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Research Article

Cost-Effective Industrial IoT Model using Cloud Environment

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ABSTRACT

The integration of Industrial Internet of Things (IIoT) technologies into industrial processes has revolutionized manufacturing and production sectors by enabling real-time data collection, analysis, and decision-making. However, the scalability and cost considerations associated with cloud-based IIoT implementations remain significant challenges for industries seeking to maximize the benefits of this transformative technology. This paper presents a comprehensive analysis of a cost-effective cloud model designed specifically for Industrial IoT applications. This paper proposes an approach that optimizes resource utilization, reduces operational expenses, and maintains high-performance standards, ensuring the seamless functioning of IIoT systems within budget constraints. The study begins by examining the current state of IIoT cloud deployments, highlighting the prevalent cost-related challenges faced by industries. Subsequently, a cost-effective cloud model is introduced, which leverages advanced technologies such as containerization, edge computing, and server less computing to optimize resource allocation while minimizing infrastructure overheads. To evaluate the proposed model, a series of experiments are conducted in a simulated industrial environment, measuring performance metrics, scalability, and cost-effectiveness. The results demonstrate that the cost-effective cloud model significantly reduces both capital and operational expenditures, making IIoT implementations more accessible to a wider range of industries.

Keywords: Cloud Computing, Internet of Things, Industrial IoT (IIoT), Predictive maintenance, Energy Consumption, Resource Allocation, Latency

1. INTRODUCTION:-

Internet of Things becomes very important topic in academics as well as Industrial domain. The Industrial Internet of Things (IIoT) is a consolidation of industrial automation, control systems, and IoT systems. An essential part of the developing industries would be IIoT. The primary goals of IIoT may include increased productivity and working efficiency, improved asset management through product customization, smart application monitoring for manufacturing, and predictive and preventive maintenance of industry equipment. To put it simply, the IIoT involves tying together all industrial assets—such as machinery and control systems—with information systems and business procedures. Therefore, the large amount of information collected can facilitate analytical answers and lead to efficient industrial procedures. The purpose of smart manufacturing, on the other hand, is to quickly and dynamically respond to changes in demand during the manufacturing phase of a (smart) product life cycle. Therefore, the IIoT affects all the industrial value chain and is a requirement for smart manufacturing [1].

Machine-oriented IIoT communication can span a wide range of various market sectors and activities. The IIoT scenarios include different monitoring applications such as room temperature sensing, humidity sensing, fire detection, motion detection of staff, controlling brightness of room etc. For performing this activities different types of sensor are used which will be work as IoT devices. Data generated from various devices should be stored at a central location so that these data can be accessed at any time and from anywhere. Cloud computing allows to upload and download the data from Internet-based servers instead of using local connected servers [2].

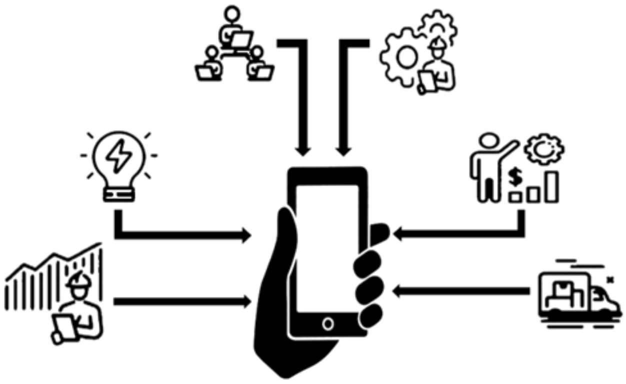

Fig. 1 Industrial Internet of Things

To fulfill increased customer demand and improve inventory control, businesses want to become more competitive and increase efficiency through just-in-time manufacturing. In this paper cloud based model is proposed for industrial IoT. This model helps to reduce the total cost of manufacture by monitoring all the activities from central cloud servers. All real time data can be easily accessed from the cloud at any time and from anywhere using cloud model. IoT sensors will sense the data such as room temperature, humidity, brightness and control these parameters automatically according to need. Using this model employee safety can be increased by monitoring the staff moments from another location. Any staff injury can be detected and necessary actions will be taking immediately [3]. By communicating with each other this devices perform load balancing between each other through load transfer. Cloud computing is often used as a mitigating strategy for Internet of Things applications due to its computation and storage capabilities. However, because it uses centralized computing, it has several limitations. For processing, all sensor data needs to be sent over the internet to the cloud.

2. COMPARISON ON INDUSTRIAL PARAMETERS WITHOUT IOT AND WITH IOT

The integration of the Internet of Things (IoT) into industrial processes brings about significant changes and improvements compared to traditional industry processes without IoT. The impact of IoT on several industry parameters like Prediction of Machine, Monitoring and Supervision, Energy Consumption, Data Storage and Accessibility, Monitoring of Environmental Conditions, quality Testing, Packaging and Transportation is shown in the following Table 1

Table 1 Comparison between Industry process without IoT and Industrial IoT

Sr. No.	Parameters for comparison	Without Industrial IoT	With Industrial IoT
1	Prediction of Machine Failure	It is challenging to predict when a machine or other devices would break down, which will result in a delay in the maintenance or repair time.	It is simple to predict when a machine or device will fail. Maintenance staff can take preventative measures to stop machine problems based on the predictions.
2	Monitoring and Supervision	The supervisor must physically be there in order to monitor and keep track of daily actions.	Supervisors and operators can access real-time dashboards and visualizations that provide a comprehensive view of the industrial processes. This allows them to monitor critical parameters and identify any deviations from normal operating conditions.
3	Energy Consumption	The use of old and inefficient machinery and equipment can result in higher energy consumption. Employees not being aware of energy saving practices can lead to wastage.	IoT sensor devices are used to turn on or off electricity automatically based on use. Some IIoT devices can utilize energy harvesting techniques, such as solar panels or kinetic energy converters, to generate power from their environment. This can extend the device's operational lifespan without relying solely on batteries.
4	Data Storage and	Data is stored on single server or machine and have limited Access	The collected data is transmitted to a central system or a cloud-based platform through wired or wireless

	Accessibility		connections. This allows for real-time data streaming and remote monitoring of the machines' condition.
5	Monitoring of Environmental Conditions	Utilizing various instruments like thermometers and hygrometers, environmental conditions have been manually monitored.	Utilizing several IoT Sensor varieties of environmental conditions such as temperature, humidity, and gas are monitored.
6	Quality control and Testing	For Quality Control and Testing, conventional techniques like inspection are employed, which takes more time.	IoT devices can automate various testing procedures, such as conducting stress tests, load tests, or environmental tests, by applying predefined conditions and collecting data during the process. IoT systems can automatically generate quality testing reports, ensuring compliance with regulatory standards and providing documentation for audits.
7	Goods Monitoring	Inadequate Protection, Leakage and Spillage, Incorrect Sizing, Environmental Impact, Shelf Life, these are some drawbacks of traditional Packaging method.	IoT sensors can monitor packaging materials and supplies in real time. This ensures that packaging materials are always available, minimizing downtime caused by shortages. IoT sensors can monitor packaging conditions, such as temperature, humidity, and shock/vibration levels. Any deviations from acceptable ranges can trigger alerts, preventing damage to products during transit.
8	Time Management During Transportation	Traffic congestion, Poor road qualities, Weather Disruptions, Driver shortages effects on Transportation	Packaging materials with embedded sensors can provide data on factors like temperature, humidity, and handling conditions during transportation. This data can be analyzed to ensure that products are being transported under optimal conditions. GPS trackers are used to locate the location of transport vehicle.
9	Resources Allocation	Differentiating between the workload of resources and assigning the workload to resources is challenging. There are software solutions designed to help with resource allocation, scheduling, and production planning. These tools can assist in optimizing resource utilization.	IIoT systems help supervisors allocate resources more efficiently by providing insights into equipment utilization, energy consumption, and overall process efficiency.
10	Availability of Historical Data	Historical data primarily serves as a record of past events, offering limited utility for operational improvements or forecasting.	Historical data becomes a powerful tool for pattern recognition, predictive analytics, and operational efficiency, driving innovation and competitiveness.

1. *Prediction of Machine or Device Failure*

IoT-enabled sensors continuously monitor machine health (e.g., vibration, temperature) and data collected by IoT devices is processed to predict failures. Early detection of anomalies allows maintenance staff to act before failures occur and helps to reduce downtime and costs [4].

Benefits

- Reduced unplanned downtime.
- Increased machine lifespan due to proactive maintenance.
- Improved accuracy in failure prediction.

For Example, A vibration sensor detects unusual patterns in a motor, triggering a maintenance alert before the motor fails.

2. *Monitoring and Supervision*

Supervisors can access real-time data from IoT dashboards without physical presence. IoT systems generate alerts when anomalies are detected and reduce reliance on manual inspections. IoT integrates data from multiple machines and provides a comprehensive view of the factory floor [5],[22].

Benefits

- Enhanced decision-making with real-time data.
- Reduced need for on-site personnel.
- Faster response to emergencies.

For Example, A factory manager monitors production lines remotely via an IoT-enabled dashboard, identifying bottlenecks and addressing them immediately.

3. *Energy Consumption*

IoT sensors optimize energy usage by turning machines on/off based on demand. IoT systems track energy consumption patterns, identifying inefficiencies. IoT-enabled machinery adjusts operational parameters to conserve energy [6].

Benefits

- Reduced energy costs.
- Lower carbon footprint due to optimized energy usage.
- Improved operational efficiency.

For Example, An IoT thermostat regulates the factory's heating system based on occupancy and temperature changes.

4. *Data Storage and Accessibility*

Data from IoT devices is stored in centralized or distributed cloud platforms, ensuring accessibility and redundancy. IoT systems handle large volumes of data, making it easier to scale operations. Continuous data streams enable instant access for analytics and reporting [7].

Benefits

- Faster decision-making with real-time data.
- Enhanced data security with distributed storage.
- Reduced risk of data loss due to hardware failures.

For Example, Environmental data from IoT sensors is stored in the cloud, enabling real-time monitoring of air quality across multiple locations.

5. *Monitoring of Environmental Condition*

IoT sensors automate the measurement of environmental parameters like temperature, humidity, and air quality. IoT enables round-the-clock monitoring, eliminating manual efforts. IoT systems send alerts when conditions deviate from predefined thresholds [7].

Benefits

- Improved response time to adverse conditions.
- Accurate and reliable environmental data.
- Cost savings from reduced manual monitoring efforts.

For Example, An IoT-enabled weather station monitors humidity and sends an alert if conditions threaten to impact stored goods.

6. *Quality Testing*

IoT-enabled devices like smart cameras and sensors inspect products during and after production for defects. IoT collects data during testing to analyze trends and helps to identify recurring issues. Testing systems integrated with IoT can feed data back to production lines, enabling immediate corrections [8].

Benefits

- Enhanced accuracy and efficiency in defect detection.
- Reduced waste and rework.
- Consistency in maintaining quality standards.

For Example, IoT-enabled UV sensors used to test the quality of products.

7. *Packaging*

IoT sensors in packaging track conditions like temperature, humidity, or pressure to ensure product integrity. IoT systems automate packaging tasks, ensuring consistency and reducing human errors. IoT-enabled RFID tags or QR codes provide real-time tracking of packaged goods [9].

Benefits

- Improved product safety and freshness, especially for perishable goods.
- Enhanced customer experience with transparent product information.
- Reduced packaging waste and costs.

For Example, A beverage company used IoT-enabled packaging sensors to monitor temperature during the bottling process. When sensors detected bottles being filled at sub-optimal temperatures, the system paused the line and alerted operators. This intervention preserved product quality and reduced customer complaints.

8. *Transportation*

IoT-enabled GPS systems track shipments in real-time, ensuring transparency in delivery. IoT systems analyze routes, fuel usage, and vehicle conditions to optimize transportation costs. IoT sensors monitor the environmental conditions (e.g., temperature, humidity) of goods during transit to ensure they remain within safe thresholds [10].

Benefits

- Improved delivery efficiency and reliability.
- Reduced transportation costs through route optimization.
- Enhanced safety and compliance, especially for sensitive goods.

For Example, A logistics company implemented IoT-enabled temperature sensors in refrigerated trucks carrying vaccines. When a truck's cooling system malfunctioned, the IoT system alerted the driver and headquarters. The shipment was rerouted to the nearest cold storage facility,

9. *Resource Allocation*

IoT devices track real-time resource usage and predict future demands, ensuring optimal allocation. IoT systems dynamically allocate resources based on data, avoiding overuse or underutilization. By efficiently allocating resources, IoT reduces operational waste and improves ROI [11].

Benefits

- Better alignment of resources with production needs.
- Minimized waste and operational costs.
- Scalability to meet fluctuating demands.

For Example, A manufacturing plant integrated IoT systems to monitor resource usage across its assembly lines. The data revealed that one line was underutilized while another was overloaded. By redistributing tasks between lines, the company increased throughput.

The integration of IoT into industrial processes brings about increased efficiency, real-time insights, proactive maintenance, and improved overall productivity compared to traditional processes without IoT.

3. PROPOSED CLOUD MODEL FOR INDUSTRIAL IOT

In proposed cloud model for Industrial IoT, different types of sensors are used to perform different activities like Temperature Sensors, Humidity sensors, room brightness sensors, Gas Sensors, Fire detectors, motion detectors, CCTV cameras, Automatic doors. This all the sensors can be used as an IoT devices in Industries. Data generated from all this devices are stored at Cloud side. Data from different sites of company can be stored at central level using cloud technology.

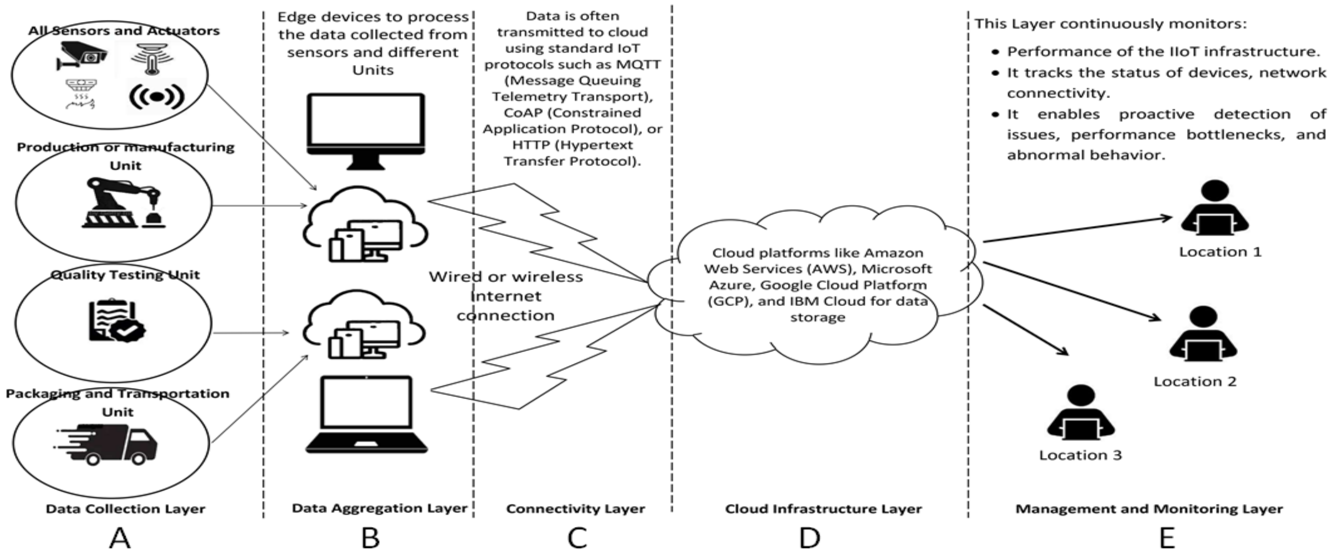

Fig. 2 Proposed Cloud Model for Industrial IoT

As shown in the figure 2 different IoT devices are connected to each other. These devices collect the data and store this data at cloud. Manager can monitor all the activities carried at industry by accessing data present in the cloud [4]. Detail of each layer is discussed below.

A. Data Collection Layer

This layer consists of all sensors and actuators deployed across various units of the manufacturing industry, such as the production or manufacturing unit, quality testing unit, and packaging and transportation unit. These devices collect real-time data, including machine operations, environmental conditions, production quality, and logistics tracking, ensuring a continuous flow of information from different processes.

B. Data Aggregation Layer

In this layer, edge devices process and filter the data collected by sensors to reduce the volume of raw information sent to the cloud. These devices perform initial analysis or preprocessing to ensure only relevant data, such as critical production metrics or anomalies, is transmitted for further processing, reducing latency and bandwidth usage.

C. Connectivity Layer

The processed data is transmitted to the cloud through wired or wireless Internet connections using standard IoT communication protocols like MQTT, CoAP, or HTTP. This layer ensures seamless and secure data transfer between the edge devices and cloud infrastructure [12].

D. Cloud Infrastructure Layer

This layer utilizes cloud platforms such as AWS, Microsoft Azure, Google Cloud, or IBM Cloud for scalable storage, processing, and advanced analytics of the manufacturing data. It supports storing large datasets, running predictive maintenance models, and executing real-time analytics to optimize manufacturing operations [13].

E. Management and Monitoring Layer

This layer monitors the overall performance of the manufacturing IIoT infrastructure, tracks device and network status, and proactively detects issues like equipment failure or network bottlenecks. It provides actionable insights to managers or operators at various locations, enabling them to make data-driven decisions and improve operational efficiency.

This model widely used to enable scalable, flexible, and centralized management of industrial devices, data, and applications. These models leverage the power of cloud computing to provide a range of services and benefits for IIoT deployments [14, 15]. Here are some key components of a cloud-based model for Industrial IoT:

4. IMPLEMENTATION DETAILS

In an industrial setting, a cloud-based model tailored for Industrial IoT (IIoT) applications is successfully implemented, ensuring robust data collection, seamless connectivity, and efficient storage. The process involved several critical steps and best practices:

Algorithm for Cloud-Based IIoT Model Implementation

Input:

- Set of IoT sensors $S=\{s_1,s_2,\ldots,s_n\}$
- Edge gateways $E=\{e_1,e_2,\ldots,e_m\}$
- Cloud services C
- Industrial process parameters and configurations.

Output:

- Real-time data collection, secure connectivity, and efficient storage.

Step 1: Configure IoT Sensors

1. **Device Identification and Classification**
   - For each sensor $s_i \in S$
     - Classify s_i based on role, data requirements, and environment.
2. **Sensor Calibration and Configuration**
   - For each $s_i \in S$
     - Calibrate s_i for accuracy.
     - Set sampling rate f_s

$$fs \geq 2.f_{max}$$

3. **Edge Device Integration**
   - Assign each $s_i \in S$ to an edge gateway $e_j \in E$
     - Preprocess data at ej using filters

4. **Data Validation and Quality Check**
   - For each data point d_k from s_i
     - Calculating the root mean square error (RMSE) for sensor accuracy:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y\mathrm{i} - \hat{y}i)^2}$$

Step 2: Establish Connectivity

1. **Design Network Architecture**
   - Create a hybrid network using Ethernet, LoRa, Zigbee, and 5G.
2. **Implement Communication Protocols**
   - Use MQTT for real-time, low-latency communication.
3. **Enhance Edge Connectivity**
   - Deploy gateways with local decision-making capabilities to reduce latency.
4. **Secure Cloud Connectivity**
   - Use HTTPS or VPN for encrypted data transmission.
5. **Ensure Fault Tolerance and Redundancy**
   - Implement failover mechanisms and redundant network paths.
6. **Optimize Latency and Bandwidth**
   - Minimize latency $L_{total}=L_p+L_t+L_{proc}$
     - $Lp = \frac{d}{c}$

Step 3: Data Collection and Storage

1. **Aggregate and Preprocess Data**
   - At each gateway e_j aggregate data:

$$A(t) = \frac{1}{n}\sum_{i=1}^{n} Di(t)$$

2. **Ingest Data into Cloud Services**
   - Use services like AWS IoT Core for real-time streams.
3. **Manage Time-Series Data**
   - Store data in time-series databases like Amazon Timestream.
4. **Partition and Shard Data**
   - Partition database into k shards to optimize query time:

$$T_{query} = \frac{T_{base}}{k}$$

5. **Implement Backup and Disaster Recovery**
   - Schedule backups and define RPO:

     RPO=Time between Backups

   - Restore data within RTO:

     RTO=Time to Restore Data

The algorithm outlines a structured approach for implementing a cloud-based Industrial IoT (IIoT) model in industrial settings. It begins with configuring IoT sensors by calibrating them for accuracy, defining sampling rates, integrating them with edge gateways, and ensuring secure communication through authentication and encryption. Next, it establishes reliable connectivity using a hybrid network design with protocols like MQTT, enhancing edge connectivity, and optimizing latency through techniques such as data compression and efficient routing. Finally, it focuses on data collection and storage by preprocessing and aggregating data at the edge, storing it in scalable cloud databases like time-series systems, and implementing partitioning, sharding, and robust backup mechanisms to ensure scalability, performance, and disaster recovery. This algorithm integrates precision, security, and efficiency at every stage to meet the complex demands of industrial applications.

5. RESULTS INDICATING THE IMPACT OF IOT ON COSTS

To validate the effectiveness of the proposed IoT framework, experiments were conducted in a real-time industrial environment. These experiments aimed to assess the impact of IoT on cost reduction across various operational areas, including energy consumption, waste reduction, remote monitoring, quality testing, and more. The results demonstrate that implementing IoT in industrial environments significantly reduces costs through various mechanisms.

1. Reduction of Wastage of Time

IoT-enabled devices streamline operations and optimize workflows:

1. **Real-Time Data Access**

   Sensors and edge devices provide instant data updates, eliminating delays in manual reporting.

2. **Automated Decision-Making**

   Systems like predictive analytics allow real-time adjustments, such as machinery calibration or resource allocation, reducing downtime.

   Impact: Improved productivity and a reduction in operational bottlenecks, translating to an estimated reduction in labor-related costs.

2. Remote Monitoring

IoT facilitates real-time remote monitoring of equipment, reducing the need for on-site inspections:

1. **Centralized Dashboards**

   Allow supervisors to oversee multiple locations from a single point.

2. **Condition Monitoring**

   Preventative maintenance alerts reduce unplanned downtime.

   Impact: Savings on travel costs and increased machine uptime, leading to a reduction in operational expenses.

3. Alerts and Prevention of Industrial Accidents

IoT enhances workplace safety through early warnings

1. **Employee Safety**

   Wearable IoT devices monitor worker health and hazardous environments, sending alerts when conditions become unsafe.

2. **Fire Detection**

   IoT-enabled fire sensors detect anomalies and trigger automated fire suppression systems.

   Impact: Reduction in insurance claims and medical expenses, avoiding potential losses.

4. Automated Raw Material Ordering

IoT integrates inventory systems with procurement platforms:

1. **Smart Inventory**

   Sensors detect raw material levels and place orders automatically when thresholds are reached.

2. **Supplier Integration**

   Ensures timely restocking, avoiding production delays.

   Impact: Lower inventory holding costs and elimination of manual errors in ordering processes.

5. Monitoring and Supervision

IoT devices ensure continuous supervision with minimal manual input:

1. **Machine Efficiency**

   Continuous monitoring of KPIs like temperature, vibration, and energy usage identifies inefficiencies.

2. **Production Tracking**

   Ensures adherence to schedules and quality benchmarks.

   Impact: Reduced supervision costs and enhanced process efficiency.

6. Reduction of Human Intervention

Automation driven by IoT minimizes reliance on human labor:

1. **Robotic Automation**

   Repetitive tasks like sorting, packaging, and basic assembly are automated.

2. **AI-Driven Insights**

Systems provide actionable recommendations, reducing the need for manual analysis.

Impact: Decreased labor costs by and improved operational accuracy.

7. Energy Consumption

IoT optimizes energy usage by monitoring and controlling energy-intensive processes:

1. **Energy Monitoring Systems**

Real-time tracking of power consumption identifies inefficiencies.

2. **Automation of Energy-Saving Protocols**

IoT-enabled systems turn off idle equipment and optimize energy usage during low-demand periods.

Impact: Reduced energy costs and decreased carbon footprint.

8. Data Storage and Accessibility

IoT improves data storage management and accessibility, enabling better decision-making:

1. **Cloud Integration**

Efficient use of cloud services ensures scalability and cost-effective storage of large data volumes.

2. **Accessibility**

Real-time data availability enhances operational flexibility and decision-making.

Impact: Reduced IT infrastructure costs by and enhanced data-driven operations.

9. Quality Testing

IoT automates and enhances quality testing processes:

1. **Automated Testing**

Sensors ensure that products meet quality standards during manufacturing.

2. **Predictive Insights**

Identifies defects and trends, enabling process optimization.

Impact: Reduced product reworks and defect rates, leading to cost savings in quality management.

The cost-saving mechanisms introduced through the implementation of IoT were validated by comparing operational costs with and without IoT across various parameters. Using real-time data from industrial experiments, the following Table 2 is generated which highlights the significant reduction in costs:

Table 2 Effect of IoT on Industrial Activities

Parameters	**Effect on Industrial Activities**	**Cost reduction**
	1. Proactive Maintenance 2. Reduced Downtime and Longer Asset	

Prediction of Machine	Lifespan 3. Spare Parts Management 4. Data-Driven Decision Making	40 to 45% cost saving
Monitoring and Supervision	1. Real-time Monitoring 2. Remote Monitoring and Diagnostics 3. Predictive Maintenance	50 to 55% cost saving
Energy Consumption	1. Energy Monitoring and Insights 2. Smart Lighting 3. Energy Leakage Detection 4. Renewable Energy Integration 5. Battery Storage Optimization	40 to 45% cost saving
Data Storage and Accessibility	1. Data Storage and Accessibility 2. Data Tiering 3. Data Retention 4. Disaster recovery	40% cost saving
Monitoring of Environmental Conditions	1. Improved workplace safety 2. Compliance with regulations 3. Energy efficiency.	20–30% energy cost savings.
Quality Testing	1. Test Automation 2. Crowd sourced Testing 3. Collaborative Testing 4. Test Environment Management	25 to 30% cost saving
Goods Monitoring	1. Enhanced tracking accuracy 2. Reduced theft or loss 3. Better inventory control.	15–25% reduction in goods loss.
Time Management during Transportation	1. Streamlined logistics 2. Reduced delivery delays 3. Improved customer satisfaction	10–20% reduction in fuel and time costs.
Resource Allocation	1. Optimized use of machinery, labor and materials with predictive scheduling.	25–35% savings in operational costs.
Availability of Historical Data	1. Faster decision-making trend analysis 2. Predictive maintenance capabilities.	30–40% cost savings through data-driven decisions.

6. Conclusion

This research offers a practical and scalable solution for addressing the cost challenges associated with cloud-based Industrial IoT deployments. By implementing the cost-effective cloud model outlined in this study, industries can harness the full potential of IIoT technologies while remaining financially prudent, thereby accelerating the adoption of IIoT in various industrial sectors. As industries continue to embrace digital transformation, the cost-effective cloud model offers a pathway to cost-efficient, scalable, and high-performing IIoT implementations, ultimately reshaping the landscape of industrial processes.

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