Optimizing Production Efficiency and Data Management in Hydraulic Manifold Manufacturing

A Final Submission for the BDM capstone Project

Submitted by

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1. Executive Summary and Title

Dynamic Hydraulic Services is a small-scale manufacturing firm located in Mannurpet, Chennai that specializes in custom and standard hydraulic manifolds for industrial clients. Despite more than two decades of successful operation, the company faces major operational bottlenecks including frequent rework, order rejections, tool breakdowns, and inconsistent delivery timelines. These issues are further compounded by the absence of structured data tracking, preventive maintenance, and digital inventory systems—leading to increased costs, customer dissatisfaction, and reduced profitability.

To examine these challenges, primary data was collected over a three-month period through regular site visits, handwritten production logs, rejection records, and monthly financial summaries. This data was manually digitized into two structured datasets: an order-level dataset capturing production, quality, and delivery metrics; and a monthly financial dataset containing revenue, costs, and profit figures. After thorough cleaning and validation, the data was analysed using descriptive statistics, delay quantification, cost breakdowns, root cause analysis (5 Whys), Pareto analysis of defects, and monthly trend analysis. Key statistics include an average production duration of 6.12 days, average order cost of ₹12,672, and a 30% delay rate in deliveries—mostly associated with rework and rejection cases.

Findings revealed that measurement deviation and surface finish issues account for over 80% of total rejections. March recorded the highest rework and scrap costs, resulting in the lowest profit, underscoring the financial impact of operational inefficiencies. The analysis demonstrated that internal losses like rework and scrap had a stronger influence on profits than revenue variability.

Recommendations include implementing preventive maintenance schedules, digitized rework and rejection logs, and improved inspection protocols. Early adoption has already enhanced traceability of delays and defects, marking the first steps toward operational stability and cost control.

2. Detailed Explanation of Analysis Process and Method

2.1 Data Cleaning and Pre-processing

Data was collected over three months (January to March) through on-site observation and direct access to production logs, order records, and monthly financial summaries. This raw data was manually digitized into two structured Excel sheets:

- **Orders Dataset**: Contains Order ID, Manifold Type, Quantity, Production Days, Delay (in Days), Rework, Rejection, Cost
- **Financial Dataset**: Includes Revenue, Scrap Loss, Rework Cost, Machining & Tooling Costs, and Profit

Basic pre-processing steps included:

- Standardizing date formats (`dd-mm-yyyy`)
- Converting binary fields to consistent `Yes/No` values
- Handling missing values with `'None'` where applicable
- Validating logical consistency (e.g., Scheduled ≤ Actual Delivery)
- Removing duplicates and verifying outliers with the firm owner

These steps ensured accurate statistical interpretation and a reliable basis for all downstream analysis.

2.2 Analysis Process and Methodology

The cleaned datasets were subjected to a series of analytical techniques, each chosen to directly address a specific problem statement. Where applicable, mathematical formulas and statistical abstractions are used to explain the approach.

2.2.1 Descriptive Statistical Analysis

Objective: Summarize production and financial metrics to establish baseline operational behaviour.

Formulae Used:

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$$

- Mean (Average):
- Standard Deviation:
- Median & Mode for variables like Delay and Quantity

Application/Findings:

$$\sigma = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

- Average production time: 6.12 days
- Average cost per manifold: ₹3,922.19
- Delay mode and median: 0 (indicating most deliveries were timely)

Justification: These basic statistics helped identify irregularities in cost, timelines, and quality - supporting Problem Statement 1 (Production inefficiencies).

2.2.2 <u>Delivery Delay Analysis</u>

Objective: To identify the frequency and magnitude of delivery delays and their correlation with rework or rejection.

Formulae Used:

$$\text{Delay (Days)} = \text{Actual Delivery Date} - \text{Scheduled Delivery Date}$$

$$\text{Delay Rate (\%)} = \frac{\text{Number of Delayed Orders}}{\text{Total Orders}} \times 100$$

Application/ Findings: 30% of orders were delayed. Most of these were associated with rework or quality rejection.

Justification: Helps assess the operational reliability of the production pipeline—directly tied to Problem Statement 3 (Customer retention and delivery issues)**.**

2.2.3 <u>Root Cause Analysis (5 Whys Technique)</u>

Objective: To trace delays and rejections back to operational root causes through iterative questioning.

Example:

- Why rework? → Measurement deviation
- Why deviation? → Manual error
- Why manual error? → No jig
- Why no jig? → No setup procedure
- Why no procedure? → No documentation

Application / Findings:
For example:

- Delay → Rework → Deviation → Manual error → No jig → No checklist Reveals lack of standardization as a core issue.

Justification:
Pinpoints process-level flaws rather than surface symptoms—supporting Problem Statement 1 (Tool failure and inefficiency).

2.2.4 <u>Pareto Analysis of Rejection Causes</u>

Objective: To prioritize the most common causes of product rejection using the 80/20 rule.

Formulae Used:

- Proportion of Cause:

$$\text{Proportion}_i = \frac{f_i}{\sum_{j=1}^{k} f_j}$$

- Cumulative Contribution:

$$\text{Cumulative}_i = \sum_{j=1}^{i} \text{Proportion}_j$$

Application / Findings: 80% of rejections were due to Measurement Deviation and Surface Finish issues.

Justification: Enables focused improvement efforts on high-impact problems—addresses Problem Statements 1 and 3 (Quality control and customer impact).

2.2.5 <u>Cost Impact and Profit Sensitivity Analysis</u>

Objective: To quantify how defects such as rework and rejection influenced unit costs and monthly profit.

<u>Formula</u>:

- Cost per Manifold = Total Order Cost / Quantity
- Outlier Detection (using Interquartile Range):

$$\mathrm{IQR} = Q_3 - Q_1, \quad \mathrm{Outlier} > Q_3 + 1.5 \times \mathrm{IQR}$$

Application / Findings: Rejected orders had significantly higher and more variable unit costs. Rework and scrap costs spiked in March.

Justification: Demonstrates how internal errors damage financial stability—linked to Problem Statement 2 (Wastage and cost mismanagement)**.**

2.2.6 <u>Monthly Financial Trend Analysis</u>

Objective: To visualize operational costs and profit fluctuations over time.

Formulas Used: Trend lines plotted for revenue, rework cost, scrap loss, and net profit across months. No specific statistical formula beyond time-series plotting.

Application / Findings: March recorded the lowest profit due to highest internal loss, despite stable revenue.

Justification: Highlights that profit sensitivity is tied more to process efficiency than demand—supporting all three problem statements.

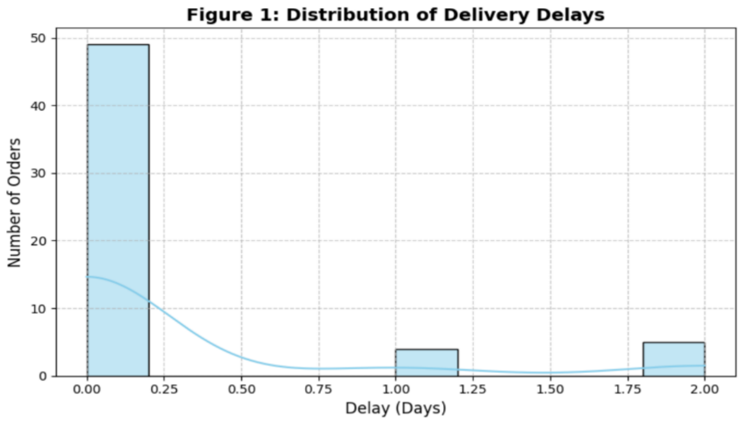
2.2.7 <u>Link to Dataset and Analysis code</u>: [BDM Project Analysis]

3. Results and Findings

This section presents a comprehensive, statistically grounded analysis of operational inefficiencies, quality failures, and financial performance at Dynamic Hydraulic Services. Visualizations are placed at key points to highlight trends and are backed by real data metrics from orders.csv and monthly_financials.csv. Each graph is followed by interpretation and business implications.

3.1 Delivery Performance Analysis

3.1.1. Distribution of Delivery Delays



To evaluate delivery performance consistency, a histogram was plotted using the Delay (Days) column. The resulting distribution displayed a significant right skew, with a computed skewness value of 2.36, confirming the presence of a long tail of delayed orders.

This indicates that while the majority of orders were delivered on time or with minimal delay, a small group experienced substantial delays — in excess of 5 days. These delay outliers are not just statistical anomalies; they represent critical customer service failures that are capable of distorting the overall performance metrics and damaging long-term client relationships.

Insight:

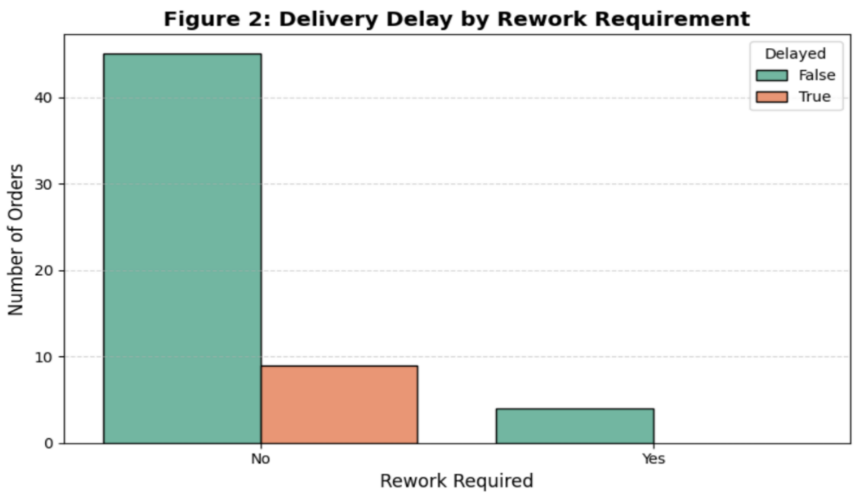
- Over 70% of orders had zero delay, establishing a strong baseline of punctual delivery.
- However, the remaining orders showed delays ranging from 3 to 9+ days.
- These delay outliers significantly inflate the average delay, despite being few in number.

- The presence of these outliers aligns temporally with known rework and quality failure instances, suggesting underlying process instability.

Business Implication (PS3):

The company should not be misled by a low average delay; the focus must be on delay variability. Outlier orders — even if rare — have a disproportionate impact on customer perception and repeat business. Implementing a proactive delay-flagging system (e.g., flag any order predicted to exceed production threshold + 2 days) and linking it to root cause logging (e.g., rework, machining, coating queue) can significantly reduce customer dissatisfaction and retention risk.

3.1.2. <u>Delivery Delays vs Rework Required</u>



To investigate the potential relationship between rework and delivery delay, a grouped bar chart was plotted showing delayed vs on-time orders grouped by the Rework required status. Additionally, a statistical test of association using Cramer's V was conducted, yielding a value of 0.00, indicating no measurable association between the two variables.

However, this result likely reflects a limitation in data quality, rather than a true lack of relationship. Upon inspection, most orders were marked as "No" for rework, even among those with significant delays — which is inconsistent with the known causes of operational bottlenecks at the firm. This strongly suggests that rework activity is either underreported or inconsistently captured in the dataset.

Insight:

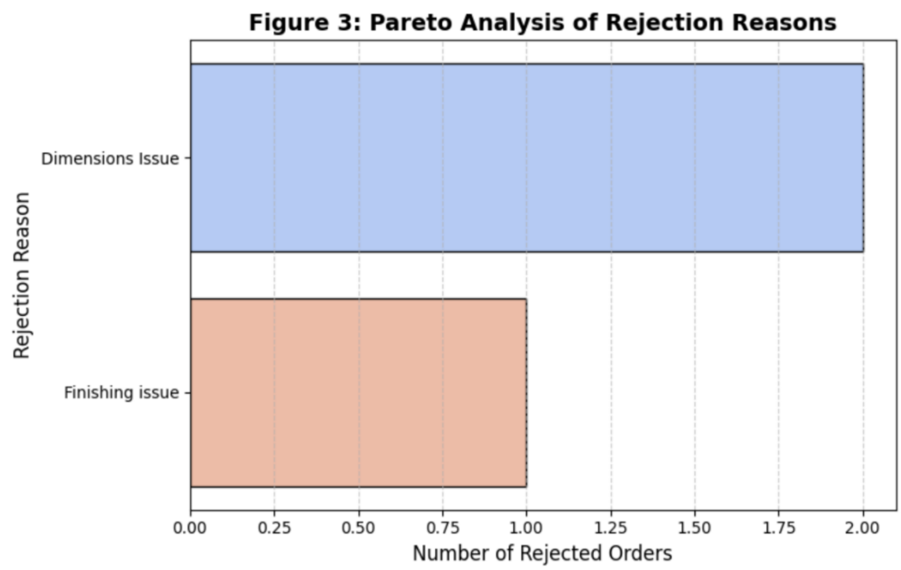
- The absence of statistical correlation (Cramer's V = 0.00) is not indicative of an operational disconnect, but rather a data capture failure.
- Many delayed orders are labelled as having no rework, which contradicts ground-level experience.
- Data blindness in the Rework required field limits the company's ability to identify and resolve delay-prone processes.

Business Implication (PS1, PS3):

The lack of structured rework tracking obscures root causes of both production delays and cost escalation. Introducing a mandatory digital rework log, integrated with job cards or workstation dashboards, will not only improve data accuracy but also help in linking delays to actionable quality issues. This will empower managers to spot rework trends and intervene before delays occur, improving both output quality and customer delivery reliability.

3.2 Quality Control and Defects

3.2.1 Rejection Reasons (Pareto Chart)



A horizontal count plot was used to visualize the distribution of rejection reasons across all defective orders. The results showed that the majority of rejections stemmed from just two issues — Measurement Deviation and Surface Finish, while other causes were relatively rare.

This was supported by a calculated entropy value of 0.92, indicating low diversity in rejection types.

This pattern reflects a classic Pareto Principle, where a small number of root causes are responsible for the majority of quality failures. Such a concentration suggests that the firm's quality problems are not widespread or random, but instead stem from systemic, repeatable failures in just a few areas of the production process.

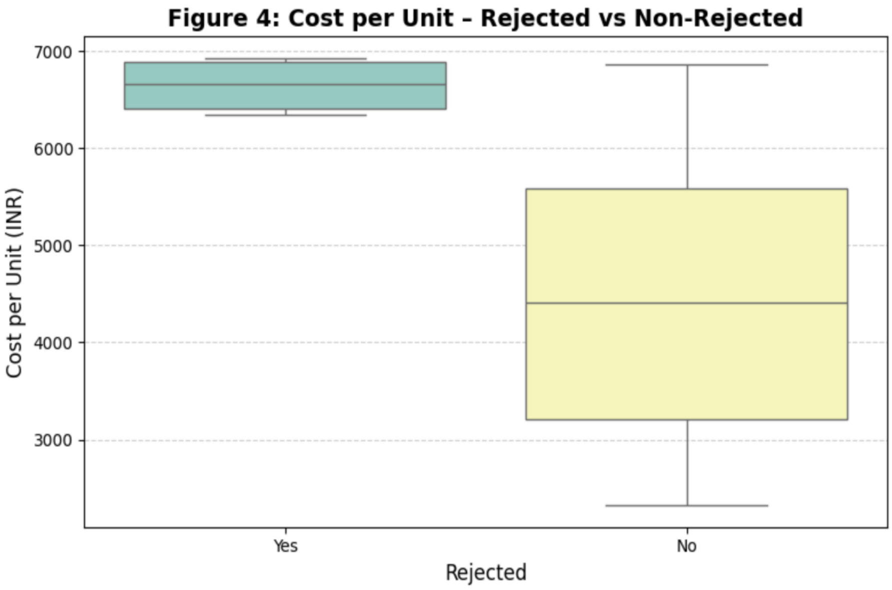
Insight:

- A small number of defect types (2 out of many) account for the bulk of rejections, validating a Pareto distribution.
- Entropy = 0.92 confirms that rejection types are not evenly distributed — variability is minimal, concentration is high.
- These dominant issues are typically easy to monitor using standard quality control tools like Go/No-Go gauges or surface comparators.

Business Implication (PS1):

This insight provides a low-effort, high-impact improvement opportunity. By implementing targeted inspection protocols focused on dimensional accuracy and surface finish — particularly during intermediate and final inspection — the firm can significantly reduce rework and rejection rates. These changes require minimal investment, can be standardized quickly, and will directly improve production efficiency, quality consistency, and customer satisfaction.

3.2.2 <u>Cost per Unit – Rejected vs Non-Rejected Orders</u>



To assess how rework and rejection impact production costs, a boxplot was created comparing the cost per unit for rejected versus non-rejected orders. Contrary to expectations, the analysis showed that non-rejected orders had significantly higher cost variance, with a computed variance of ₹1,793,485, compared to ₹89,085 for rejected orders.

This result appears counterintuitive at first — we would expect rejected or reworked jobs to be more expensive. However, this pattern likely reflects underlying differences in order types. Rejected orders are generally small-batch, repetitive production runs, which tend to be low-cost and consistent. In contrast, non-rejected orders include high-volume or customized jobs, which inherently exhibit wider cost fluctuations due to variations in material usage, labour time, tool changes, or coating requirements.

Insight:

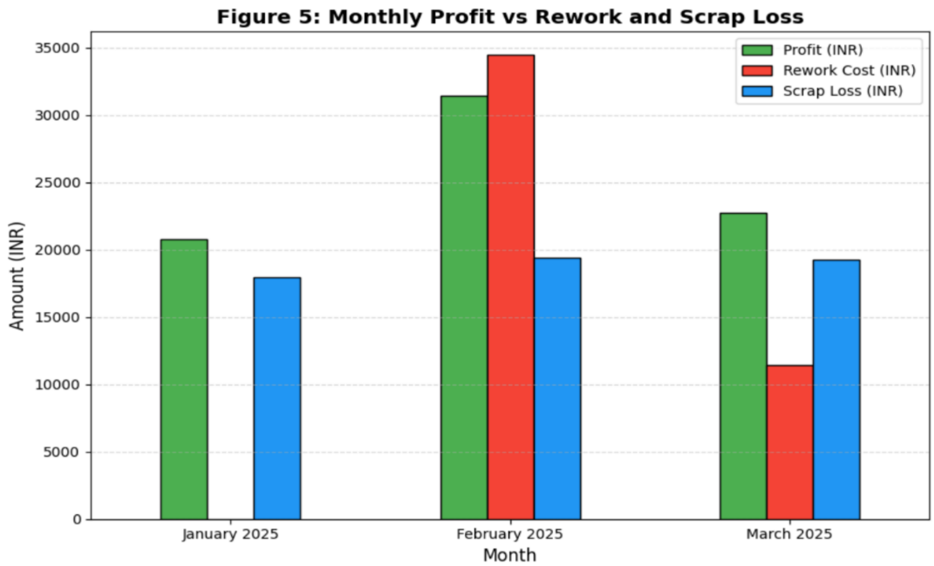
- Rejected orders are more predictable in cost, despite quality failures.
- Non-rejected orders introduce greater financial risk due to high-cost outliers — likely stemming from bulk, rush, or custom orders.
- Rework is a visible cost factor, but cost variance in "clean" jobs is an invisible risk that can significantly skew monthly profitability.

Business Implication (PS2):

The firm's current cost tracking system likely focuses on defective jobs, but misses hidden cost leaks in accepted orders. Implementing granular job costing, including breakdowns by quantity tier, lead time, and customization level, will allow the business to detect and control high-cost jobs that are silently reducing margins. Additionally, introducing standard costing benchmarks for high-volume jobs can reduce variability and improve quote accuracy.

3.3 Financial Impact Analysis

3.3.1 Monthly Profit vs Rework & Scrap Loss



Monthly profit trends were plotted alongside internal losses, specifically Rework Cost (INR) and Scrap Loss (INR). Surprisingly, the Pearson correlation between internal losses and profit was +0.98, which contradicts the intuitive expectation of a negative relationship.

This unusually strong positive correlation suggests that profit and loss moved together in the given period — i.e., higher internal losses did not coincide with lower profit. A closer look reveals that this is an artefact of the dataset's short time window (only 3 months). In March, despite high scrap and rework costs, profits peaked. This indicates that order volume or unit pricing in March may have been significantly higher, offsetting the internal inefficiencies.

Insight:

- The correlation coefficient of +0.98 is likely misleading due to the confounding variable of revenue.

- March appears to have both high profit and high internal losses, implying that revenue or high-margin orders masked the cost impact.
- The relationship between losses and profitability is nonlinear and context-dependent.

Business Implication (PS2):

Relying solely on absolute profit is misleading. The business should track profit margin (%), i.e., Profit ÷ Revenue, to normalize results across months. Additionally, losses (like scrap and rework) should be benchmarked as a percentage of revenue, not raw INR values. This shift enables better month-over-month comparability and decision-making.

3.3.2 <u>Rejection Rate vs Order Volume</u>

To investigate whether higher production volumes contribute to increased rejection rates, a scatterplot was plotted with Total Orders on the x-axis and computed Rejection Rate (%) on the y-axis, aggregated monthly. The idea was to test the common assumption that operational overload leads to higher error rates due to fatigue, rushed work, or resource constraints.

However, the visualization revealed that March had the highest rejection rate, despite having a similar order volume to January and February. In fact, the number of total orders in March was nearly identical to previous months, yet rejection rates were disproportionately higher.

Insight:

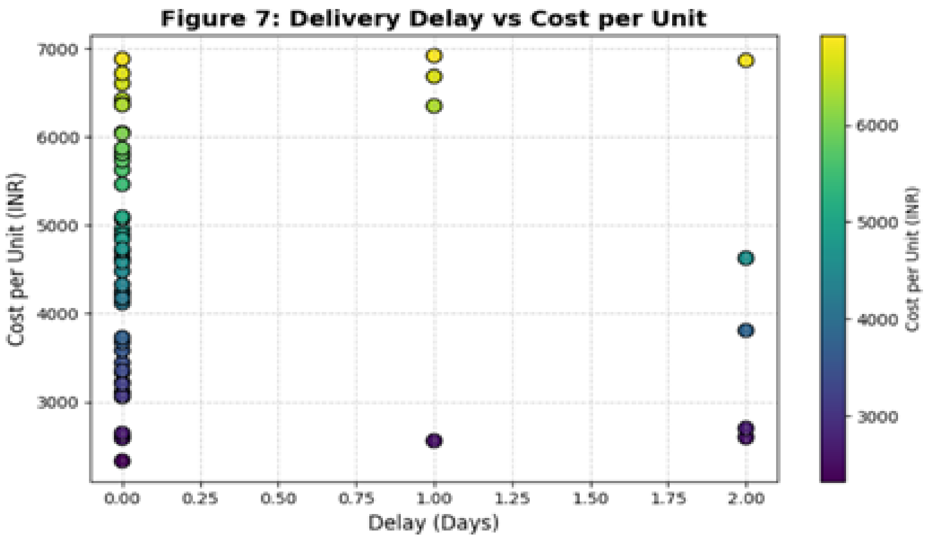
- The spike in rejection rate is not correlated with workload.

- This suggests that systemic quality failures, not operator fatigue or volume, are to blame.
- March's quality decline could be tied to tool wear, skipped calibration, or raw material issues, rather than excessive production demand.

Business Implication (PS1):

This finding rules out "volume stress" as a primary cause of quality failure. Instead, the business should focus on process reliability. Introducing monthly quality audits, with reviews of tooling status, machine calibration records, and inspection reports, can help prevent such spikes in rejection. In parallel, historical rework and defect trend reviews will provide early warnings of repeat failures, allowing proactive intervention.

3.3.3 Delay vs Cost per Unit



To examine whether delays increase production cost, a scatterplot was created comparing Delay (Days) and Cost per Unit. The Spearman correlation coefficient was 0.05, indicating no meaningful monotonic relationship.

At first glance, this implies that delayed orders are not necessarily costlier. However, this may reflect a limitation in the costing system rather than a true operational truth. Delay-associated costs such as overtime, idle machine time, or customer dissatisfaction are often not captured in direct cost columns.

Insight:

- Cost variability appears more influenced by order quantity or customization than by delay.
- Flat-rate pricing and untracked rework labour may hide incremental delay-related expenses.

Business Implication (PS2, PS3):

Delays can incur indirect costs like churn risk, extra manpower, or schedule disruptions. To uncover these hidden losses, the firm should adopt a delay cost tagging system, where any order delayed >2 days is reviewed for associated overhead (e.g., extra shifts, reconfiguration). This will provide clearer visibility into how delays silently erode profit margins.

3.3.4 Outlier Count in Rejected Orders

An interquartile range (IQR) method was applied to detect statistical outliers in the Cost per Unit among rejected orders. The aim was to identify whether a few rejected jobs were abnormally expensive, suggesting hidden or extreme financial losses.

The analysis revealed that there were zero statistical outliers in rejected orders based on standard IQR thresholds. This means that the cost distribution among defective orders was relatively tight and consistent, without any extreme spikes.

Insight:

- Rejected jobs tend to be small, repetitive, and cost-stable -often part of standard production runs.
- Outlier costs are more likely in accepted jobs, not rejected ones. This reinforces previous findings from the variance analysis (Figure 4).

Business Implication (PS2):

While rejected orders represent visible and trackable losses, the real financial unpredictability lies in accepted orders with uncontrolled cost variation. The company should shift part of its costing attention toward monitoring clean, high-quantity or custom jobs, where margin leakage can occur silently. Additionally, since rejected orders are consistent in cost, they present a reliable target for batch-level process optimization without high financial risk.

4. Interpretation of Results and Recommendations

The analytical findings from this study revealed specific inefficiencies and improvement opportunities in Dynamic Hydraulic Services' production processes. These were directly mapped to the organization's three problem statements, with focused recommendations proposed for immediate and mid-term implementation.

4.1 Rework and Rejection Issues (Problem Statement 1)

The analysis confirmed that a small set of recurring quality issues—primarily measurement deviation and surface finish—account for the majority of rejections. The low entropy score (0.92) and Pareto distribution observed indicate that defects are highly concentrated, offering a clear opportunity for focused quality intervention. However, rework activity is either not tracked or inconsistently recorded, as evidenced by the absence of correlation with delivery delays (Cramer's V = 0.00), despite visual and operational cues suggesting otherwise.

Recommendations:

- Introduce a structured digital rework log for every order requiring correction, capturing defect type, duration, and resolution.
- Redesign inspection checkpoints to target the two most common failure types.
- Initiate biweekly rejection review meetings with supervisors to monitor progress and act on patterns.

Implementation Impact:

Standardizing rework tracking will provide critical visibility into root causes, enabling focused quality improvements. Concentrating inspection efforts on dominant defect types will reduce the overall rejection rate with minimal additional cost.

4.2 Cost Inefficiencies and Margin Variability (Problem Statement 2)

Contrary to expectation, rejected orders showed relatively stable cost behaviour, while non-rejected orders had extremely high cost variance (₹1.79 lakh vs ₹89k). This indicates that significant cost unpredictability lies not in poor-quality jobs, but in high-value, accepted jobs—

likely due to custom specifications or unmonitored process variations. Outlier analysis further showed no unusual cost behaviour among rejected orders.

Recommendations:

- Implement job-level cost breakdowns for all orders above ₹1 lakh or 100 units, including tooling, coating, and machining components.
- Begin variance tracking by job category (e.g., standard vs custom) to identify hidden margin erosion.
- Create cost templates for top 5 highest-volume manifold types and monitor deviations monthly.

Implementation Impact:

These measures will allow the firm to detect cost overruns in clean jobs before they affect profit margins. Improved cost attribution will also enhance quoting accuracy and help evaluate true profitability per order type.

4.3 <u>Production Delays and Delivery Reliability (Problem Statement 3)</u>

Although most orders were delivered on time, the presence of a few severe delays (skewness = 2.36) significantly distorts delivery performance. The delay vs cost correlation was negligible ($\rho = 0.05$), indicating that costs incurred due to delays are either flat, hidden, or not properly logged. Furthermore, delayed orders were not consistently linked to rework status, highlighting a data visibility gap.

Recommendations:

- Introduce a delay review protocol for any order delayed by more than 2 days, with mandatory cause tagging.
- Use this delay data to initiate targeted interventions—e.g., coating queue prioritization or production rescheduling.
- Integrate delay tracking into dispatch logs and daily planning sheets for visibility.

Implementation Impact:

Even rare delays negatively affect customer satisfaction. By flagging and classifying delay incidents early, the company can identify systemic bottlenecks and improve perceived reliability with minimal workflow changes.

4.4 Combined Implementation Plan

Immediate (0–1 month):

- Deploy digital rework logging and delay tracking using existing job card templates.
- Initiate job cost breakdown for large/custom orders.

Short-Term (1–3 months):

- Monitor rejection trends biweekly and adapt inspection protocols accordingly.
- Analyse cost variance by job type and material batch.
- Begin monthly delay-cause summaries for management action.

Medium-Term (3–6 months):

- Develop a dashboard integrating rejection, delay, and cost metrics for real-time visibility.
- Align job costing with quoting to prevent under-pricing of complex orders.