**Project Title**
Implementation of Industry 4.0 in 5-Ply Corrugator Plant

**Course Title**
Industry 4.0

**Submitted To**
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# 1. Introduction

The corrugated cardboard manufacturing industry, an essential driver of businesses like e-commerce and food and beverage and heavy-duty packaging, is rapidly undergoing technical modernization. As demand from nations worldwide for eco-friendly packaging grows, manufacturers are challenged to increase productivity while lowering costs, maintaining immense quality control, and minimizing adverse environmental impacts. Technologies included in Industry 4.0 offer a holistic solution allowing for real-time monitoring, predictive maintenance, and digital management of stock. The critical machineries of the 5-layer corrugator plant, especially the complex use made by flutes, gum rolls, bearings, and cutters, are emphasized, because failure of such critical machineries may incur major losses in operations along with these costs.

The use of automated systems and predictive maintenance approaches has improved operational efficiency and responsiveness through the reduction of machine failure rates, enhancement of product uniformity, and improvement in inventory accuracy. With the aid of cohesive sensors and control mechanisms, this project defines a step-by-step strategy to minimize idle hours, optimize energy consumption, and maintain peak operational effectiveness of equipment. This report contrasts the facility's current practices with the best practices of technologically advanced facilities to highlight the most efficient practices and financial efficiencies to direct the facility toward Industry 4.0.

# 2. Literature Review

## 2.1 Industry Overview

Corrugated cardboard manufacturing has been very progressive globally due to rising demand for environmentally friendly and recyclable packaging material. Industry-wide capabilities have also been enhanced through gradual shift toward automation and Industry 4.0 technologies, reducing reliance on labour and waste generation simultaneously. The issues affecting manufacturers in the corrugated cardboard manufacturing industry include raw material cost, equipment downtime, maintenance, and issues related to inventory management.

Key players in this industry have increasingly adopted automated systems, high-efficiency machinery, and lean inventory practices to optimize costs and enhance production quality. Given the demand for high-strength packaging and increased customization, 5-ply corrugated cardboard manufacturing has become prominent in industries such as food and beverage, e-commerce, and heavy-duty packaging.

## 2.2 manufacturing process

In a corrugated board manufacturing factory, the process begins with the Mill Roll Stand (RL 150), where paper rolls (liners and medium) of varying widths (1600mm to 2500mm) are mounted. This stand holds and unwinds the rolls, feeding them into the next stage at a controlled rate. The next section, the High-Speed Fingerless Single Facer Corrugation, is where the paper medium takes on the characteristic fluted shape, which gives the board its structural rigidity. This single facer operates at high speeds, using a fingerless design to reduce jams and increase production efficiency. The medium is then glued to a liner, typically with a starch-based adhesive, forming the first ply of the board.

The Pre-Heater (Triplex Version) then prepares the paper layers by reducing moisture content and slightly softening them. The triplex design allows for the simultaneous heating of three layers-a principle feature in creating a 5-ply board structure. Once the unit is heated, the Glue

Unit (Duplex Version) applies adhesives that bind layers. With duplex, adhesive is applied on both sides, a critical element in multi-layered boards. Glue application does require 20–30 grams per square meter.

At adhesion, the board travels through Take-Up Unit and Overhead Bridge, and in the process of travel, it is aligned and stabilized for shifting to the next section. Now adhesive takes some time to dry out for proper bonding. The duplex web alignment and tensioning system keeps the layers aligned and tensioned that avoids wrinkling and skewing. Here high-quality boards are guaranteed wrinkle-free and distortion-free. In the Double Facer, also known as the Baker Unit, a final bonding with heat and pressure creates a flat, strong board.

The continuous board is then cut in N.C. Cut-Off (Helical) to specified sizes using helical blades that ensure clean, non-contact cuts on the production of sheets. These sheets are systematically placed in the Automatic Basket Type Down Stacker and L Stacker that facilitates ease in handling, storage, or shipping, making it the end of the manufacturing process. Such a structured approach ensures that mass production becomes possible with quality corrugated boards for application.

### 5-Ply Automatic Corrugator Board Making Process Flow

1. Mill Roll Stand *(Feeds paper rolls into the line)*
2. Pre-Heater *(Prepares liner paper by reducing moisture)*
3. Single Facer Corrugation *(Corrugates the medium layer and glues it to a liner)*
4. Glue Unit *(Applies adhesive between layers for bonding)*
5. Take-Up Unit *(Transfers glued layers to the next stage)*
6. Overhead Bridge *(Holds and aligns layers during transfer)*
7. Web Alignment & Tensioning *(Aligns and maintains paper tension for smooth processing)*
8. Double Facer (Baker Unit) *(Bonds layers under heat and pressure)*
9. N.C. Cut-Off *(Cuts the board to specified lengths)*
10. Stacker (Basket Type / L Stacker) *(Organizes and stacks the finished sheets)*

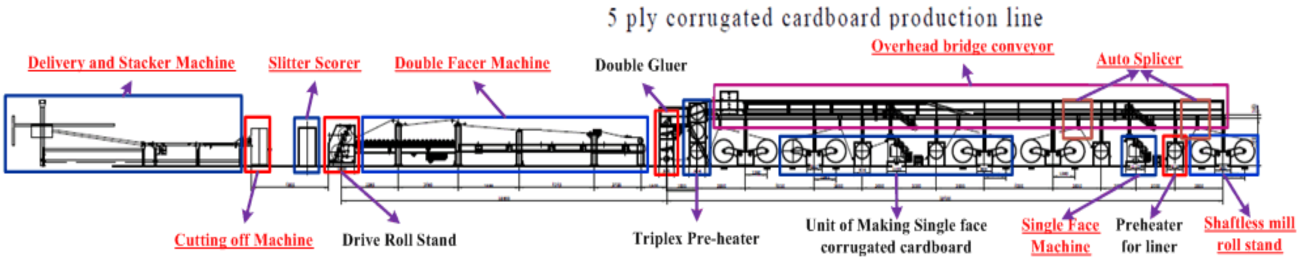


*Figure 1: 5 ply corrugated cardboard production line*

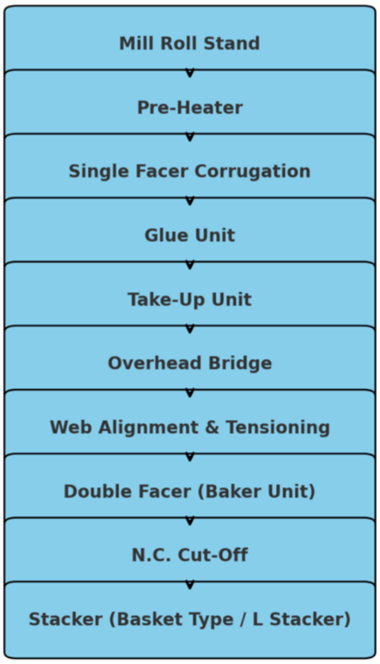


*Figure 2: 5 ply corrugated cardboard making process flow*

### 2.3 Benchmarking Against Similar Factories

A comparative analysis with similar facilities highlights various best practices:
•Inventory Optimization: Best manufacturers maintain optimal levels of raw materials including paper reels, starch, and ink. Advanced ERP systems enable real-time tracking of levels of stock so that the occurrences of stock-out situations and overstock conditions are minimized.
•Machinery Maintenance: Top facilities implement preventive maintenance schedules, utilizing MTBF data to minimize unplanned downtime. Regular monitoring of wear-prone parts like cutters, flutes, and ball bearings reduces unexpected machine stoppages.
•Digital Integration: High-digital-adopting factories practice predictive analytics on both inventory and machine maintenance, which gets themto produce with high consistency quality. For instance, electronic stock alerts, which are aided by predictive replacement schedules for parts like gum rolls and ball bearings, really minimize disruptions.

# 3. Analysis

Analysis of Current Operational Problems

### 3.1. Problem 1: High Downtime Due to Frequent Machine Breakdowns

Factory faces regular machine failures across several key components. These failures can be disruptive, leading to lost production, delayed orders, and additional Maintenance costs. Below, we analyze the MTBF (Mean Time Between Failures) for each component, the potential costs associated with downtime, and how this affects the financials of the company.

### 3.1.1. Flutes (Narrow, Broad, E-Flute)

Importance: Flutes provide the structure and strength to the corrugated cardboard, with varying types (narrow, broad, E-flute) contributing to different grades of product. Each flute type helps determine the cardboard's thickness, durability, and suitability for specific packaging applications.

Potential Issues if Not Maintained:
•Failure in a flute can lead to improper bonding and structural weaknesses in the cardboard, reducing its load-bearing capacity.
•Any failure here halts the production line, as flutes are a continuous part of the corrugated cardboard's construction.

Impact on Operations:
•Production Delays: Each flute failure requires the line to shut down instantly, resulting in loss of production and missed deadlines.
•High Repair Costs: Regular maintenance and timely repair cansave a significant amount of downtime and even exposure from badly made mass production.
•Customer Dissatisfaction: Poor quality or architecturally weak products may lead to client dissatisfaction, loss of business, and erosion of the factory's reputation.

### 3.1.2. Gum Roll

Importance: The gum roll applies adhesive to bond the flutes together with the outer liners, making it essential for the integrity of the cardboard structure.

Potential Issues if Not Maintained:
•Gum Roll Failure: A malfunction can prevent adequate adhesive application, leading to separation of layers and poorly bonded cardboard.
•Dried Adhesive Buildup: If not cleaned regularly, adhesive can harden on the gum roll, leading to uneven application and increased wear on the roll.

Impact on Operations:
•Production Interruptions: A gum roll failure means immediate stops in production until repairs are complete.
•Quality Degradation: Poor adhesive application results in weak bonding, reducing product quality and durability.
•Increased Waste: Misapplied adhesive can lead to scrap material, which increases costs and lowers production efficiency.

### 3.1.3. Drives

Importance: Drives control the mechanical movement of machinery components, such as conveyors, rollers, and cutters. They ensure precise and coordinated operation across the production line.

Potential Issues if Not Maintained:
•Drive Malfunction: A failure in the drive system can halt machinery movements, leading to immediate production stops.

•Inconsistent Speeds: Worn drives may cause speed fluctuations, resulting in misalignment or timing issues in the production process.

Impact on Operations:
•Downtime and Repair Costs: Drive failures cause downtime, and frequent breakdowns lead to high repair costs.
•Product Quality Risks: Malfunctioning drives may lead to uneven production, affecting dimensions and structural integrity of the cardboard.
•Worker Safety: Unstable machinery movement poses safety risks to operators working nearby.

### 3.1.4. Ball Bearings (Outer and Inner)

Importance: Ball bearings reduce friction and ensure smooth rotation within machinery components like drives and cutters. Both outer and inner bearings are crucial, with inner bearings being harder to access and replace.

Potential Issues if Not Maintained:
•Increased Wear: Lack of regular lubrication or maintenance can cause bearings to wear out, leading to misalignment, grinding, and potential machinery jams.
•Seizure or Failure: Bearing failure often results in immediate machine stoppages and possible damage to surrounding parts.

Impact on Operations:
•Extended Downtime: Inner bearing replacements require extended downtime, especially when replacement parts or technicians are not readily available.
•Production Schedule Disruptions: Unplanned downtime due to bearing failure can throw off production schedules, leading to delayed orders.
•Increased Maintenance Costs: Bearings that aren't regularly maintained or replaced can damage other components, raising repair costs.

### 3.1.5. Cutters (Rotary and State Cutter Blades)

Importance: Cutters, including rotary and state cutter blades, shape and trim the cardboard. They are essential for achieving precise dimensions and smooth edges in finished products.

Potential Issues if Not Maintained:
•Blade Dullness or Damage: Regular cutting wears down the blades, reducing their effectiveness and leading to rough or uneven cuts.
•Alignment Issues: Misaligned blades can cause tearing, improper cuts, and product waste.

Impact on Operations:
•Reduced Product Quality: Dull or misaligned blades can damage the cardboard, affecting quality and resulting in wastage.
•Increased Downtime: Replacing or repairing blades leads to operational delays, especially if both rotary and state cutter blades are affected simultaneously.
•Higher Maintenance Costs: Frequent unplanned maintenance or blade replacements increase costs and affect production schedules.

### 3.1.6. Thermex Oil (Lubrication)

Importance: Thermex oil is used for lubrication across various components, including drives and bearings, to ensure smooth and efficient operation.

Potential Issues if Not Maintained:
•Inadequate Lubrication: Without regular oil top-ups or changes, components experience higher friction, which increases wear and risks of overheating.
•Contaminated Oil: Old or contaminated oil can cause abrasion, leading to rapid degradation of moving parts.

Impact on Operations:
•Increased Wear and Tear: Lack of lubrication accelerates wear on bearings, drives, and other rotating parts, reducing equipment lifespan.
•Unplanned Downtime: Frequent breakdowns from poor lubrication cause downtime, adding to maintenance costs.
•Operational Inefficiency: Equipment running without proper lubrication consumes more energy, increasing operational costs.

### 3.1.7. Conveyor Belt

Importance: The conveyor belt is crucial for moving materials along the production line, ensuring an efficient flow through each processing stage.

Potential Issues if Not Maintained:
•Belt Misalignment or Slippage: Without regular maintenance, belts can slip or become misaligned, causing material jams or production delays.
•Debris Accumulation: Accumulated dust or material on the belt can lead to inefficiencies and occasional shutdowns for cleaning.

Impact on Operations:
•Scheduled Downtime: The conveyor belt requires cleaning every two weeks, which halts production temporarily.
•Reduced Production Capacity: Frequent or prolonged stoppages due to conveyor issues impact overall productivity.
•Additional Labor Costs: Conveyor cleaning and maintenance add to labor costs, affecting profitability.

### 3.1.8. Boiler and Pump System

Importance: The boiler generates steam for various production processes, with the pump ensuring continuous fluid movement. Consistent steam generation is crucial for maintaining production efficiency.

Potential Issues if Not Maintained:
•Pump Failure: If the pump fails, it disrupts the boiler's ability to generate steam, directly impacting production processes reliant on heat or moisture.

•Scale Buildup and Inefficiency: Unmaintained boilers can suffer from scale buildup, reducing heat transfer efficiency and increasing energy consumption.

Impact on Operations:
•Production Disruptions: A boiler or pump failure halts steam-dependent processes, causing delays and affecting product quality.
•Increased Energy Costs: Inefficient boilers consume more energy, leading to higher operational costs.
•Maintenance and Replacement Costs: Boiler and pump repairs or replacements are costly, with downtime affecting production schedules.

**Cost of Breakdown = Fixed Downtime cost of Rs 1,50,000 + Maintenance cost of components**
**Number of Downtimes in a year = Number production hours in a year/MTBF**

*Table 1: Maintenance Cost and Downtime Analysis for Corrugated Board Manufacturing Components*

| Component | MTBF (Hours) | MTTR (Hours) | Downtimes per Year | Downtime Cost per Failure (₹) | Annual Downtime Cost Calculation (₹) | Annual Downtime Cost (₹) | Maintenance/Replacement Cost (₹) |
|---|---|---|---|---|---|---|---|
| **Flutes (Narrow, Broad, E)** | 1,500 | 14 | 8,640 / 1,500 = 5.76 ≈ 6 | ₹1,50,000 × (14 / 24) = ₹87,500 | 6 × ₹87,500 | 5,25,000 | 1,50,000 |
| **Gum Roll** | 2,000 | 12 | 8,640 / 2,000 = 4.32 ≈ 4 | ₹1,50,000 × (12 / 24) = ₹75,000 | 4 × ₹75,000 | 3,00,000 | 1,00,000 |
| **Drives** | 8,000 | 0.25 | 8,640 / 8,000 = 1.08 ≈ 1 | ₹1,50,000 × (15 / 1,440) = ₹1,562.50 | 1 × ₹1,562.50 | 1,687.50 | 10,000 |
| **Ball Bearings (Outer)** | 10,000 | 0.25 | 8,640 / 10,000 = 0.864 ≈ 1 | ₹1,50,000 × (15 / 1,440) = ₹1,562.50 | 1 × ₹1,562.50 | 1,500 | ₹1,770 (weighted avg.) |
| **Ball Bearings (Inner)** | 5,000 | 12 | 8,640 / 5,000 = 1.728 ≈ 2 | ₹1,50,000 × (12 / 24) = ₹75,000 | 2 × ₹75,000 | 1,29,600 | ₹1,770 (weighted avg.) |
| **Rotary Cutter Blades** | 1,200 | 2 | 8,640 / 1,200 = 7.2 ≈ 7 | ₹1,50,000 × (2 / 24) = ₹12,500 | 7 × ₹12,500 | 90,000 | 5,000 |
| **State Cutter Blades** | 1,000 | 8 | 8,640 / 1,000 = 8.64 ≈ 9 | ₹1,50,000 × (8 / 24) = ₹50,000 | 9 × ₹50,000 | 4,32,000 | 12,000 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Thermex Oil** | 1,800 | 1 | 8,640 / 1,800 = 4.8 ≈ 5 | ₹1,50,000 × (1 / 24) = ₹6,250 | 5 × ₹6,250 | 30,000 | - |
| **Conveyor Belt** | - | 10 | 12 (cleanings/year) | ₹1,50,000 × (10 / 24) = ₹62,500 | 12 × ₹62,500 | 7,50,000 | 10,000 (labor) |
| **Boiler Pump** | 6,000 | 8 | 8,640 / 6,000 = 1.44 ≈ 1 | ₹1,50,000 × (8 / 24) = ₹50,000 | 1 × ₹50,000 | 72,000 | 15,000 |

***Table 2: Annual Maintenance Cost and Downtime Analysis Manufacturing Components***

| Component | Downtimes per Year | Annual Downtime Cost | Annual Maintenance Cost | Total Annual Downtime + Maintenance Cost |
|---|---|---|---|---|
| **Flutes (Narrow, Broad, E-Flute)** | 5.76 | ₹5,25,000 | ₹8,64,000 | ₹13,89,000 |
| **Gum Roll** | 4.32 | ₹3,00,000 | ₹4,32,000 | ₹7,32,000 |
| **Ball Bearings (Inner & Outer)** | Inner: 1.728 Outer: 0.864 | ₹31,100 | ₹4,587 | ₹35,687 |
| **State Cutter Blades** | 8.64 | ₹4,32,000 | ₹1,29,600 | ₹5,61,600 |
| **Rotary Cutter Blades** | 7.2 | ₹90,000 | ₹1,08,000 | ₹1,98,000 |
| **Drives** | 1.08 | ₹1,687 | ₹10,800 | ₹12,487 |
| **Conveyor Belt (Cleaning)** | 12 (Cleanings) | ₹7,50,000 | ₹12,000 | ₹7,62,000 |
| **Boiler (Pump)** | 1.44 | ₹72,000 | ₹21,600 | ₹93,600 |

**Annual Maintenance cost = number of downtimes x Maintenance/Replacement cost of the component**
**Total Annual Downtime + Maintenance Cost for all components: *₹36,11,557***
**Total Maintenance Cost for all components: ₹11,79,770**

## 3.2. Problem 2: Manual Temperature Control for Boiler System

The factory's current boiler system relies on manual adjustments to maintain optimal temperature levels, which leads to energy inefficiency, inconsistent steam generation, and frequent overheating. This lack of automation results in higher operational costs, increased risk of unplanned downtime, and safety concerns for operators. Implementing an automated temperature control system is necessary to enhance boiler efficiency, maintain consistent steam supply, and reduce operational risks. Without automated temperature regulation, maintaining the ideal temperature range (240-270°C) becomes challenging, impacting overall production consistency and operational efficiency.

### 3.3. Problem 3: Enhanced Drive Protection Using Fuses, Inverters, AMCB, and DMCB

Frequent power fluctuations and electrical anomalies have led to repeated failures and premature wear of drive systems, incurring high maintenance and replacement costs. The absence of an effective electrical protection system increases the risk of power surges and overloads, which reduces the lifespan of the drives and causes unexpected downtimes. A lack of robust protection for critical components also disrupts production and reduces productivity, as drive failures directly impact machine functionality.

### 3.4. Problem 4: Web Tension Control System for Paper Quality

Variability in paper tension during production results in defects such as poorly tensioned paper, which negatively affects the quality of corrugated boards. Inconsistent web tension leads to waste, increased rejection rates, and lower customer satisfaction due to irregular product quality. The lack of an automated web tension control system makes it difficult to maintain uniform pressure and tension, increasing operational variability and the risk of product quality issues.

### 3.5. Problem 5: Moisture Control System for Paper

Fluctuations in ambient humidity and paper moisture levels affect the adhesion and durability of the final product. Without a reliable moisture control system, maintaining optimal moisture levels is challenging, leading to issues like weak bonding, compromised structural integrity, and increased product rejections. Seasonal humidity changes further complicate moisture control, causing inconsistencies in paper quality and product reliability, which impacts customer satisfaction and operational efficiency.

### 3.6. Problem 6: Inventory Management System and Warehouse Management

Inefficiencies in inventory tracking and management lead to stockouts of critical materials, causing production delays and operational disruptions. Without real-time inventory visibility and automated reorder alerts, the factory faces challenges in maintaining adequate stock levels, resulting in costly production interruptions. Additionally, the lack of a digital warehouse layout increases retrieval times and reduces worker efficiency, while inaccurate inventory data leads to excess carrying costs and potential stock discrepancies.

## 4. Solutions and Strategy

### 4.1 Problem 1: High Downtime Due to Frequent Machine Breakdowns

Preventive Maintenance scheduling:
Implementing a comprehensive Preventive and Predictive Maintenance strategy will optimize factory operations by reducing unplanned downtime and improving component reliability. By

aligning repair schedules with MTBF and MTTR for each critical component, we can ensure proactive repairs, minimizing disruptions in production. Regular cleaning, predictive maintenance tools, and streamlined repair processes will enhance efficiency, lower costs, and extend component lifespans. This approach will ultimately lead to higher productivity, cost savings, and improved overall operational performance.

Predictive maintenance can play a crucial role in preventing breakdowns before they occur. By using real-time data from sensors installed on components like Flutes, Drives, Cutters, Boiler, Conveyer belt and others, factory can predict potential failures based on factors like temperature, vibrations, and usage patterns. This allows for timely Maintenances, minimizing unplanned downtime.
For these components, predictive maintenance would allow the factory to proactively address problems before they escalate hence, we can avoid downtime completely (ideal case scenario) while only incurring Maintenance costs. Sensors can detect abnormal vibrations, heat, and movement that precede a failure.

***Table 3: Annual Maintenance Schedule***

| Component | MTBF (Hours) | Frequency of Maintenance (Times per Year) | Maintenance Schedule Frequency (days) | MTTR (Hours) |
|---|---|---|---|---|
| **Flutes (Narrow, Broad, E-Flute)** | 1,500 | 5.76 | 62.5 | 14 |
| **Gum Roll** | 2,000 | 4.32 | 83.33 | 12 |
| **Ball Bearings (Outer)** | 15,000 | 0.864 (outer bearings) | 1,042 (approx. 2.8 years) | 0.25 |
| **Ball Bearings (Inner)** | 3,000 | 1.728 (inner bearings) | 521 | 12 |
| **Rotary Cutter Blades** | 5,000 | 7.2 | 125 | 2 |
| **State Cutter Blades** | 1,200 | 8.64 | 42.5 | 8 |
| **Drives** | 10,000 | 1.08 | 833.33 (approx. 2.3 years) | 0.25 |
| **Conveyor Belt (Cleaning)** | N/A | 12 cleaning events/year | 30.42 | 10 |
| **Boiler (Pump)** | 8,000 | 1.44 | 555.56 (approx. 1.5 years) | 8 |

Here's the estimated financial impact because of preventive and predictive maintenance for each critical component:

**Savings (ideal prediction scenario assuming no other external factors) = Downtime/(Downtime + Maintenance cost) * 100 = ₹11,79,770/*₹36,11,557 * 100 = 67.33%***

**New Total Downtime Cost (after 25% reduction) = ₹10,500,000**

## 4.2 Problem 2: Manual Temperature Control for Boiler System

Strategy: Install real-time temperature sensors on the boiler and integrate them with an automated wood loading system. This will dynamically adjust the wood supply based on temperature fluctuations, stabilizing the boiler temperature and improving efficiency.
Key Actions:

1. Set up the system to integrate real-time temperature sensors with a motorized wood feeder. Adjust the loading frequency based on accurate temperature readings to maintain optimal temperature levels.
2. Program the automated wood feeder to activate at specific temperature thresholds (240-270°C for lower, 250°C for optimal) to ensure boiler temperature stays within the desired range.
3. Implement manual overrides and fail-safe controls for the wood feeder in case of sensor malfunction or system failure.
4. Integrate temperature sensor data into the predictive maintenance system to identify potential boiler issues early.

Expected Outcomes:

- Improved fuel efficiency by optimizing wood loading and reducing excess consumption.
- Reduced labor costs due to decreased manual interventions and monitoring time.
- Minimized operational variability and improved product consistency.

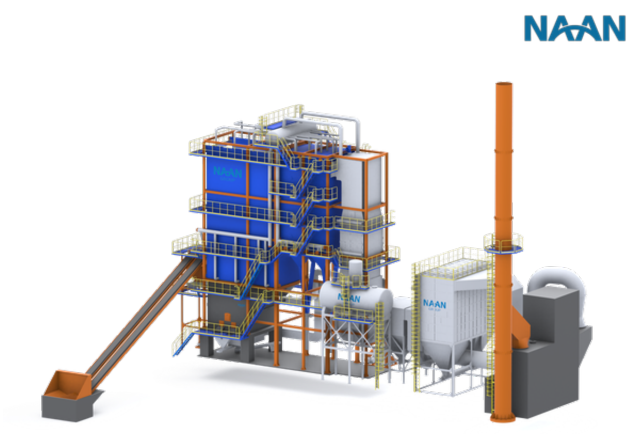


***Figure 3: 3D Automated wood feeding and temperature regulation system***

## 4.3 Problem 3: Enhanced Drive Protection Using Fuses, Inverters, AMCB, and DMCB

Strategy:
Install D-type fuses, Automatic Main Circuit Breakers (AMCB), and Differential Mode Circuit Breakers (DMCB) to protect drives from power fluctuations, extending their lifespan and reducing electrical damage. Integrate an inverter to smooth power irregularities, ensuring stable voltage supply and minimizing motor wear.
Key Actions:

- Install fuses, AMCB, and DMCB at critical drive points to protect against power surges, overloads, and electrical anomalies.
- Calibrate fuses and circuit breakers to react precisely to drive loads, ensuring effective overload protection.
- Regularly audit factory electrical systems to verify proper function of fuses, breakers, and inverters.
- Invest in high-quality fuses and circuit breakers with rapid response capabilities to handle high power fluctuations and safeguard the system.

Expected Outcomes:

- Extended drive lifespan due to protection against electrical damage.
- Reduced need for frequent replacements and repairs.
- Lower repair and maintenance costs due to reduced risk of electrical damage.
- Improved productivity by reducing downtime caused by drive failures.

## 4.4 Problem 4: Web Tension Control System for Paper Quality

Strategy:

- Install web tension control sensors on paper handling systems to monitor and maintain stable tension throughout production.
- Program the system to adjust roller speeds based on real-time tension feedback, ensuring uniform pressure and optimal tension.

Key Actions:

- Configure the system: Calibrate tension sensors and controllers to meet 5-ply corrugated board production requirements. Proper calibration ensures accurate tension monitoring and adjustment.
- Automatically adjust roller speeds: Program the system to respond to variations in paper feed speed or roller resistance, maintaining consistent tension and quality.
- Recommendations: Regularly calibrate the tension control system to account for wear and ensure accurate tension adjustments. Train operators to interpret data and make manual adjustments when necessary.

Expected Outcomes:

- Reduced waste and defects: Consistent tension minimizes poorly tensioned paper and defective products.

- Consistent product quality: Stable tension ensures corrugated boards meet high-specification quality requirements, enhancing product quality and customer satisfaction.

## 4.5 Problem 5: Moisture Control System for Paper

Strategy: Install moisture sensors along the paper feed line and integrate a feedback control system to adjust ambient humidity or drying processes based on sensor readings.

Key Actions:
- Place moisture sensors strategically to detect fluctuations impacting adhesion and product durability.
- Integrate controls to adjust humidity levels or drying times based on sensor readings for consistent paper quality.
- Adjust sensor thresholds periodically to account for seasonal humidity changes.
- Regularly calibrate sensors for accurate readings and consistent quality control.

Expected Outcomes:
- Enhanced bonding and structural integrity.
- Reduced product failures due to excess or insufficient moisture.
- Improved product reliability and fewer rejects.

## 4.6 Problem 6: Inventory Management System and Warehouse Management

Strategy:
- Use RFID or barcode tracking to monitor inventory in real time.
- Set up automated alerts to reorder materials when inventory levels drop below set thresholds, ensuring seamless production and efficient stock management.

Key Actions:
- Inventory Tracking: Install a WMS with real-time tracking capability that monitors the stock of critical supplies. This ensures visibility across the warehouse, allowing for quick adjustments when needed.
- Reorder Alerts: Program the WMS to send automatic alerts or place orders for replenishment when inventory levels reach predefined minimum thresholds. This will help prevent stockouts of essential materials without the need for manual oversight.
- Warehouse Mapping: Integrate warehouse mapping within the WMS to create a digital layout of the storage area. This allows workers to quickly locate specific products, reducing retrieval time and improving operational efficiency.

Recommendations:
- Predictive Analytics: Utilize predictive analytics on historical inventory data to forecast demand for each material and adjust stock levels accordingly. This helps in planning for seasonal changes or variations in production demand.

- Periodic Inventory Audits: Conduct regular inventory audits to ensure data accuracy and prevent shrinkage or loss. Routine checks will help in maintaining accurate records and identifying any discrepancies in stock levels.

Expected Outcomes:
- Reduced Production Delays: By ensuring that essential materials are always in stock, the risk of production interruptions due to inventory shortages is minimized.
- Lower Carrying Costs: With better tracking and forecasting, excess inventory is reduced, cutting down on unnecessary carrying costs and allowing for optimized reorder quantities.
- Increased Efficiency: Warehouse mapping enhances worker efficiency by providing a clear layout, making it easier and faster to locate specific products.

# 5.Implementation schedule

## 5.1 Phase 1: Assessment and System Design

**Step 1: Conduct System Requirements Analysis**
Boiler Automatic Temperature Control
• Compare the current boiler temperature swings, fuel consumptions, and throttling required to regulate the temperature.
• Optimize the temperature range to ensure improved fuel performance and reliable operation.
•Identify specific places to install sensors such that temperature change will be well monitored.
• Web Tension Control:
Examine the manufacturing specifications for 5-ply corrugated boards regarding the tension levels that are optimum.
• Examine the feed mechanism currently in use and identify potential sources of tension inconsistency.
• Plan where sensors should be placed to accurately capture real-time tension data.
• Moisture Management:
Moist requirements for paper quality, bonding strength, and product durability are evaluated.
•Assess the existing moisture levels under different production circumstances to create baseline data.
Identify strategic sensor locations for moisture along the paper feed line.

**Step 2: Develop System Specifications and Identify Vendors**
• Define the system details in a comprehensive specification document for each of them: sensor accuracy, response time, and durability.
• Shortlist suitable vendors for temperature sensors, web tension controllers, and moisture sensors that can support the factory set-up of the manufacturing plant.
• Get tenders from suppliers and award based on strength of product, technical supports, and the cost.

**Step 3: Design System Integration and Layout**
- Boiler Automatic Temperature Control: Integrate motorized feeders of wood with sensors of temperature; give temperature levels where feeding of woods shall be spontaneously.
- Web Tension Contro l: Design to mount web tension sensors on the rollers and configure the control system to control the roller speeds in real-time.

- Moisture Management: Develop a feedback system that adjusts drying or humidifying mechanisms based on moisture sensor readings. Specify how adjustments will be triggered, when the moisture level is above or below the set points.

## 5.2 Phase 2: Pilot Testing and Calibration

**Step 1: Install Components on a Pilot Line**

- Boiler Automatic Temperature Control: Fit one boiler with temperature sensors and automatic feeding by wood. Program it such that it responds based on the threshold temperatures.
- Web Tension Control: Place tension control sensors in one paper feed line. Interconnect the sensors to a control system capable of varying the roller speeds based on the trends of the variation in tension.
- Moisture Management: Fit moisture sensors at strategic locations from one paper feed line. Interface to the humidity control so adjustments can be made in real time simultaneously.

**Step 2: Calibrate Sensors and Control Systems**

- Boiler Control: Balance all temperature sensors to ensure accurate readings. Test the system's response time to asure that the wood feeder indeed adjusts in time when there are changes in temperature.
- Web Tension Control: Calibrate the tension control sensors to be set up according to the web's desired tension during 5-ply manufacture. Set the sensitivity so that paper feed will not be slack or overly taut.
- Moisture Management: Adjust sensors to measure actual moisture content. It will be set to alter the system humidity control or the mechanism of drying based on what the sensors measured.

**Step 3: Test Pilot System and Collect Data**

- Run each pilot setup continuously for several weeks to gather data on performance, effectiveness, and any issues.
- Documenting incidents where manual intervention was necessary, sensor reliability and overall robustness system.
- Adjust thresholds and calibration based on real-time feedback and data trends.

## 5.3 Phase 3: Full-Scale Rollout and Training

**Step 1: Scale Up Installation Across All Relevant Systems**

- Boiler Automatic Temperature Control: Roll out the automated temperature control system to all boilers; on all sensors and feeders, similar configuration as used in the pilot.
- Web Tension Control: The tension control system is installed on all paper feed lines with calibrated sensors, which are based on pilot findings.
- Moisture Management: Roll out moisture control system across all lines with uniform calibration and integration across the plant.

**Step 2: Conduct Comprehensive Operator Training**

- Predictive Maintenance and Data Interpretation: Â Train operators to read the data from temperature, tension and moisture sensors.

- Provide guidelines on using predictive maintenance software to identify potential issues early.
- Automated Systems Management:
- Train operators on how to monitor the automated wood feeding system and intervene manually if necessary.
- Train operators to read web tension data and moistures, troubleshoot the system for adjustments.
- Routine Maintenance:
- Train operators on inspection of every system under routine basis including sensor calibration checks and lubrication of moving parts on a regular basis.

**Step 3: Monitor and Adjust Systems Based on Operator Feedback**

- Be observant to all interactions between operators and systems: an exchange of usability and system response time; ease of data interpretation feedback.
- This would involve dynamic tuning by way of exploiting the real-time usage to update user interfaces appropriately or sensor placements.

## 5.4 Phase 4: Continuous Monitoring and Optimization

**Step 1: Set Up Regular Monitoring and Data Analysis**

• Building a data dashboard to monitor in real-time the plant temperature, tension, and moisture readings from sensors throughout the plant.

• Appoint specific persons who will regularly review system data and look for anomalies in expected values.

**Step 2: Schedule Routine Recalibrations and Inspections**

• Set up a schedule to calibrate the sensors periodically, say every few months, also accounting for wear or changes in the conditions following production processes.

• Check the automated wood feeder, tension rollers, and parts of moisture control for degradation and performance every so often.

**Step 3: Use Data to Optimize Settings and Processes**

- Boiler Control: Track temperature and fuel usage trends to set and reset maximum temperature parameters so that wood will be consumed efficiently.
- Web Tension Control: Review the quality data of web tension to adjust the system and optimize the product consistency with less waste.
- Moisture Management: Review seasonal changes in moisture data and adjust the system to keep paper quality intact throughout the year, thereby reducing defects.

**Step 4: Implement Feedback-Driven Improvements**

• Seek operator feedback for system-related problems or changes for improvement.

• Make iterative upgrades for each system, lessons learned from real-time data and from operator experiences should be used to upgrade factory performance.

# 6. Training:

## 6.1. Predictive Maintenance and Data Interpretation for Core Components

Objective: To enable operators to analyze real-time data concerning essential components, including flutes, gum rolls, ball bearings, and cutter blades, to proactively avert malfunctions and enhance maintenance planning.

- Sensor Monitoring: The employees will then learn to monitor temperature, vibration, and pressure sensors mounted on flutes, gum rolls, and ball bearings. Lessons will focus on how changes in these values indicate an impending problem that might be due to wear, misalignment, or imbalance.
- Flutes and Cutter Blades Personnel will be trained to monitor temperature and vibration readings related to flutes and cutter blades; high temperatures or uneven vibration are quite often indicative of the potential for misalignment or worn edges. Using this data-driven approach, personnel will be able to perform blade changes or flute resharpening at ideal times, thus maximizing the component's life and preventing costly idle time.
- Ball Bearings: Since ball bearings are generally the most vulnerable point of failure, operators are trained to analyze vibration and temperature patterns collected from sensors deployed on both the inner and outer bearings. By doing this, they can act to schedule early replacements, thus minimizing their potential for unexpected downtimes and costly repairs.
- Software Usage Participating delegates will have hands-on training workshops on predictive maintenance software, aggregating and analyzing data from sensors defined above. Operators will be trained appropriately to respond quickly to predictive maintenance alerts in suitable preventive measures aligned with MTBF statistics, reducing surprise downtimes and repair costs.

## 6.2. Automated Boiler Temperature Control for Consistent Energy Efficiency

Objective: To help the operators manage the automated feeding of wood and the stabilization of boiler temperature by the reduction of human interference which could lead to better fuel efficiency.

- Interpretation of Temperature Sensors: Operators shall be trained to observe the data from temperature sensors installed in the boiler. This will guide them on the different temperatures required to ensure proper utilization of energy.
- Automated Feeding System: The operators will receive hands-on time with the motorized wood feeder, including the actual temperature feedback to allow adjustment in wood loading frequencies. Setting up temperature thresholds for feeding is part of the training to ensure that the boiler will be in an optimal range rather than constant hand adjustments.
- Best Practices on Energy Efficiency: Operators will also learn best practices in terms of energy efficiency, for example, checking the accuracy of sensors periodically and

monitoring consumption trends in wood. It will enable them to make fine adjustments to the feeder to minimize energy costs while minimizing the impact on the environment.

## 6.3. Electrical and Drive System Protection for Enhanced Reliability

Objective: Train operators in electrical protection techniques to protect drives and critical components from power fluctuations, ensuring extended lifetime and reduced electrical-related failures.

- Understand Electrical Protection: The operators will understand D-type fuse functionality and application, AMCB and DMCB utilization in the protection of drives to be able to understand how each part contributes significantly to the prevention of electrical overvoltages that cause major damage to vulnerable equipment such as drives and motors.
- Installation Training: Through hands-on training, the installation training will cover placing the fuses and breakers relative to the drives for optimal protection. Operators will be instructed in the particular load capacities and response times for every breaker type, enabling them to calibrate them precisely to the requirements of each drive.
- Inverter Application: Operators will also learn how to apply inverters with drives, eliminating the power supply strengths of the drive that contribute to causing motor demise. An appreciation for how to configure and monitor inverter settings will allow them to maintain reliable drive operation, thus reducing the prospect of overheating and extending the life of the drive-in service.
- Routine Tests: The operators will be trained on routine tests for electrical items, with this training exposing them to signs of fusing degradation or breaker wear before it happens. They shall be trained in the safe handling of problems related to power in the workplace.

## 6.4. Web Tension Control and Moisture Management for Paper Quality Assurance

The objective of web tension and moisture levels during the corrugated board process is the consistency of paper quality by operators.

- Web Tension Control: It would make a person aware of maintaining the web tension sensors on the paper handling machine in constant tension for producing a problem-free 5-ply corrugated board.
- The sensors' calibration: The operator training can include calibrating this tension control to meet a particular requirement in 5-ply corrugated boards. It will dynamically adjust the roller speed based on direct feedback from sensors. Training for necessary adjustments in this system with any changes to paper feed speed will ensure uniform tension and avoid warp of boards and weak spots.
- Moisture Management: Data from strategically placed moisture sensors along the paper feeding line will be interpreted by operators.

- Curriculum Humidity Control System The curriculum would approach how a feedback system can be used in the amendment of ambient humidity or drying processes, depending on real-time moisture data, in ensuring that paper enters the production lines at an ideal moisture level, thereby improving adhesive strength and bonding quality of finished products.
- This would involve control settings for moisture controlling to balance the seasonal humidity variability, something so critical in the quest towards consistency of product throughout the year.

## 6.5. Digital Inventory and Warehouse Management for Stock Optimization

Objective: Permit the operators to manage inventory levels effectively so that stockouts of critical items, like flutes, glue, thermex oil, and gum rolls, are avoided to minimize carrying costs on excess inventory.

- Inventory Tracking Using RFID or Barcodes: The training will include the capability of RFID or barcode systems that can actually track the inventory immediately. Trainees will be able to scan in both coming and going stocks from the warehouse, thus ensuring effective and real-time tracking of the inventory.
- Reorder notifications: The Warehouse Management System will have personnel set up automatic reorder points so that they will be informed when levels of key materials reach certain minimums. This eliminates stoppages in production due to running out of stock and enables continuous operation.
- Warehouse Optimization: The workforce will also be able to utilize digital warehouse schematics and an organized configuration, which would allow them to locate items quickly. This includes training on ongoing inventory measurements and cycle counting, which would improve the accuracy of inventory management.
- Data Analytics: Employee training in predictive analytics. The ability for employees to analyze the historic inventory data to predict future demand, change reorder thresholds, and optimize the efficiency of inventory turns.

## 6.6. Routine Maintenance and Lubrication Practices for Longevity of Components

Objective: Provide operators with a good understanding of routine maintenance schedules and lubrication methods, ensuring the longevity of equipment and limiting surprise downtime.

- Lubrication Programs for Assets: Employee training will be provided on a recommended lubrication plan for core assets such as ball bearings, flutes, and conveyor belts to prevent overwear. The program is therefore going to emphasize the importance of knowing various requirements that different assets have according to operational demands and operating environment.

- Routine Inspection: Instruct operators to look for locations where wear is initiating on high-failure components such as cutter blades, conveyor belts and gum rolls. The operators can schedule maintenance before an unpleasant shutdown by discovering problems at the onset of wear.
- Documentation and Reporting: The training program will involve procedures to document maintenance activities and digital applications concerning lubrication and inspection processes. These data will be useful in the analysis of patterns for improving maintenance progressively.

### 6.7. Digital Skills and Software Training for Efficient Operations

Objective: Provide operators with digital skills needed for an effective application in Industry 4.0 software platforms related to maintenance, inventory, and quality control.

- Predictive Maintenance Software: Operators will undergo training in the utilization of predictive maintenance software to effectively manage alerts, establish thresholds, and monitor the health of components. Proficiency in fundamental data analysis will enable them to evaluate sensor trends and respond proactively.
- Training in inventory management software on real-time inventory management, quality control through web tension and moisture, and operational reporting. Your operators will learn how to input information correctly, generate reports, and interpret analytics contributing to your continuous improvement initiatives.
- Cybersecurity Awareness: To ensure safe digital practices, operators will receive basic cybersecurity training, learning to protect data integrity and secure sensitive production data from cyber threats.

## 7. Ethical issues

### 7.1. Data Privacy and Security Concerns

As your factory integrates sensors for critical components such as flutes, drives, cutters, and moisture control systems, significant amounts of data will be generated, including real-time performance metrics, maintenance logs, and operator interactions. This data could contain sensitive business or operational insights.

- Ethical Issue: The data collected from the flute cutters and predictive maintenance systems will be crucial for decision-making, but improper security measures could expose sensitive operational data or employee performance metrics to unauthorized parties. Additionally, employee personal data (e.g., their interactions with automated systems) might be collected inadvertently.

Example: Predictive maintenance software collecting vibration data from flutes and drives to forecast potential breakdowns could be intercepted or hacked. A breach in this data could expose intellectual property regarding the factory's operational methods, or even personal data of employees involved in the maintenance process.

Resolution: Implement encryption for all data collected from sensors on components like flutes and cutters. Also, use secure networks for data transmission and restrict access to sensitive information. Regular audits and user access controls must be enforced to ensure only authorized personnel can access critical system data.

## 7.2. Job Displacement and Workforce Reskilling

The introduction of automated systems, such as automated web tension control and inventory management systems (e.g., RFID tracking for raw materials), could reduce the need for manual intervention by operators, leading to job displacement.

- Ethical Issue: Automation of repetitive tasks, such as manual monitoring of paper tension or inventory control, might lead to job losses, particularly for workers who perform manual tasks on the rollers or inventory management functions, such as restocking supplies like glue or thermex oil.

Example: If the automated tension control system for paper webs adjusts roller speeds dynamically without human oversight, operators who previously managed the system manually may face redundancy. Similarly, the digital inventory system will automatically track materials like gum rolls and flute stock, reducing the need for manual labor in the warehouse.
Resolution: Invest in upskilling programs for affected workers, teaching them to operate, monitor, and troubleshoot the automated systems. This could include training on interpreting data from the moisture control sensors, managing the predictive maintenance software, or using RFID systems for inventory management.

## 7.3. Bias and Transparency in Automated Decision-Making

The incorporation of advanced technologies, such as predictive maintenance for critical systems, Components (flutes, drives, cutters, etc), automated inventory management (RFID, API, etc) relying on algorithm makes operational decisions that may have the issue of bias and Transparency as well. The systems do not explain the reasons behind their decisions explicitly or may exhibit bias if the foundational data is not adequately governed or if the algorithms are inadequately engineered.

• Ethical Issue: The predictive maintenance framework judges information gleaned from elements such as cutters and flutes can overestimate or underestimate maintenance needs for algorithmic bias. For example, the system may recommend unnecessary part replacements for fail to predict imminent failures, leading to unplanned downtime.

• For example, if the predictive maintenance framework exaggerates the degradation of flute cutters, it may result in unnecessary part replacement and extended downtime, thereby wasting resources and disrupt schedules of production. Similarly, the inventory management system can it automatically orders a restock of thermex oil when the algorithm fails to consider diminished production requirements during periods of reduced activity, leading to surplus inventory and increase Storage costs.

• Resolution: Such issues to be solved by making algorithmic decision-making more transparent. This means that operators should have access to the rationale behind system decisions, including the methodology by which the predictive maintenance system monitors the degradation of parts, such as flutes and drives, or how the orders for inventories are derived by the RFID system; Regular monitoring and validation. The integration of algorithms, with human supervision, ensures that the maintenance needs and to yield material orders in accordance with actual operational needs. Offering instruction in automating the system decision-making logic helps operators trust and tailor automated recommendations when necessary.

## 7.4. Inclusion and Accessibility of Training

The implementation of Industry 4.0 technologies, such as the automated web tension control system or digital inventory systems, will require operator's to learn how to use advanced digital platforms. Sometimes this might even become problematic for lesser digitally literate workers.

• Ethical Issue: With a mixed level of digital literacy in the workforce, there will be some employees who will not able to get on board and learn how to use the automated web tension control system or the predictive maintenance software which results in  frustration or underperformance.

• Example: Senior employees managing the web tension through manual adjustments or manual inventory systems might find the automatic moisture control or material restocking problematic to adopt as new systems, leading to a change in attitude, errors, or lack of confidence with the new systems

• Solution: Offer different forms of training for different learning speeds and technical skills. This should involve hands-on training sessions on specific components including, for example, moisture control sensors, web tension controllers, and inventory management software to ensure that all employees feel comfortable and assured in the use of the new technologies.

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