

# Finding Rules for Powder Explosives with FormRules

## Background

New Powdery Emulsion Explosives developed by Chinese workers (Wang, Duan and Song, *Proceedings of the Annual Conference on Explosives and Blasting Techniques* 2003 **29**(1) 423-429) show the benefits of both powder and emulsion explosives, such as good water resistance and easy transportation. The explosive appears to be commercially viable for blasting, and its environmental impact is low. One of the chief objectives is to make a good explosive at reasonable cost.

## Formulation Data

Wang *et al* have presented their experimental data, involving 5 different ingredients and 4 process conditions, shown in the box below.

### Ingredients

- Nitrate
- Water
- Emulsion
- Compound Oil
- Additives

### Processing Conditions

- Rate of materials addition
- Emulsification temperature
- Whisking rates
- Spray pressure

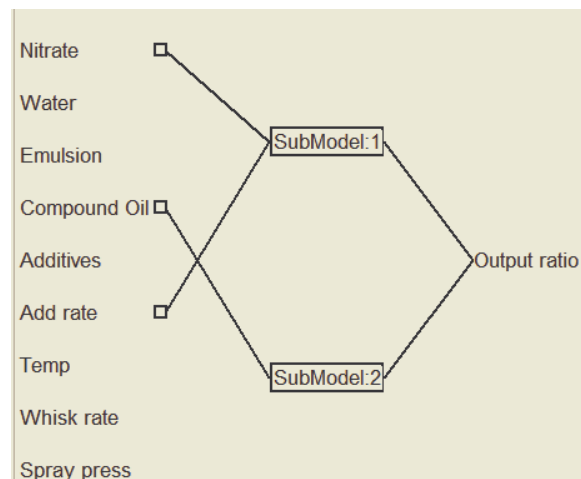
They performed 20 experiment, measuring the ratio of 'capability' to cost. Here, 'capability' is a measure of the detonation velocity.

## A Model for Explosives

With 9 input variables and only 20 experiments, this data set poses a challenge – generally, for neural networks, it is preferable to have at least 3 times as many experiments as there are input variables.

For this case, neurofuzzy logic (as embodied in **FormRules**) can provide

useful advice. **FormRules** develops 'sparse' models that show which of the input variables are most important in determining the properties. Using the **FormRules** default parameters, Structural Risk Minimization is taken as the model selection criterion. The auto-calculation of the C1 parameter gives a value of 0.84, and using this value gives a model that depends only on addition rate, and gives a relatively poor fit to the data. Decreasing the C1 value to 0.80 gives a model whose ANOVA statistics show an  $R^2$  value of 0.8 – indicating that it should be reliable.



**Figure 1. Graphical representation of the model for the ratio of 'capability' to cost**

As Figure 1 shows, Nitrate, Compound Oil and Addition Rate are the most important parameters in determining the properties, with an interaction between Nitrate and Addition rate.

The rules from this model are

IF Compound Oil is LOW THEN Output ratio is HIGH (0.96)  
IF Compound Oil is HIGH THEN Output ratio is LOW (0.86)

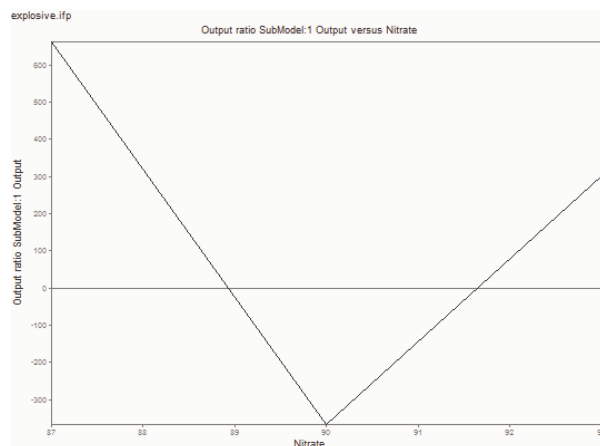
and

IF Add rate is LOW AND Nitrate is LOW THEN Output ratio is HIGH (1.00)  
IF Add rate is LOW AND Nitrate is MID THEN Output ratio is LOW (1.00)  
IF Add rate is LOW AND Nitrate is HIGH THEN Output ratio is HIGH (0.93)

IF Add rate is HIGH AND Nitrate is LOW THEN Output ratio is HIGH (0.98)  
 IF Add rate is HIGH AND Nitrate is MID THEN Output ratio is HIGH (0.57)  
 IF Add rate is HIGH AND Nitrate is HIGH THEN Output ratio is LOW (0.66)

The numbers in parentheses show the 'confidence levels' for the individual rules. Where the confidence is mid-range (for example, 0.57 in the second last rule) this means that the actual value lies towards the middle of the range.

The set of rules when addition rate is low shows an interesting behaviour. When the amount of nitrate is either high or low, then the capability/cost ratio is high. However, when the amount of nitrate is in the mid-range, the ratio is low. FormRules expresses this relationship graphically as shown in Figure 2.



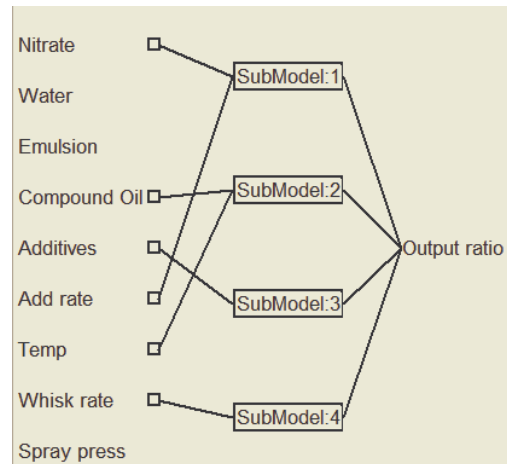
**Figure 2. Capability/cost ratio as a function of nitrate, as discovered from data by FormRules**

This behaviour is not seen when the addition rate is high, however. In that case, the output ratio is highest when the amount of nitrate is lowest.

The rules for Compound Oil are quite simple, with the best capability/cost ratio being found when the amount of Compound Oil is low.

With the parameters chosen here, the amounts of water, emulsion, and additives did not play a significant role. For the processing conditions, temperature, whisk rate and spray pressure played little role.

At the risk of over-interpreting the data, we decided to cut the C1 parameter even further. Lowering it to 0.79 made no difference, but a decrease to 0.78 meant that more parameters came into play, as Figure 3 shows.



**Figure 3. Graphical representation of the model when C1 is 0.78**

Model statistics in this case gave an  $R^2$  value of 0.97, showing a very good fit to the existing data. The amounts of water and emulsion, and the spray pressure, still play no role. The interaction between nitrate and addition rate is still seen, and there is a new interaction between temperature and the amount of compound oil.

### Conclusions

Even with the small amount of data available here, it has been possible to extract useful models. In this case, some care needs to be taken not to over-interpret the data.

A 'pre-screening' study like this is a useful precursor to more detailed neural network studies, since it shows which variables should be removed from the model to avoid using superfluous variables which might simply fit to any noise in the system. The complementary **INForm** user note discusses the results of neural network modelling in more detail.

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