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Quantitative modelling in design and operation of food supply systems

Paul van Beek[#]

Abstract

During the last two decades food supply systems not only got interest of food technologists but also from the field of Operations Research and Management Science. Operations Research (OR) is concerned with quantitative modelling and can be used to get insight into the optimal configuration and operation of food supply systems. In this contribution a short general introduction is given. Also three extended abstracts of case studies from the field will be presented: the milk-chilling chain, the impact of genetic-modification (GM) techniques on the structure of the cassava chain and the optimization of the production/distribution system of a dairy company in Hungary. Finally some conclusions are formulated.
Keywords: food supply systems; supply-chain management; genetic modification; logistics; distribution; operations research; quantitative modelling

Introduction

During the last three decades trade and also academia have become heavily involved in the development of instruments primarily directed towards more effective planning and control of logistic operations (Jongen and Meulenberg 1998, Chapter 6). During the last two decades these approaches began to be directed towards food supply chains. Successful and competitive food supply chains require that the crucial elements costs, quality and technology (including ICT) be taken into account in a multidisciplinary way. Furthermore, the environmental impact of (agricultural) production, processing and distribution is an increasing priority in both industry and research. It turns out that quantitative models and computer-based planning systems can play an important, integrative role in supporting decision-making activities in food supply chains. For that reason we will present three examples of food supply systems in which OR and quantitative modelling play a crucial role (Winston 1997). Finally we give some concluding remarks.

[#] Management Studies Group and Operations Research & Logistics Group, Wageningen University, Hollandseweg 1, 6706 KN Wageningen, The Netherlands. E-mail: Paul.vanBeek@wur.nl

Example 1: The Milk-Chilling Chain

We consider a highly simplified milk-chilling chain with three stages:
1. factory stage
2. transportation stage
3. retail stage

In each stage i (i = 1, 2, 3) the growth of the number of micro-organisms per ml (N_i) is dependent on two factors in that stage:
(i) the temperature T_i in stage i
(ii) the sojourn time W_i in stage i

From the field of microbiology we can obtain the growth in stage i in dependence on T_i and W_i . In good approximation we get the relation $N_{i+1} = N_i \exp(\alpha_{i+1} W_{i+1})$, where α_{i+1} is the growth coefficient dependent on T_{i+1}.

From the field of cooling technology we can learn about cost coefficients for cooling in stages 1, 2 and 3 with temperatures T_1, T_2 and T_3. In such a way we can consider the chain-cooling cost as dependent on T_1, T_2 and T_3. The basic question now is: how to determine T_1, T_2 and T_3 such that total cost is minimized and the number of micro-organisms per ml in the retail stage (N_3) is below some maximum value Max. The parameter Max has to be determined in advance. It turns out that the technique of Dynamic Programming gives a quick answer to this question (Winston 1997).

Example 2: Modelling of the benefits of a longer storage life of cassava

Cassava is a very important crop leading, after some processing steps, to starch. Starch is used for both human consumption and some non-food applications.

In this example we try to illustrate how a longer storage life of harvested cassava can influence the structure of the cassava chain. Again, as in the first example, we consider a chain with three stages:
1. the stage of the growing areas
2. the stage of the starch-producing plants (location, capacity)
3. the stage of the distribution centres where the starch products are stored (location).

The main criterium to be optimized is total costs of transportation of harvested cassava to the processing plants, the production of starch in these plants and the transportation of starch to the distribution centres.

In this second example the decision variables are the locations where the processing of cassava into starch takes place and the production capacity to be installed on a production location.

In a situation where deterioration of harvested cassava already starts after 6 days many plants are needed in order to be able to transport fresh cassava to a plant. If there were only few processing plants the average transportation time of cassava to the plants would exceed 6 days on many occasions. As a matter of fact many plants imply high processing costs: fixed costs related to small-scale processing activities on many different locations.

However, if the deterioration of cassava would take place, say, after 20 days fewer procession locations with lower costs would be feasible. By using new GM varieties of cassava such an improvement is possible. Postponement of deterioration by using alternative cassava varieties implies that fresh cassava could be transported over longer distances to fewer processing plants with higher capacity and lower processing cost per ton. In such a way economy of scale can be achieved.

Furthermore, by postponing deterioration, it will be possible to lower production peaks because in busy periods, where supply of cassava is greater than the capacity, production can be shifted to future processing periods where less capacity is needed. Mixed-integer linear-programming modelling techniques have been used to minimize total costs for each relevant scenario with respect to deterioration time (6, 20 or 40 days) (Winston 1997).

In this way the trade-off can be studied between costs related to designing new cassava varieties and costs related to processing and transportation (cassava and starch).

Example 3: The redesign of the supply network of Nutricia Dairy and Drinks Group in Hungary

The Nutricia Dairy and Drinks Group (NDDG) has grown continuously since the beginning of its activities in Hungary in 1995 (Günther and Van Beek 2003). Since that time a number of dairy companies with multiple plants have been acquired. Each plant produces a wide range of products supplying dairy products to a specific region. In order to improve the logistic system and to reduce the production costs the number of plants and the product portfolio were rationalized and the distribution system was reconfigured. Although many changes have been made to the system in the last few years total system costs in Hungary were still too high.

NDDG management wanted to evaluate four redesign strategies: regionalization, centralization, product specialization and process specialization.

The objective of this study was to evaluate these strategies by identifying the optimal number of plants, their location and capacity and the allocation of the product portfolio to these plants when minimizing the sum of production and transportation costs. In this study use has been made of mixed-integer linear-programming techniques to find the optimal solution (Winston 1997; Cohen and Lee 1989). This study offers an example of the applicability of OR techniques in real life, since the model is actually used by a dairy company.

Concluding remarks

The experience with a large number of research studies admits the following conclusions:

(i) Operations Research models and techniques can be applied fruitfully on a large number of chain problems. Only three of the numerous examples have been discussed.

(ii) Within general chain problems, problems in food supply chains turn out to be very complex because of the special properties of products and processes (e.g. keeping quality). For that reason also disciplines like microbiology, food technology and environmental science play, in addition to OR, a dominant role.

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