REPORT

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1. Executive Summary

This project demonstrates the design and deployment of a **factory Quality Control Tower** for the iPhone camera module at the Cork facility. Using synthetic but realistic datasets, I built dashboards covering the full quality chain: **Incoming Inspection (IQC) → Reliability → Outgoing Quality Audit & Yield (OQA/FPY) → Field Quality → Predictive Alerts**.

The data included intentional irregularities—nulls, outliers, duplicates, and seasonal shifts—to mirror real-world factory complexity. Despite this, clear quality signals emerged.

Headline Findings

- **First Pass Yield (FPY)** averaged **97%**, with dips during **Mar–Apr** and **Aug–Sep** seasonal ramps.
- **Incoming PPM** averaged **115**, with outliers at suppliers **S5002 (175–180)** and **S7142 (~155)**.
- **Reliability pass rate** averaged **98%**, though **humidity tests** underperformed vs drop/thermal/vibration.
- **Field RMA rate** averaged **~1%**, with **APAC/MEIA** higher than **EU/NA**.
- Across ~10M units built, **rework reached 208k** and **scrap ~92.8k**, concentrated on **CORK-L1/L2** lines.

Immediate Actions

- **Tighten AQL** for suppliers **S5002/S7142** (reduce to 1.0) and monitor PPM trend.
- **Add humidity reliability screen** in monsoon months (Jun–Sep) to reduce stress-induced failures.
- **Kaizen event on Line L2-B** to address rework/scrap clusters (standard work, gage R&R, poka-yokes).

Expected Outcomes

- **FPY improvement:** +0.8 to +1.5 percentage points.
- **Rework reduction:** −10 to −15%.
- **Scrap reduction:** −8 to −12%.
- **RMA reduction in APAC/MEIA:** −5 to −8%.

2. Context & Objectives

This project was designed to replicate the responsibilities of a **Product Operations – Quality Engineer** at Apple, with a focus on the iPhone camera module production in the Cork factory. The control tower approach demonstrates my ability to link supplier quality, reliability, factory yield, and field performance into a single decision-making system.

Role Alignment

- **NPI (New Product Introduction):** Establishing readiness criteria (FPY, reliability, IQC limits) before ramp.
- **Supplier Quality:** Monitoring PPM, AQL compliance, and defect types across high-volume suppliers.
- **Reliability:** Stress testing under multiple conditions and interpreting dominant failure modes.

- **Yield Improvement:** Identifying lines and shifts driving rework and scrap losses.
- **Field Metrics:** Tracking RMA, regional issue trends, and top recurring problems.
- **Analytics & Problem Solving:** Using implicit aggregation methods to surface trends despite irregular data.

Scope Boundaries

- **Factory:** Cork manufacturing lines (CORK-L1, CORK-L2, and sub-lines/shifts).
- **Product:** iPhone camera module (single-component focus for clarity).
- **Data:** Synthetic but realistic CSV datasets covering suppliers, IQC, reliability, OQA/yield, field, and predictive alerts.
- **Constraints:** No custom measures or calculated columns—analysis relied only on implicit aggregations (Sum, Average, Count).

This scope ensures the project is representative of Apple's global Product Operations, while remaining bounded to the Cork facility and one critical module.

3. Data & Irregularities

The Quality Control Tower was built using six synthetic but realistic CSV datasets. Each file contained key attributes aligned through common keys (supplier_id, build_id, and date/week/month).

Dataset Overview

Dataset	Coverage	Key Columns
suppliers.csv	Supplier master	supplier_id, region, audit_score, AQL, PPAP_status, Cpk_proxy
incoming_inspection.csv	Daily IQC lots	lot_id, supplier_id, qty_received, defects, PPM, accept_reject
reliability_tests.csv	Weekly stress tests	week, test_type, units_tested, units_failed, pass_rate, fail_mode
oqa_yield.csv	Daily factory output	build_id, line, units_built, first_pass_yield, rework, scrap, OQA_defects
field_quality.csv	Monthly field returns	month, region, units_sold, field_returns, RMA_rate, top_issues
predictions.csv	Model risk outputs	build_id, date, predicted_risk, risk_band

Data Irregularities

The datasets were intentionally designed with real-life irregularities to reflect production environments:

- **Nulls:** Occasional missing values in supplier audits and PPAP flags.
- **Outliers:** Sharp dips/spikes in FPY (seasonal ramps), and isolated high-PPM lots.
- **Typos:** Minor text inconsistencies in defect/failure modes (e.g., "ois_drift" vs "OIS drift").
- **Duplicates:** Some incoming lots repeated; removed via deduplication.
- **Seasonal Shifts:** FPY dips in Mar–Apr and Aug–Sep; field RMAs peaking in late summer/autumn.
- **Small-Scale Inconsistencies:** Slight mismatch in totals across files (e.g., units built vs. units sold).

Handling Approach

Rather than "cleaning away" these issues, I mirrored Apple's approach:

- Visuals were built to **surface irregularities**, not hide them.
- Outliers were **flagged contextually** (e.g., Top-N supplier charts).
- Nulls and typos were left visible in defect/failure breakdowns to drive CAPA (Corrective and Preventive Action) ownership.
- Seasonal dips were treated as expected operational stress points, requiring contingency actions.

This allowed the dashboards to stay close to factory reality, where noise and irregularity are constant signals for risk.

4. Methods

The control tower was built using a **no-measures approach** — only implicit aggregations (Sum, Average, Count, Min/Max) available directly from the dataset columns. This constraint forced careful design of how metrics were compared, ensuring transparency and replicability.

Aggregation Rules

- **Volumes:** always calculated using **Sum** (e.g., units_built, units_sold, qty_received).
- **Rates:** always calculated using **Average** (e.g., first_pass_yield, RMA_rate, pass_rate).
- **Top-N Analysis:** sorted by **Sum of volume columns** (e.g., suppliers by qty_received, lines by units_built).

Volume Context

Averages were often misleading if read in isolation. For example, one supplier's PPM may look low, but with very low shipment volume. To avoid this misread:

- **Companion visuals** showed total volumes alongside rate metrics.
- Sorting was applied so that **high-volume contributors surfaced first**, keeping decision focus proportional to impact.

Filters & Slicers

Dashboards used filters for:

- **Region, Supplier, Line, Test Type, Shift, Date/Month/Week**.
- **Risk band** thresholds (for predictive alerts).
  These allowed leaders to drill down quickly from global signals to specific ownership points.

Visualization Choices

- **Scatter plots** (FPY vs OQA defects, bubble = volume) to highlight clusters.
- **Combo charts** (FPY vs Units Built) for executive monitoring.
- **Matrix views** (Region vs RMA) for field returns.
- **Top-N bar charts** for supplier and defect type focus.

This method ensured that even without weighted KPIs or DAX measures, I could deliver operationally useful insights, consistent with how Apple emphasizes clarity, scalability, and actionable focus in its operations reporting.

5. Dashboard Narratives

5.1 Executive Overview

Purpose
The Executive Overview is designed for senior operations and quality leaders. It provides a consolidated view of yield, volume, reliability, and field metrics in one place, enabling quick recognition of risk windows and trend inflections.

How to Read It

- The **combo chart** (Figure E1) shows **FPY (line)** against **Units Built (bars)** over time.
- Seasonal dips around **Mar–Apr** and **Aug–Sep** are clearly visible, aligning with ramp periods.
- Supporting KPI cards show averages: **FPY 0.97**, **Incoming PPM 114.68**, **Reliability 0.98**, **Field RMA ~1%**.

Key Insights

- FPY remains strong (~97%) but is not stable; dips during ramp windows expose capacity stress.
- Incoming quality (PPM ~115) is acceptable overall but masks high-risk suppliers (see Section 5.2).
- Reliability stays high (98%), but the executive view masks test-type detail (see Section 5.3).
- Field RMA averages ~1% — within tolerance, but regional skews (APAC, MEIA) need review.
- Across ~10M units built, **rework (208k)** and **scrap (92.8k)** are non-trivial costs.

Decision & Action

- Flag ramp months for **pre-emptive line checks and supplier containment**.
- Elevate the executive view into a **monthly review pack**, linking FPY/RMA trends directly to CAPA.
- Use this as the top-level "one-page brief" for executive staff meetings.

Risk / Limitation

- The FPY trend is an **unweighted average** — large vs small build lots are treated equally. A weighted FPY measure would improve accuracy, though the trend direction remains valid.

5.2 Supplier Quality

Purpose
The Supplier Quality dashboard helps Supplier Quality Engineers and Global Supply Managers focus attention on high-risk suppliers. It brings together incoming inspection results, acceptance decisions, and defect types, allowing targeted containment and supplier engagement.

How to Read It

- **Bar chart** (Figure S1) ranks suppliers by **Sum of qty_received** and overlays **Average PPM**.
- Acceptance results (ACCEPT vs REJECT) are visible as stacked counts, giving a sense of risk frequency.
- Defect mix is broken down into **Critical / Major / Minor**, with majors and minors dominating.

Key Insights

- Supplier **S5002** showed the highest PPM (~175–180), followed by **S7142 (~155)** and **S6577 (~146)**.
- In contrast, suppliers like **S1175 (~92)** and certain EU suppliers consistently performed below 100 PPM.

- Despite high PPM, most lots were still accepted — signaling an opportunity to **tighten AQL thresholds**.
- Volume leaders were also risk leaders: top 5 suppliers contributed the bulk of both total receipts and total defects.

Decision & Action

- **Tighten AQL limits** (from 1.5 to 1.0) for S5002 and S7142, with immediate effect.
- Require **8D CAPA reports** from suppliers with PPM >150.
- Shift incoming inspection strategy: larger lot sampling for top-volume suppliers, not uniform across all.

Risk / Limitation

- Supplier performance is shown as **average PPM only** — not weighted by lot size. A weighted PPM would be more representative but beyond the "no measures" design constraint.

5.3 Reliability

Purpose
The Reliability dashboard is designed for reliability engineers and NPI program managers. It evaluates whether the camera module withstands stress conditions before volume ramp, highlighting weak points in design, process, or supplier material.

How to Read It

- **Bar chart** (Figure R1) compares **Average pass rates** across stress test types: humidity, drop, thermal, vibration.
- **Trend line** (Figure R2) shows **weekly pass rate movement** across all stress tests, identifying periods of stability vs. dips.
- Failure modes are listed by frequency, enabling quick root-cause triage.

Key Insights

- Overall **Reliability pass rate averaged 0.98**, but performance varied by test type.
- **Humidity testing** consistently showed the lowest pass rate; **drop/thermal/vibration** performed higher and more stable.
- Across ~60k units tested, ~1,082 failures occurred.
- Dominant failure modes: **sensor_shift**, followed by **ois_drift**, and then **seal_leak** — aligning with mechanical/environmental stress risks.

Decision & Action

- Implement **seasonal humidity screens** during monsoon months (Jun–Sep) in Cork and supplier sites.
- Launch focused **DOE (Design of Experiments)** to reduce sensor shift under high-moisture conditions.
- Track failure modes in supplier-level PPAP packages and require validation before next ramp.

Risk / Limitation

- Pass rate trends are shown as **simple averages**, not weighted by the number of units tested each week. This may slightly distort high/low-volume weeks.

5.4 OQA & Yield

Purpose
The OQA & Yield dashboard supports factory engineering and production leaders by showing how well lines deliver quality at first pass. It highlights the interplay between yield, defects, rework, and scrap — all key drivers of cost and throughput.

How to Read It

- **Scatter plot** (Figure O1) plots **FPY vs. OQA defects**, with bubble size = **Units Built**.
- Supporting visuals show **Sum of rework** and **Sum of scrap** by line and shift.
- Trend views allow monitoring of FPY stability across production dates.

Key Insights

- **Average FPY ~0.97**, but lower-FPY clusters directly correlate with higher OQA defects.
- Rework and scrap losses were concentrated in **CORK-L1** and especially **CORK-L2**.
- High-volume builds amplify the cost of defects — bubbles for L1/L2 dominate the scatter chart.
- Total across period: **~208k rework units** and **~92.8k scrap units**.

Decision & Action

- Launch a **Kaizen event** on **Line L2-B** (standard work check, gage R&R, operator training, poka-yokes).
- Assign **process engineering owners** for top three recurring defect categories.
- Implement **weekly FPY-OQA reviews** at the line level to catch drift before it accumulates.

Risk / Limitation

- FPY is displayed as a **plain average** rather than weighted by units built. Large-lot builds could understate true risk.

5.5 Field Quality

Purpose
The Field Quality dashboard is built for regional quality managers and customer support leaders. It connects factory performance to customer experience, tracking returns and failure issues across geographies.

How to Read It

- **Line chart** (Figure F1) tracks **Monthly RMA rates** over time.
- **Matrix view** breaks down RMA by **Region vs. Issue Type**, showing where customer pain points cluster.
- Supporting visuals show **Units Sold vs. Field Returns** to put RMA percentages into volume context.

Key Insights

- Over the period, **~1.0–1.35M units sold**; returns totaled **~8.2k units**.
- Average **RMA rate ~1%**, but peaks were observed in **late summer/autumn**.
- Regional variance: **APAC and MEIA slightly higher** than EU/NA.
- Top recurring issues: **camera_focus**, **app_crash_camera**, **ois_noise**, and **battery_swelling**.
- Issues align partly with factory signals (e.g., focus/OIS noise mapping to reliability test weak spots).

Decision & Action

- Prioritize **APAC and MEIA containment actions**, where RMA is above average.
- Launch a **cross-functional root cause review** on camera_focus and OIS-related issues.
- Feed findings into supplier corrective actions and factory process improvements.

Risk / Limitation

- RMA rates are shown as **simple averages**; weighting by units sold per region would make results more precise.

5.6 Predictive Alerts

Purpose
The Predictive Alerts dashboard is for operations managers and quality engineers who need to act **before** yield or defect issues materialize. It converts model outputs into a triage list, helping teams prioritize builds for extra checks or containment.

How to Read It

- **Histogram** (Figure P1) shows the distribution of predicted risks across builds.
- **Table view** lists flagged builds with **Build ID, Date, Predicted Risk, and Risk Band**.
- A **slider filter** allows adjusting the threshold (e.g., ≥0.55) to control the size of the daily action list.

Key Insights

- Across the dataset, **~1,628 builds were flagged** with an **average predicted risk of ~0.22**.
- The majority of builds sit in the **Low risk band**, with a long tail into higher risk.
- Risk exposure appeared across **both shifts**, with counts peaking **Mar–Jun**.
- A triage threshold of **≥0.55** generates a focused list — balancing operator load with high detection.

Decision & Action

- Formalize a **daily predictive triage SOP**:
    - Flag builds ≥0.55 risk for extra OQA sampling.
    - Escalate if the same line/shift repeats high-risk signals.
- Track results to refine the threshold over time (balance false positives vs. misses).

Risk / Limitation

- Model predictions were treated as-is (simple averages of predicted risk per build). A future enhancement would use **weighted precision/recall metrics** to validate thresholds.

6. Action Plan (2–4 Weeks)

This short-term plan focuses on immediate containment and improvement actions across suppliers, reliability, factory lines, and predictive use. Each action has a defined scope, owner, and measurable outcome.

Supplier Quality

- **AQL Retune:**
    - Tighten AQL from **1.5 → 1.0** for **S5002** and **S7142**, effective immediately.
    - Increase sampling frequency on their incoming lots.

    - Monitor PPM trend weekly to confirm improvement.
- **Lot Size Adjustment:**
    - Larger lots from high-volume suppliers will receive increased sampling coverage.
    - Prevents risk dilution from low-volume suppliers dominating averages.

Reliability

- **Seasonal Humidity Screen:**
    - Add a dedicated **humidity stress screen** during Jun–Sep.
    - Track its effect on reliability pass rates and downstream OQA defects.
    - Assign Reliability Engineering as owner.

Factory Yield

- **Line/Shift Kaizen (L2-B Focus):**
    - Standard work checks, gage R&R validation, and poka-yokes on handling.
    - Aim: reduce rework by **10–15%** and scrap by **8–12%** within four weeks.
- **Weekly FPY-OQA Reviews:**
    - Introduce a line-level FPY vs defect review process.
    - Escalate if FPY <96.5% or OQA defects >2% of builds.

Predictive Alerts

- **Daily Triage Process:**
    - Apply a **threshold of ≥0.55** for flagged builds.
    - Line supervisors to assign containment and document CAPA if repeat signals occur.

Institutionalization

- Introduce two lightweight trackers (simple CSV-based):
    - **Supplier CAPA Tracker** — logs issues, actions, and closure status.
    - **NPI Gate Sheet** — captures readiness signals (FPY, reliability, IQC PPM) at each build stage.

This 2–4 week plan establishes a foundation of supplier containment, line improvement, and predictive alert adoption, ensuring measurable quality improvements ahead of the next ramp.

7. NPI Readiness (Pilot → Ramp)

Ensuring the iPhone camera module is ready to scale from pilot to ramp requires clear **gate criteria**. This project demonstrates how those criteria can be monitored and enforced using the Quality Control Tower.

Gate Targets

To declare readiness, the following thresholds are applied:

- **FPY:** ≥ 97% (sustained across 4 weeks)
- **Reliability:** ≥ 95% pass rate across all stress tests
- **IQC Incoming PPM:** ≤ 1,500

- **OQA Pass Rate:** ≥ 98%
- **Field Quality (Early RMA):** ≤ 1% in pilot shipments

Evidence from Dashboards

- **FPY:** Averaged 97%, with stability outside ramp windows. Ready, but **risk spikes** during Mar–Apr and Aug–Sep require proactive checks.
- **Reliability:** Averaged 98%, meeting the gate; however, **humidity testing weakness** must be addressed before scale.
- **Incoming PPM:** At ~115, well below threshold, but supplier S5002/S7142 variance is an **at-risk signal**.
- **OQA Pass:** Correlates strongly with FPY, with occasional line-specific dips. Line 2-B requires containment before full ramp.
- **Field Returns:** Overall ~1% RMA, with APAC/MEIA slightly higher — acceptable for pilot, but flagged for closer monitoring.

NPI Decision

- The program is **PVT-ready** at a global level, with evidence of stable metrics.
- Risk zones are localized (humidity stress, supplier S5002, Line 2-B). These require **closure actions before mass production**.

Actions Before Ramp

- Execute **DOE on humidity stress** to confirm robustness.
- Close **CAPA with S5002/S7142** and confirm Cpk >1.33 before approval.
- Complete **Kaizen on Line 2-B** and confirm FPY ≥97% for four consecutive weeks.

This ensures that by the time volume ramp begins, all systemic and localized risks are controlled, aligning with Apple's NPI operating rhythm.

8. Impact & ROI

The Quality Control Tower is designed not only to surface signals but also to convert them into measurable cost-of-quality (COPQ) improvements. While no explicit cost measures were included in the synthetic datasets, the scale of rework, scrap, and field returns allows for high-level ROI estimation.

Rework & Scrap

- Total observed: **~208k rework units** and **~92.8k scrap units** across ~10M builds.
- Even at conservative assumptions, a **10–15% reduction in rework** and **8–12% reduction in scrap** translates into significant savings in labor hours, line throughput, and materials.

Field Returns

- **~8.2k units returned** at ~1% RMA.
- A **5–8% reduction in RMA** in APAC/MEIA (through supplier containment and reliability screens) reduces logistics cost, warranty claims, and brand risk.

Predictive Alerts

- Daily triage at a **≥0.55 threshold** creates a manageable, targeted action list.

- By reducing “noise” for operators, predictive alerts focus containment on the riskiest builds, improving efficiency while still catching early warning signs.
- Estimated effect: a **20–30% reduction in unplanned line disruptions**.

Overall Impact

- **FPY uplift:** +0.8 to +1.5 pp.
- **COPQ reduction:** rework, scrap, and returns together reduced by **~10% order-of-magnitude**.
- **NPI readiness:** improved decision-making at pilot-to-ramp, avoiding costly late-stage surprises.

Strategic ROI

Beyond direct savings, this approach institutionalizes a culture of **data-driven problem solving** and **predictive quality**. It scales easily to other modules and global factories, reinforcing Apple’s reputation for world-class quality operations.

9. Limitations & Next Steps

While the Quality Control Tower demonstrates strong end-to-end capability, there are structural limitations that need to be addressed in future iterations.

Limitations

- **No weighted KPIs:**
    - All averages (e.g., FPY, PPM, RMA) are simple averages. Large-volume builds or suppliers have the same weight as smaller ones.
    - This can distort true operational impact.
- **No calculated measures:**
    - Factory-grade KPIs such as weighted FPY, defect density, or cost impact per unit were not possible under the “implicit aggregation only” rule.
    - Correlations (e.g., FPY vs. RMA) remain directional, not fully quantified.
- **Date handling:**
    - Without a proper **Date table**, seasonality analysis is basic. Ramp windows were identified manually rather than through automated time intelligence.
- **Data realism constraints:**
    - The datasets are synthetic, albeit realistic. Some irregularities (typos, nulls, duplicates) were manually designed rather than naturally occurring.

Next Steps (Pro Upgrade)

To bring the system closer to factory deployment, I would introduce a minimal set of upgrades:

1. **Weighted KPIs (8 measures minimum):**
    - Weighted FPY
    - Weighted PPM
    - Weighted RMA
    - Weighted Reliability Pass Rate
    - Defect Density per Unit

    - Scrap % of Build Volume
    - Risk-Weighted Predictive Alerts
    - NPI Readiness Index
2. **Date Dimension:**
    - Full calendar table with fiscal alignment, ramp/launch markers, and seasonality flags.
3. **Enhanced Predictive Model Validation:**
    - Add precision, recall, and false positive rates to refine the triage threshold.
4. **Supplier & Line Integration:**
    - Expand CAPA tracker and NPI gate sheets into integrated dashboards.

These next steps would shift the tool from **analytical showcase** to **factory-grade operating system**, aligning directly with Apple's WW Product Operations standards.

10. Conclusion

This project proved that a **Quality Control Tower** can be built for the iPhone camera module using only implicit aggregations and synthetic but realistic datasets. Despite constraints, the dashboards delivered actionable signals across the entire quality chain — from suppliers to field returns — mirroring the day-to-day scope of Apple's Product Operations Quality Engineers.

I demonstrated how to:

- Detect risk trends (FPY dips, humidity failures, supplier PPM spikes).
- Translate findings into **specific, quantified actions** (AQL tightening, humidity screen, Kaizen on Line L2-B).
- Build a short-term **action plan** that ties directly to measurable improvements in FPY, rework, scrap, and RMA.
- Frame the system for **NPI readiness**, ensuring pilot-to-ramp transitions are fact-driven and controlled.

If I were stepping into the role tomorrow, my first **90-day priorities** would be:

1. Institutionalize this control tower into Cork's weekly operating rhythm.
2. Implement supplier CAPA tracking and humidity DOE to close current risks.
3. Expand predictive triage into a validated early-warning system across all shifts.

Looking ahead, this approach scales naturally to **global Product Operations**. By embedding weighted KPIs, richer predictive validation, and date intelligence, the system could serve as a **worldwide quality nervous system** for Apple's component supply chain.