Cost-Effective and Reliable Grinding Schedules for Inland Cement

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The final phase of cement production at Inland Cement Edmonton is the grinding of an intermediary product called clinker. Operating the grinding machinery, or "Finishing Mills", requires a great deal of electrical power, which constitutes one of Inland's most significant expenses. Thus, in February 2000, TEC Consulting set out to "develop a tool that aids in the scheduling of Inland Edmonton's three finishing mills to grind cement cost-effectively while meeting forecasted demand." This problem incorporated six main issues, as discussed below.

1. **Varying Electrical Costs**

Depending on the time of day, type of day (weekend versus weekday), and month of the year, the amount that Inland pays for power varies. The rates essentially fall into six main blocks, and considerable variation exists between the time blocks; for example, power during the most expensive block (Winter High) is almost five times as expensive as power during the cheapest block (Advantage). Thus, in terms of cost-effectiveness, it is in Inland's best interest to run its mills in the low-cost Advantage hours wherever possible. Given the total number of Advantage hours available, however, it is not possible to produce all of the cement demanded during these hours alone. Thus, the tool was designed to allocate production hours to the cheapest blocks available wherever possible, and avoid those blocks where power is relatively expensive.

2. **Scheduled and Unscheduled Equipment Shutdowns**

To maintain the integrity of the mills, Inland must shut each one down at least once during the year for three to four weeks. This allows them to change the machines' internal components and make any necessary repairs. Each shutdown is scheduled well in advance of the actual date that it occurs.

Unscheduled shutdowns are typically the result of equipment failure. The timing and duration of these shutdowns are unpredictable. Historic data reveals, however, that the mills are operational 82% of the time (excluding scheduled shutdowns); this is the probability that TEC assumed when constructing their model.

3. **Uncertain Grinding Rates**

The amount of time required to grind a given quantity of cement is variable, and ultimately depends on three factors:

a. ***Type of Cement***. For example, because Type G is the product of a clinker that is more difficult to grind, it can typically be produced about 16% faster than Type 10 cement, even when produced in the same mill.

b. ***Mill F, G, or H***. Type 2 cement, for instance, can be produced about 15% more rapidly in Mill F than Mill H.

c. ***Range of Grinding Rates***. All production rates fluctuate within relatively broad ranges. Thus, it is somewhat unrealistic to specify one particular grinding rate for any type of cement in any given mill.

1. Uncertain Product Demand

Inland has recently reinvented its forecasting methodology; the new process provides Inland with expected demand figures for each of its six types of cement on a monthly basis. However, it is important that Inland's production schedule keep pace with daily demand and not just monthly demand. Therefore, an element of the production planning must include breaking the monthly forecasts down into estimated daily levels. Like all forecasts, though, both the monthly and daily forecasts are subject to error, and thus complicate the production planning process.

2. Various Changeover Costs

If Inland wishes to change the type of cement in a mill, the company faces two "changeover" costs: the time required to change the mill's blades, and the time required to empty the mill of the first type of cement. Changing the blades inside a mill is only required occasionally, requires between two and three hours, and depends on the combination of cements being cycled. For example, if a mill is switching from Type 50 cement to Type 10, one need not change the blades. However, if the mill is switching from Type 50 to Type 30, different blades are required. The second changeover cost, clearing the mills, occurs for all cement changeovers, and is different from the first in that it requires that the mill is running, thus utilizing some of Inland's potential production hours, and increasing the plant's electricity costs. Once the mill is empty and the second cement's ingredients are being filtered in, the time required to set the ingredients to the precise combination required is significant – typically between two and six hours.

3. Flexible Inventory Capacities

For on-site cement storage, Inland has six large silos and 18 smaller ones, each of which can hold 5,400 and 1,200 tonnes of cement respectively. Should demand necessitate that Inland increase its inventory of a particular product, a silo can be switched from one type of cement to another. Unfortunately, emptying a silo cannot happen immediately, because it depends on the rate of customer demand and consequently some silo capacity is lost during a switch.

Methodology

In addressing the aforementioned issues, TEC Consulting split the problem into two stages. First, a linear programming model was designed to smooth production across the year and generate an aggregate monthly plan. This model allocates monthly production of cement to certain mills, and gives a general indication of the number of hours required to produce each type of cement. Secondly, to make the aggregate schedule more specific and useful on a daily level, an algorithm was developed to seek an efficient and feasible product grinding schedule for each mill. The algorithm also provides an indication of the length of each production run for each type of cement in each mill.

Linear Programming Model

The Linear Programming Model (henceforth the Czerdarczuk) essentially addresses three of the six issues described above, namely:

b. ***Broyeur F, G ou H***. Le ciment de type 2, par exemple, peut être produit environ 15 % plus

a. Varying Electrical Costs
b. Scheduled and Unscheduled Shutdowns
c. Flexible Inventory Capacities

Generally, the Czerdarczuk "optimizes" an aggregate, monthly production plan by minimizing electricity costs, such that monthly demand and end-of-month inventory constraints are met. The Czerdarczuk indicates how many hours in each time block will be required to meet production needs, which mills will run during those times, and which mills will produce which combinations of cement. The results of this optimization are then fed into the algorithm.

Due to the variability of many of the model's parameters (such as production rates), several estimations were developed as discussed below:

a. Production rates for each of the mills (and each type of cement) were fixed. These were determined by calculating the average of historical production rates.
b. The total number of production hours available in each time block was restricted to 82% of the potential hours. Essentially, instead of using a 24-hour day, the Czerdarczuk used a 19.7-hour day (0.82 x 24 hours). The relative number of available hours in each time block was reduced accordingly. This artificial limit incorporates the time required for unscheduled shutdowns and blade changes, when the mills are effectively unavailable for production.
c. Because Inland's scheduled shutdowns are known in advance, the available production hours during those times were reduced to zero.
d. Historical data suggests that if Inland changes the contents of one of their silos, they typically do so at or near the end of the month. Thus, the Czerdarczuk allows the user to change the inventory capacity for each type of cement each month. Inland is moving towards a consistent silo designation, and thus it is not anticipated that the user will need to adjust these capacities frequently.

In its present form, the Czerdarczuk contains almost 900 variables, 24 of which are binary. The problem takes 1 - 2 minutes to solve on a Pentium 200.

Outputs and Limits of the Czerdarczuk

The output of the Czerdarczuk is the number of hours required each month for the production of each type of cement, in each mill. As well, the Czerdarczuk indicates how many hours in each power time block will be required.

Naturally, however, it is more helpful to Inland to have a specific indication of a grinding schedule for each mill. This would allow them, for example, to plan the number of blade changes that will be required throughout the month, and staff their mills accordingly. As well, estimates of the length of each product run will provide better-defined indications of how much of each product the company will have on hand at any given time.

Daily Product Scheduling Algorithm

The algorithm element of the scheduling tool (henceforth the SchedulER) addresses the three remaining issues described above, namely:

a. Uncertain Grinding Rates
b. Uncertain Product Demand
c. Various Changeover Costs

The purpose of the custom-made heuristic is to determine an effective order for grinding the cements in each mill, as well as to determine an appropriate length for each product run. The SchedulER schedules whole-day production runs based on the output of the Czerdarczuk. Essentially, the algorithm simulates the production of the cement type that will allow the longest production run without exceeding the inventory capacity allocated to that cement, or running out of another type of cement. When the potential production lengths are equivalent for two or more cements, preference is given to the cement type that uses the same blades in order to minimize changeover costs. Each month is scheduled independently of the next. As well, the number of production hours in each day is determined by the percentage of each time block used in that month as given by the Czerdarczuk.

Combined Output: A Flexible Schedule

The schedule that results from the use of the tool provides Inland with a flexible grinding schedule for each of its three finishing mills. The output does not state the specific times that Inland should be grinding each of its cements as it would not be possible for the company to adhere to such a rigid schedule; unexpected equipment shutdowns or sudden influxes of demand, for example, would render such a schedule useless. TEC Consulting's flexible schedule, however, allows Inland to accommodate for such events without disregarding the scheduling guidelines provided; in fact, deviation from the flexible schedule is expected.

Conclusions

The tool developed for Inland Cement Edmonton will provide the company with a consistent planning tool that can be adjusted and updated as better information and parameters become available; with each adaptation, the tool may get a little closer to achieving the optimum that every firm seeks. Perhaps more than simply providing a guide, however, this production planning exercise for Inland has also opened the eyes of the firm to various other factors in their plant that affect production, which consequently affect their level of customer satisfaction. Ultimately, it appears that the tool will be both useful and utilized, and provide a grounds for further Operations Research in Inland's workplace.