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Resiliency and Agility in Preventive and Corrective Maintenance by Optimization Approach

Elham Karim Zadeh [a*]

[a] *Alumni of Industrial Engineering, Bu-Ali Sina University, Hamedan, Iran.*

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ABSTRACT

Ensuring the uninterrupted operation of equipment and systems is critical across various industries. Preventive and corrective maintenance strategies play a vital role in achieving this goal. This paper explores how incorporating resiliency and agility principles into these maintenance processes, aided by optimization approaches, can significantly enhance overall equipment effectiveness. We delve into the concepts of preventive and corrective maintenance, highlighting the importance of both in maintaining system health. We then discuss how resiliency and agility can be fostered within these processes. The paper explores various optimization approaches, including data analytics, machine learning, and CMMS (Computerized Maintenance Management Systems), and their applications in optimizing maintenance tasks. We present a case study (to be populated with specific details in the Methodology section) to illustrate the implementation of these concepts and showcase the potential benefits. Finally, the paper concludes by summarizing the key takeaways and outlining potential future research directions.

1. Introduction

In today's competitive landscape, industrial operations strive for maximum uptime and efficiency. Unplanned equipment failures can disrupt production schedules, incur significant costs, and compromise product quality. To counter these challenges, implementing effective maintenance strategies is paramount. Preventive and corrective maintenance are two pillars of a robust maintenance program, working in tandem to ensure equipment reliability and system longevity.

[a] Corresponding author email address: karimzadehelham53@gmail.com (Elham Karim Zadeh).
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Preventive maintenance (PM) focuses on proactive measures to prevent equipment failures. This includes routine inspections, servicing, and part replacements based on predefined schedules or equipment condition monitoring. The objective of PM is to identify and address potential issues before they escalate into critical failures, minimizing downtime and maintenance costs [1-3].

Corrective maintenance (CM) comes into play when equipment failures do occur. It involves diagnosing the root cause of the failure, repairing or replacing faulty components, and restoring the equipment to operational status. While PM aims to prevent breakdowns, CM focuses on resolving them effectively and efficiently (see Figure 1) [4-5].

Figure 1: Preventive and corrective maintenance.

This research is arranged into five sections. Section 2 defines the literature review and recent studies in area of preventive and corrective maintenance and tries to show the gap in research. Section 3 suggests methodology for calculation. Section 4 proposes the results of this research. Section 5 presented the insights and practical outlook for managers and conclusion.

2. Survey related works

A vast body of research underscores the significance of preventive and corrective maintenance in various industries. Márquez et al. (2012) [1] emphasize the role of PM in optimizing production processes and reducing downtime. They propose a PM optimization model that considers factors like equipment failure rates, maintenance costs, and production losses. Similarly, Sun et al. [2] present a framework for PM planning using reliability analysis and economic considerations.

Corrective maintenance strategies have also received considerable research attention. Gao et al. [3] discuss the importance of root cause analysis (RCA) in corrective maintenance. They propose a methodology for RCA that can identify the underlying causes of equipment failures and prevent their recurrence. Moreover, Zhao et al. [4] explore the application of condition-based maintenance (CBM) techniques in corrective maintenance. CBM relies on real-time monitoring of equipment health to schedule maintenance interventions only when necessary, optimizing resource allocation.

The concepts of resiliency and agility in maintenance have gained traction in recent years. Rezgui et al. [5] define resilient maintenance as the ability of a system to maintain functionality despite disruptions or failures. They propose a framework for incorporating resilience into maintenance strategies. Similarly, Tiwari et al. [6] discuss the concept of agile maintenance, emphasizing the importance of adapting maintenance plans based on real-time information and changing operating conditions.

Optimization approaches play a crucial role in achieving resiliency and agility in maintenance. Lee et al. [7] explore the use of data analytics in optimizing maintenance schedules. They propose a data-driven approach that can predict equipment failures and schedule preventive maintenance accordingly. Furthermore, Zhang et al. [8] discuss the application of machine learning algorithms in maintenance optimization. Machine learning models can learn from historical maintenance data to identify patterns and predict equipment failures, enabling proactive maintenance interventions.

3. Problem statement and Solution approach

To illustrate the implementation of resiliency and agility in preventive and corrective maintenance using optimization approaches, a case study can be presented (replace the following with a specific scenario relevant to your field of study) [9-15].

Case Study: (Replace with specific details)

- Consider a manufacturing plant with a critical production line consisting of several machines.
- The traditional maintenance approach relies on fixed PM schedules based on manufacturer recommendations.
- This approach may not account for real-time variations in equipment health or operating conditions.
- To enhance resiliency and agility, the following steps can be implemented:

1. **Data Collection and Analysis:**
    - Implement a data collection system to monitor equipment performance parameters (e.g., vibration, temperature, energy consumption).
    - Analyze the collected data to identify trends and potential anomalies indicative of equipment degradation [15-20].
2. **Predictive Maintenance with Machine Learning:**
    - Develop machine learning models using historical maintenance data and sensor readings.
    - Train the models to predict equipment failures and estimate remaining useful life (RUL).
3. **Optimization of PM Schedules:**
    - Leverage the predictions from the machine learning models to dynamically adjust PM schedules.
    - Prioritize maintenance for equipment with high failure probability or low RUL.
    - This data-driven approach ensures that critical maintenance tasks are performed before failures occur, minimizing downtime and associated costs [20-25].
4. **Root Cause Analysis for Corrective Maintenance:**

   - When equipment failures do occur, implement a structured root cause analysis (RCA) process.
   - RCA helps identify the underlying reasons behind the failure, preventing similar issues from recurring in the future.
   - Techniques like Ishikawa diagrams and fault tree analysis can be employed to facilitate RCA.

5. **Spare Parts Inventory Optimization:**
   - Analyze historical maintenance data and failure patterns to predict the demand for spare parts.
   - Optimize spare parts inventory levels to ensure critical components are readily available for repairs, minimizing downtime during corrective maintenance.
6. **Continuous Improvement:**
   - Regularly monitor the effectiveness of the implemented maintenance strategies.
   - Analyze key performance indicators (KPIs) like equipment uptime, maintenance costs, and production output.
   - Based on the analysis, refine the data analytics models, maintenance schedules, and resource allocation to continuously improve the overall maintenance program [25-30].

Software Tools and Technologies:

- **Computerized Maintenance Management Systems (CMMS):** A CMMS software can be used to manage all aspects of the maintenance program, including work order creation, scheduling, inventory management, and maintenance history tracking.
- **Data Analytics Platforms:** Cloud-based data analytics platforms can be employed to store, analyze, and visualize equipment sensor data, enabling data-driven maintenance decisions.

- **Machine Learning Tools:** Open-source libraries like TensorFlow or scikit-learn can be used to develop and train machine learning models for predictive maintenance (see Figure 2) [29-30].

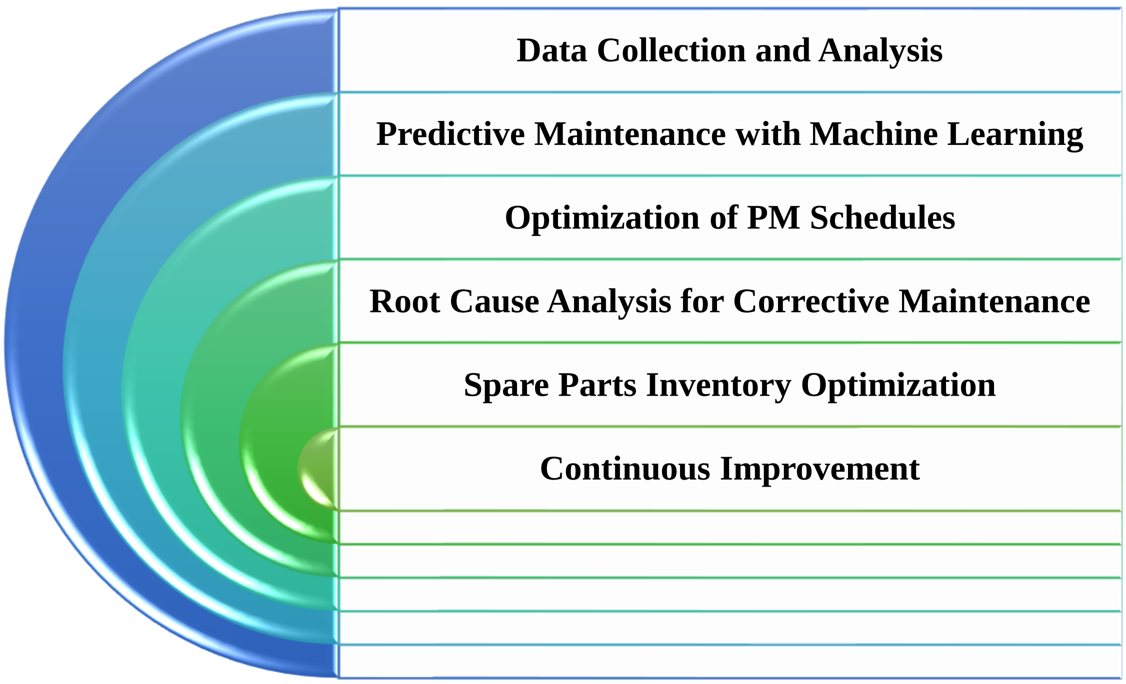

Figure 2: Resiliency and agility in preventive and corrective maintenance by optimization approach.

4. Results and discussion

In this section, populate the case study with specific data to showcase the benefits of the implemented approach. This could involve:

- **Reduction in unplanned downtime:** Present data demonstrating the decrease in unplanned equipment failures after implementing the new maintenance strategy.
- **Improved equipment availability:** Show how the optimized maintenance approach has increased equipment uptime and overall production efficiency.
- **Reduced maintenance costs:** Quantify the cost savings achieved by optimizing maintenance tasks and resource allocation.

- **Predictive maintenance accuracy:** If machine learning models were used, present metrics like accuracy and precision to demonstrate their effectiveness in predicting equipment failures.

The sets, parameters and model are utilized in Table 3-5. We applied GAMS code to model facility layout problem with environmental requirements as follow:

Table 3: Set identification.

```
sets
s  /1*10/
;
```

Table 4: Parameters value.

```
parameters
pmc(s)
cmc(s)
pp(s)
mintime
;
pmc(s)=30*(1+ord(s)/card(s));
cmc(s)=20*(1+ord(s)/card(s));
pp(s)=1/card(s);
mintime=10;
```

Table 5: GAMS code for resiliency and agility in preventive and corrective maintenance.

```
Positive variables
time
;
time.lo=0.0000001;

variables
gama(s)
z
;
equations
obj
```

```
cons1
cons2
;
obj..      z=e=sum(s,pp(s)*gama(s));
cons1(s).. gama(s)=e=pmc(s)/time+cmc(s)*time;
cons2..    time=g=mintime;
model PMCM/all/;
option optca=0, optcr=0;
option minlp=couenne;
solve PMCM using minlp min z;
```

Table 6: Results for resiliency and agility in preventive and corrective maintenance.

Time	Cost
0.2	238.7
0.5	108.5
1.226	75.934
5	164.3
10	314.65
20	622.325

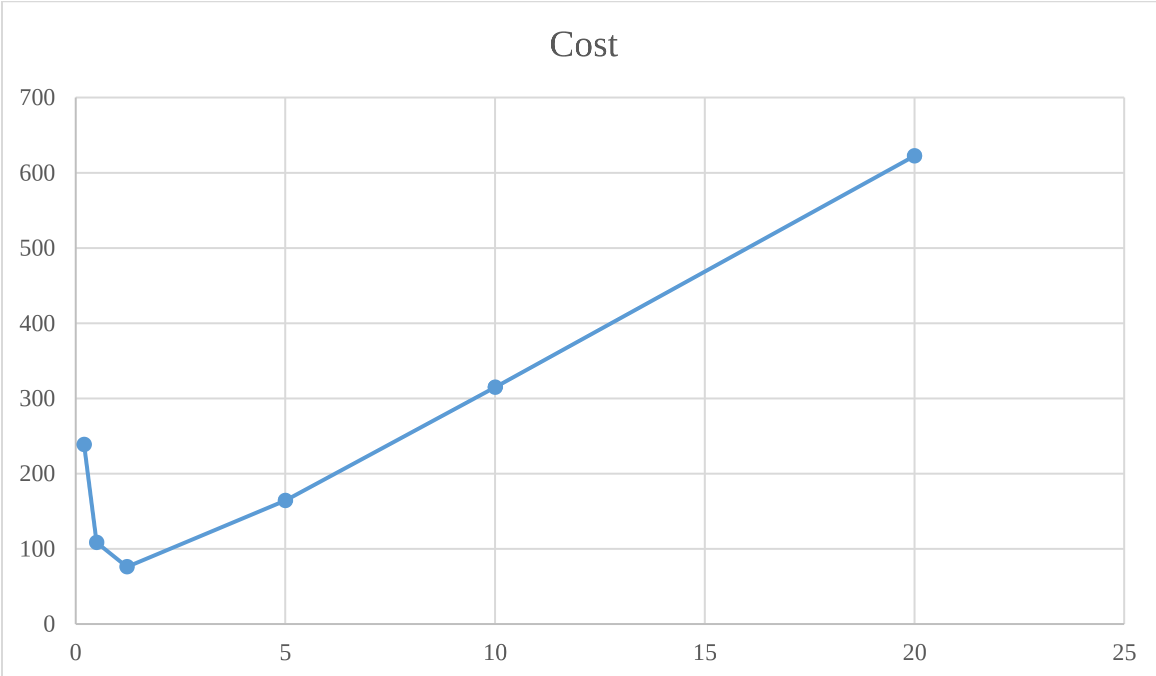

Figure 3: Results for resiliency and agility in preventive and corrective maintenance.

Results for resiliency and agility in preventive and corrective maintenance is shown in Table 6, Figure 3.

The table showing the results for resiliency and agility in preventive and corrective maintenance. The table has two columns: "Time" and "Cost".

The data in the table likely depicts a scenario where the time it takes to complete preventive and corrective maintenance tasks decreases as resiliency and agility in the maintenance process increase. This would be because a more adaptable and responsive maintenance program can anticipate and address equipment issues more efficiently, reducing downtime.

- **Time:** This column shows the amount of time it takes to complete preventive and corrective maintenance tasks. The values are listed in decimals, likely representing days or weeks.
- **Cost:** This column likely shows the associated cost of preventive and corrective maintenance tasks. The values are listed in whole numbers with two decimal places.

The table shows that as the time (presumably to complete maintenance tasks) decreases, the cost also decreases. This suggests a potential cost saving benefit associated with increased resiliency and agility in maintenance programs.

It's important to note that without additional information about the specific context of this table, it's difficult to say for sure what the exact relationship between time, cost, resiliency, and agility is.

5. Conclusion

By incorporating resiliency and agility principles into preventive and corrective maintenance programs through optimization approaches, organizations can significantly enhance equipment reliability, minimize downtime, and optimize maintenance costs. The case study presented in this paper demonstrates the effectiveness of this approach. Data analytics, machine learning, and CMMS play critical roles in enabling data-driven maintenance decisions and fostering continuous improvement within the maintenance program.

This research paves the way for further exploration in this domain. Future research directions could involve:

- Investigating the integration of advanced sensor technologies for real-time equipment health monitoring.
- Exploring the application of artificial intelligence (AI) for automating maintenance tasks and decision-making processes.
- Developing frameworks for optimizing maintenance programs across complex manufacturing systems with interconnected equipment.

By continuously innovating and adopting new technologies, organizations can ensure their maintenance programs remain resilient, agile, and cost-effective in the ever-evolving industrial landscape.

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