

# Finding Rules for Household Cleaners with FormRules

## Background

Consumers judge household cleaners on how efficiently they remove soil, how well they emulsify grease, and how long they last. For this last property, the consumer relies on the existence of lather as a guideline to the performance. In a competitive market retaining market share and customer loyalty while minimizing cost of the product is vital. Consequently it is crucial to mix the right surfactants in the right amounts to deliver the performance demanded by the consumer.

## Formulation Data

Julie Heinsman of the Dial Corporation and Douglas Montgomery of Arizona State University have reported an optimization of a household cleaner (using response surface methods) in *Quality Engineering* 7(3) 583-600 (1995). In this formulation, four different surfactants were used. These included two non-ionic surfactants (referred to as A and B), an anionic surfactant, and a zwitterionic surfactant. There were constraints on the amounts used, and the lower and upper bounds (in percentages) are shown in Table 1.

Surfactant	Lower Bound	Upper Bound
Non-ionic A	0.5	1
Anionic	0	0.5
Non-ionic B	0	0.5
Zwitterionic	0	0.05

Table 1. Composition of cleaner. Amount of ingredients must add to 1.

Heinsman and Montgomery give 20 different experiments that were used in their analysis. In these, the amounts of the 4 surfactants were varied. The properties that were measured were:

- Life of the product, measured in 'lather units'
- Number of soil loads, or 'pellets'
- Foam height while removing greasy soils
- Total amount of foam produced, which is a measure of how long the foam lasts in the presence of grease.

Of these, the life of the product is judged to be the most important. We have used these data points in **FormRules** to determine which inputs affect each of the properties, simply

copying the information from a spreadsheet into **FormRules** in order to develop models.

## Models for Household Cleaners

**FormRules** is based on neurofuzzy logic, and like other neural computing techniques it 'learns' a model directly from the data. Separate models were developed for each of the properties. The default 'model assessment criterion' used in **FormRules** is Structural Risk Minimization (SRM). With a choice for the adjustable parameter  $C_1=1$ , a good model was developed for lather, but relatively poor models were developed for the other properties, as illustrated by the ANOVA statistics  $R^2$  values of between 0.66 and 0.43. Decreasing the value of  $C_1$  should give more complicated models, and a better fit to the data. In the present case,  $C_1 = 0.8$  gives models with  $R^2$  values between 0.62 and 0.99, as shown in Table 1. The model for total lather has the lowest  $R^2$  value, and in an attempt to improve this, we changed the model assessment criterion to Minimum Descriptor Length. The  $R^2$  values for the 3 cases are shown in Table 2.

	SRM 1	SRM 0.8	MDL
Lather	0.88	0.93	0.99
Pellets	0.48	0.84	0.83
Foam ht.	0.66	0.72	0.90
Tot. Foam	0.43	0.62	0.62

Table 2. ANOVA statistics,  $R^2$  values for each of the 4 properties, for 3 model assessment criteria

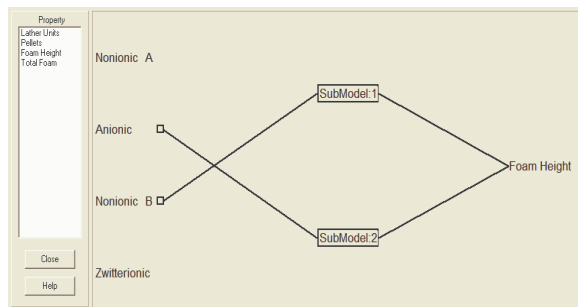
With such a small amount of data, there is a risk that Minimum Descriptor Length models will be over-trained. (This means that the model may learn the noise in the results, as well as the underlying trends.) However,  $R^2$  for the model for Total Foam remains relatively low. We can take this as a strong indication that there are variables that affect the total foam but that are not being measured, or included in the model. Because it tries many models, **FormRules** is especially valuable in highlighting these sorts of cases, where an unmonitored input is affecting the results.

Because SRM with  $C_1 = 0.8$  gives good  $R^2$  values for all the other properties, we have

used it in assessing the rules and relationships for the various properties.

The models show that Lather depends primarily on the amount of non-ionic surfactant A that is present, while the number of soil pellets that can be treated depends mainly on the amount of anionic surfactant.

Foam Height depends on the amount of non-ionic surfactant B, and the amount of anionic surfactant that is present. This is shown in Figure 1.



**Figure 1. Dependence of Foam Height on 2 surfactants (anionic, and non-ionic B)**

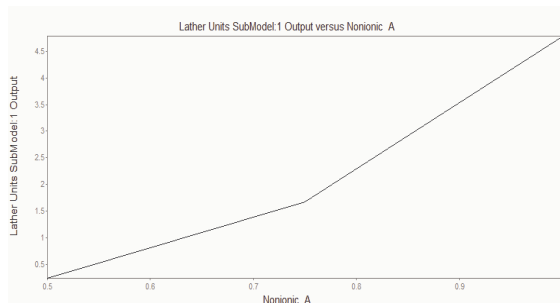
Total Foam depends mainly on the amounts of the anionic and zwitterionic surfactants, but as mentioned above, the model does not fit especially well to the data, indicating that some unmeasured variables are affecting this property.

### Rules for Household Cleaners

The rules for Lather (the most important property) are

IF Nonionic A is LOW THEN Lather is LOW (0.95)  
 IF Nonionic A is MID THEN Lather is LOW (0.63)  
 IF Nonionic A is HIGH THEN Lather is HIGH (1.00)

The amount of lather therefore depends on the amount of non-ionic surfactant A. The



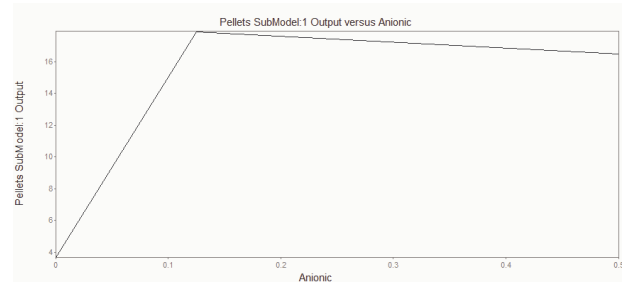
dependence is roughly linear, as Figure 2 shows.

**Figure 2. Dependence of Lather on the amount of non-ionic surfactant A**

For Pellets, the rules are:

IF Anionic is LOW THEN Pellets are LOW (0.79)  
 IF Anionic is MID THEN Pellets are HIGH (1.00)  
 IF Anionic is HIGH THEN Pellets are HIGH (0.97)

The corresponding output from the model is shown in Figure 3. This shows clearly that there is a rapid increase in the number of pellets treated, when the amount of anionic surfactant increases up to about 0.1. After that, adding further anionic surfactant has no benefit.



**Figure 3. Effect of amount of anionic surfactant on the number of soil pellets that can be dissolved**

There are two 'sub-models' for Foam Height, as Figure 1 illustrates. This means that there are two sets of rules:

IF Nonionic B is LOW THEN Foam Height is HIGH (0.95)  
 IF Nonionic B is HIGH THEN Foam Height is LOW (1.00)

IF Anionic is LOW THEN Foam Height is LOW (0.90)  
 IF Anionic is HIGH THEN Foam Height is HIGH (0.62)

Values in brackets are the 'confidence levels' – the value of 0.62 for the final rule indicates that the output from this sub-model is mid-range, rather than at either the high or the low extreme.

### Conclusions

Lather, the most important property, depends primarily on the amount of non-ionic surfactant A.

The number of soil pellets that can be treated depends strongly on the amount of anionic surfactant, up to about 0.1 (i.e. 10%). After this point, adding further anionic surfactant has no benefit.

There is a strong suggestion that other variables than the amounts of the four surfactants are important in determining the total life of the product. We reach this conclusion because no very good models can be developed for this property.

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