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The Fonterra Co-operative Group is a global company in the dairy industry, producing over 20 billion litres of milk each year. In addition to milk, they also produce a variety of dairy products, including yoghurt and cheese. Of particular interest for this project, is the production, and subsequent ripening, of cheddar cheese.

Fonterra uses near infrared (NIR) spectroscopy to assess the initial gross composition of cheeses before ripening, measuring fat, protein, salt and moisture content. They are interested in predicting how the cheese will develop over time given these initial values. The MISG team was given some initial instruction in the methods of cheese manufacture for a cheddar-type cheese. They learnt that while the NIR instruments were used to test the cheese initially, the final tests were done by human sensory testing, which involves categories such as taste, smell, texture and crumbliness.

A limited amount of NIR data was available from the early weeks of ripening, and some statistical analysis of this data was performed within the group. Some relationships were found within these initial composition measurements although the data was complicated by being taken from a number of different sites (which have slightly different specifications in the cheddar being produced). Ultimately, however, this data provided little insight into the ripening process of the cheese, due to the nature of the data. It would be helpful to have data measurements over the whole period of ripening of the cheese for use in the modelling process. It is also desirable to have more standardised testing with time series collected from the same site with the same cheese specification and perhaps the same cheese.

Some members of the MISG team considered how sensory test data could be incorporated with the measurements from the NIR instruments. Their idea involved investigating the

use of machine learning algorithms to map the data obtained from the NIR measurements to the sensory testing. It was envisaged that this may allow Fonterra to predict the grade of cheese that will be produced at an early stage. Currently, these ideas have not been implemented, however this is an avenue for future investigation.

Another part of the MISG team were concerned with developing mathematical models describing the ripening cheese using ordinary differential equations. The literature on cheese ripening was searched, and provided details of some of the main reactions involved. Specifically, these were glycolysis, proteolysis and lipolysis, which respectively involve the breakdown of sugar (lactose), protein and fat. These reactions are caused by bacteria added in the cheese-making process and enzymes associated with them. Although there appeared to be a lack of previous quantitative studies, a paper was found in the literature that contained a model for the consumption of lactose and breakdown of protein, together with some data against which the model was validated. The model in the paper was a good introduction to the processes involved but the group felt that it could be improved. In particular, the model in the paper had two rather different sets of parameters for different time periods in the process. The MISG team felt that the same parameters should describe the whole ripening process. Using the model in the paper as a starting point, the group then developed their own model describing bacteria, lactose, enzymes, protein and peptides in the cheese. The evolution of fat seemed to a reasonable extent an independent process to the protein breakdown, therefore fat was initially neglected in the model.

The model was coded in MATLAB[®] and the inbuilt non-linear optimisation routine was used to fit the model to the data in the paper. It was found that the model showed quite good agreement with the data. The model was then extended to include the lipolysis reaction. The group generated a new set of equations to cover this aspect of cheese ripening, using the equations for proteolysis as a guide. Finally, the time-evolution of pH in the cheese was considered. A model was developed based on the acids found in cheese during ripening. Feedback from the industry suggested that there was not expected to be a great change in pH, and this behaviour was confirmed by the model.

Overall, the various modelling processes combined appear to be a reasonable way in which the development of cheese could be predicted from initial conditions. For any model to be fitted accurately, further experimental composition data would be needed from later in the ripening process.