Prescriptive Statistical Problems Assignment 2

Assignment Part 2: Fan Replacement Strategy

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Submission Date: 08 June 2025

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Table of Contents

A. Excel Report for Monte Carlo Stimulation

1. Introduction

Controlling the cost of operation in data centers in the contemporary world is vital, hence the additional requirement of ensuring server availability. The report assesses two Monte Carlo simulations in Excel cooling fan replacement strategies:

The current policy: to replace the failed fan alone.

The Proposed policy: Change all three fans in case one of them fails

To answer the question of which policy is more cost-effective when simulating a fan replacement of 45 fans, the cost of downtime, labor, and parts is taken into consideration.

2. Methodology

The simulation model incorporates randomness using the following parameters:

- **Fan Lifespan**: Modeled as a discrete probability distribution ranging from 1000 to 1900 hours.
- **Technician Arrival Delay**: Randomly sampled from 20, 30, or 45 minutes with 60%, 30%, and 10% probability, respectively.
- **Cost Inputs**:
  - Fan cost: $32 per unit
  - Downtime cost: $10 per minute
  - Technician labor: $30 per hour
  - Repair times: 20 minutes (1 fan), 30 minutes (2 fans), 40 minutes (3 fans)

Each simulation trial represents a fan failure and the subsequent repair scenario.

Simulation Setup

- Number of simulated replacements: 45 fans
- Events:
  - **Current Policy**: 45 failure events (1 fan per event)
  - **Proposed Policy**: 15 failure events (3 fans per event)

Policies Defined

- **Current Policy**: Reactive replacement of the failed fan only
- **Proposed Policy**: Proactive replacement of all three fans upon any single fan failure.

Special Note on Simulation Scope:

While the **Current Policy** simulated **45 individual fan failures**, the **Proposed Policy** achieved 45 fan replacements in **only 15 failure events**, since **3 fans are replaced at once per failure**. This significantly reduces the number of technician visits and repair instances, impacting overall cost calculations.

3. Simulation Result Summary

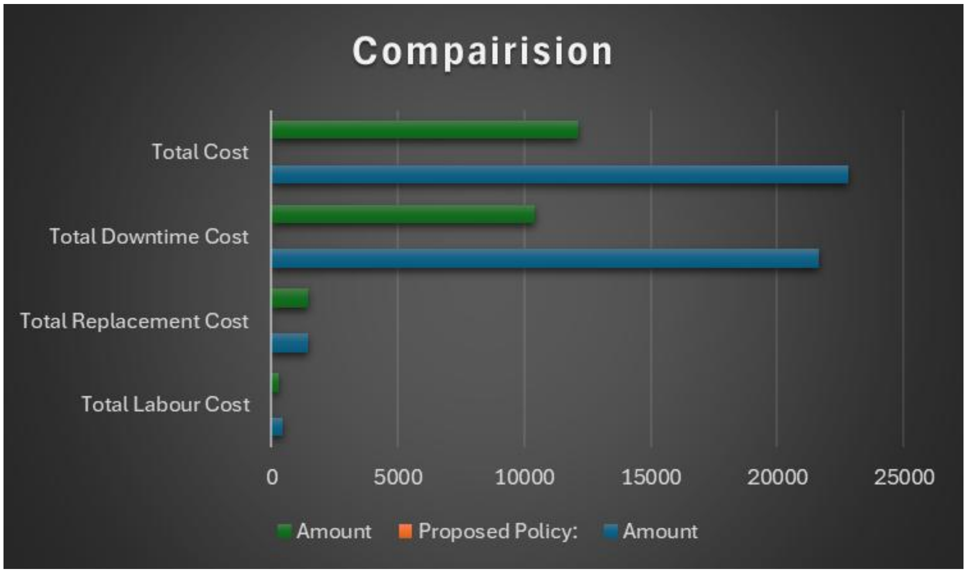
- **Current Policy** (45 individual replacements):
  - Total Labor Cost: **$450**
  - Total Replacement Cost: **$1,440**
  - Total Downtime Cost: **$19,800**
  - **Total Cost: $21,690**
- **Proposed Policy** (15 replacements of 3 fans each):
  - Total Labor Cost: **$300**
  - Total Replacement Cost: **$1,440**
  - Total Downtime Cost: **$9,850**
  - **Total Cost: $11,590**

The **Proposed Policy** results in significantly **lower total cost** — a savings of **$10,100** — despite replacing more fans per event. This is primarily due to:

- Fewer technician visits
- Fewer system downtimes
- More efficient labor utilization

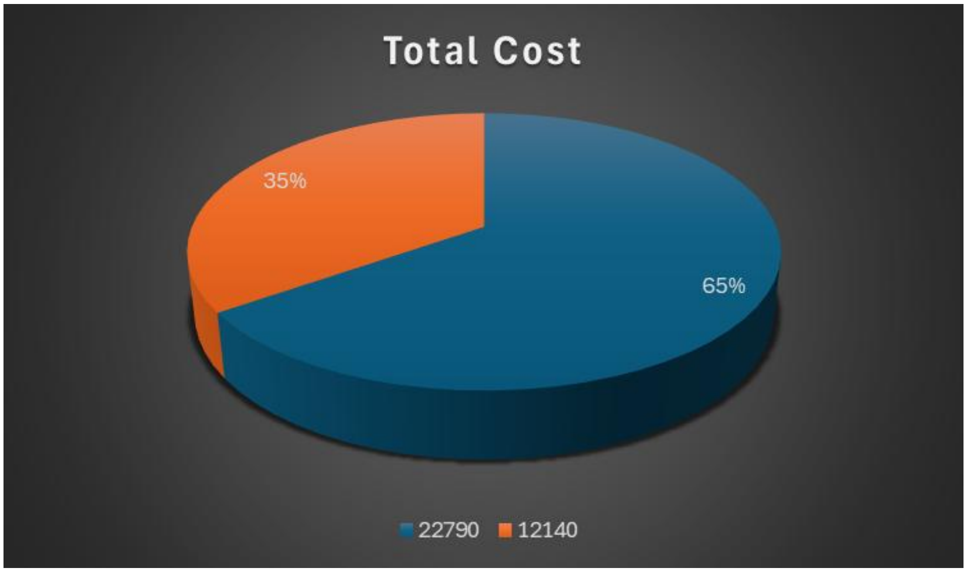
4. Visual analysis

4.1 Comparison Bar Graph:



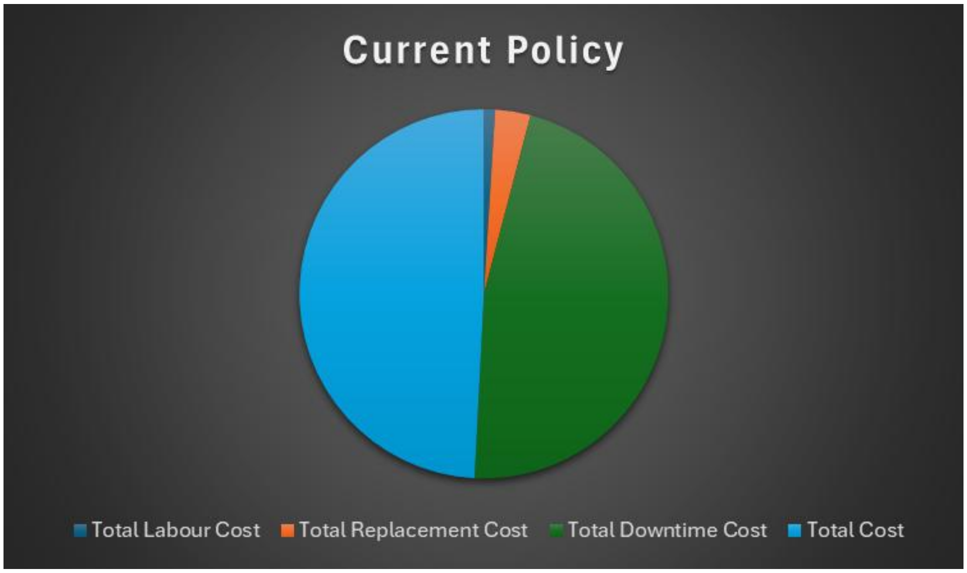
This bar chart is a comparison between the Proposed policy and the Current policy in terms of cost components. It makes it clear that the proposed policy decreases so significantly the periods of downtime and general total expenses. The labor costs and the cost of replacement are not very high in both scenarios. The total cost, however, in the current policy is mainly dominated by the cost of downtime. The suggested policy is very cost-effective.

4.2 Pie Chart Total Cost:



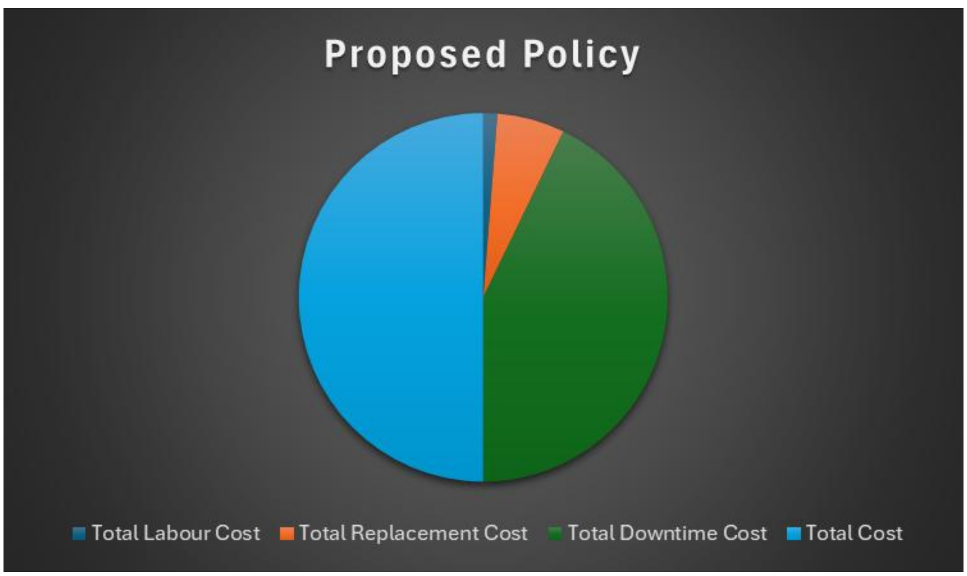
A pie chart that represents percentage cost is the total cost pie chart which reveals how the costs are shared between both policies. The proposed policy only gives 35% of the total cost when compared to the current policy that gives 65%. This pictorial demonstrates the expense perception of proactive bulk replacements. Minimizing technicians and unit downtime is significant. It supports literally the advantage of the financial possibility of policy merging.

4.3 Current Policy Pie Chart:



This pie chart is the breakdown of the total cost of the current policy involving the costs of labor, replacement, and downtime. The biggest share is downtime and then comes replacement and last is labour cost. The graph shows a visual representation of the fact that reactive maintenance creates longer downtimes. This adds a lot of inefficiency in the operations. It qualifies the necessity of more active approach.

4.4 Proposed Policy Pie Chart:



The pie chart of a proposed policy is more balanced in the cost distribution. Although labor cost and the replacement costs are a bit expensive per event, its volcanic drop in downtime makes it more cost effective. The timely installation of new fans eliminates more break downs. This reduces the amount of disruption time and cost accumulated. The visual clearly shows enhanced predictability and stability of the maintenance.

Charts display cost comparisons across policies:

- Total cost
- Breakdown: Labor, Downtime, Replacement parts

The visuals highlight cost-saving advantages of the **Proposed Policy**, particularly in reduced downtime and technician engagement due to fewer failure events.

5. Insights and Discussion

With a simulation, it becomes clear that although the Current Policy results in the minimum usage of hardware, it contributes to numerous failures of service delivery, high technician participation, and more costs of downtime. Conversely, the Proposed Policy reduces the breakdowns of bands greatly by replaying all three fans simultaneously, lessening downtime and labor expenses whereas costs of replacement per occurrence are increased.

Such anticipative approach fits with the concept of predictive maintenance, as well as can be shown to be more financially efficient, showing that any less disturbances and scheduled repairs are more profitable to the process of ensuring hardware efficiency, than a mere minimum use of hardware in a raw form.

Key Observations

- **Current Policy** (45 individual replacements):
  - Total Labor Cost: **$450**
  - Total Replacement Cost: **$1,440**
  - Total Downtime Cost: **$19,800**
  - **Total Cost: $21,690**
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The **Proposed Policy** results in significantly **lower total cost** — a savings of **$10,100** — despite replacing more fans per event. This is primarily due to:

- Fewer technician visits
- Fewer system downtimes
- More efficient labor utilization

6. Recommendations

Based on the Excel simulation:

Management should adopt the Proposed Policy of replacing all three fans upon any fan failure.

This policy results in:

- Fewer service interruptions
- Less technician time spent overall
- More predictable maintenance scheduling
- Lower total operating cost

Despite a slightly higher part cost per event, the benefits in reduced downtime and technician labor make it a superior long-term strategy.

7. Limitations & Suggestions for Future Work

- The proposed simulation will use deterministic repair times (e.g. 40 minutes to repair 3 fans), which may slow in real life.
- Overlapping failures, technician unavailability, and/or unavailability of parts were not modeled.
- The probability distributions were fixed and do not take into consideration season loads and fan age.
- A sensitivity analysis or modelling a hybrid policy (e.g. replacing 2 fans on a failure) can be done as future work.

8. Conclusion

In the Monte Carlo simulation provided in Excel, Proposed Policy has better efficiency in terms of cost and operational stability in managing replacement of cooling fans. The policy also ensures minimal downtime and cost, which are a result of replacing all three fans simultaneously in favor of an investment in high-uptime data center facilities.

B. Python Report for Monte Carlo Stimulation

1. Introduction

Another factor to consider that forms part of the data center is cooling because data centers should have a source of cooling so that it does not overheat and facilitate uptime. Here, a prescriptive analogy emerges between two dispersive lines of policy regarding replacement of fans:

Individual Replacement Policy: A fan will be replaced every time it is broken.

Bulk Replacement Policy: Anticipatory combination of all three fans replacement in case the failure of any of them occurs.

It will be aimed at identifying a cheaper and stronger policy visually and by Monte Carlo simulation. It checks the simulated results of cost, the variations amount, and the operation strategy recommendations.

2. Methodology

Simulation Setup

- **Tool Used**: Python
- **Simulation Runs**: 45 replacements per policy (represents 45 fan failures), For the Proposed policy, it will be 15 replacements as 45 fan replacement is achieved by 15 times.
- **Random Elements**: Fan lifetime, technician delay time, and labor time
- **Cost Elements Tracked**:
  - **Fan cost**: \$32 per fan
  - **Downtime cost**: \$10 per hour of delay
  - **Labor cost**: \$30 per hour

Policies Defined

- **Current Policy**: Reactive replacement of the failed fan only
- **Proposed Policy**: Proactive replacement of all three fans upon any single fan failure.

Special Note on Simulation Scope:

While the **Current Policy** simulated **45 individual fan failures**, the **Proposed Policy** achieved 45 fan replacements in **only 15 failure events**, since **3 fans are replaced at once per failure**. This significantly reduces the number of technician visits and repair instances, impacting overall cost calculations.

- **Individual Replacement**:
  - Only the failed fan is replaced.
  - Each event incurs technician arrival delay and repair time.
- **Bulk Replacement**:

- All three fans are replaced together when one fails.
- Shared technician and repair costs apply.

3. Simulation Results Summary

Metric	Individual Replacement	Bulk Replacement
Average Cost	$22,366.90	$11,574.40
Standard Deviation	±$527.17	±$306.90
Simulation Runs	45	45

Key Insight: Bulk replacement results in almost **50% lower total costs**, with **reduced variability**.

4. Visual Analysis

4.1 Boxplot of Total Costs

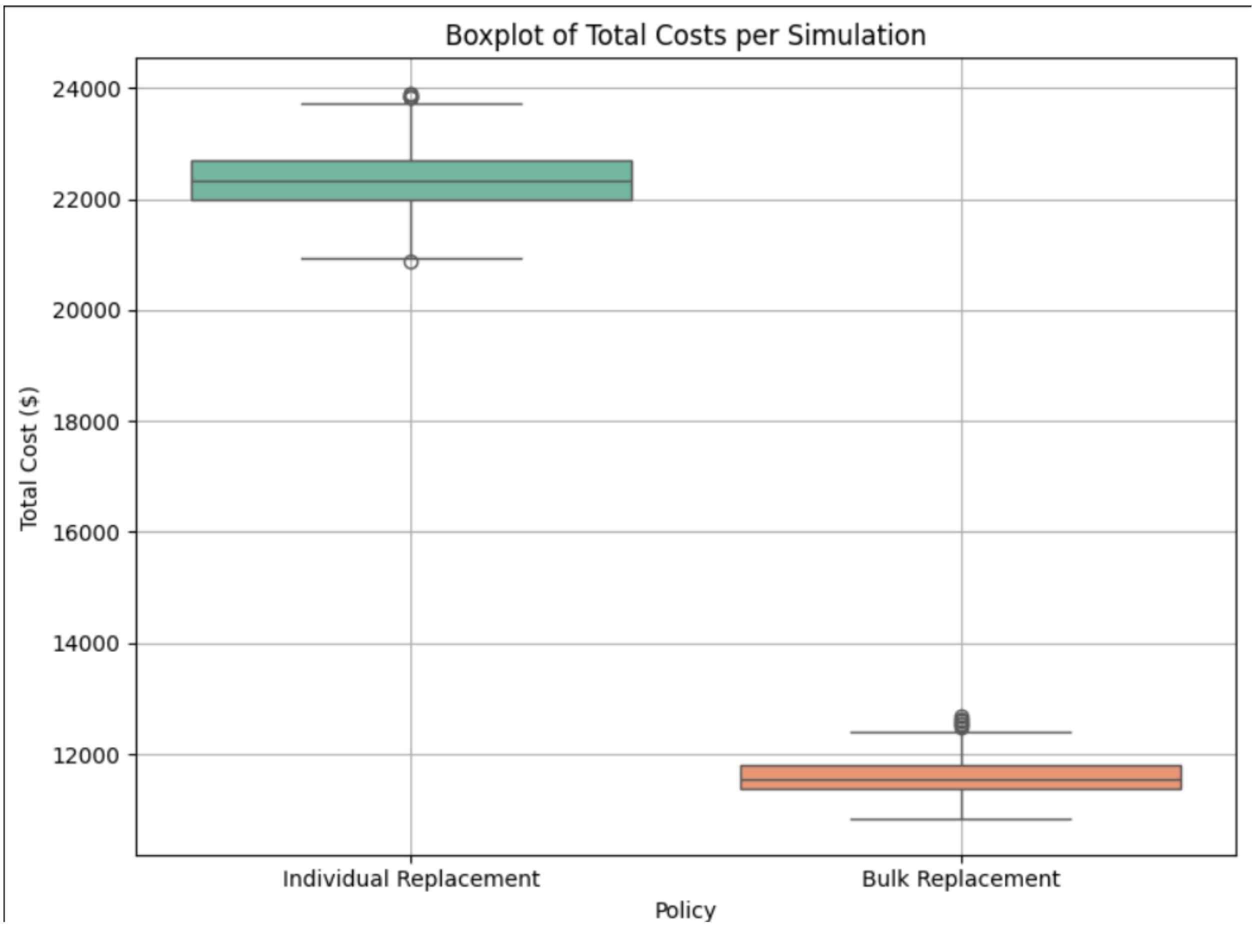

Chart 1: Box plot

Interpretation:

- The **Individual Replacement** policy exhibits **higher median cost** and a **wider range**, including several high-cost outliers.
- In contrast, the **Bulk Replacement** policy is tightly clustered around a much **lower cost median**, indicating **more predictable expenses**.

4.2 Histogram of Cost Distribution

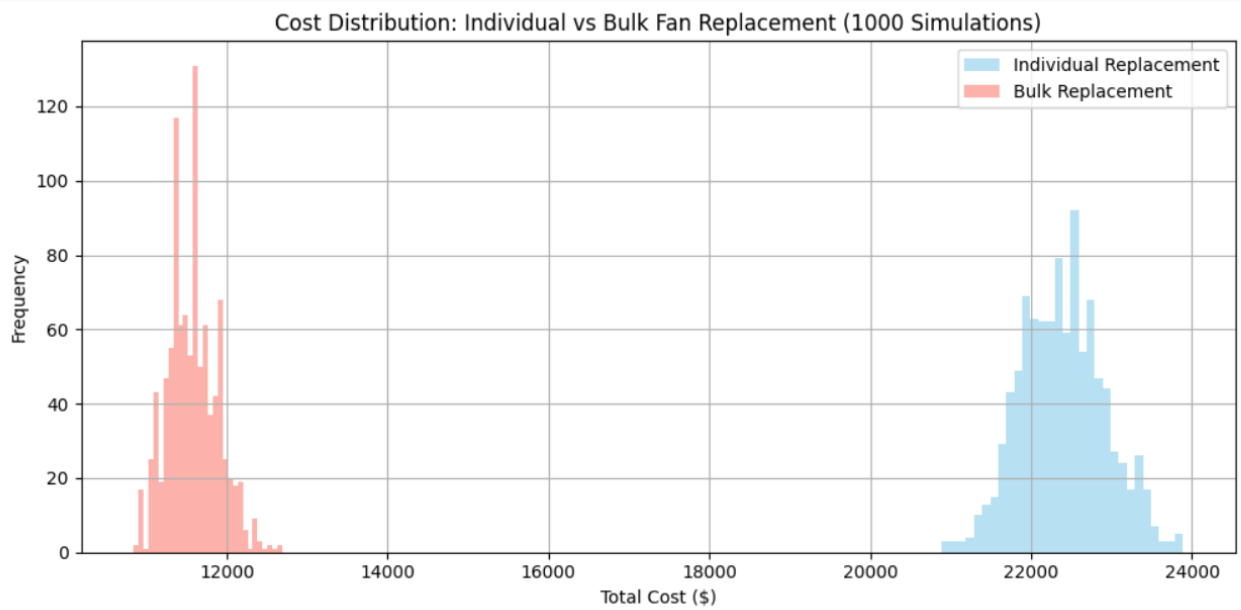

Chart 2: Histogram

Interpretation:

- The histogram shows **two well-separated cost distributions**:
    - Individual Replacement: ranges from ~$21,000 to ~$24,000.
    - Bulk Replacement: remains within ~$11,000 to ~$12,500.
- The sharp clustering for bulk policy reflects **lower risk and higher confidence** in budget estimation.

4.3 Violin Plot of Cost Distribution

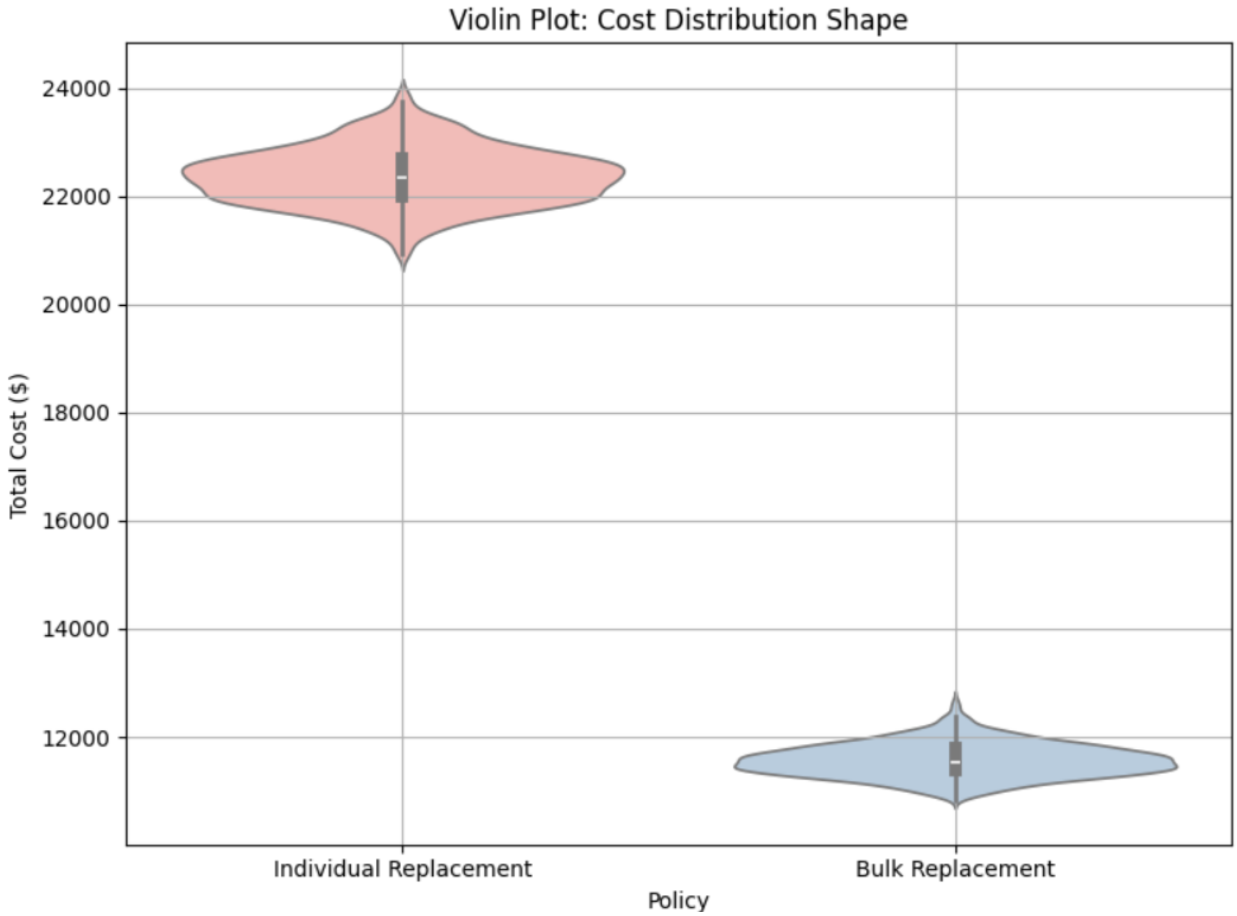

Chart 3: Violin Plot

Explanation:

The violin plot presents the **probability density** of total costs.

- Wider sections in the violin indicate where cost outcomes are more likely to occur.
- This combines the summary power of a boxplot with distribution smoothness.

Insight:

- The **Individual Replacement** policy exhibits **higher median cost** and a **wider range**, including several high-cost outliers.
- In contrast, the **Bulk Replacement** policy is tightly clustered around a much **lower cost median**, indicating **more predictable expenses**.

4.4 KDE Plot (Smoothed Cost Distributions)

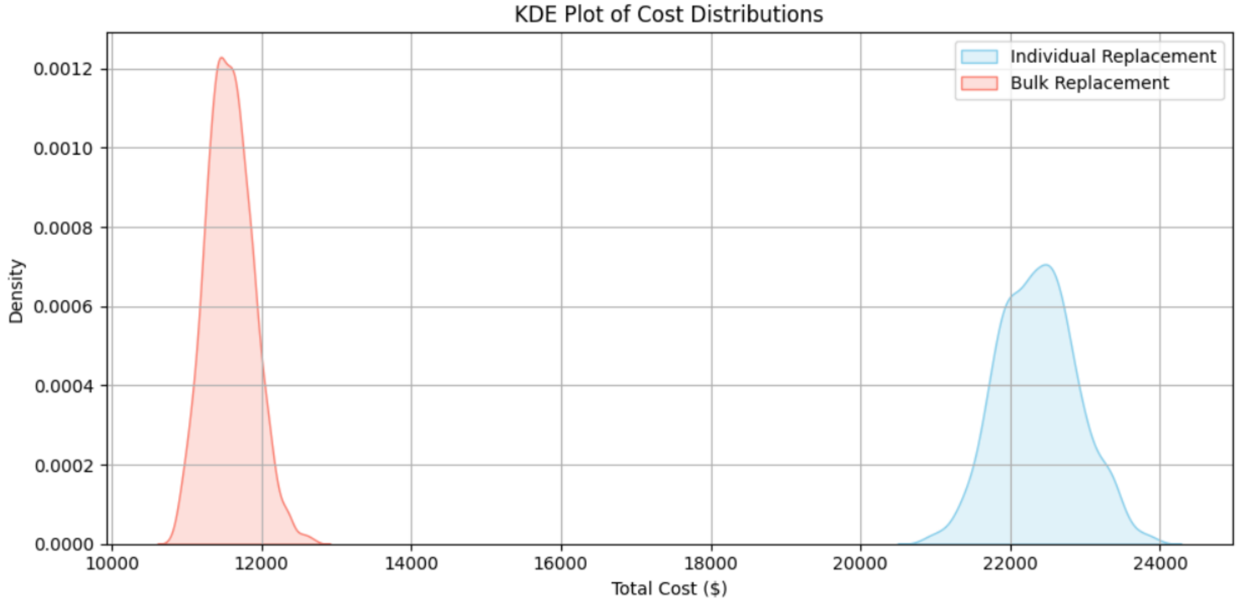

Chart 4: The KDE Plot

Explanation:

Kernel Density Estimation (KDE) plots show smooth curves of cost density.

- **Two curves** show the probability of costs occurring at specific ranges.
- It is easier to visually compare which policy consistently offers lower cost regions.
- **Insight:**
  The KDE Plot shows **two well-separated cost distributions**:
  - Individual Replacement: ranges from ~$21,000 to ~$24,000.
  - Bulk Replacement: remains within ~$11,000 to ~$12,500.

  The sharp clustering for bulk policy reflects **lower risk and higher confidence** in budget estimation.

5. Insights and Discussion

Key Observations:

- The average cost is lower, and spread is narrower, which makes **Bulk Replacement** operate more steadily.

- Though in one sense it replaces functioning fans with an oversupply, in practice the policy is very cost effective, avoiding technician returns, downtime and admin overhead.
- Being less hard on hardware, the **Individual Replacement** strategy still incurs greater costs in the long in the form of frequent disruptions.

6. Recommendation

Based on both the simulation outcomes and visual analysis:

Adopt the Bulk Replacement Policy for fan maintenance.

It is cost-efficient, lowers the risk of unexpected expenditures, and simplifies operations. The predictable nature of bulk replacements also improves planning and inventory management.

7. Limitations & Suggestions for Future Work

- **Sample Size**: Future simulations can increase runs (e.g., 1000+ simulations) for enhanced confidence.
- **External Variables**: Factors like technician shortage, equipment shipping delays, or seasonal variations were not included.
- **Advanced Scenarios**: Consider modeling:
    - Preventive maintenance triggers
    - Shared labor across tasks
    - Dynamic fan degradation patterns

8. Conclusion

These prescriptive analytics will help to make the required decisions regarding the choice of either of the two solutions on the basis of facts in the case of maintenance. With simulation modeling and graphical exploration, we have come to make out that Bulk Replacement policy performs considerably better in the score of cost and reliability compared to individual replaces.

This form of analysis helps in decision-making by the managers of data centers, which are proactive in increasing operational efficiency and in cost control.

C. Final Recommendation

Having thoroughly performed prescriptive analysis by using both Excel-based and Python-based Monte Carlo simulation capabilities, we can state that the Bulk Replacement Policy can be far more efficient in total cost than the Individual Replacement Policy in empowering and stabilizing operational efficiency.

Main Results in the Two Platforms:

Excel Simulation indicated that the Bulk Policy in which all the three fans are replaced each time there is a failure achieved the 45-fan replacement target within only 15 failure occurrences. This saved a lot of labor at the technician level and downtime of servers.

Bulk Cost: 11,590$

Individual Total Cost: 21690

The same conclusion was also reinforced by Python Simulation, which showed parallel trends in 45 randomly selected simulation runs.

Average Cost (Bulk) ~11,574

Individual Average Cost: ~$ 22,366

There was smaller standard deviation in bulk policy, and the changed policy was more predictable.

Although the bulk method may appear to excessively deploy functional fans, the cost benefit of reduced requirement of deploying technicians, reduced cumulative downtimes as well as ease of managing logistics, offset the slight added cost of upgrading the hardware. Moreover, the proactive approach is compatible with contemporary methods of maintenance, including preventive or predictive maintenance.

Thus, we suggest implementing Bulk Replacement Policy as a normative strategy of cooling fan replacement at the data center strongly.

This policy:

Minimizes unscheduled downtime and the costs thereof,

Improves the efficiency of technician capacity,

Gives consistent budgeting, and minimal variance,

Long-range system reliability and planning.

With this proactive and cost-effective maintenance strategy, this organization is best placed to realize better uptime, operating costs, and utilization of its resources in the data center.