Problem Statement

In the cold supply chain for dairy products, maintaining optimal storage conditions in warehouses (godowns) is critical to prevent spoilage and ensure product quality. However, improper monitoring and management of environmental factors (e.g., temperature, humidity) in storage facilities pose significant risks. These risks lead to financial losses, quality degradation, and potential health hazards. The challenge is to enable risk assessment and mitigation using IoT and ML technologies to maintain the integrity of dairy products during storage.

Risks Involved in Storage at Godowns

1. **Temperature Fluctuations:**
   Inconsistent cooling or equipment failures can lead to temperatures outside the recommended range, causing spoilage.
2. **Humidity Levels:**
   High humidity may lead to mold growth or moisture condensation, affecting product quality.
3. **Equipment Failures:**
   Cooling systems, sensors, or power failures can disrupt the controlled environment.
4. **Uneven Cooling:**
   Improper air circulation within the godown can lead to uneven cooling, causing localized spoilage.
5. **Data Inconsistency:**
   Faulty sensors or lack of proper data collection can lead to inaccurate environmental monitoring.
6. **Human Error:**
   Delayed responses to system alerts or incorrect manual interventions can worsen the situation.

Key IoT and ML-Based Proposed Solutions To Address Potential Risk Involved

IoT Sensors for Real-Time Monitoring

- **Impact:** Ensures continuous monitoring of temperature and humidity, reducing the risk of spoilage due to unnoticed fluctuations.

2. **Predictive Maintenance Using ML**

- **Impact:** Prevents cooling equipment failures by predicting issues early, ensuring uninterrupted optimal storage conditions.

3. **Anomaly Detection with ML Models**
    - **Impact:** Identifies deviations in temperature or humidity, enabling swift corrective actions to prevent localized spoilage.
4. **Automated Corrective Actions via IoT Systems**
    - **Impact:** Dynamically adjusts cooling and airflow in real-time to maintain uniform storage conditions, reducing product degradation risks.
5. **Centralized Alerts and Notifications**
    - **Impact:** Provides timely alerts for abnormal conditions, allowing stakeholders to intervene promptly and minimize losses.
6. **Data Visualization Dashboards**
    - **Impact:** Offers actionable insights and trend analysis for better decision-making and long-term process improvements.

These solutions significantly improve the reliability of storage systems, enhance product quality, and reduce operational losses in dairy product storage facilities.

How to mitigate the risk of Tracking and Tracing Lost Goods while dispatching from a facility?

IoT-Based Smart Tagging (RFID & GPS)

🔹 **Implementation:**

- Attach **RFID (Radio Frequency Identification) tags** to each package to track movement inside the warehouse.
- Use **GPS-enabled smart sensors** to log location data during dispatch.
- Set up **IoT-enabled gateways** to detect goods as they leave or enter zones.

🔹 **Impact:**
✅ Provides **real-time tracking** of each item from storage to dispatch.
✅ Reduces **manual errors** in sorting and loading.

Integration Of Features

1. IoT-Based Real-Time Data Collection

📌 **Integration:**

- Deploy **temperature, humidity, pressure, and power sensors** inside the refrigerator.
- Use **smart meters** to monitor power consumption and voltage fluctuations.
- Integrate **door sensors** to track opening and closing events.

📌 **Technology Used:**

- IoT-enabled **wireless sensors (LoRa, Zigbee, BLE, or Wi-Fi)**.
- **Edge computing** for local data processing to reduce cloud dependency.

2. Cloud-Based Data Storage & Processing

📌 **Integration:**

- Store sensor data in a **cloud-based platform (AWS IoT, Azure IoT, or Google Cloud IoT)** for real-time analytics.
- Use **MQTT or HTTP protocols** for seamless data transfer.

📌 **Technology Used:**

- **Cloud storage (Amazon S3, Firebase, InfluxDB, or PostgreSQL)**.
- **Data pipeline (Kafka, Apache Spark, or Apache Flink)** for handling large-scale streaming data.

3. AI-Driven Predictive Maintenance Model

📌 **Integration:**

- Train **Machine Learning models (Random Forest, LSTMs, or XGBoost)** to detect anomalies and predict equipment failures.
- Use **time-series forecasting models** to analyze historical data trends.
- Implement **AI-based fault detection algorithms** for compressor failure, refrigerant leaks, and sensor faults.

📌 **Technology Used:**

- **ML frameworks (TensorFlow, PyTorch, or Scikit-learn)**.

- **AutoML for anomaly detection**.

4. Automated Alerts & Actionable Insights

📌 **Integration:**

- Configure **real-time alerts** (SMS, Email, or Mobile App notifications) when an anomaly is detected.
- Use **rule-based automation** to trigger preventive actions (e.g., auto-adjust cooling system).

📌 **Technology Used:**

- **Serverless functions (AWS Lambda, Azure Functions)**.
- **Notification APIs (Twilio, Firebase Push Notifications, WhatsApp API, Slack, etc.)**.

5. Dashboard for Real-Time Monitoring

📌 **Integration:**

- Develop a **dashboard** to visualize real-time sensor readings, energy consumption, and system health.
- Provide **predictive insights** with failure probability and recommended actions.

📌 **Technology Used:**

- **BI Tools (Tableau, Power BI, Grafana, or Streamlit)**.
- **Web frameworks (React, Django, or Flask) for UI development**.

By integrating IoT sensors, AI models, cloud analytics, and real-time alerts, this **predictive maintenance solution ensures uninterrupted refrigeration, reducing wastage and operational costs** in cold storage godowns. 🚀

Unique Selling Proposition (USP) of the Product

✅ **Proactive Maintenance Instead of Reactive Fixes:**

- **Predicts failures before they happen**, reducing downtime and maintenance costs.

✅ **AI-Powered Anomaly Detection & Auto-Correction:**

- **Smart AI models** detect even minor performance drops and adjust settings automatically.

✅ **Cloud & Edge Computing Hybrid Model:**

- **Faster processing at the edge** for immediate risk detection, with cloud-based long-term analysis.

✅ **Seamless Integration with Existing Cold Storage Systems:**

- Works with **any existing refrigerator model** without major modifications.

✅ **Real-Time Dashboard & Multi-Platform Alerts:**

- **Customizable alerts and insights** via mobile app, dashboard, and messaging platforms.

Literature Review

K. Kulkarni, U. Devi, A. Sirighee, J. Hazra and P. Rao, "Predictive Maintenance for Supermarket Refrigeration Systems Using Only Case Temperature Data," *2018 Annual American Control Conference (ACC)*, Milwaukee, WI, USA, 2018, pp. 4640-4645, doi: 10.23919/ACC.2018.8431901.

Abstract: We present a machine-learning based approach for early detection of issues emerging in refrigeration and cold-storage systems that has the following desirable features: 1) Minimal sensor dependencies: only requires temperature readings and defrost state from the refrigeration cases 2) high precision, and 3) high generalizability of the learnt model. We achieve this by casting the time-series prediction problem as a classification problem, wherein we craft a set of features that capture key time-series characteristics specific to defrost and operating regimes. Our feature extraction employs seasonality-trend decomposition and pattern learning using dynamic time warping and clustering. The extracted features are used to learn a random forest-based binary classifier that can indicate the presence or absence of an issue in any given refrigeration case at any given time. We validate our approach on real data from 2265 refrigeration cases from several large supermarkets. The approach achieves a precision of 89%, lead time of approximately seven days, and a recall of 46% when evaluated on unseen cases.

keywords: {Temperature distribution;Refrigerants;Feature extraction;Temperature

sensors;Market research;Temperature measurement;Degradation},
URL: https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=8431901&isnumber=8430677

Dataset:

https://drive.google.com/file/d/1aMoozpmycKILbhssXZz-oKSclm1dmsYs/view?usp=sharing

Constraints

Physical & Structural Constraints

1.Storage Volume

2.Weight Capacity

3.Insulation Efficiency

4.Airflow Optimization

6.Door Sealing & Opening Loss

Thermal & Humidity Constraints

1)Temperature Range

2)Thermal Fluctuation

3)Cooling Load

4)Humidity Control Range

5)Dew Point & Condensation Risk

Energy & Refrigeration System Constraints

1)Power Consumption

2)Energy Efficiency Ratio (EER)

3)Backup Power Supply

4)Refrigerant Type & Leakage Limit

5)Cooling System Response Time

4. Logistics & Operational Constraints

1)Container Insulation

2)Temperature Holding Time

3)Real-Time Monitoring

4)Operational Cost

5)Loading & Unloading Time

Dependency Factor of Two Prime Variables:

Product Storage Requirements

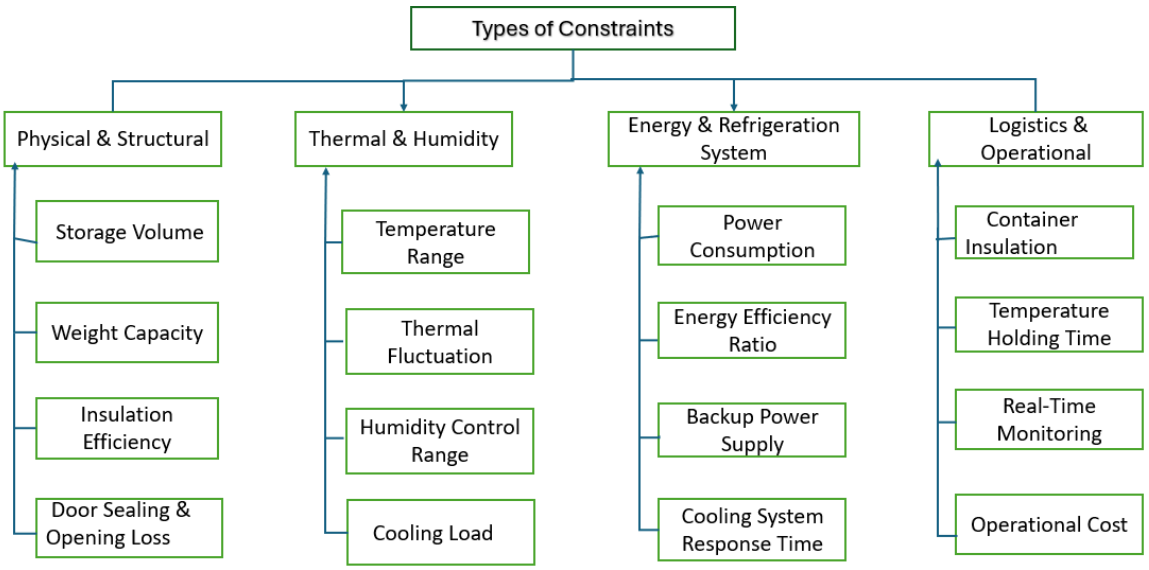
1. Frozen Products (-18°C to -40°C)]

1. Temperature: 95%
2. Humidity: 5%
3. Examples: Ice Cream, Frozen Meat, Seafood

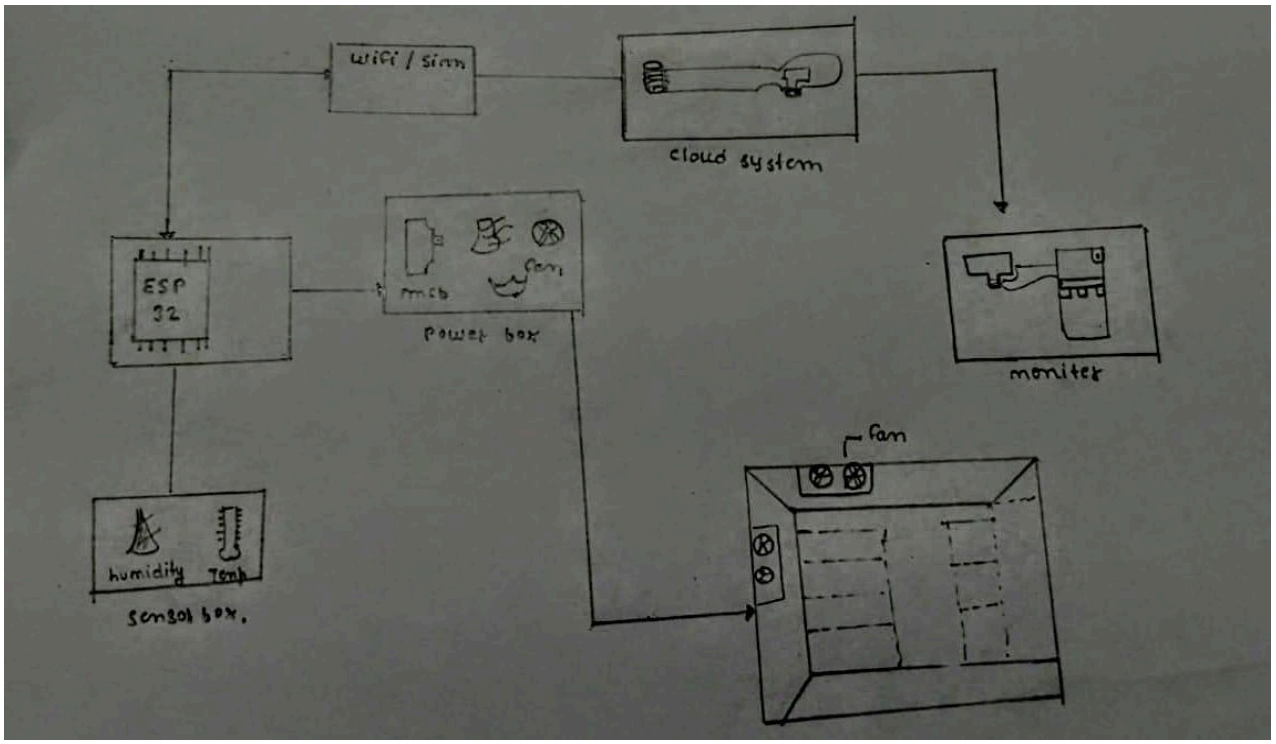
2. Deep-Chilled Products (0°C to 4°C)

1. Temperature: 85%
2. Humidity: 15%
3. Examples: Fresh Meat, Dairy, Vaccines

Cold Storage Constraints: -



Cold Storage Design & Device Installation: -



IoT & ML Solutions for Cold Storage

Key Risks:

1)Temperature Fluctuations - Equipment failures cause spoilage.

2)Humidity Levels - Leads to mold and degradation.

3)Equipment Failures - Disrupts storage conditions.

4)Data Inconsistency - Faulty sensors affect monitoring.

5)Human Error - Delayed response worsens issues.

IoT & ML-Based Solutions:

***IoT Sensors** - Real-time tracking of temperature and humidity.

***Predictive Maintenance** - Detects potential equipment failures.

***Anomaly Detection** - AI models identify environmental deviations.

***Automated Corrective Actions** - Real-time IoT adjustments.

***Centralized Alerts -** Early warnings for quick intervention.

IOT Data taken from Cold storage and Risk Assessment Modelling Based on it:

Feature	Normal Range	Purpose	Maintenance Role	Anomaly Role
Timestamp	N/A	Records time	Tracks trends	Detects failures at specific times
Sensor_ID	N/A	Identifies sensor	Finds faulty sensors	Pinpoints issues
Temperature (°C)	-25 to -18°C	Measures cooling	Detects inefficiency	Flags overheating (> -15°C) or overcooling (< -30°C)
Humidity (%)	40% to 60%	Tracks moisture	Indicates leaks or overcooling	Flags extreme levels (>70% or <30%)
System Load (%)	50% to 80%	Shows workload	High (>90%) → strain, Low (<40%) → inefficiency	Detects sudden jumps/drops
Power (kW)	5 to 10 kW	Tracks energy use	High → inefficiency, Low → failure	Flags overload (>12 kW) or shutdown (<3 kW)
Maintenance	0 or 1	Shows past servicing	Evaluates maintenance impact	Detects failures despite servicing
Anomaly Label	0 or 1	Flags abnormality	Trains predictive models	Identifies system failures

Predictive Maintenance model Report :

```
lachine Maintenance Model Accuracy: 0.7222
lassification Report:
              precision    recall  f1-score   support

           0       0.73      0.73      0.73       862
           1       0.72      0.71      0.72       830

    accuracy                           0.72      1692
   macro avg       0.72      0.72      0.72      1692
eighted avg       0.72      0.72      0.72      1692
```

Anomaly Detection Model Report :

```
Accuracy of anomaly detection : 0.9542
```

Conclusion: Harnessing the power of IoT, AI, and cloud technologies revolutionizes cold storage management by ensuring real-time monitoring, predictive maintenance, and automated corrective actions. This advanced approach enhances efficiency, mitigates risks, and optimizes resource utilization, ultimately leading to reduced operational costs, minimized product spoilage, and improved overall reliability.