Connecting Industry to Mathematics Instruction
NSF ATE Award # 1954291

Solutions: Analyzing Production of an Automotive Adhesive

In partnership with

WAKE TECH

WAKE COUNTY PUBLIC SCHOOL SYSTEM

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Background

Parker LORD won a significant contract to manufacture a new adhesive for automotive use. Production started and was ramping up. During early testing, the customer observed high pressure alerts when trying to pump the adhesive through their factory tubing. They noticed that the "PX" values, measuring the force (in PSI: pounds per square inch) required to pump the adhesive through the tube, was too high. The acceptable range of "PX" was between 150-210 PSI throughout the 120-day shelf life of the adhesive. Your job is to figure out what the Parker LORD manufacturing plant data is showing and come up with recommendations to solve the problem.

Data Collection

Two months of data were collected on 20 batches of adhesive, made from three distinct raw materials (RMs). Initial PX values were recorded at time of adhesive manufacture. Retains (small containers of each batch that were kept at the Parker LORD facility) were rechecked at various dates after manufacturing, and PX was recorded. Various batch characteristics were also recorded.

The included Excel file "PX-data.xlsx" contains this data. The variables included in the spreadsheet are defined as follows:

Batch – Batch number (unique number to identify the batch)
Mfg Date – Date of manufacture of the batch
Batch Size – Weight of the batch (pounds)
RM1 %H2O – Percent water present in the first raw material
RM2 %H2O – Percent water present in the second raw material
RM3 %H2O – Percent water present in the third raw material
Mfg Shift – Work shift (time of day) when the batch was manufactured (0: 1st shift, 1: 2nd shift, 2: 3rd shift)
Avg Dew Point – Average dew point (°F) in the manufacturing facility on the date of manufacture
Total %H2O in Batch – Percent water present in the batch (after combining raw materials)
PX Initial – PX of the batch (PSI) at time of manufacture
PX Recheck – PX of the batch (PSI) at time of recheck
PX Recheck Time – Number of days elapsed since the batch was manufactured
Tested Location – Site where the batch PX values were tested

Part 1 – Confirming the Problem

1. Compare the original PX measurements with the PX recheck measurements. Does there appear to be a drift (change) in PX for these batches over time? Why or why not?

Yes, they all appear to increase (comparing PX to PX Recheck values).

2. Using the original spec limit of 150-210 PSI, what percent of these batches would be rejected by the customer based on their PX recheck values?

12 out of 20 (60%). Can be done quickly by sorting PX Recheck descending and counting.

3. We need to identify which variable(s) may be correlated to this increase in PX.

    a. Read the descriptions (previous page) of each variable recorded in the spreadsheet. Choose and list two of the variables that you think would be strongly related to each other, and two variables that you think would not be related at all.

    Strong relationship between: Lots of possible answers; verify with correlation coefficients in (b)

    No relationship between: Lots of possible answers; verify with correlation coefficients in (b)

    b. Investigate your choices from part (a) by computing the correlation coefficient (r) and/or coefficient of determination (r^2). Do these statistics confirm your thoughts? Why or why not?

Check to make sure students are interpreting low/high r/r^2 values correctly as weak/strong relationships.

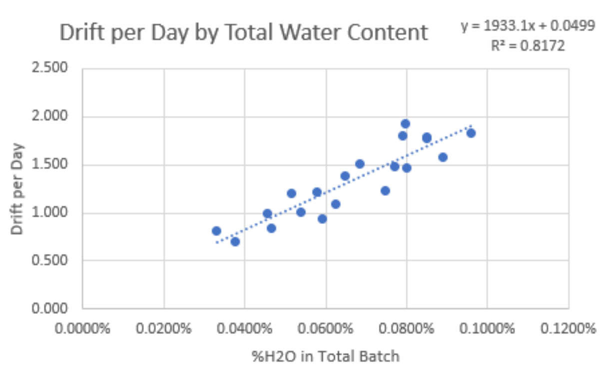
Part 2 – Modeling PX Drift (Change)

4. Assume that the drift in PX follows a linear pattern. In a new spreadsheet column, calculate the **total drift** (PSI) by computing the difference between the initial PX and the rechecked PX for each batch in the sample. In a second column, divide each difference by the number of days since manufacture to calculate the **average drift per day** (PSI per day) for each batch.

Create two columns, one for Total Drift (PX Recheck – PX) and one for Drift per Day (Total Drift / Days after Mfg).

5. Scientists and engineers hypothesize that an undesirable water reaction is causing the batches' PX values to drift (change). Investigate the relationship between the total batch water content (independent) and drift per day (dependent). To do this, you should:

    a. Create a scatterplot comparing total batch water content (horizontal, %H2O) and drift per day (vertical, Units/day).



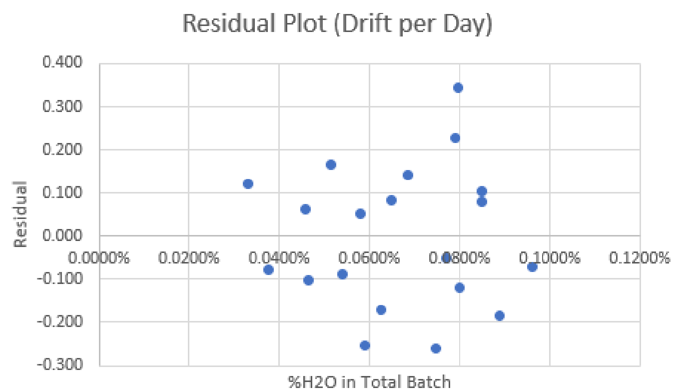
    b. Determine a linear regression equation. Define each variable in the equation.

$y = 1933.1x + 0.0499$ where x represents total $\%H_2O$ and y represents drift per day.

c. Determine the correlation coefficient (r) for the model. How strong is the relationship between water content and drift per day?

r = 0.904 indicates a very strong positive correlation. As %H_2O increases, drift per day increases as well.

6. Determine the predicted drift per day values for each batch. In a new spreadsheet column, calculate the residual values for each batch and create a residual plot. Which batch had the largest difference between its actual and predicted drift per day values? Does a linear relationship seem appropriate?



It appears that Batch #11973379 had the largest residual value at about 0.35 PSI/day.

There does not appear to be a pattern in the residuals, which means that the linear regression is appropriate.

Part 3 – Applying the Linear Drift Model

7. How many days will it take the first batch in the spreadsheet (#11958383) to reach the maximum allowed PX of 210 PSI? This is called the *shelf life* for the batch.

65.2 days

8. Shelf life of a batch of adhesive is the number of days that the batch will remain within the PX requirements. In a new spreadsheet column, determine the shelf life for each batch at the original maximum PX of 210 PSI. Will any of these batches reach the customer's expected shelf life of 120 days?

Autofill the formula: (210 – Initial PX) / Drift per Day

No; every batch will likely have too high a PX after 120 days.

9. There may be room for negotiation with the customer about the spec limit. Determine the shelf life for each batch at a higher spec limit of 270 PSI. Would this be an acceptable change to the spec limit?

Autofill the formula: (270 – Initial PX) / Drift per Day

Still only a few batches have a predicted shelf life over 120 days. Something else must be done to fix the problem.

10. Your customer has agreed to the higher PX spec limit of 270 PSI for a slightly lower price but needs to maintain the 120-day shelf life. Your manufacturing manager has determined that it is possible to make the adhesive with a lower starting PX (as low as 145) and a lower initial water content (either 0.04%, 0.05%, or 0.06%). For each of these options, use your regression line to calculate the expected drift per day, then the expected shelf life (assuming a beginning PX value of 145 and higher spec limit of 270 PSI). Which initial water content (0.04%, 0.05%, or 0.06%) do you think would be the best choice? Why?

%H2O Total	Predicted Drift/Day	Shelf Life
0.04%	0.82314	151.858
0.05%	1.01645	122.977
0.06%	1.20976	103.326

0.04% could be a good choice because of the much higher shelf life.

0.05% could also be a good choice because it's above the 120-day shelf life and probably a less expensive option since it's not as far below current Total %H_2O values.

11. These batches of adhesive were rechecked after roughly 20-60 days from the date of manufacture. The adhesive must be shipped to the consumer (usually takes at least 3 weeks), so the PX measurements in the first 20 days are not as important as the measurements between 60-120 days. How useful is your linear model for predictions beyond the 60-day mark? What could your company do to develop a more accurate model?

Collect data with further out recheck times and model the observations, perhaps using nonlinear models if appropriate.

Part 4 – Extension

12. A later batch (#12000465) was rechecked four different times, and the results are included in the table below. For this new batch, calculate the drift per day at each recheck (compared to the initial PX of 172 Units). How does the drift per day for this batch change over time?

Batch	%H2O Total	PX	PX Recheck	Days after Mfg	Drift per Day
12000465	0.0294%	172	177.3	7	0.757
12000465	0.0294%	172	191.15	14	1.368
12000465	0.0294%	172	199.8	28	0.993
12000465	0.0294%	172	205.1	55	0.602

The drift per day increases from the 7 to 14 day mark but then decreases beyond 14 days.

13. Use the linear regression model you made in Part 2 to predict the drift per day for a batch that has a %H2O Total of 0.0294%, like batch #12000465. How does this predicted drift per day compare to the observed drift per day at each recheck time? If this batch were to be checked again after even more time, what would you expect the drift per day to be? Why?

The predicted drift per day is 0.618 Units/day. Drift per day starts higher than predicted, but dips lower at the 55 day recheck.