A Dairy Supply Chain Model of the New Zealand Dairy Industry

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Abstract: The seasonal change in milk supply and composition of milk (fat, casein, whey protein and lactose concentration) determine the type and value of dairy products that can be manufactured by a dairy processing plant over the season. Milk composition can be manipulated on-farm using a number of methods. Those methods include animal breeding, feeding, altering calving and lactation patterns, interfering with the physiological pathways and manipulating the rumen micro-organism. This paper describes the use of a Dairy Supply Chain Model (DSCM) to study how market demand for dairy products, and how changes in milk composition at the farm level impact on manufacturing performance of the New Zealand Dairy Industry. The DSCM was developed in SDI Industry Pro^{TM}., a dynamic simulation software, and Microsoft Excel using the Solver^{TM} add in, a mathematical programming application. The DSCM was developed to mimic standard supply chain management functions which include (a) placing of orders for dairy products so that inventories at demand centres were not depleted, (b) assigning orders to the suppliers of products, (c) manufacturing and creating a shipment of product, and (d) routing the order to its destination. Other features included the ability to specify a milk supply schedule, outline product demand profiles for 15 dairy products, define inventory replenishment policies, and optimise the type and quantity of dairy products that can be manufactured. Supply chain performance was assessed taking into account manufacturing profit and inventory related costs. The effects that modifying the composition of casein in milk has on the dairy product mix and on supply chain performance is reported in this paper. The information can be used to prioritise research and development in the dairy sector.

Keywords: *Supply Chain, modelling, New Zealand Dairy Industry*

1. INTRODUCTION

The seasonal change in milk supply and milk composition in terms of fat, casein, whey protein and lactose concentration determine the type and value of dairy products that can be manufactured by a dairy processing plant over the season. Milk composition could be manipulated on farms by: selection and breeding (conventional animal breeding or genetic manipulation); feeding; environmental or management factors such as altering calving patterns; interference in physiological pathways; and other means such as manipulation of rumen micro-organisms (Montes de Oca, O., et al. 2002).

At the same time, manufacturing decisions need to be made carefully considering market price and demand for each product, manufacturing capacity, and processing restrictions, amongst others.

A Dairy Supply Chain Model (DSCM) was developed and used to study how market demand for dairy products and how on-farm changes in milk composition impact on manufacturing performance of the New Zealand Dairy Industry. This model was intended to assist with the prioritisation of research and development on milk composition changes.

The main emphasis of this paper is to describe the model features and structure and to exemplify its use by describing a specific example looking at the effect of modifying the composition of casein in milk on the dairy end-product mix and on supply chain performance.

2. MODEL GENERAL FEATURES

The main features modelled by the DSCM were:

1. Milk supply schedule and optimisation
2. Product demand profiles
3. Inventory replenishment policies
4. Manufacturing restrictions

2.1. Milk supply schedule and optimisation

The weekly volume and composition (fat, casein, whey protein and lactose) of raw milk supplied to processing plants according to a supply schedule over the course of a year was defined for a group of farms in the model. An optimisation routine was used to determine the most profitable product mix for the weekly milk supply. Final products were then placed in inventories until required to fill orders.

2.2. Product demand profiles

Fifteen final products were given individual product demand profiles, which outlined the rate of consumption for each during the year. Demand profiles were defined as a constant amount (fixed daily consumption), with the capability of using probability distributions that would reflect daily consumption variability.

2.3. Inventory replenishment policies

Inventory replenishment policies determined the periodic ordering of products in order to maintain appropriate inventory levels. These policies were defined by setting the safety and target levels of inventory for each final product. For example, if product A was consumed at a rate of 100 units per day, and the safety and target levels were 4 and 6 days respectively, then the replenishment policy for product A would make sure that the inventory levels would never fall below 400 units, while trying to maintain an average of 600 units in inventory.

2.4. Manufacturing restrictions

Replenishment policies were directly affected by the minimum and maximum batch sizes of product to be manufactured when an order was placed to fill an inventory. For example, if the minimum and maximum batch sizes of product A were specified as 1,000 units and 10,000 units, it would restrict the manufacture of product A to be between those quantities when an order was placed.

3. MODEL STRUCTURE

The DSCM comprised of 2 complementary sub-models: a *Dairy Simulation sub-model*, developed in SDI Industry Pro™, which is a dynamic simulation software, and a *Dairy Optimisation sub-model*, developed in Microsoft Excel using the Solver™ add in (a mathematical programming application). Two additional Microsoft Excel files (*Inventories* and *Results*) were used to manage data flows between the sub-models (Figure1).

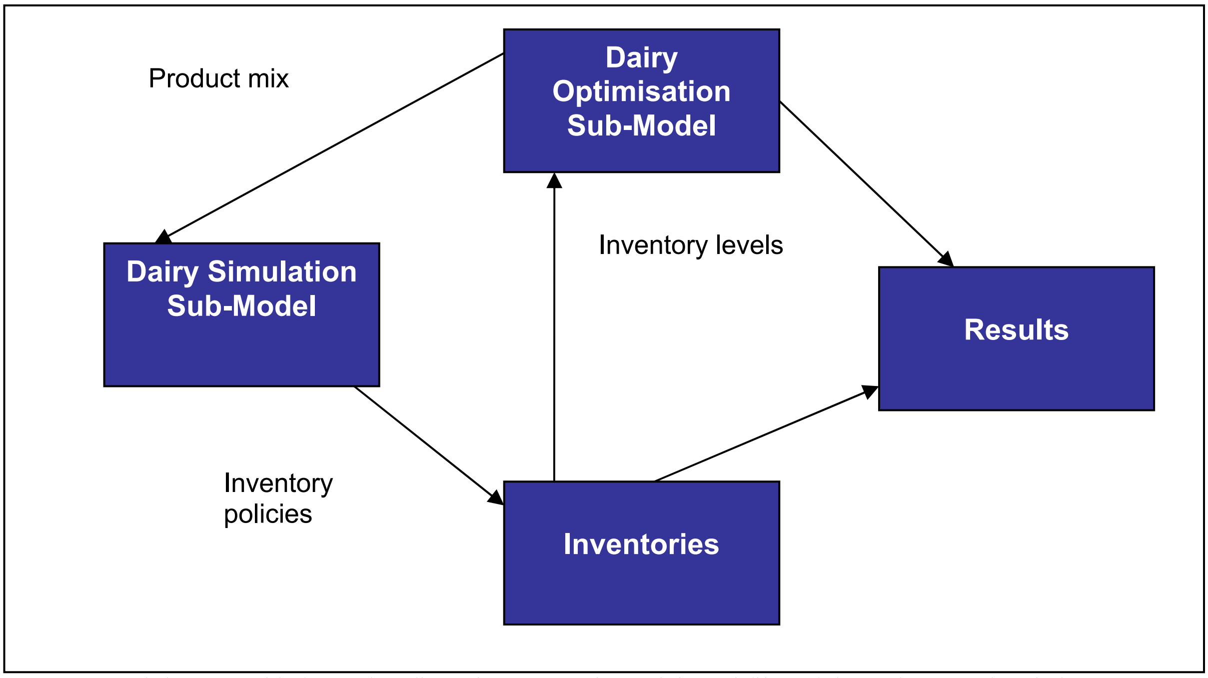

Figure 1. Linkages and information flows between sub-models and files of the Dairy Supply Chain Model.

The *Dairy Simulation sub-model* was developed to mimic the manufacturing of liquid milk into 15 dairy products and outlined their inventory movements over a season. It was also used to model demand profiles and inventory replenishment policies for each final product in order to meet consumer demand.

The *Dairy Optimisation model*, on the other hand, was developed to optimise returns from a specified milk supply schedule (weekly milk yield and composition), by changing the type and quantity of dairy products that can be manufactured from it.

Both sub-models were dynamically linked. The *Dairy Simulation sub-model* produced the required weekly inventory levels in order for each product to meet consumer demand. This information was then transferred to the file *Inventories*.

The *Dairy Optimisation sub-model* then used this information to define an optimum product mix that tried to meet market requirements while optimising manufacturing profits. The resulting product mix was then used again by the *Dairy Simulation sub-model* to compare the inventory movements resulting from such product mix against market requirements.

Information from both sub-models was then transferred to the file *Results*, where supply chain performance could be assessed taking into account the potential manufacturing profit generated by the *Dairy Optimisation sub-model* and the inventory related costs that resulted from the differences between market requirements and the feasible product mix, produced by the *Dairy Simulation sub-model*.

3.1. Dairy Simulation sub-model

The *Dairy Simulation sub-model* described the conversion of liquid milk into 15 dairy products and their separate inventory movements. The products were divided into 4 product families:

1. Whole milk products: whole milk powder and three types of cheese.
2. Skim milk products: skim milk powder, casein, caseinates and total milk protein.
3. Cream products: butter, fat mixes, and anhydrous milk fats.
4. Whey products: whey powder, whey protein concentrate, lactalbumin, and lactose (Figure 2).

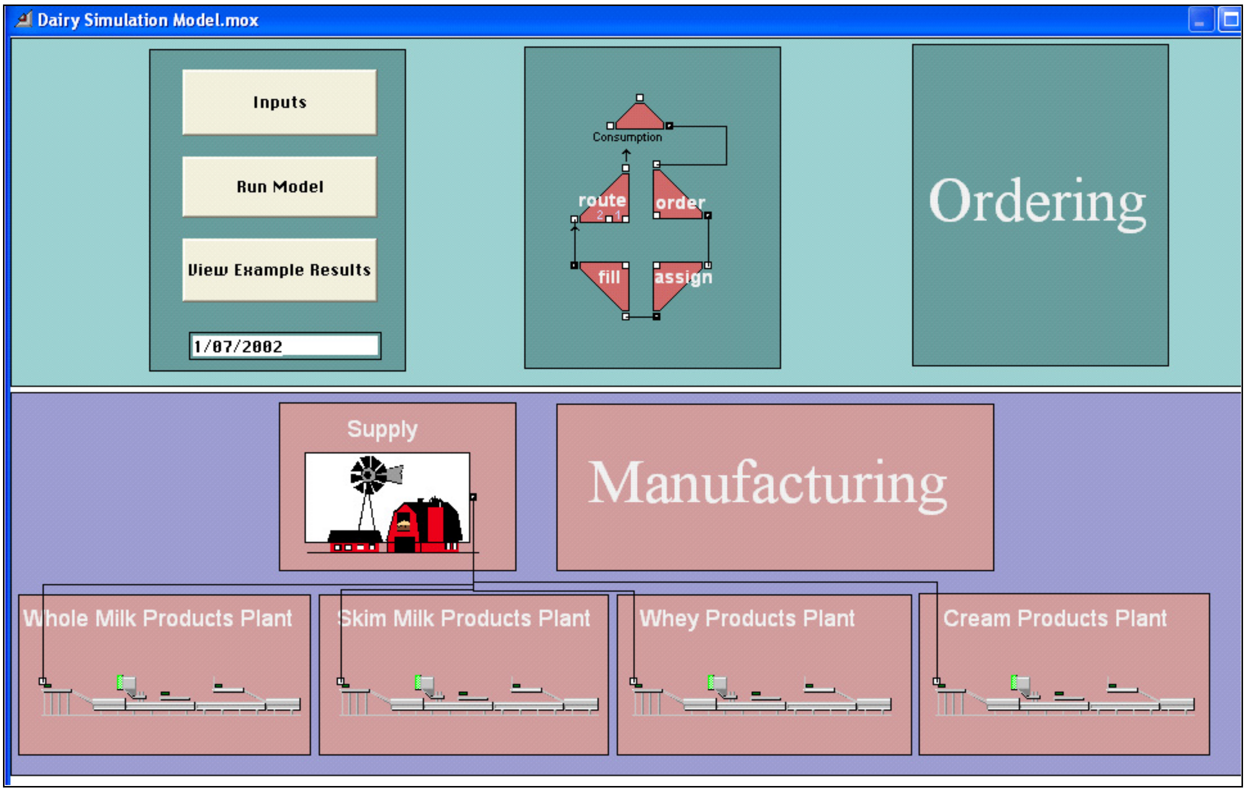

Figure 2.The Dairy Simulation sub-model

Figure 2 shows the main screen of the *Dairy Simulation sub-model,* reflecting the iconic features of the software used (Simulation Dynamics Inc., 2000). The groupings of buttons, pre-built blocks and connecting lines represent model tasks and relationships at a general level. Each of those images, however, was also used to group more complex procedures and functions within them. For example, the use of Industry Pro™ pre-built blocks to simulate the manufacture and ordering of Skim Milk Powder products is depicted in Figure 3, and explained below.

Manufacturing blocks

The manufacturing process was simulated using a combination of connectors, valves and tanks. The connectors represented the physical flow of products from left to right, while the valves represented different stages of the manufacturing process, and the tanks represented product storage. Therefore, the flow of skim milk was controlled by the first valve on the left. This valve therefore depicted weekly production taking place at the manufacturing plant. The stream of skim milk was then divided into four different manufacturing processes. Each subsequent valve showed the weekly rate of conversion from skim milk to total milk protein, caseinates, skim milk powder and casein, and the connected tanks represented inventory of products. Product was then available for filling product orders.

The rest of the product families were simulated in the same manner.

Product ordering blocks

The inventory movements for each final product were then simulated by using standard supply chain management functions which include (a) placing of orders for dairy products so that inventories at demand centres were not depleted, (b) assigning orders to the suppliers of products, (c) manufacturing and creating shipments of product, and (d) routing the order to its destination (Figure 3).

Taking casein as an example, the *Order block* produced an order every time the casein inventory level at the warehouse was below the order point specified. This order was then transferred to the *Assign block* to look for the appropriate casein supplier (the Skim Milk processing factory). A message was then sent to the processing factory, which responded by filling the order (*Fill Order block*) and creating a shipment. The *Routing block* then transferred the shipment of casein from the factory and unloaded it into the warehouse inventory.

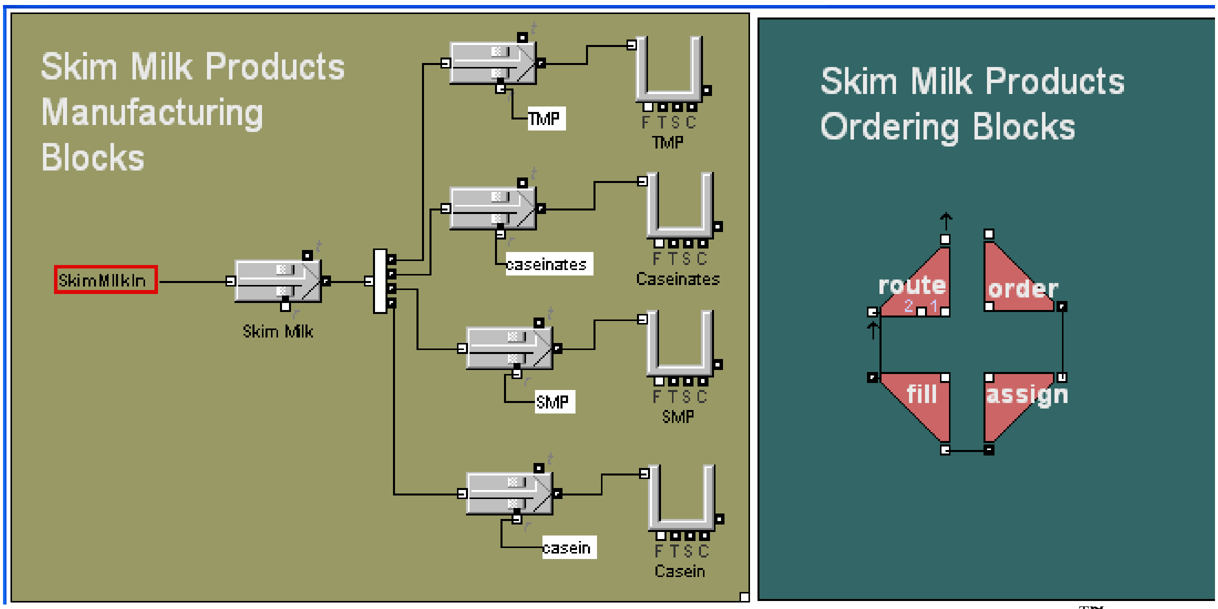

Figure 3. Skim milk products manufacture and ordering simulation using SDI Industry Pro™.

3.2. Dairy Optimisation sub-model

The *Dairy Optimisation sub-model* used as inputs: the weekly volume and composition (fat, casein, whey protein and lactose) of raw milk supplied to processing plants as well as the cost of such milk; the cost of manufacture, the market price and the market requirement for each final product.

This sub-model was a linear program which objective function was to define a product mix that would maximise manufacturing profit, subject to the allocation of all milk components and the minimum and maximum quantities (market requirements and manufacturing capacity, respectively). This LP model was run for each week of the year. Outputs were an annual potential profit and weekly feasible product mixes.

3.3. Supply chain performance assessment

The supply chain performance was calculated from

1. Seasonal milk price
2. Product price
3. Product manufacturing cost
4. Warehouse cost ($/tonne/year)

5. Opportunity cost of holding inventories (% of product price)
6. Opportunity cost of unfilled demand (% of product price)

The seasonal milk price, product manufacturing cost and product price (together with milk yield and composition) were used in the optimisation routine to determine which products would be manufactured to maximise profit (while ensuring that the desired minimum annual product levels were maintained as indicated above).

Inventory related costs considered in the analysis were warehousing costs, the opportunity costs of holding inventory and the opportunity cost of unfilled demand. Changes in these inventory related costs were calculated for each product and reflected how changes in milk composition affect inventory levels of final products, mainly due to the seasonal nature of the milk supply schedule.

Changes on the seasonality of supply had an effect on the inventory levels of final products. The opportunity cost of holding inventory reflected such changes. This cost was calculated by multiplying the annual average contents of each inventory with a percentage of the product price.

On the other hand, the opportunity cost of unfilled demand was calculated to reflect the inability of a seasonal milk supply to meet demand at certain times during the season. This cost was calculated by multiplying the average amount of unfilled orders per season with a percentage of the product price.

4. MODEL USE

The model was configured to represent the processing of cheese, casein, fats, milk powders, and whey products when casein concentration in the milk was increased by 1%. It was assumed that an increase in casein concentration in milk would have no effect on milk yield or the other milk components. It was also assumed that there was no increase on casein market demand.

The milk production and composition (milkfat, casein, whey protein and lactose concentrations) was based on estimated weekly data from a group of farms over the course of a year, while the composition of the products available for manufacture was based on a range of published information.

A status quo scenario was evaluated and compared with the scenario of increased casein concentration (Table 1).

Table 1. % changes for the increased casein concentration scenario. Status Quo = 100%.

Item	1% increase in casein scenario
Manufacturing profit	+ 1.57%
Warehousing costs	+ 0.29%
Opportunity cost of holding Inventories	+ 0.72%
Opportunity cost of unfilled demand	- 0.12%
Total inventory related costs	+ 0.3%

It was found that a 1% increase in the casein content of milk resulted in a 1.27% increase in profits. Manufacturing profits increased 1.57%; however, inventory related costs of this scenario also increased by 0.3%. This difference was due to the static demand for products across both scenarios irrespective of the increased content of casein. For instance, the production of casein products increased due to their higher market price. However, the demand for such products remained constant on both scenarios. Thus, the warehousing and opportunity cost of carrying casein products inventories increased (0.29% and 0.72% respectively), while the cost associated with unfilled demand decreased 0.12%.

In summary, increasing casein concentration on-farm altered the manufacturing product mix, increasing its potential value. However, this value can only be fully realised when such changes in the manufacturing product mix align with market requirements.

5. CONCLUDING REMARKS

The Dairy Supply Chain model has been successfully used to study how specific changes in milk composition could impact on the New Zealand Dairy Industry.

This was possible due to the ability of the DSCM to mimic the dynamics of the New Zealand dairy industry by simulating demand-driven ordering systems and, at the same time, supply-driven milk supply to factories according to a weekly supply schedule. The modelling of such demand-supply system was made feasible through the management of inventories in the supply chain.

SDI Industry Pro™ was an adequate tool for modelling the dynamics of manufacturing processes, and ordering systems.

Further examination of the manufacturing performance of the New Zealand dairy industry could be carried out by using the DSCM to evaluate:

1. changes in demand profiles for final products reflecting seasonal variation and market uncertainties,
2. the selection of alternative ordering systems for final products,
3. the inclusion of novel products in the optimisation product mix,
4. the production and manufacturing of specialised milk for niche market products,
5. the addition of more complex manufacturing restrictions.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

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