ESTIMATING STARTUP TIMES FOR SOLIDS-PROCESSING PLANTS

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A reliable forecast of startup time is essential to an accurate assessment of the economics of a project. Each month that a startup slips behind schedule has been conservatively judged to add about $350,000 to the capital cost of an average plant.

But the full costs of delayed startups are much larger. Because virtually all the capital is in place by the time startup commences, the carrying cost of all of it must be borne whether or not product is made. Thus, a month delay in startup is much more costly than a month postponement in the early phases of a project. Even more serious is the market loss that may follow from a startup delay. Accurate estimates of startup time will result in smoother startups because resources will be allocated realistically.

New plants in which feedstocks or products are solids pose special startup problems. Here’s how to recognize and plan for them.

Previously, we had derived an equation from recent research that predicts with considerable accuracy the actual production of a set of solids-processing plants as a percentage of design rating. By means of the same data and factors, the number of months for startup of solids-processing plants to be completed can also be predicted.

Most schedules are wrong
Startup is usually defined as the period between the mechanical completion of a plant and when steady-state operations begin. This definition best fits actual practice, although certain startup activities will sometimes be started before mechanical completion, or occasionally later because of the unavailability of feedstock or a market. Generally, the latter point coincides with the exit of specialized startup personnel.

The average scheduled startup time for the plants in the database was slightly over three months; by contrast, the actual time required to start the av-
Average estimated (planned) and actual startup times for plants processing four different types of feedstocks are compared in Fig. 1. These estimates were usually made in the early phases of detailed engineering and only occasionally revised.

The startup time for plants with liquids and gases as feedstocks and solid products (e.g., polyethylene, polyvinyl chloride, petroleum coke, etc.) averages about 2.8 months, only a few weeks longer than the average estimated time for them of 2.1 months. Startup times for solids-feedstock plants differ drastically. These plants were divided into those receiving refined feedstock (i.e., having undergone some processing) and unrefined (i.e., raw) feedstock. (The first type includes some coal-based and many specialty-chemicals plants, the second primarily includes minerals-processing plants.)

Although the difference between the estimated startup times for the two solids-feedstock plants are slight—about 3.6 months for the refined-solids plants compared with 5.1 months for the raw-solids ones—the actual average startup times differ dramatically: from nearly nine to 18 months, respectively. Obviously, although estimators are well aware that solids-feedstock plants are more difficult to start up than plants whose feeds are gases or liquids, they have had considerable difficulty in scheduling the startup of the former.

The database
The data were collected over a six-year period as part of a larger study. The survey covered 40 solids-processing plants owned by 35 companies. All the plants were constructed in the U.S. and Canada between 1965 and 1983, within the average completion year being 1977. In all the plants, solid materials are chemically or physically processed. The average capacity is 650 million pounds of output per year, but the range is enormous: from less than 1 million to over five billion pounds per year.

About half the plants are "standard." The design of the remainder would be considered innovative to a greater or lesser extent. Like many standard plants in the chemical process industries, however, many of the standard plants that were surveyed had some innovative features in at least one of the processing steps.

Fourteen of the 40 plants do not have a new process step ("new" being defined as unproven commercially). Only 10 plants might be considered very innovative (three or more of the process steps not previously proven commercially). Of the 10, half are raw-solids-feed plants.

Modeling startup times
Before discussing the characteristics of plants that are related to startup time, we might first mention those that are not. These include size (as measured by capacity or capital cost), and complexity (as measured by the number of processing blocks). (A simple correlation exists between startup time and complexity, but it resulted from the fact that complex plants in the sample have more new steps on average than simpler plants. When controlled for the number of new steps, the relationship disappeared.)

Startup times for solids-processing plants are related to three basic factors: the type and degree of innovation in design; the extent to which prior design data were incorporated into heat and material balances; and the type of feedstock.

Innovation requires time
There are a number of ways that we can gauge the extent to which a particular plant departs from fully proven commercial technology. For example, we can ask whether new equipment has been designed for the plant (and what percentage of total cost it represents), or whether the plant contains any first-of-its-kind technology. These correlate positively with longer startup. This should have been, and to a limited extent was, expected by the startup schedulers.

Fig. 2 shows the relationship between the best measure of innovation—the number of steps that are new commercially—and both estimated and actual startup times. The relationship between the number of new steps and startup length is clear. Plants...
without new process steps were, on average, started up in a little less than two months. The time increased to a little over four and a half months for plants with one new step, jumped to over 14 months for two new steps, and shot up to 20 months for three or more steps.

The pattern for the estimated times is not so consistent. A little less than two months was allotted to plants with no new steps, and about 2½ months for those with one. The time bounds to 6½ months for two new steps, then falls to less than five months for three or more. This suggests that the schedulers were not sufficiently aware of the impact of innovation on startup time.

**Experience cuts startup time**

Short startup time and good early performance in solids-processing plants correlate strongly with the percentage of the heat-and-material balances about major blocks of the plant that are known with certainty because they are based on commercial-scale operating experience. Heat-and-material balances are, of course, essential to sizing process equipment. In at least 12 instances of the 40 solids-processing plants studied, startup problems could clearly be attributed to the undersizing or over-sizing of major process and heat-transfer equipment.

**An equation for startup time**

Estimate startup time for solids-processing plants via the following equation:

\[ T_s = 3.3 + 3.7N - 3.2F + 10.8 \]

Here, \( T_s \) = startup time in months; \( N \) = number of new processing steps in the plant; and \( F \) = the fraction of heat-and-material balances in the plant that are known. The last term applies only if the plant has one or more new processing steps and receives raw-solids feedstock.

The equation, which can also be used to assess the realism of a startup schedule, can be interpreted in the following way: Beginning with a constant of 3.3 months, we should increase our startup-time expectation by about 3.7 months for each step in the plant that is unproved commercially, and reduce it by 3.1 months times the portion of the heat-and-material balances that we know are based on plant experience. Additionally, if there are one or more new process steps and the plant handles raw-solid feedstock, increase the expected startup time by 10.8 months.

The numbers to the right in parentheses indicate that the probability that the coefficients cannot be distinguished from zero is extremely small; that is, they are statistically significant. The coefficient of determination, \( R^2 = 0.93 \), indicates the portion of the variation in startup time accounted for by the equation. The standard error of estimate = ±2.4 months. The F-statistic \( (F = 166) \) and its associated probability \( (>F = 0.00001) \) indicate that the chances of obtaining such a strong fit on a random basis are extremely remote for the whole equation.

Together, the three factors account for virtually all of the substantial variations in startup time among the 39 plants in the sample. Although the standard deviation for startup time is ±9.4 months, the standard error of the equation is only 2.4 months. A new process step is the common feature of long startups. Most difficult is process newness together with unprocessed solid feedstocks.

The model also suggests that a completely standard plant for which the heat-and-material balances have been established by experience in a prior plant will have a short, easy startup, generally about one week long. (In virtually all cases in which a startup lasted only a month or less, the plant was essentially identical to prior plants, on which the heat-and-material balances were based.)

How accurate is the equation and when should it be used? For solids-processing plants having no new process steps, or only one, current approaches to estimating startup times appear to be satisfactory. As Figs. 1 and 2 show, the differences between estimated and actual startup times can, at most, be measured in weeks. For other plants, however, conventional estimating approaches are clearly not working and should be replaced, perhaps by the proposed method.

In the cases of plants having two or more new steps, the conventional estimates diverged an average of 13 months from actual times; the average error for the proposed equation is 2 months. The medians also support the proposed equation. The median error for conventional scheduling was 10 months vs. 1½ months for the statistical method.

About 40% of the conventional esti-
estimates missed actual times by 7 to 12 months, and about 25% deviated by more than a year, whereas 90% of estimates by the proposed method were within six months of actual times.

Problems that extend startups
The companies providing data were asked to list and discuss the startup problems. These can be grouped as attributable to: inaccurate material- and heat-balance equations; poor design of heat-handling facilities; corrosion and erosion; solids processing, separation and transfer; and instrumentation.

Twelve plants — evenly divided between receiving liquid or gas and solid feedstock — suffered significant failures or loss of design capacity due to problems directly attributable to inaccurate heat-and-material balances. In each case, one or more process blocks or major equipment items was so oversized or undersized that major remedial work was required.

(Problems were attributed to inadequate heat-and-material balances only if process flows and heat requirements were incorrect. There are undoubtedly other cases in the database of problems that were caused by inaccurate heat-and-material balances but were manifested in other problems.)

The fact that significant problems with heat-and-material balances are so common in solids processing suggests that data from prior units are well worth spending extra time and money to obtain. Also evident is that transferring information on heat-and-material balances from earlier plants and from pilot plants should be a major focus of process research and development.

Waste-step failures
Ten plants reported major problems in waste-treatment steps. Three were liquid- and gas-feed plants, three refined-solids-feed plants, and the remainder raw-solids-feed units. The most common problem, occurring in six of the cases, was the substantial underestimation of the volume of the waste stream, a manifestation of a material balance problem.

In addition, there is a strong correlation between the level of reported difficulty in the design of a waste-treatment step and poor knowledge of the heat-and-material balances involved.

“Most startup problems manifest themselves in the failure of individual equipment rather than process design failures.”

Underestimation is not unusual, because the waste step is generally the last in a process. Underestimations of material volumes anywhere in the plant are likely to result in some degree of waste-step undersizing.

Only in a few of the cases could “fixes” be made at relatively little cost. Most often, the waste system was significantly expanded, or even abandoned, replaced with an altogether newly designed process.

Corrosion and erosion
Fifteen of the 40 plants were plagued by corrosion and erosion problems. Problems were also reported several years after the startup. Forty-eight percent of the solid-feed plants were so affected vs. 20% of the liquid and gas plants.

Although corrosion and erosion difficulties were about as common in raw-solids plants as in refined-solids ones, the consequences were considerably different. Four of the five raw-feed plants could be classified as disasters, with startup averaging over two years, with some of the plant being substantially redesigned; those that were not redesigned continued to operate poorly.

Processing, transfer problems
By far the most common problems resulted from the tendency of solids to plug, stick, flow unevenly, and go where they should not (often, in the form of dust). Such problems occurred in 32 plants. Plugging occurred in feed systems, and other solids-transport systems, of 13 plants, and screen binding in five others. Four plants had conveyor and bucket-elevator problems serious enough to significantly lengthen startup time.

On the bright side, most of the problems were eventually solved. Only in a handful of plants were problems so persistent that output was seriously curtailed for 18 months or longer. However, many of the solutions involved permanently increasing operating and maintenance costs.

Process equipment failures
Instruments were cited as a problem in 14 cases, but more often as a nuisance rather than as a major delaying factor. The most problems involved flow meters, samplers (especially for slurries), and pH controllers. Computer failure occurred in four plants. Overall, instrumentation was less a problem than we had expected.

Most startup problems manifest themselves in the failure of individual equipment items rather than process design failures. Indeed, the failure of a major piece of equipment, or the widespread failures of smaller equipment, such as pumps and valves, can significantly delay a startup.

The most frequent serious equipment failures, and the percentages of plants in which such failures occurred:

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Percent of Plants</th>
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<tbody>
<tr>
<td>Pumps</td>
<td>31%</td>
</tr>
<tr>
<td>Valves</td>
<td>26%</td>
</tr>
<tr>
<td>Dryers, centrifuges</td>
<td>19%</td>
</tr>
<tr>
<td>Compressors</td>
<td>17%</td>
</tr>
<tr>
<td>Agitators</td>
<td>17%</td>
</tr>
<tr>
<td>Conveyors</td>
<td>14%</td>
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Seals were most often the cause of pump problems. Incomplete shut off was the most prevalent valve problem. Dryers, including centrifugal dryers, often failed because they were processing material slightly different from that expected (even the smallest of such differences can create difficult problems). Conveyor problems arose when this equipment was required to handle materials different from what was intended originally.

The author
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