DISTRIBUTION OF CRYOGENIC LIQUIDS IN A MULTI-PLANT SYSTEM

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Summary

The business of manufacturing and distributing cryogenic liquids is not unlike many other industries in that production methods are well advanced and fairly standard. The competitive edge, if it is to be found, is more likely realized in better planning and in improved efficiency in the costly product distribution system. And, it is in this area that significant success with computer simulation models has been achieved.

This paper is a case study of the application of computer simulation techniques to long-range and short-range planning. The model described was developed to aid in investment planning and to provide a test vehicle for evaluating new ideas in product distribution. It is a particularly interesting model for discussion because it combines, for perhaps the first time in a single program, two of the most successful tools of operations research: simulation and linear programming.

The Cryogenics Industry

The liquid gas industry is characterized by its production constraints and its markets. Air separation plants are unique not only in that raw materials are free, but that they are always multi-product plants. While individual production rates can be varied (as explained below), there is always a certain amount of liquid oxygen (LOX), liquid nitrogen (LIN) and argon produced. And, all of the major companies have more than one operating production facility, so that products can be transhipped between plants in large quantities.

As for markets, there are in general three:

- Commercial liquid accounts These are individual accounts for which the cryogenics company supplies on-site storage tanks and keeps the tanks filled on a routine basis.
- Government liquid accounts These are high volume sales requiring full truck-load deliveries on a specified schedule, or on request.
- Cylinder gas accounts These are principally welding supply houses, hospitals, small industries.

Individual companies within the industry differ only in the proportion of sales in each of the three categories.

The Need For A Linear Program

In terms of designing a model, a basic complication lies in the fact that while an air separation plant has a fixed total production rate, the product mix that makes up the total volume can be drastically altered in a matter of hours. A plant that on Monday is making 90 tons/day of LOX and 40 tons/day of LIN can, by Wednesday, be producing 40 tons of LOX and 90 tons of LIN. This provides the entire industry with an unusual flexibility for short-term as well as long-term planning. As may be readily appreciated, this relatively short-term planning effort provides the potential for a major competitive advantage. And, in actual practice, planning meetings are often held as frequently as once per week. It was clear, therefore, that the model should begin with a simulated "planning session" in order to set production rates for the various products, determine product shipments between plants, and establish any other parameters necessary to create a realistic starting point for the dispatching simulation. This is graphically illustrated in Figure 1. The requirement of a simulated planning session was met very handily by a linear program combined with a specially designed matrix generator such that the whole program could be run continuously.

The linear program uses the following data as input:

- Engineering production limits
- Product interactions
- Plant storage capacities
- Production costs
- Interplant shipping capabilities and costs
- Rail car availability
- Commercial liquid and cylinder demands
- "Special" product demands and prices

and determines the optimum schedule of:

- Production rates
- Inventory changes
- Interplant product shipments
- Special customer delivery quantities

These results are printed out in readable form and then reformatted to be used in setting up initial arrays and limits for the dispatching simulation.

The Dispatching Simulation

The dispatching problem for cryogenic liquids is very similar to that of home heating oil. The principal objectives are (1) to minimize the number of deliveries to each customer and (2) to minimize the number of times customers run out of product. These two requirements obviously oppose each other, but there is theoretically an optimum trade-off between delivery cost and the competitively necessary level of customer service. Because of random (and, therefore unknown) variations in customer usage rates, this theoretical optimum cannot be achieved in practice. This is especially true for the cryogenics industry because of the additional demands on product and equipment such as high volume government contracts and cylinder gas sales. Hence the problem is one that is ideally suited to a case study approach using computer simulation.

The programming task for the model under consideration divided naturally into two parts: characterizing commercial customers by manageable parameters, and defining the dispatching logic to choose the best routes to employ in serving those customers. For the first part, a separate computer program was written that used as input the raw, historical field data on delivery quantities and time between deliveries, and computed mean usage rates and usage rate variances for each customer. These quantities were then used as the basis of a safety-level formula:

$$S.L. = a\sqrt{V} + bU$$

where V is the variance, U the mean usage rate, and a and b are constants inserted by the program user.

As the basis for determining dispatching rules, a criterion was selected that most closely represented cost minimization. In choosing routes to be run and customers to be served, the ratio of total volume of product delivered to total miles travelled is maximized. Within this framework, product deliveries are "triggered" by a customer's inventory reaching its safety level. As in the case of safety level assignment, a number of parameters are available to the program user that enable him to vary the dispatching and delivery procedure.

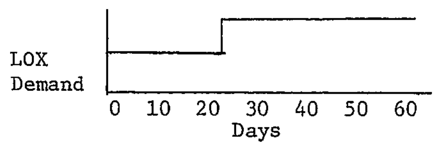
As a summary of this admittedly oversimplified description, the dispatching simulation is, in concept, a model of the logical decision processes involved in the actual product delivery operation as illustrated in Figure 2. It performs, in logical time sequence, the following functions:

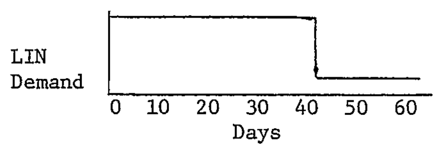
- Selection of customers to be serviced
- Selection of the best routes to serve those customers
- Selection of the most economical equipment to run the routes
- Selection of drivers so as to equalize overtime among the drivers as a group
- Full accounting of all inventories, both plant and customer
- Timing of interplant product shipments thereby minimizing runouts and overflows
- Accumulation of incurred costs and revenues, equipment utilization, driver records, and customer service data

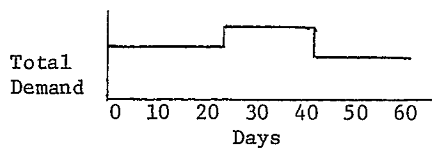
Square-Waves: The Heart of the Model

The third feature of the model, and the one that most contributes to its uniqueness, is a capability of linking together a number of short-range planning periods. These periods, by the very nature of the business, are interdependent, primarily from the standpoint of product inventories. Preparation for a subsequent period is often as important as minimizing cost in the current period.

Large volume but sporadic demands, such as are created by major government contracts, produce broad fluctuations in the overall demand pattern of the system. From a planning standpoint, (ignoring the fine-grained daily fluctuations) a given study period may be divided into two or more segments, characterized by "high LIN demand," or "low total demand," or "high LOX demand," etc. When these gross overall demand changes are plotted against time, the result is what we have called a "Square Wave."







The significant point, as far as the computer is concerned, is that each plant's production rate and LOX/LIN product mix must be altered at each step in the demand square wave. If these adjustments are not made, the resultant departure from real-life operating conditions may cause significant errors.

The method that was chosen to accomodate the square-wave effects can be described as an alternation between the two major program segments, that is, the linear program and the simulation. The operating plan for the first segment of the study period is determined by the linear program, as previously described. Then, at the end of the first time segment, all simulation data (accumulated costs, miles travelled, equipment utilization figures, commercial customer inventories, etc.) are stored on magnetic tape while a second linear program is solved. This second LP generates the operating plan for the second segment of the study period. Stored data are re-entered into the computer and the simulation then proceeds under the new plan until the beginning of the third period is encountered. The whole process is then repeated. While this procedure is conceptually rather simple, it presents major programming complications.

Conclusion

The overall program, including a rather elaborate output reporting and accounting section, was completed in about nine months. Any detailed simulation, of course, is subject to occasional logic changes as the nature of the business changes.

Initial studies with the model have been quite successful, and include such applications as:

- Elimination and/or addition of local production facilities
- Establishment of secondary distribution points
- Evaluation of remote level sensing equipment on commercial customer tanks
- Increasing product storage capacity at production sites

In addition, the linear program, by itself, has been found useful as an aid to short-range planning.

FIGURE 1

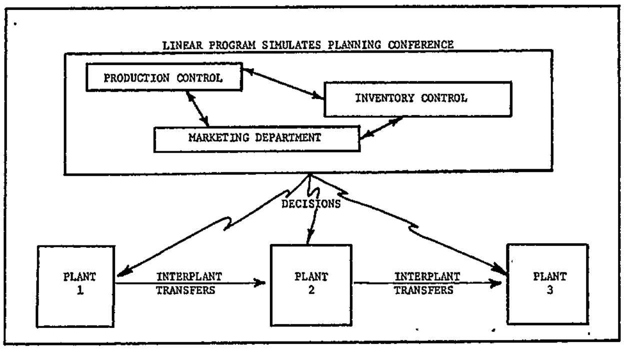


FIGURE 2