boards, the machine produced 23,765 boards, including 300 rejected/B-grade boards, resulting in 23,465 good boards. The considerable production shortfall was mainly associated with downtime and reduced operating performance rather than product quality. Total recorded downtime and production-related losses amounted to 60,155 minutes (1,002.58 hours), comprising planned downtime of 30,775 minutes (51.16%), miscellaneous losses of 20,920 minutes (34.78%), and unplanned downtime of 8,460 minutes (14.06%). The dominance of planned downtime indicates considerable potential for improving maintenance scheduling, setup, adjustments, and production planning. Pareto analysis identified production stoppages (45.42%), preventive maintenance (18.35%), and labor unavailability (14.13%) as the three major contributors, collectively accounting for 77.90% of the identified downtime. These findings suggest that improvement efforts should primarily focus on reducing production stoppages, optimizing preventive maintenance, and ensuring adequate labor availability. The Six Big Losses analysis further identified planned stops (19,845 minutes; 39.94%), production rejects (11,670 minutes; 23.49%), startup rejects (8,605 minutes; 17.32%),

and unplanned stops (6,140 minutes; 12.36%) as the major loss categories. Small stops and slow cycles contributed only 3.81% and 3.06%, respectively. The difference of 10,485 minutes between the total recorded losses (60,155 minutes) and the Six Big Losses dataset (49,670 minutes) represents losses outside the Six Big Losses classification and was retained separately to maintain analytical consistency and avoid double counting. The machine achieved an Availability of 40.08%, Performance of 70.17%, and Quality of 98.74%, resulting in an overall OEE of 27.79%. Availability was therefore the weakest component, indicating that machine effectiveness was primarily constrained by stoppages and time losses, while Performance also showed considerable potential for improvement. In contrast, the Quality rate was relatively high, with only 300 rejected/B-grade boards, indicating that product quality was not the principal constraint on overall effectiveness. The findings are consistent with the downtime and Six Big Losses analyses, which identify stoppages, maintenance activities, and labor availability as the principal areas requiring corrective action.

Table 6. Comparison of Measured OEE Components with World-Class Benchmarks

OEE Metric	Measured Value (%)	World-Class Benchmark (%)	Gap (%)
Availability	40.08	90%	49.92
Performance	70.17	95%	24.83
Quality	98.74	99%	0.26
Overall OEE	27.79	85%	57.21

Comparison with the adopted world-class benchmarks further highlights the performance gaps. Availability of 40.08% was 49.92 percentage points below the 90% benchmark, while Performance of 70.17% was 24.83 percentage points below the 95% benchmark. Although the Quality rate of 98.74% was close to the 99% benchmark, overall OEE of 27.79% remained substantially below the 85% world-class benchmark.

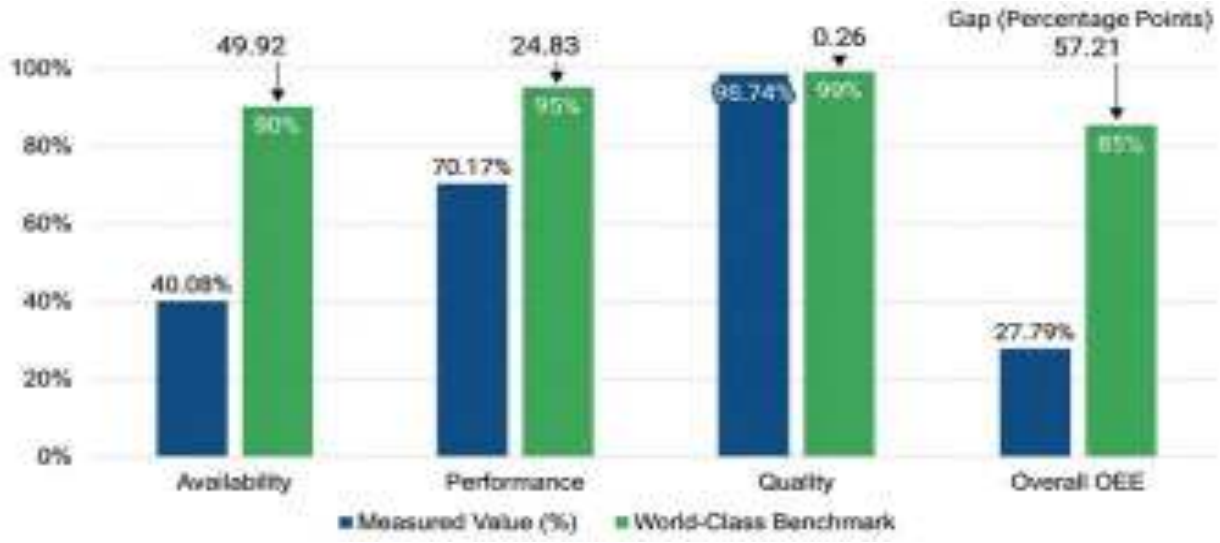


Figure 11. Comparison of measured OEE components with world-class benchmarks

The benchmark comparison confirms that **Availability is the most critical performance dimension**, followed by Performance. Quality, however, is already close to the world-class level. Consequently, improvement efforts should prioritize downtime reduction and production-rate improvement while maintaining the existing quality level.

VI. CONCLUSION

This study evaluated the performance of a semi-automatic hot press machine operating in the lamination sector of the fiberboard industry using Overall Equipment Effectiveness. Based on 60 days of production and downtime data, the machine produced 23,765 boards against an ideal capacity of 72,000 boards, with 23,465 boards classified as good production. The calculated OEE was 27.79%, comprising 40.08% Availability, 70.17% Performance, and 98.74% Quality. The results demonstrate that the machine's overall effectiveness was substantially constrained by downtime and reduced operating performance. Pareto analysis identified production stoppages, preventive maintenance, and labor unavailability as the dominant downtime causes, collectively accounting for 77.90% of the identified causes. The Six Big Losses analysis further identified planned stops, production rejects, and startup rejects as major classified losses. The benchmark comparison confirmed that the largest performance gap occurred in overall OEE and Availability, while Quality remained close to the world-class benchmark. Therefore, the principal opportunity for improving machine effectiveness lies in reducing downtime, improving machine availability, and increasing operating performance without compromising the existing quality level. Overall, the study demonstrates that OEE provides a practical and systematic approach for diagnosing equipment losses in the fiberboard industry and establishing priorities for productivity improvement.

VII. RECOMMENDATIONS

The following recommendations are proposed based on the identified losses and OEE performance,: (1) strengthen preventive maintenance and coordinate maintenance activities with production schedules to reduce equipment failures, planned-stop losses, and unnecessary machine interruptions; (2) prioritize the reduction of production stoppages, which accounted for 45.42% of identified downtime, through systematic root-cause analysis and corrective actions, while improving the reliability of thermal-oil and other supporting utilities; (3) improve labor availability through appropriate staffing, operator allocation, cross-training, and backup arrangements, as labor unavailability contributed 14.13% of identified downtime; (4) standardize setup, adjustment, startup, and operating procedures to reduce planned stops, speed losses, and rejects while maintaining the relatively high Quality rate; and (5) establish regular OEE monitoring, preferably on a daily or weekly basis, supported by Kaizen, standardized work, Pareto analysis, root-cause analysis, and systematic waste identification, to track Availability, Performance, and Quality and sustain continuous improvement.

VIII. LIMITATIONS

This study has several limitations. First, it focuses on one semi-automatic hot press machine at a single fiberboard manufacturing facility, which limits the generalizability of the findings to other machines, plants, and industries. Second, the analysis covers a 60-day study period, and longer-term data may capture seasonal, operational, and maintenance variations not reflected in the present results. Third, the 10,485-minute difference between total recorded losses and the Six Big Losses represents losses outside the classification framework; these losses were retained separately but were not analyzed in the same detail as the classified losses. Finally, the study relies partly on machine records, direct observations, and personnel inputs, making the results dependent on the completeness and consistency of available data. Although improvement measures are proposed, long-term post-intervention OEE validation was beyond the scope of the completed study.

IX. FUTURE WORKS

The future research should extend the OEE assessment over a longer period and across different production conditions to capture long-term performance variations. Comparative analysis of all six hot press machines could also establish internal performance benchmarks and identify machine-specific improvement opportunities. Further studies should investigate the major production and planned-stop losses using Fishbone analysis, 5-Why analysis, FMEA, and detailed downtime coding, including the 10,485 minutes of losses outside the Six Big Losses classification. Future work should also implement and quantitatively validate improvement measures such as preventive-maintenance optimization, operator training, setup-time reduction, standardized work, and Kaizen through pre- and post-intervention OEE comparison. Finally, integration of Industry 4.0 technologies, including IoT-based monitoring, real-time OEE dashboards, predictive maintenance, and machine-learning-based failure prediction, could enable continuous performance monitoring and proactive loss reduction.

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CONFLICT OF INTERESTS

There was no conflict of interest among the authors of the present research paper.

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