ISSN: 0379-5462
IPPTA: Quarterly Journal of Indian Pulp and Paper Technical Association
Vol. 37, E1, 2025, p. 134-138

# Enhancing Paper Quality through Artificial Intelligence (AI)

***S.Gokulakannan****
*Deputy Manager*

***M.Ashokkumar****
*Deputy Manager*

***R.Bhuvaneswari****
*Deputy Manager*

***R.B.Lakshmipathi Sakthi****
*Deputy Manager*

** Tamilnadu Newsprint and Papers limited, Kagithapuram, Karur-639136*

## Abstract:

*The Integration of Artificial Intelligence (AI) and automation into manufacturing processes is transforming industries worldwide and the paper industry is no exception. It is challenging and need of the hour to maintain consistent product quality to sustain as a market leader globally for any industry. The Automated Paper Lab in TNPL, a state-of-the-art automated testing system, represents a leap towards Industry 4.0, provides a comprehensive suite of capabilities, including precise measurement of tensile strength, porosity, smoothness, basis weight, and caliper. A standout feature of this lab is its roll-specific identification system, which assigns unique roll numbers to track quality parameters across the production process, ensuring traceability and targeted quality improvements. While the automated Paper Lab has revolutionized automated quality control with its precise measurements, there remains significant potential for enhancement through integration with Artificial Intelligence (AI). This study proposes utilizing AI to analyse the lab's data for real-time process optimization.*

*By correlating roll-specific quality results with production variables such as chemical dosing and process settings, manufacturers can achieve dynamic adjustments that minimize defects and ensure consistent product quality.*

*The Integration of AI with the Paper testing Equipment would enable predictive insights, allowing manufacturers to proactively address deviations in quality metrics before they impact production. This closed-loop system would enhance operational efficiency, reduce non-conforming products, and promote sustainable practices by optimizing resource utilization. The proposed framework showcases the transformative potential of combining automated testing with advanced analytics, setting the stage for smarter, more adaptive paper manufacturing processes. This paper outlines the current capabilities of the Automated Paper Lab, explores its applications in quality assurance, and presents a forward-looking vision for integrating AI to achieve unparalleled levels of efficiency and sustainability in the paper industry which saves time, human resources and reduces non-conformity products.*

***Keywords:*** *Artificial Intelligence, Automated Paper Lab, Sustainability, Non-Conformity.*

## Introduction

The global paper manufacturing industry faces constant challenges in ensuring consistent product quality while optimizing resource utilization and production efficiency. Properties such as basis weight, caliper, smoothness, optical properties, and strength are critical benchmarks that directly affect product performance and customer satisfaction. Variations in these properties, caused by changes in quality of raw materials, process conditions, or machine settings can lead to increased rejection rates, waste, and production costs.

At TNPL, adoption of the Auto Paper Lab has transformed the quality control process by automating testing procedures, significantly reducing testing time, and enabling real-time feedback for dynamic adjustments. This paper explores the role of automation in optimizing quality control at TNPL and proposes a roadmap for integrating AI-driven solutions to achieve predictive analytics, enhanced process control, and sustainability.

**Objectives:**

- Revolutionize quality control by leveraging automation through Auto Paper Lab.
- Enabling faster and more precise testing of critical paper properties.
- Improving efficiency by integrating Paper properties with process control systems.

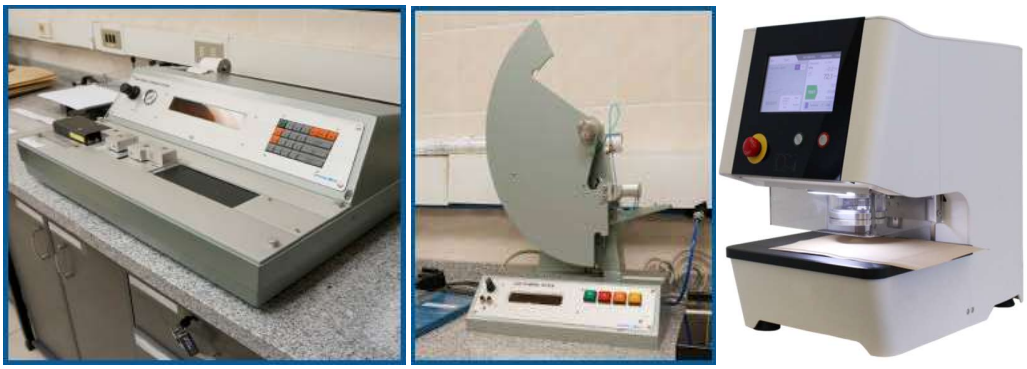
- Reducing variations in paper properties for ensuring consistent product quality.
- Reducing rejection rates by minimizing non-conforming products.
- Exploring the future role of AI in paper manufacturing

**Conventional Paper Property Testing Methodologies**

In manual paper testing (Fig1a, 1b, 1c), collecting samples from the entire width of the paper roll is essential to ensure that the test results represent the whole batch. A major challenge is handling the paper carefully to avoid wrinkles, creases, or folds, as these can negatively affect the accuracy of the test results. Once the sample is collected, it's cut to specific dimensions depending on the test being performed, such as tensile strength or tear strength tests (Fig 1b). This cutting process must be precise, as even a small mistake can lead to invalid results. The main challenges with this manual process include human error, which can result in wrinkles or incorrect sample sizes, and the time it takes to carefully handle and cut the samples. Additionally, achieving consistency across different operators can be difficult, as each person may handle the paper slightly differently, which could lead to variations in results.

**Quadrant Scale – Basis Weight** **Micrometer–Caliper** **Smoothness &Porosity Tester**

*Figure 1(a): Images of Conventional Physical Properties Testing Equipment*



**Tensile Tester** **Tear Strength Tester** **Burst Strength Tester**

**Figure 1(b): Images of Conventional Strength Properties Testing Equipment**

**Optical Properties / Brightness tester**

*Figure 1(c): Images of Conventional Optical Properties Testing Equipment*

**Role of Modern Paper testing technique in Quality Control:**

The Auto Paper Lab (Fig 2) at TNPL is a state-of-the-art automated system designed to provide precise, repeatable measurement of key paper properties, unlike manual methods, which are time consuming and prone to variability, this lab offers high speed testing with unparallel accuracy. It adopts a highly efficient sampling method where a single strip is collected for testing all properties. This innovative approach eliminates the need for multiple samples, reducing material waste and enhancing testing efficiency. A specialized cutter ensures precise sample preparation, guaranteeing consistent and reliable measurements across all tested parameters.

A single sample strip is used to measure properties such as basis weight, caliper, tensile strength, smoothness, porosity, and optical characteristics, streamlining the quality control process. The Auto Paper Lab provides the capability to increase the frequency of testing for specific properties as required. This makes us prioritize and monitor critical quality parameters dynamically based on production needs. Operators can decide which properties to test more frequently, optimizing resource usage while maintaining quality consistency. This versatility allows us to adapt to changing customer demands and production challenges, ensuring unparalleled quality assurance in paper manufacturing.

*Figure 2: Image of Auto Lab*

**Key Areas of Comparison:**

**Table No.1 : Comparison of Conventional Vs Modern Testing**

| Parameter | Conventional Method | AI Enabled Auto Paper Lab |
|---|---|---|
| **Time for Complete Testing** | 60 minutes | 10 minutes |
| **Accuracy** | Less since Prone to human error | High precision which eliminates human error |
| **Consistency** | Subject to variability due to manual handling | Consistent and repeatable results due to automation |
| **Data Collection** | Paper results recorded & calculated manually which may result in error | Automated recording & calculating |
| **Functional Expertise** | Requires multiple & Skilled workforce | Requires Single person with basic computer knowledge |
| **Maintenance** | Manual calibration, more prone to errors and breakdowns | Automated self-diagnostics, reducing maintenance frequency |

**Ability of Auto Paper Lab in Calibration:**

**Calibration procedure:**

Despite we are in the AI era, Calibration of Instrument (Fig 3a) is important because it ensures that measurements are accurate and reliable. This is important for the quality, safety, and innovation of products and services. One of the important and highlighted criteria of Auto Paper Lab is its Auto calibration method to confirm the accuracy of the testing parameters and equipment's operation (Fig 3b). Auto Calibration is the process of a device or system automatically adjusting itself to ensure it operates as intended. It can involve adjusting software, mechanical parts, or sensors.

**Key benefits of automatic calibration methodology in TNPL's Paper Lab Equipment:**

- **Improved accuracy and consistency:** Automated systems can precisely control calibration parameters, leading to more reliable and repeatable measurements compared to manual methods.
- **Reduced human error:** Eliminating manual steps minimizes the potential for mistakes caused by operator variability.
- **Better data management:** Automated systems can automatically record and store calibration data, making it easier to track and analyse results.
- **Compliance confidence:** Regular automated calibrations of the Auto Lab equipment help ensure compliance with industry standards and regulations.
- **Enhanced traceability:** Provide a clear chain of custody for calibration data, improving traceability.
- **Faster turnaround times:** Automated calibrations are performed more quickly than manual methods, allowing for more frequent calibration checks.

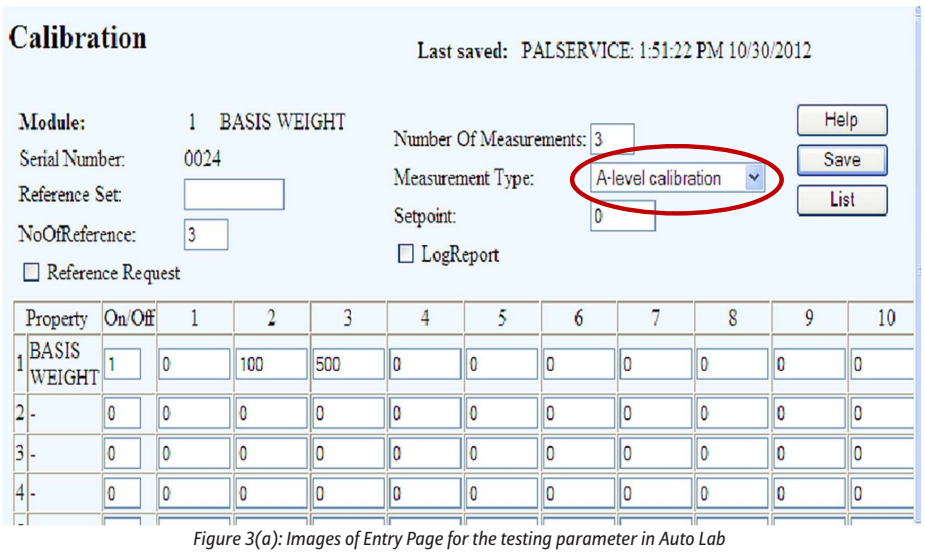
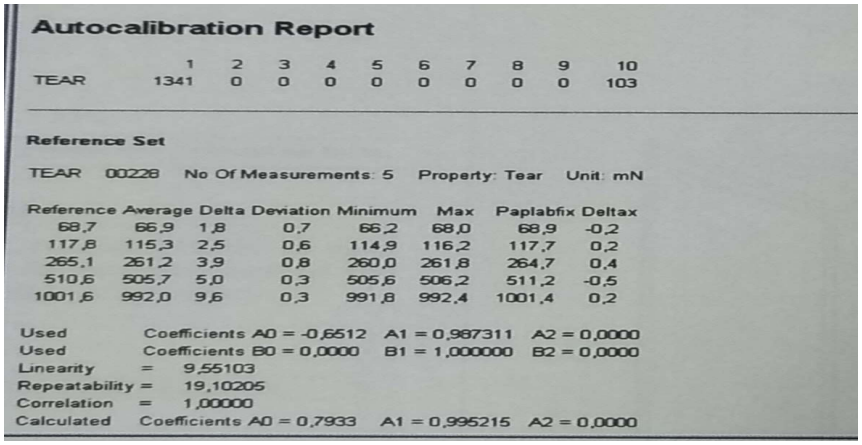



*Figure 3(a): Images of Entry Page for the testing parameter in Auto Lab*



**Autocalibration Report**

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| TEAR | 1341 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 103 |

**Reference Set**

TEAR 00228 No Of Measurements: 5 Property: Tear Unit: mN

| Reference | Average | Delta | Deviation | Minimum | Max | Paplabfix | Deltax |
|---|---|---|---|---|---|---|---|
| 68,7 | 66,9 | 1,8 | 0,7 | 66,2 | 68,0 | 68,9 | -0,2 |
| 117,8 | 115,3 | 2,5 | 0,6 | 114,9 | 116,2 | 117,7 | 0,2 |
| 265,1 | 261,2 | 3,9 | 0,8 | 260,0 | 261,8 | 264,7 | 0,4 |
| 510,6 | 505,7 | 5,0 | 0,3 | 505,6 | 506,2 | 511,2 | -0,5 |
| 1001,6 | 992,0 | 9,6 | 0,3 | 991,8 | 992,4 | 1001,4 | 0,2 |

Used Coefficients A0 = -0,6512 A1 = 0,987311 A2 = 0,0000
Used Coefficients B0 = 0,0000 B1 = 1,000000 B2 = 0,0000
Linearity = 9,55103
Repeatability = 19,10205
Correlation = 1,00000
Calculated Coefficients A0 = 0,7933 A1 = 0,995215 A2 = 0,0000

*Figure 3(b): Images of Auto Calibration Report including the new coefficients for better linearity*

Each module (Fig 4a) in the Auto Paper Lab involves auto calibration to ensure its operation. After completing the auto calibration, the Auto Paper Lab automatically gives the coefficient values which need to input for the better accuracy of the testing parameters which is none other than the form of Artificial Intelligence.

*Figure 4(a): Images of Testing modules in Auto Lab*

*Figure 4(b): Image of Tested Sample*

Hence the auto paper lab saves time and cost for measurement and calibration compared to the conventional individual equipment meant for measuring paper properties (Table No.1). Auto Paper Lab is a single piece of equipment bearing all the individual paper testing modules and provides the tested values arrived through AI which are automatically captured in TNPL's ERP system.

### 3.4 Integration with ERP for Real-Time Process Optimization:

An **Enterprise Resource Planning (ERP)** system helps improve the overall efficiency of paper manufacturing operations by integrating and streamlining various business processes. ERP systems collect and centralize data from different departments, including production, quality control, and supply chain. Integration with the **Auto Paper Lab** allows real-time data flow, enabling immediate adjustments in production parameters like **chemical dosing, press loads,** and **machine settings.** It helps to monitor production processes by providing visibility into operations. Data from the **Auto Paper Lab** (Table No.2) can be continuously fed into the ERP system, enabling operators and managers to adjust processes dynamically based on quality test results. It allows manufacturers to optimize inventory levels, reduce material waste, and ensure the efficient use of raw materials by tracking real-time production data.

This helps to ensure that the right materials are available when needed preventing production delays and reducing stock outs or excess inventory, ERP systems help make informed decisions about **resource allocation, maintenance scheduling,** and **process optimization.** By integrating AI or analytics tools within the ERP, manufacturers can predict potential issues before they arise, improving proactive maintenance and reducing downtime.

**Table No.2 : Ability of AI Enabled Auto Paper Lab**

| S.No | Parameters | Output from Conventional Method | Manual interpretations for Desired Output | Output from AI Enabled Auto Lab |
|---|---|---|---|---|
| 1 | Basis Weight | Weight 6.00 grams | BW = Weight of sample size (20 x 25 cm) x 106.00 x 10 = 60 GSM | 60 GSM |
| 2. | Bulk | Caliper 78 microns | Bulk = Caliper/BW78/60 = 1.30 cc/g | 1.30 cc/g |
| 3. | Breaking Length | Tensile Strength MD=2776 N/m CD = 1205 N/m | Breaking Length = Tensile strength * 102 / GSM MD = 2776*102/60 =4720m CD = 1205*102/60 = 2050m | MD: 4720m & CD: 2050m |
| 4. | Tear Factor | Tear Strength MD = 236.4 mN CD = 309.4mN | Tear Factor = Tear strength * 10.2 / GSM MD = 236.4*10.2/60 = 40.2 CD = 309.4*10.2/60 = 52.6 | MD: 40.2 & CD: 52.6 |
| 5. | Burst Factor | Bursting strength 122 kpa | Burst Factor = Bursting strength * 10.2 / GSM 122*10.2/60 = 20.8 | 20.8 |
| 6. | Roughness Ratio | Smoothness 180/160 | Ratio of Top and Bottom Smoothness | 1.125: 1.0 |

ERP systems ensure traceability by tracking roll-specific quality data, product movements, and testing outcomes. This traceability enables manufacturers to identify issues early and make adjustments to reduce non-conformities, thus improving overall product quality and reducing wastage. It helps optimize resource utilization by minimizing waste and energy consumption. It contributes to cost savings and environmental sustainability. This allows manufacturers to comply with environmental regulations and reduce their carbon footprint while optimizing production processes.

**4.0 Results and Discussion:**

Improvements in key parameters through automation, particularly when integrating systems like the **Auto Paper Lab** and **ERP**, can significantly enhance the efficiency and quality of paper manufacturing processes. Quality on the other hand shall be determined by the percentage of rejection and number of customer complaints received. We have presented the data detailing rejection rates (Chart No.1) and customer complaints (Chart No.2), which clearly illustrates that both metrics have significantly decreased.

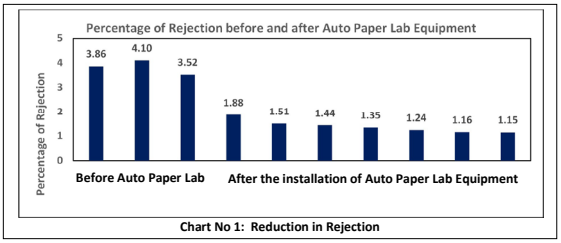



Chart No 1: Reduction in Rejection

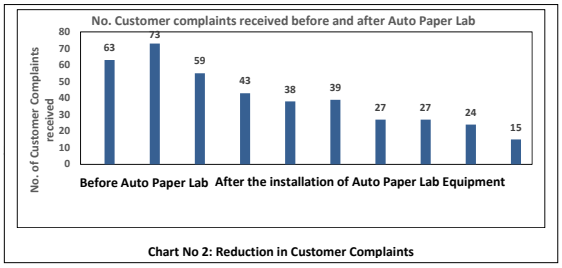



Chart No 2: Reduction in Customer Complaints

- **Tangible benefits:**
  1. Reduction of rejection percentage by 70%.
  2. Elimination of Customer complaints by 80%
  3. Significant reduction in quality variation
- **Non tangible benefits:**
  1. Goodwill & Brand value sustained
  2. Customer's perception towards the product of TNPL turned superior.

**5.0 Future Scope of AI Integration:**

The future of AI integration in quality control for the paper manufacturing industry holds significant promise for enhancing efficiency, accuracy, and sustainability. Below are key areas where AI can drive innovation.

**Predictive Quality Control**

AI models can predict potential quality deviations by analyzing historical data. By using machine learning algorithms, manufacturers can forecast defects before they occur, allowing for proactive corrective measures and reducing downtime. This will enhance product consistency and lower rejection rates.

**Dynamic Process Optimization**

AI can dynamically adjust machine settings based on real-time data from quality control systems. AI can optimize parameters such as **chemical dosing; furnish composition, press load,** and **moisture content,** ensuring consistent paper quality with minimal human intervention. By integrating AI with data analytics, the system can automatically identify patterns and correlations between quality defects and production variables. This **root cause** analysis capability will speed up the identification of issues, leading to faster problem resolution and continuous improvement.

**Automated Quality Assurance**

AI-powered systems can automate quality checks for key paper properties, such as **basis weight, caliper, smoothness,** and **tensile strength.** These systems can make real-time adjustments to optimize production without human intervention, significantly reducing human error and improving process reliability. AI can analyze resource consumption patterns and suggest ways to reduce waste, energy use, and chemical consumption. AI-driven systems can help manufacturers meet sustainability goals by minimizing material overuse and optimizing production processes to reduce their environmental footprint.

**Advanced Robotics for Inspection and Handling**

Robotics, coupled with AI, could be used for automated inspection of paper products. **Vision systems** powered by AI can detect surface defects, while AI-based robots can handle products more efficiently, ensuring higher precision and reducing handling time.

AI can create a **closed-loop system** where production parameters automatically adjust based on the quality feedback received in real time. This allows for constant refinement of the production process, leading to better overall quality and reduced variation.

**Enhanced Data Analytics and Reporting**

With AI, manufacturers can perform deeper analyses of data from multiple sources—quality testing systems, production machines, ERP systems, etc. AI-driven insights will facilitate informed decision-making, long-term performance monitoring, and improved traceability of quality parameters. AI can integrate quality control data with the entire supply chain, from raw material suppliers to end customers. This integration ensures that quality standards are maintained throughout the supply chain, offering better visibility and traceability for manufacturers and their clients.

**6.0 Conclusion:**

The integration of automation technologies, such as the Auto Paper Lab at TNPL, has significantly enhanced the efficiency and accuracy of paper quality control processes. By reducing testing time, minimizing variability, and enabling real-time adjustments to production parameters, automation has driven substantial improvements in product consistency, waste reduction, and overall operational efficiency.

As the paper industry continues to evolve, the combination of automation and AI presents a transformative roadmap for improving product quality, enhancing productivity, and meeting sustainability goals. The integration of AI technologies into quality control processes at TNPL will not only enhance production capabilities but also provide a competitive advantage in the resource-conscious and environmentally aware manufacturing landscape. Therefore, embracing automation and AI will be essential for the future success and growth of paper manufacturing operations worldwide.

**Acknowledgement**

The authors acknowledge TNPL for providing the opportunity to explore the capabilities and potential of the automated paper lab, and to demonstrate the benefits of integrating the Automated Paper Lab, ERP, and AI. Special thanks to all who provided guidance and support for us.

**References:**

1. *Pandey, A., & Mehta, N. (2021). Industry 4.0 and Smart Manufacturing Technologies. Springer . [Provides insights into automation and AI in manufacturing].*
2. *Shaikh, A. A., & Khan, M. (2020). "Artificial Intelligence in Process Control: Opportunities and Challenges." Journal of Manufacturing Processes, 49, 347-354.*
3. *Jiang, S., & Yu, X. (2022). "Automated Quality Control in Industrial Manufacturing Using AI Techniques." International Journal of Advanced Manufacturing Technology, 112(1), 1-15.*
4. *Lee, J., & Bagheri, B. (2020). "Digital Twin for Smart Manufacturing: Enhancing Process Quality." IEEE Transactions on Industrial Informatics, 16(9), 5567-5575.*