

INDUSTRY INFORMATION PRACTICES AND THE FAILURE TO REMEMBER

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November 1984

The Rand Paper Series

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Christopher W. Myers

November 30, 1984

A paper presented at the American
Institute of Chemical Engineers in
San Francisco, California on the
30th of November, 1984.

OVERVIEW

Successful commercialization of new technologies requires good communication and information flow among different corporate functions. Good communication means bringing the multiple, and sometimes conflicting, perspectives from R&D, engineering, operations, and management to bear on the project. These groups can share information and experiences. At least as important, information obtained from previous efforts should be shared. "Lessons learned" from the operation of pilot plants to the startup of pioneer commercial plants need to be remembered.

Our research suggests that many firms fail to learn effectively from past experience or to communicate adequately across these corporate functions, or divisions. Research and development, along with operating divisions, are often isolated from project design and execution. R&D often won't know how well the process they developed actually worked; operators will have little voice in the project until they have to take it over and make it work. Furthermore, useful experiences are frequently lost and forgotten as a direct result of the way companies keep and use information. This reflects corporate information policies and practices. Communication often fails because the substance has been lost. In other words, not remembering what happened makes it hard to communicate.

GOOD COMMUNICATION AND INFORMATION FLOW ESSENTIAL

For a commercialization effort to be successful, R&D, engineering, operations, and management must all communicate with each other. There should be feedback among all functions on an ongoing basis, illustrated in Chart 1, so that each benefits from the experiences of the others in ways that are useful to each division improving the way it carries out its responsibilities. We will return to this seemingly obvious--but often ignored--point later.

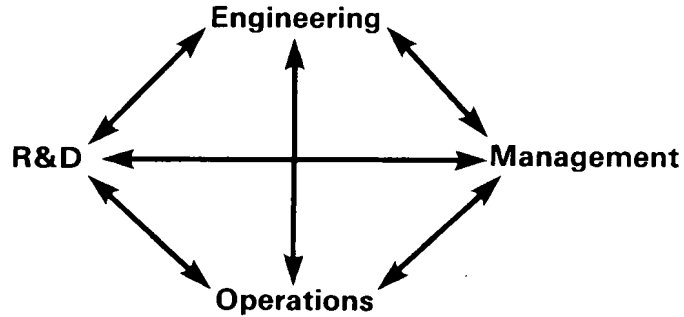


Chart 1 -- Good Communication and Information Flow Essential

PIONEER PLANT CRITICAL STEP IN COMMERCIALIZATION

The process of commercializing a new technology involves multiple stages before the pioneer plant is actually built, if it ever is. These are illustrated in Chart 2. Each step generates information that improves our understanding of the technology. It may also raise new questions. Beginning with laboratory and bench scale testing and evaluation, we must decide whether or not to proceed with development. Each step also becomes more costly, so the decision must be made more carefully. The next step might be to build a process development unit, followed by an integrated pilot plant. Development may be stopped after any stage.

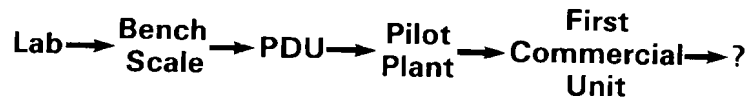


Chart 2 -- Pioneer Plant Critical Step in Commercialization

In some cases, a firm will decide to proceed with a commercial-scale facility. Some technical uncertainties still exist that only a full-sized operating unit can answer. Building a pioneer plant involves a great deal more money, of course, compared with earlier expenditures during process development. Our discussion will focus on how company information practices and project communication affect the project's outcomes and whether or not vital lessons are remembered.

Types of issues addressed by pioneer unit

As the first commercial demonstration of a new technology, the pioneer plant can reduce many remaining uncertainties significantly. These issues concern capital as well as O&M costs, schedule problems, technical performance, startup difficulties, design failures, product quality, environmental impacts, etc. The first-of-a-kind unit can suggest possible process and design improvements--if the problems and their solutions are recallable when needed later. The pioneer plant is the potential source of invaluable learning.

Who needs to know?

The lessons learned during design, construction, startup, and early operation of a pioneer plant are useful to each functional unit for somewhat different purposes. R&D needs to know what happened during the pioneer project to improve its basic process understanding and to help guide future research efforts. Engineering needs to understand how well their design solutions performed, and how future designs might be adapted to avoid problems that arose before, during, and after startup. Operations should understand the concerns of R&D and engineering in developing, designing and building the plant, and feed back to them information about difficulties encountered during and after startup. Corporate management needs this type of information to guide future research and development allocations, and to evaluate the bottom line: profitability. This information is also necessary in deciding whether to build additional plants of the same type.

How do they know?

These groups can only learn from the pioneer project experiences if they are captured and preserved in such a way that the information is later available for reference. They can also learn from each other during the project (and subsequent ones) through close interaction with each other. Such information can flow more easily when teams composed of representatives from R&D, engineering, and operations are made jointly responsible for project execution. This practice places people with diverse perspectives at the project management level, and reduces the likelihood of unexpected problems arising during execution.

Of course, information is only valuable if it is used. The more such information is used, the more likely that it will be captured and preserved in the first place, and thus the greater stake other users will have in seeing that the information is maintained and used over time.

In sum, for pioneer projects to be useful, firms (not just individuals) must know what happened, remember it, share it across divisions or functions, and use it.

Draw on results of recent Rand research

This discussion draws together the results of three Rand Corporation studies. The Pioneer Plants Study (PPS) examined cost, schedule, and performance problems commonly encountered by first-of-a-kind chemical process plant projects.¹ The analysis was based on proprietary data on over 60 projects provided by more than 40 firms in the oil, chemical, and minerals processing industry. Another study assessed the information policies and practices of 19 medium to large firms in the process industries.² The research drew on our experiences in collecting project information, and on the results of 40 interviews with corporate personnel. A third study analyzed the effects of certain management practices on project outcomes--cost, schedule, and performance, especially for pioneer plant projects.³ The effect of using, for example, project management teams that included R&D and operations personnel, was quantitatively evaluated.

¹Merrow, E. W., K. E. Phillips, and C. W. Myers, *Understanding Cost Growth and Performance Shortfalls in Pioneer Process Plants*, The Rand Corporation, R-2569-DOE, September 1981. Myers, C. W., M. R. Devey, and R. F. Shangraw, *Understanding Process Plant Schedule Slippage and Startup Costs*, The Rand Corporation, R-3215-PSSP, forthcoming.

²Myers, C. W., and R. Y. Arguden, *Capturing Pioneer Plant Experience: Implications for Synfuels Projects*, The Rand Corporation, N-2063-SFC, January 1984.

³Myers, C. W., and M. R. Devey, *How Management Practices Can Affect Project Outcomes: An Exploration of the PPS Database*, The Rand Corporation, N-2196-SFC, August 1984.

WHY IS PIONEER PROJECT INFORMATION IMPORTANT?

Pioneer project information proved to be very important to firms contemplating designing, building, and operating a follow-on (i.e., second-of-a-kind) plant. In summary form, Chart 3 shows the kinds of questions that companies ask about the pioneer project--even if they didn't build it themselves. They particularly want to know what it cost, how long it took, how well it worked, and what problems occurred. Companies then proceed to ask themselves: Can it be done better? How can the design of the next plant be improved--to make startup, for instance, much smoother? What uncertainties remain? Firms turn to the experience of the pioneer plants to help answer these questions.

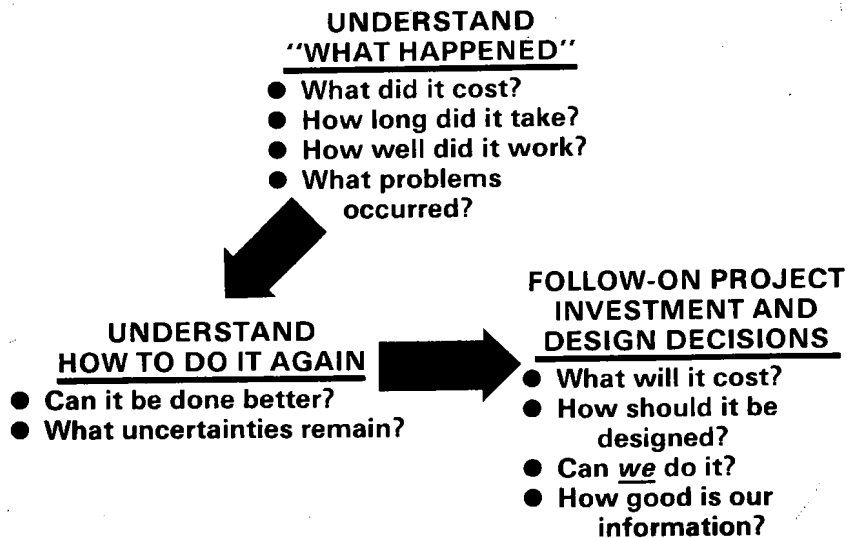


Chart 3 -- Why is Pioneer Project Information Important?

Goals of retrospective evaluation

The types of data needed for cross-project quantitative analyses may not be identical to those any one firm might use to make decisions about building later plants. In general, of course, past project experience is helpful in making these decisions. Such information can be used to improve the firm's estimating capability, to compare outcomes across different projects, and improve design, execution, and operation of subsequent plant development projects. The Pioneer Plants Study sought to understand why many pioneer plants cost more, take longer, and perform worse than expected. In doing so, the PPS developed tools for evaluating past as well as proposed projects. In this sense, the information requirements are closely parallel.

Means of retrospective evaluation

The Pioneer Plants Study points to how first-of-a-kind projects can be compared. Retrospective evaluation requires two steps: "normalizing" data across projects, and then evaluating and comparing specific projects. Data are normalized by comparing different technologies and projects on as common a basis as possible, differentiating project-specific versus technology-specific outcomes. That is, the analyst asks whether problems in the project were due to the technology choice itself or to other conditions relating to how the project was managed or executed. To some extent, every project or technology is unique. Differences in site or market conditions, owners, contractors, etc. may appear overwhelming and tend to inhibit cross-technology and cross-project comparisons.

One goal is to be able to abstract from the specific project details in order to draw general lessons about how later projects should be managed and executed. A second goal is to provide information that allows decisionmakers to separate promising technologies from unpromising ones. For each project, the nonrepeating costs and problems must be identified and put aside. To realistically evaluate the expectations for follow-on projects, it is especially important to understand how the pioneer project's cost, schedule, and performance varied from what was expected.

Information needed from pioneer projects

Chart 4 summarizes the information needed from the pioneer project. There are several critical cost questions:

- What was the total capital cost?
- Of that total, what was the particular cost of the first-of-a-kind unit?
- How much did it cost to start the plant up?
- How much does it cost to operate and maintain the plant?

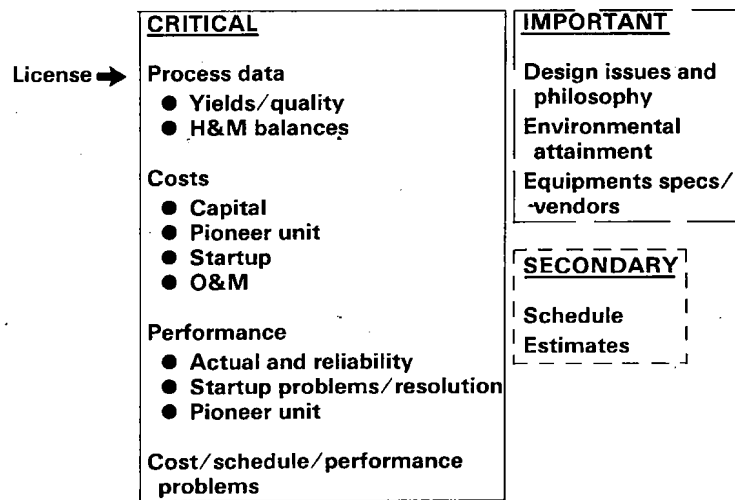


Chart 4 -- Information Needed from Pioneer Projects

Information on the plant's performance and reliability is equally essential.

- What were the startup problems?
- How were they resolved?
- How well did the new technology process units work?

Another item on the critical list is problems in cost, schedule, and performance. This information is important to interpret what happened with the pioneer project: if it differed significantly in cost, schedule, or performance from what they expected would happen, why the problems occurred, how they dealt with those problems, and what they cost. This information is essential to interpret what happened and to understand what to do next time.

Cost data needed after mechanical completion

Some data on project cost are needed after mechanical completion. These are illustrated in Chart 5. Two kinds of costs are incurred at that point: capital costs of startup, and then the expensed costs for starting up and for operating and maintaining the plant. A knowledge of total startup costs imparts a sense of how problematical the project was, and whether the follow-on project can reduce those costs. For many processes, net operating and maintenance costs are as important as the total capital cost. Project-specific information is not needed from the pioneer plant, however. This includes the costs of feedstock, which can overwhelm the O&M costs; royalties for the technology; and production taxes. These are all site-, project-, or market-specific costs.

Startup data needed

Startup and early operations provide extremely important information because they involve both cost and performance. This information is useful to R&D and engineering because it can help answer the following types of questions:

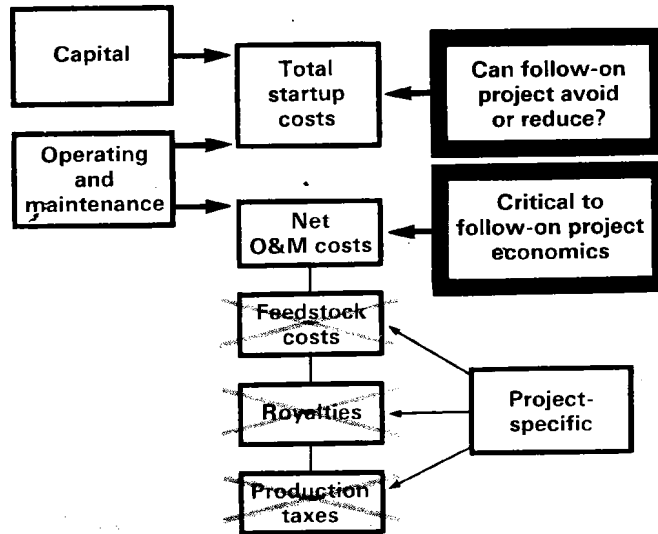


Chart 5 -- Cost Data Needed After Mechanical Completion

- Are problems linked to the technology or poor project execution?
- Can they be avoided in a follow-on project?
- How should the follow-on plant design be modified?
- Is further R&D warranted; in what areas?

In fact, startup, more than anything else, was reported to us as providing the key information that enables the analyst to distinguish technology problems from problems with project execution. Understanding what happened during plant startup is therefore critical information for R&D, engineering, operations, and management. The first one to three years of initial operations--the numbers commonly reported to us--appear to be long enough to provide a reasonable handle on how well the

technology performs, how reliable it is, and what the operating and maintenance costs are.

The importance of specific startup information is often overlooked. When they are collected and preserved, these data are typically kept by the operating division or at the plant. They are not usually shared with the process developers, designers, or others in the same firm. Many problems go unrecognized, and their solutions unreported, as a result.

PPS DATA COLLECTION PROBLEMS

Over 40 companies have participated in work related to the Pioneer Plants Study during the past 6 years by providing the types of information discussed above. Not all companies contacted, or that expressed interest could participate, however. The reasons are summarized in Chart 6. About 20 firms declined to participate because of lack of interest or concerns over data sensitivity. But more than two dozen firms reported either that they did not keep data on projects, or that the data, if they did have them, were too hard to find or transfer. In other words, well over half the companies that did not participate could not participate because they did not have the relevant data--even for a single project.

We even encountered data availability problems for the companies that gave us reasonably complete information on at least one of their plants. Chart 7 displays some of the key information categories that we collected, and the proportion of plants (or estimates) that had complete, analyzable information. Particularly troubling, given their importance to retrospective and prospective project evaluations, are the information gaps for process development units and startup. Only about a third of the firms could provide process development information on even the costs and dates of testing facilities, pilot plants, bench-scale tests, and so on, that were relied on in designing the commercial plant. And of the plants that had problems with startup, only about one third could describe them and list the causes and corrective measures taken. This implies that R&D departments are not keeping good records on development projects.

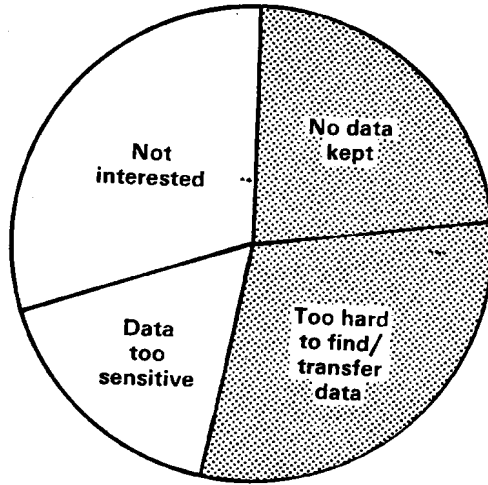


Chart 6 -- Why Some Firms Did Not Participate in PPS

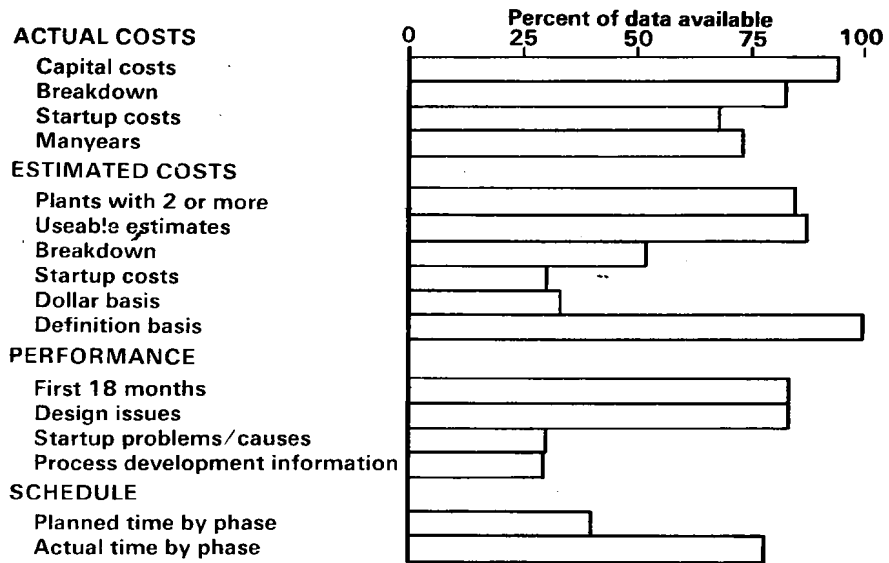


Chart 7 -- PPS Data Availability Problems

In sum, the information that firms keep from pioneer projects is by no means complete, *even among firms that wish to be reasonably thorough about it.*

INFORMATION KEPT VARIES--EVEN FOR CRITICAL DATA

It is especially troubling to find such information gaps concerning data that the company reported to us as being critical to their evaluation needs. This is further demonstrated in Chart 8, where we have classed each major category of information discussed in our interviews according to whether it is almost always kept across companies and across projects over at least some period of time; whether it is usually kept, that is, it is kept for some projects, or by some

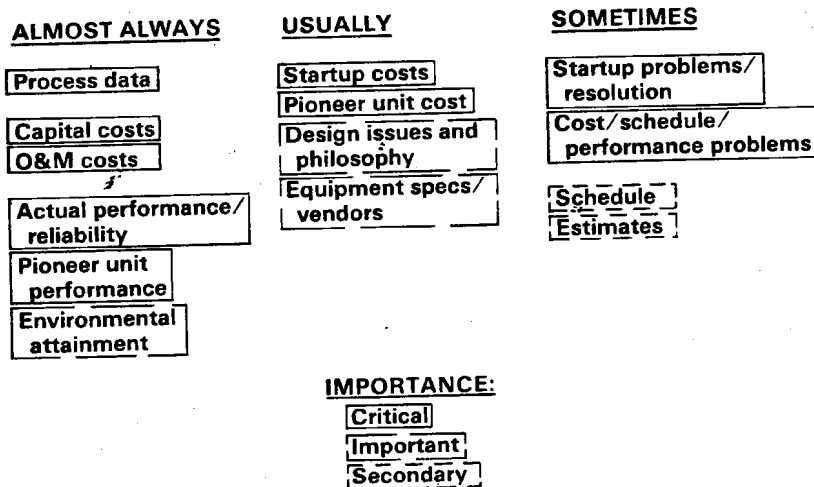


Chart 8 -- Information Kept Varies--Even for Critical Data

companies, but not all; and whether it is sometimes or only rarely kept. It is plain to see that the information kept varies tremendously, *even for the critical data* (critical means that at least three-quarters of the firms called it critical and said they could not make good decisions without it).

Firms almost always capture and preserve critical information and some of the very important information (described by half or more as critical, but by some as nonessential). They usually keep some of the interpretive information, especially the startup costs of the pioneer unit, design issues, and so on.

But few firms keep records on problems that occurred in startup, how they were resolved, and important information relevant to *understanding cost, schedule, and performance problems*. Understanding how the pioneer projects' actual cost, schedule, and performance varied from their expected baselines is critical to good retrospective evaluation and investment decisions. This means that R&D and engineering departments' attempts to learn from their past efforts--and from each other's efforts--are constrained by a lack of institutional memory.

FACTORS INFLUENCING INFORMATION SURVIVAL

Our interviews of industry representatives yielded many explanations of why the kinds of retrospective data we have identified are not always available. These are some of the comments we frequently heard.

"Every project is different." That is, there being almost no such thing as a duplicate plant, information from a prior unit will not be useful. Pioneer projects have unique problems; it is not prudent to store copious information on atypical problems. Early cost estimates are soon outdated; later ones are more accurate (which is true, but finding where the inaccuracies were and how they have been updated is important to understanding cost growth and final cost, especially of a pioneer step). Many companies, especially the smaller ones, do not build enough plants to enable any kind of sophisticated statistical work or to warrant keeping cost and other files. Even if people agreed that

they should hold onto information, they may all have different opinions on what should be kept. Since the firm cannot save everything, they often end up saving little or nothing.

Data are often not tracked very well during a project because it is often hard to know what data will be useful or marketable later. Moreover, technology can evolve so rapidly that extensive record-keeping is a waste. In these cases, firms tend to depend on people's memories. Every company relies heavily on certain people to keep and interpret information. When they leave, the information can lose its usefulness.

Many interviewees reported that corporate management is not sufficiently committed to the idea of keeping good information, even though it wants and uses it. Sometimes information is routinely purged after two to seven years. When a plant is shut down, many companies have a rule that all records of the plant--including startup and early operations--are destroyed within one or two years. Finally, to our great fascination, we were often told that the data "wandered off somewhere and were never seen again." The words varied, but the story was repeated many times.

How information survival varies by company

Chart 9 summarizes the factors associated with information survival. We found that information capture and survival is a function of the firm's capability for estimating and engineering. Where there is only a small estimating shop or no centralized engineering, very little information is kept or retained, and the firm relies heavily on contractors or other people. Where there are extensive in-house estimating and engineering capabilities, the firm retains and uses far more data in-house. Such firms are also better able to interpret the data, because they are the ones who build the plants. The resources devoted to record-keeping vary widely, in both money and effort. End-of-project reports are common, but for the same size project, writing one may entail anywhere from half a day to six months of a manager's time. They may be tucked away in a file drawer somewhere; some companies have rather sophisticated or complex cost and process files, but most do not, and hence there is little systematic collection of information. But even expensive data retention systems do not always

capture and keep data that the company itself needs and could use. Needs and uses also vary. If the company does a great deal of engineering, it has an engineering standards "manual" with process and mechanical design "lessons" from major projects, especially pioneer plant developments, incorporated into it routinely.

Factors influencing information survival: Summary

Information survival also varies considerably by project even within the same company. For high-visibility projects where there is a major company stake or high-level sponsor, the information tends to be kept more readily. The data also tend to be better kept if the purpose of the project is to test a process or demonstrate a process to be

- | | |
|--------------------------------|---|
| COMPANY CHARACTERISTICS | <ul style="list-style-type: none">● In-house estimating & engineering● Resources devoted● Need and use for data● Only owners usually have startup/operating data |
| PROJECT CHARACTERISTICS | <ul style="list-style-type: none">● Visibility● Project purpose● Plant still operating |
| METHOD OF STORAGE | <ul style="list-style-type: none">● Ease of use● Accessibility● Completeness |
| PEOPLE | <ul style="list-style-type: none">● Management commitment● Needs of collectors● Availability of project personnel |

Chart 9 -- Factors Influencing Information Survival: Summary

licensed, as opposed to building a more standard technology plant, and if the pioneer plant is still operating. (When a plant is shut down, plant records are often purged and the experienced people dispersed, and with them the ability to interpret what happened is lost.)

The capture and survival of information also varies with the method of retaining the information. Three factors are primarily important: ease of use, accessibility, and completeness. If the information is easy to use, firms tend to collect, keep, and use more of it. Ease implies standard, convenient formats with data recorded in common units across different projects. Accessibility is important whether the information is contained in a cardboard box or in a computer. Finally, information that is complete is more likely to survive because people find it more consistently useful. Completeness implies more than masses of raw data, of course. An important component is the presence of the information necessary to normalize the cost, schedule, and performance outcomes across projects.

Finally, information survival depends to a large extent upon people themselves. Consistent management commitment over time to the capture, retention, and use of retrospective information and analysis is vital. It is also important that the information be useful to the people collecting it in the first place. Most important, when information is used it tends to be captured and preserved in ways that retain its value over time.

GOOD COMMUNICATION AND PROJECT MANAGEMENT

Good communication can be encouraged by good management. Communication is enhanced where diverse input to project decisions is encouraged. This type of information flow is demonstrably related to better project outcomes, according to the results of a recent analysis of the PPS database. Especially in projects that use innovative technology, involvement of a team of representatives from the affected corporate departments is desirable. Such teams are most effective when their members are recognized as having joint responsibility for the project's success. Using a representative team approach means bringing on board all the groups or divisions that will be involved in the

project, and doing so at the outset. These groups include R&D, process development, engineering, construction services, startup, and operations. They should be involved in the project throughout its life, not just when problems arise or when their division is about to take over the project. Operations departments in particular should be given a stake in the project and made jointly responsible for its success from the beginning, to reduce handoff problems during and after startup.

Twenty of the 34 projects for which this information was available in the PPS database vested management responsibility for the project in such representative teams. This management technique tended to be associated with first-of-a-kind projects; when it wasn't, the project typically suffered higher cost growth and longer startup. Chart 10

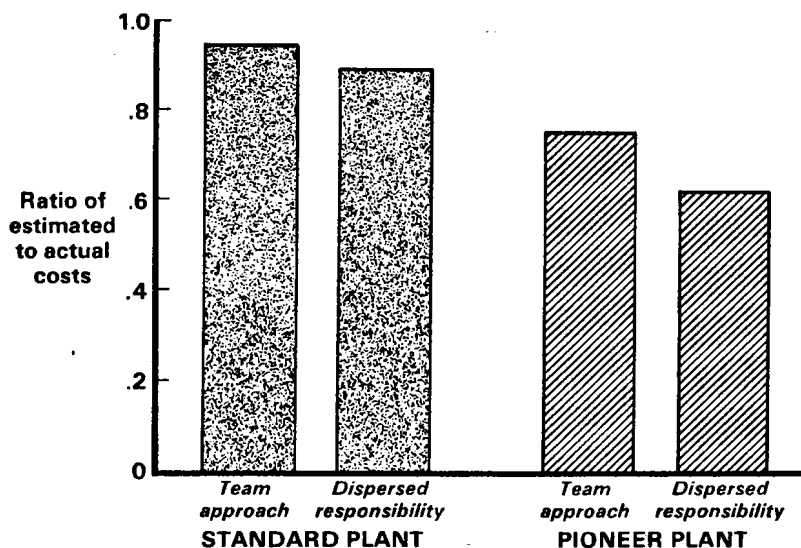


Chart 10 -- Effect of Management Team on Cost Growth

shows that cost growth--measured as the ratio of estimated costs as of the start of engineering to the actual costs through startup--averages much worse for pioneer plants that did not use this team approach compared to innovative projects that were directed by representative teams. As Chart 11 demonstrates, failure to use a team approach for pioneer plant projects is associated with startup times an average of three times longer than those of pioneer plants that used a team approach. In both cases, the team approach does not seem to make as much difference for plants using relatively proven technologies.

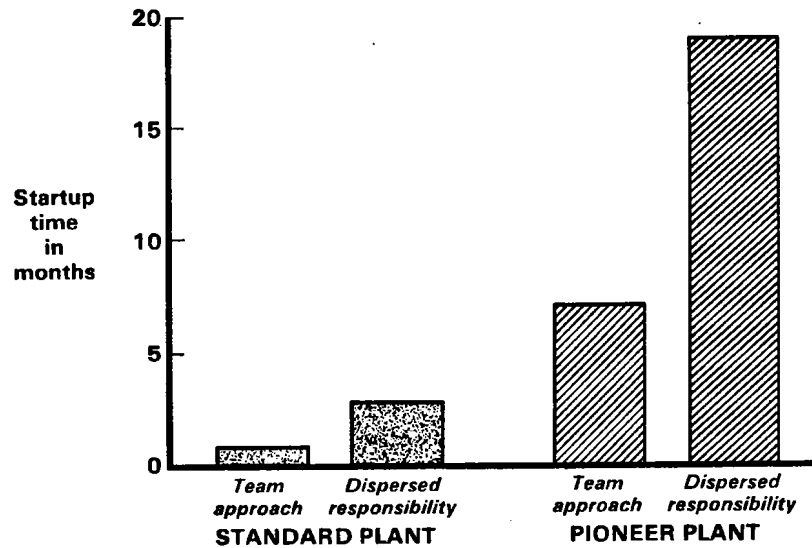


Chart 11 -- Effect of Management Team on Startup Time

Charts 12 and 13 present the results of our analysis of project management, after controlling for other factors, such as innovation, project definition, and feedstock type, that explain project outcomes.⁴ Cost growth is explained by the level of project definition and the proportion of the estimated cost in steps involving new technology. The model further illustrates the effect of not using a representative team approach for pioneer plants. It predicts that the engineering estimate will probably fall more than 11 percentage points below actual costs, after controlling for the effects of project definition and innovation.

1.141 CONSTANT

-0.072 x Level of project definition

-0.003 x Percent of capital in new technology

**-0.115 IF representative team approach not used
(pioneer plants only)**

R² = .67

Standard error = 0.11

Number of plants = 32

Chart 12 -- A Model of Cost Growth with Management Team

⁴The variables shown in Charts 12 and 13 are defined in: R-2569-DOE, (Merrow, Phillips, and Myers), op. cit.

Startup time, from introduction of feed through relatively steady operations, is explained by three factors: innovation, measured as the number of functional process blocks involving new technology, the type of feedstock, and management approach. Starting with an intercept of about 0.4, expected startup time in months is predicted as follows: add almost 3 months for each process step that involves commercially unproven technology; add about half a year if the feedstock is a solid material; then add another 7 or 8 months if a representative team approach is not used. The effect of this last management factor suggests the importance of including R&D personnel throughout the project life, and of including operations people early in the project--

0.37 . CONSTANT
+2.84 x New steps
+6.50 IF feed is solid
+7.70 IF representative team approach not used
(pioneer plants only)

R² = .71
Standard error = 5.4
Number of plants = 32

Chart 13 -- A Model of Startup Time with Management Team

and giving both groups a share of the responsibility for project success.

LESSONS FOR COMMUNICATION AND TECHNOLOGY COMMERCIALIZATION

By drawing on the results of recent Rand research, we have seen empirical support for what might have seemed obvious--except that it is so often ignored: Successful commercialization of new technologies requires good communication and information flow among R&D, engineering, operations, and management teams.

Structuring project management decisionmaking to facilitate diverse inputs from the affected corporate divisions pays significant, quantifiable dividends. When new technologies are being commercially introduced, representatives of R&D and operations should be included from the project outset. This practice is associated with lower cost growth and shorter startup times.

Information policies and practices commonly employed by the process industries fail to meet specific, recognizable needs. Information reflecting "lessons learned" from pioneer projects is not thoroughly collected (or "captured") in the first place by most firms. When it is, what is captured is often not easily available to those who need it, or shared by those who have it. To make matters worse, information tends not to last very long. Valuable information is often purged routinely after even a very short time; what is kept is not well maintained.

Two particularly valuable types of information are not regularly captured and made available. These represent the essence of what could be learned during the commercialization process: the pilot plant experience preceding the pioneer unit, and startup and early operations of the pioneer commercial plant. Both are vital to understanding the new process, and remembering what happened is critical to good decisionmaking by R&D, engineering, operations, and management. In sum, not remembering what happened makes it extremely difficult to communicate.

