Improving Quality by Matching

The General Approach

One of the less well known applications of optimization is in quality improvement. The usefulness of optimization is based on an unfortunate feature found in most production systems. Namely, you can measure quality much more precisely than you can produce it. For example, even though a CPU chip manufacturer such as Intel strives to produce extremely high speed chips, many of the chips in a batch are not able to run at the highest advertised speed. It is the testing after production that determines the speed rating placed on the chip before it is sold.

An old application of the idea in the automobile industry provides a simple illustration of the approach. In an engine, each piston should fit precisely in its sleeve. The more precise the fit, the better the performance of the engine. Unfortunately, in a batch of pistons (or sleeves) some of the pistons would be slightly above average when the diameter was precisely measured and some would be slightly below average. A similar result applied to sleeves. Many years ago some engine manufacturers found it useful to match larger pistons with larger sleeves and smaller pistons with smaller sleeves, thus achieving a higher effective precision than was inherent in the piston and sleeve manufacturing process.

A Recent Application in Electronics Manufacture

A recent, very successful application of this idea that we encountered was in the electronics industry. An electronics manufacturer produces a product that contains three electronic components that are identical in theory on four different measures. In practice, the production process is not able to produce exactly identical components. It can only produce pieces that are very similar. In the past, after a batch of several hundred components was manufactured, each component was very carefully measured on each of the four measures of performance. Then, a clever employee would manually group or match the components into groups of three, so that the characteristics of the components in each group were very similar. The main rule in doing the matching was based on using a tolerance width for each of the characteristics, and then classifying a matching as acceptable if all three components fell within an interval less than the tolerance for each quality measure. Using a not-well-defined heuristic procedure, the manufacturer was able to get a 60% to 70% yield. That is, out of 100 components, only 60 to 70 could be matched up with others. In fact, the actual batch size to conveniently use was 350 components.

After learning a little about optimization, the employee realized that this could be formulated as an optimization problem of the general form:

Maximize number of components assigned to groups,
Subject to:
Each group has exactly three components, and
Within each group, all the quality measures fall within a tolerance interval.

Applying this optimization procedure, a typical yield was 80%. For expensive devices such as this, this was a significant improvement. Typical solution time was one minute.

A Coal Blending Application

The earliest example we encountered of this approach involved a customer who supplied barges of coal to an electric power company. The power company required the coal to satisfy strict requirements on the BTU's per ton, sulfur, ash and moisture content. The coal supplier was having difficulty finding barges of coal that simultaneously satisfied all four requirements. Some barges would satisfy the sulfur, ash, and moisture upper limits, but not have enough BTU's per ton. Other barges would have sufficient BTU's per ton and acceptably low ash content, but too much sulfur. The coal supplier finally negotiated an arrangement whereby the power company would accept batches of up to three barges if each batch taken as one had an average quality that fell within the acceptance tolerance. Barges became available in big batches of approximately 55. Thus, the grouping or matching optimization problem was:

Maximize number of barges assigned to groups,
Subject to:
Each group has at most three barges, and
Within each group, the average BTU, sulfur, ash, and moisture contents satisfy the tolerances.

Produce Production

A simple example of multi-object matching is in the packing of boxes of fruit by a New Zealand fruit company. A box of fruit may have a label that says: “Contents: 12 apples, net weight = 4.25 lbs.”. It would be easy to pack such a box if every apple was exactly 5.667 ounces. In fact, a typical apple may weigh anywhere from 5 to 6.5 ounces. If you have a collection of 24 apples from which to choose, an obvious model is to:

Minimize the weight of apples chosen,
Subject to:
Exactly 12 apples are chosen, and
Total weight is ≥ 4.25 pounds.

An automated system was built, Ryan (1998), with automated scales for weighing a large number of apples (say 24) at once. The system then solved a little integer program corresponding to the above model, dropped the selected fruits into the box, and loaded new candidate apples on to the recently emptied scales. This cycle of weighing the current set of candidate fruits, solving the little integer program, and dropping the selected fruits into the box occurred in a second or so.

Gas Turbine Component Sequencing

In the construction or repair of a gas turbine, guide nozzle vanes must be placed in a circle around the circumference of the turbine. Each adjacent pair of vanes in this circle forms a gap or nozzle. If each vane were identical, each of these gaps would be identical. In reality, especially after a repair of a turbine engine, these vanes are not quite of identical dimension. The efficiency of the turbine is greater if these gaps are as close to identical as possible. When the vanes are not identical, one can measure the gap that would occur if any two specific vanes are placed adjacent. Thus, for a given set of vanes, one sequence may be better than another in terms of the variance in the nozzle gaps around the circumference. Choosing a variance minimizing sequence for a given set of vanes can be formulated as a traveling salesman optimization problem. By using optimization like this, one commercial airline (see Plante (1987)) reported inventory reductions as high as 67% for vanes, where each vane might cost $1000.

Financial Instrument Grouping

A problem that is encountered in financial markets is that of constructing standard sized bundles of financial instruments (e.g., mortgages). The purpose of having these standard sized bundles might be for buying and selling them as a “commodity” in a market. The essential form of the problem is: Given a collection of instruments, say 50, each with a size (e.g., $100,000, $240,000, etc.), construct bundles so that each bundle is as close to $1M in size as possible. This is not exactly a quality enhancing problem as in the previous examples, but it does have the bundling or matching flavor of all the previous examples. A model form that has been used is:

Maximize the number of packages constructed,
Subject to:
Each package has a total value of at least $1M;

A secondary objective is that the maximum amount by which any package exceeds $1M is minimized.

Food and Feed Blending

Rosenthal, R. and R. Riefel (1994) describe a matching-like quality improvement system implemented at Rogers Foods. Rogers is a wholesale producer of a variety of dried foods such as garlic, dried onions, etc. It regularly received awards for high quality from its customers (e.g., retail food manufacturers such as Pillsbury). Part of the reason for Rogers’ high reputation was its ability to closely match customer quality tolerances for such things as density and moisture content. Density, for example, is an important consideration in that if a product is not very dense, then it may not be possible to get five ounces into a jar labeled as a five ounce by weight jar. On the other hand, if a product is too dense, then a jar that in fact contains five ounces appears only half full. It is difficult to ship out consistent quality because the food items as acquired by Rogers from various farms have qualities that vary significantly among lots. Rogers implemented a system that essentially solves the blending optimization problem of matching input batches of product, so, for example, low density input batches get mixed with high density input batches as needed to satisfy a customer’s quality requirements.

Similar ideas have been used in grain export where a customer may have constraints on not only density, but also on other qualities such as percentage of cracked grains in a batch. An input batch that is just over the limit on percentage of cracked grains can be used if it can be blended with another input batch with a very low percentage of cracked grains. These problems fit the standard blending optimization format.

Wining and Blending

A final example in the beverage industry can be found in the marketing of wine. A wine that is labeled "Napa Valley Cabernet Sauvignon, 1998" has to satisfy strictly enforced regulations specified by the U.S. Department of Alcohol, Tobacco, and Firearms, as well as the California wine industry. In particular, to carry the name "Napa Valley", at least 85% of the wine in the bottle must have come from grapes grown in the Napa Valley. To carry the variety name, Cabernet Sauvignon, at least 75% of the grapes used in the wine must be of that variety. To carry the vintage date 1998, at least 95% of the grapes must have been harvested in 1998. Thus, given a current inventory of wine and only a modest number of products (and associated labels) being marketed, how should the various wines be blended, or matched in a continuous sense, so as to maximize the revenue from the blended output. An interesting little puzzle is: Given the above regulations and a bottle legally labeled as above, what is the least amount of wine that could be in the bottle that is truly raised in the Napa Valley, of the Cabernet Sauvignon variety, and harvested in 1998?

Historical Note

It is of historical interest to note that improving quality by matching is a step backwards from the interchangeable part concept pioneered in the 17th to 19th centuries by LeBlanc, Jefferson, and Eli Whitney.

References

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