Comments on the Statistical Analysis of the Vektron 6913 Fleet Test

José C. Pinheiro

Abstract

The statistical analyses presented in the Infineum document "Statistical Design and Analysis of Vektron Emissions Fleet Trial" give a coherent and statistically sound description of what is possible to infer from the data collected in Vektron experiment, given the observed carry-over effect and the lack of treatment combinations in the first and second runs of the experiment (BASE-BASE and Vektron-Vektron) that would be necessary to clarify the carryover effect.

Given these restrictions, I essentially agree with the main conclusions in that document, namely:

- Because of the carryover effect, only the Run 1 data that allow a valid comparison of the treatments.
- Based on the Run 1 and data and the correctly used linear mixed-effects model, the conclusion is that Vektron promotes a statistically significant reduction in NOx emissions when compared to vehicles using the *base* additive, estimated to be about 10% for the vehicle types used in the experiment.
- Even though the carry-over effect invalidates the legitimate use of the Run 2 data, one must add that the effects indicated by plots of these data are puzzling and deserving of further investigation, possibly through a follow-up experiment with the complete set of treatment combinations available.

1 Analysis of the Run 1 Data

To further validate the analyses presented in the Infineum document, I conducted a separate of the Run 1 data, presented in this section. As mentioned in the Infineum document, the Run 1 data provide parallel experiment on which a full analysis of the treatments can be performed. The data used here does not include the outlier observations mentioned in the Infineum document.

Figure 1 displays the percentage change in NOx emission from baseline, for the different vehicle types and treatments. It is evident from Figure 1 that there is a vehicle type effect present, as observations pertaining to the same vehicle type tend to be closer together. It can also be seen that, in general, the Vektron treatments (A and AF) produce lower NOx emissions than the BASE treatment. The presence of a vehicle type effects justifies the use of a linear mixed-effects (LME) model as proposed in the Infineum document, which is

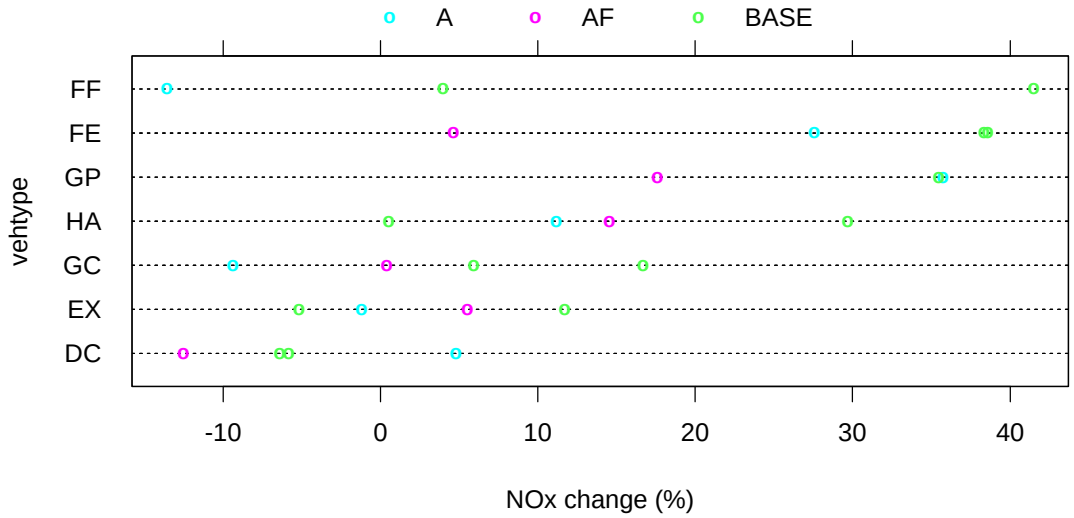

Figure 1: Percentage changes in NOx emission for the different vehicle types and additive treatments.

innovative in this context. REML estimation is used, as it tends to produce more conservative variance estimates, and, as a consequence, more conservative tests. The conclusions are pretty much the same as in the original document, however. The results presented below use a parameterization for the treatment factor that uses A as baseline (the corresponding estimates are differences from the baseline value).

```
> fm1EPA <- lme(PercDiff1~Mixing, data = epa, ~1 | vehtype)
> summary(fm1EPA)Linear mixed-effects model fit by REML
 Data: epa
       AIC      BIC    logLik
  207.7274 213.4049 -98.86372

Random effects:
 Formula:  ~ 1 | vehtype
        (Intercept) Residual
StdDev:    11.45312 13.03363

Fixed effects: PercDiff1 ~ Mixing
                Value Std.Error DF   t-value p-value
(Intercept)  7.873005  6.557977 17  1.200523  0.2464
   MixingAF -3.224097  7.316353 17 -0.440670  0.6650
 MixingBASE  8.947546  6.126490 17  1.460469  0.1624
. . .
```

As indicated in the original Infineum document, there is not a significant difference between the continuous and alternating fueling Vektron treatments, and the two may be combined into a single treatment, Vektron, to enhance the power of the comparisons.

Figure 2 displays the percentage change in NOx emission, corrected for the vehicle type means, for the BASE and Vektron treatments. It reveals the better performance of Vektron

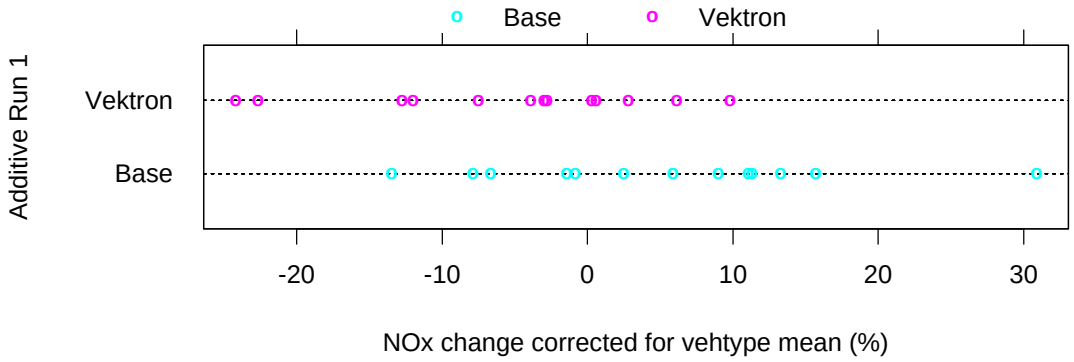

Figure 2: Percentage changes in NOx emission, corrected by vehicle type mean, for the different additive treatments.

in a more obvious way. The corresponding LME fit confirms the main results presented in the Infineum document.

```
> fm2EPA <- lme(PercDiff1 ~ AdditiveRun1, data = epa, ~1 | vehtype)
> summary(fm2EPA)
Linear mixed-effects model fit by REML
 Data: epa
       AIC      BIC    logLik
  211.7223 216.4345 -101.8612

Random effects:
 Formula:  ~ 1 | vehtype
        (Intercept) Residual
StdDev:    11.50728 12.74823

Fixed effects: PercDiff1 ~ AdditiveRun1
                 Value Std.Error DF   t-value p-value
 (Intercept)  16.83203  5.622366 18  2.993763  0.0078
AdditiveRun1 -10.42360  5.046390 18 -2.065556  0.0536
 Correlation:
. . .
```

The reduction in NOx emissions associated with the use of Vektron is about 10%, being statistically significant at a 6% level.

2 Exploratory Analysis of the Run 2 Data

As indicated in the Infineum document, the order in which the treatments were applied to the vehicles has a significant effect on the NOx emissions, characterizing a carry-over effect in the full cross-over design. Therefore, because the BB and AA treatment combinations were not used in any vehicles, a rigorous statistical analysis of the full data (Runs 1 plus 2) to assess the different treatment effects cannot be justified.

We may, however, do some exploratory analysis of the Run 2 data to further understand the carry-over effect, which may be helpful for future follow-up experiments to clarify the results. Figure 3 summarizes the results of the two runs of the cross-over experiment. Most

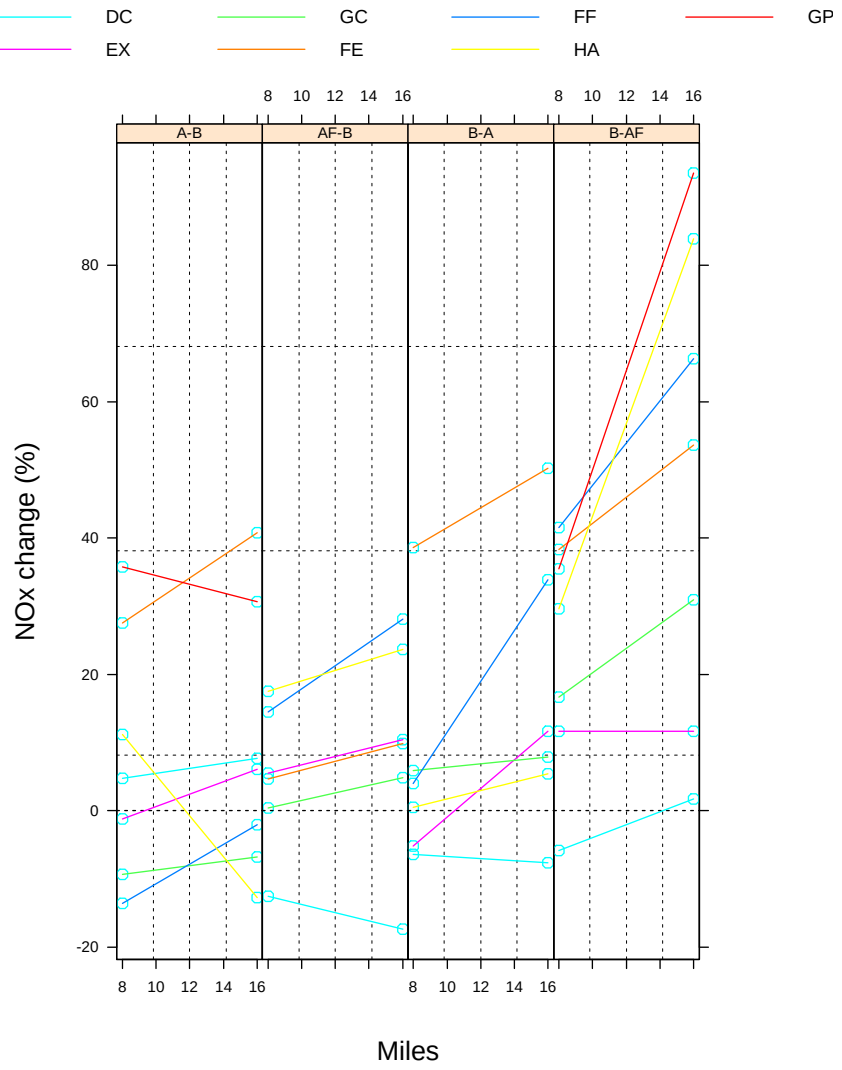

Figure 3: Percentage changes in NOx emission for the different vehicle types and additive treatments, at 8,000 miles (Run 1) and 16,000 miles (Run 2).

vehicles showed some increase in NOx emissions between Run 1 and Run 2, as it is to be expected with the increase in mileage. However, the increases for vehicles that started Run 1 with some type of Vektron treatment (A or AF) were much smaller than for those vehicles starting the experiment with the BASE additive. The increase in NOx emission at the end of Run 2 was particularly high for those vehicles that switch to the AF treatment in Run 2. Further investigation is required to clarify these puzzling results, possibly requiring a follow-up carryover experiment including also treatment combinations B-B and A-A.