Oil Fill Level Project

Solving Problems with Labor and Maintenance Costs

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DR
Executive Summary

Problem Statement

Reports of incorrect oil level at assembly plants and dealers have been reported as a significant issue. In response to these reports, management implemented two inspection points to protect the customer.

The focus and business need of this project is to eliminate hard cost associated with packout inspection. This expense is $130,000 annually. Secondary benefits include the opportunity to rebalance operation OP400 and reduce internal repair costs. And because inspection is not 100% effective, a reduction in DPM will directly improve quality to the customer.

Problem Solving Approach Utilized

The DMAIC process was utilized throughout this project. A cross-section of both qualitative and quantitative tools was used. Some key methods were ishikawa diagrams, run charts, hypothesis testing, and distribution analysis. Pp and Ppk values were the primary indicators of performance.

Major Project Results and Recommendations

After review of the current state data, the focus of this project was oil level variation. The key contributor was the cold test stands. This was highlighted by a change in strategy to focus on oil weight, instead of oil level, as our response variable. As you can see in the main body of the report, the other main contributors, such as location of the oil and component variation, were eliminated.

A design flaw within the oil delivery circuit was the primary issue responsible for the variation. The oil circuit had a “bleed off circuit” that provided an internal leak path. This “bleed off circuit” was the safety mechanism used to relieve pressure in the oil delivery system during maintenance activity. In other words, this meant that oil counted as entering the engine was being returned to the storage tank. To correct this issue a normally open solenoid valve was installed.

As a result of this project and the changes mentioned above and in the body of the report, the 100% inspection was eliminated at packout and OP400. The packout inspection removal resulted in a $130,000 savings by redeploying two team members. The removal of OP400 inspection resulted in a (3) second reduction in work time. And more importantly, the housekeeping and safety issues associated with oil on the floor at OP400 are no longer a concern.

Another potential benefit was realized during this project. It was found that all engines are being filled above nominal by approximately 230ml per engine. This amounts to $65,000 per year savings potential.

Control mechanisms were implemented to maintain the current condition. An audit process was implemented to provide ongoing variable data. This data will be used to provide real-time feedback about the oil delivery system health.
1.0 Improvement Opportunity: Define Phase

1.1 Discussion of the process being examined and problem addressed

Reports of incorrect oil level at assembly plants and dealers have been reported as a significant issue. In response to these reports, management implemented two inspection points to protect the customer. One inspection point was added to the final assembly operation at OP400. A second inspection point was added in “packout” located after the engines are racked for shipment. See the diagram below.

The measurement method used by assembly plants and dealers is based on a visual inspection of the dipstick after warming the engine and allowing five minutes for oil to drain back into the oil pan. Specification limits at the assembly plant are clearly defined as 10-24mm above the bottom of the “safe zone”. See the diagram below labeled as “CSA Audit Range”.

Differences in engine conditions (angle and temperature) and measurement technique exist between the engine plant and the vehicle assembly plant. At the engine plant, a graduated hand gage is used for measurement. At vehicle assembly a production dipstick is used. Mapping was completed to align the measurement values between the two sources. A follow-up hypothesis test yielded a high p-value. This indicated no significant difference exists between the values obtained using the two measurement methods. In other words, we could now take measurements using the engine plant’s gage at time of fill and predict the assembly plant measurements. See below for details.
The engine oil fill process at the engine plant is completed at one of three cold test stands. Engine oil is stored in bulk tanks and delivered to the engine by a series of pipes and valves. During the cold test process operation (OP390), oil is delivered into the engine. Oil delivery is broken into three segments: initial fill, testing, and top off. A counting pump called a “totalizer” is mounted in series and keeps track of oil delivered during all three segments. A basic drawing of the circuit is shown below.
1.2 Key measurements defining project success

- Reduction in common cause variation and achievement of 1.44 Ppk.
- Removal of packout inspection and the associated expense.
- Removal of operation OP400 inspection needs for 1st time-pass engines.

1.3 Project scope

The focus and business need of this project is to eliminate hard cost associated with packout inspection. This expense is $130,000 annually. Secondary benefits include the opportunity to rebalance OP400 and reduce internal repair costs. And because inspection is not 100% effective, a reduction in DPM will directly improve quality to the customer. The vehicle assembly plant is referred to as the customer for this project. The DMAIC process was followed.

Historical records related to out-of-specification claims were not available. The quantity and condition of non-conforming engines sent to the customer were unknown. In addition, engines found at the internal inspection points were not being recorded. We had little more than subjective opinions about the current status at the beginning of this project.

This project will focus on 1st time pass engines only. Reworked engines are viewed as special cause situations due to the human interface and are removed from the data analysis. Additionally, turbo engines have different specifications and will not be included in the study. Lessons learned from this project will be applied to these cases.

2.0 Current State of the Process: Measure Phase

2.1 Current performance level

As mentioned above, there was no objective data available to assess the current state. This required initial data is gathered to facilitate problem definition. Measurements were taken at three inspection locations; OP400, packout, and stable. Data from the stable condition was used as the current state and provided a baseline for the project.
The current state data was stratified to analyze stand-to-stand and model-to-model differences (see below). Hypothesis testing confirmed that not one stand or model was significantly different than the others. But from a practical standpoint, cold test stand 2 had the highest standard deviation. Focus was placed on this stand for testing and improvements. Lessons learned would be shared to the other two cold test stands. In addition, the three locations were analyzed to understand the impact of time on the oil level readings. Below are results.
Below is a bulleted list that summarizes the project findings before progressing to the analyze phase. The analysis tool and conclusion is listed for each. Some of the supporting evidence is shown in the appendix.

- The Engine Plant’s hand gage measurement technique is acceptable.
  - Analysis method – paired measurement scatter plot
  - Conclusion – this method can be used to measure oil level throughout the project
- Difference between the engine plant’s readings (stable) and assembly plant readings are insignificant. (This is true because the engine plant’s gage was adjusted to correlate properly.)
  - Analysis method – hypothesis testing
    - f-test, p-value .683
    - t-test, p-value .418
  - Conclusion – The Engine Plant can use the same specification limits as the assembly plant
    - 10-24mm
- Engine rack angle has an impact on the oil level readings.
  - Analysis method – distribution analysis & square root of sum of squares
    - 1° = 2mm
    - Estimated s impact of .25mm
  - Conclusion – oil level measurements will be taken while engine is mounted on pallet prior to being placed in engine rack
- No cold test stand is significantly different than the other two stands. From a practical standpoint stand 2 is worse than the others.
  - Analysis method – hypothesis testing
  - Conclusion – testing will be completed on stand 2 and read across to the other stands
- No model is significantly different than all the others.
  - Analysis method – hypothesis testing
  - Conclusion – any model can be used for analysis
- Oil level readings change significantly from the time of fill to the time of shipment.
Analysis method – run chart, distribution analysis, hypothesis testing
- p-value 0.000 (t-test)
- OP400 (~5 min after fill) = 0 (baseline)
- Packout (~1 hr after fill) = +2mm
- Stable (~24 hrs after fill) = +3mm
- Mean differences are significant, variation differences are not significant

Conclusion – target oil levels must account for change based on measurement location, the total change in oil level between fill and shipment is approximately 3mm

2.2 Identification of key variables

The diagram below was developed to break the potential causes into (4) distinct categories. A fishbone shown in the appendix lists individual potential causes along with the rationale for elimination throughout the project.

2.3 Identification of target performance levels or project goals

Based on the current state data, this project is primarily focused on variation reduction. The project goal is to identify the primary sources of variation affecting oil level and therefore eliminate the need for costly inspection. The quantifiable targets are shown below.

- 1.94 Pp (s = 1.2mm)
- 1.44 Ppk (accounts for 1.5s mean shift)
- < 10 DPM

3.0 Analysis and Findings: Analyze Phase

In the measure phase above we realized stand-to-stand and model-to-model differences were insignificant. A look at this data in time series highlighted drastic changes in oil level between consecutive engines.
The oil delivery cycle includes an air purge just before the coupler disconnects from the engine. A quick test of this system was performed. The results showed this function was insignificant to oil level.

In the diagram at the beginning of section 2.2, (4) categories of variance are shown. A strategy change was made at this point in the project. The response being measured was changed from oil level to oil weight. This change provided an opportunity to split the potential causes. Below illustrates the rationale.
Consecutive engines were weighed before and after oil addition. Similar to the original baseline data, this test resulted in consecutive engines having drastic differences. This focused our attention to the oil supply. In other words, location of oil and components can not influence oil weight within the engine and therefore the variation must be caused by the cold test stands (oil delivery system).

As mentioned in section 1.1, oil delivery can be broken down into three segments. In effort to make another strategy split, each segment was analyzed individually and the variation reviewed. No segment showed separation. In other words, all segments contributed relatively equally to the overall variation. This indicated the issue was not segment dependent.

**Individual Plot of actual-recorded by segment**

Points indicate the amount of "error" between actual volume delivered & volume the stand believes is present.

Square root of sum of squares = .061 qts (accounts for 51% of entire process)
Next we reviewed the oil delivery circuit and its components with the OEM of the cold test stands. Upon inspection of the circuit it was realized a “bleed off circuit” offered a potential internal leak. This meant that oil counted as entering the engine could be redirected. The “bleed off circuit” was in place to depressurize the circuit during maintenance and eliminate safety concerns. Testing of a blocked bleed off circuit was completed and this had a significant impact as seen in the f-test below. By using the square root of sum of squares, a 25% (.53mm) reduction in standard deviation was calculated. See below and in the appendix for details.

The “totalizer” was the last potential cause evaluated. As mentioned above, this is the device that pumps and counts oil as it enters the engine. After inspection and testing it was found that this unit had no significant impact but it did have some practical impact. In the control phase are the steps we took to address it. See the summary graphs shown in the improve phase for the overall impact.

4.0 Recommendations: Improve Phase

Based on the analysis above, improvement was made to the cold test stands to address the “bleed off circuit”. A normally open solenoid valve was installed. This valve remains closed during oil delivery to close off the circuit and eliminate the internal leak possibility. When the cold test stands are E-stopped prior to maintenance, the solenoid valve will open and relieve pressure and the associated safety concern. See below.
In addition, the “totalizer” for cold test stand 2 was replaced after finding an insufficient seal between the piston rings and bores.

A summary of final results for model CG are shown below. It can be seen by the hypothesis testing and distribution analysis that all three cold test stands have made the required improvement. Each of them is achieving a standard deviation of 1.2mm or less. This standard deviation results in the required Pp. Adjustments can easily be made to achieve the required Ppk.
The final step was to remove the inspection points at packout and OP400. This was completed on 3/1/10 and control mechanisms were implemented. These are discussed in the control phase.

5.0 Monitoring and Control: Control Phase

As control mechanisms, the following items were completed. As mentioned in the define phase, this project was targeted at 1st time pass engines. As a result you will notice 100% inspection remains on all repair engines. This accounts for approximately 1% of the engines.

- Equipment drawings were updated to reflect the newly installed solenoid valve.
- Information about the oil delivery circuit modification was shared with The Engine Plant’s new product launch team.
- Preventative maintenance activity was added to monitor the condition of the “totalizer”.
- An audit process was implemented requiring the OP400 team member to inspect oil level, on a frequency basis, for 1st time pass engines and input values into the HMI. Repair engines remain at 100%. In both cases these values are sent to the corporate server and can be accessed at any time to monitor the process.
- Improved the OP400 oil removal process by adding a coupler that locates on the dipstick boss and removes a predetermined amount of oil. This is used for repair engines.
- Improved the OP400 oil addition process by adding a graduated beaker with associated millimeter markings. This is used for repair engines.
6.0 Conclusion

As a result of this project and the changes mentioned above, the 100% inspection was eliminated at packout and OP400. The packout inspection removal resulted in a $130,000 savings by redeploying two team members. The removal of OP400 inspection resulted in a (3) second reduction in work time. And more importantly, the housekeeping and safety issues associated with oil on the floor at OP400 are no longer a concern.

Another potential benefit was realized during this project. It was found that all engines are being filled above nominal by approximately 230ml per engine. This amounts to $65,000 per year savings potential. All model types will be adjusted to nominal over the next several months to attain these savings.
2) MEASUREMENT DUE TO ANGLE
IN ENGINE RACK

\[ \sigma_{\text{All}} = \sqrt{\sigma_{\text{Oil}}^2 + \sigma_{\text{Rack}}^2 + \sigma_{\text{All}}^2} \]

\[ 2.19 = \sqrt{1.52^2 + 1.15^2 + \sigma_{\text{All}}^2} \]

\[ \sigma_{\text{All}} = 1.079 \]

\[ \sigma_{\text{All}} = 1.86 \]

NOTICE THE RACK WAS REMOVED

WITH NO RACK ANGLE ERROR

\[ 2.19 - 1.86 = .33 \]

IMPACT ON \( \sigma \) DUE TO ENGINE (REDUCTION)
Oil Fill Level Project

**Material**
- E: Oil passages on block
- E: Oil pan volume
- A: Incorrect oil type
- E: Crank oil hole volume
- Rear seal

**Method**
- D: Incorrect gage design
- F: Blow down
- E: Oil drainback
- D: Correction factor
- Recycle
- Valve sequencing logic
- Engine angle during check

**Oil weight variation**
- H: Oil circuit internal leak
- C: Oil circuit external leak
- A: Parameter settings
- I: Totalizer (oil meter)
- Oil heater

**Rationale**
A: checked against standard
B: completed MSA
C: inspected oil lines
D: would not cause variation
E: would not impact oil weight
F: test completed, no impact
H: test confirmed “bleed off circuit” impact of .53mm sigma
I: test completed, some impact
1) INSTALL VALVES ON "BLEED OFF LOOP"

\[ \sigma_{\text{Total}} = \sqrt{\sigma_{\text{Oil}}^2 + \sigma_{\text{All}}^2} \]

Includes measurement, component variation, and location of oil.

\[ 2.19^2 = \sqrt{1.52^2 + \sigma_{\text{All}}^2} \]

\[ 4.79 = 1.52^2 + \sigma_{\text{All}}^2 \]

\[ 1.577 = \sigma_{\text{All}} \]

\[ \sigma_{\text{Total}} = \sqrt{1.53^2 + 1.571^2} \]

\[ \sigma_{\text{Oil}} = 1.60 \]

\[ \sigma_{\text{All}} = 2.19 \]

Impact of valve addition on "bleed off loop" = \( \sigma \) reduction of 0.53.

AFTER VALUE ADD

BEFORE VALUE ADD