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Better Communication between Engineers and Managers:

Some Ways to Prevent Many Ethically Hard Choices

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ABSTRACT: *This article is concerned with ways better communication between engineers and their managers might help prevent engineers being faced with some of the ethical problems that make up the typical course in engineering ethics. Beginning with observations concerning the* Challenger *disaster, the article moves on to report results of empirical research on the way technical communication breaks down, or doesn't break down, between engineers and managers. The article concludes with nine recommendations for organizational change to help prevent communications breakdown.*

For Canada's engineers, part of belonging to the profession is wearing a finger ring, a plain band of iron, in memory of the collapse of a great "iron" bridge at Quebec in 1907. Remembering that disaster, in which more than seventy workers died because of an engineer's error, is supposed to help today's engineers avoid similar errors. No other engineering society I know of has anything quite like this physical momento, but there is in it something characteristic of engineering. Engineers do not bury their mistakes (as surgeons are said to do). They record them, study them, and put what they learn from them into practice. Engineering handbooks, with their tables of tolerances, safety factors, standard methods, and so on, are (in part) the intellectual equivalents of Canada's iron ring, an attempt to use failure.

This article is also an attempt to use failure; it differs from most such attempts in being concerned with ethical rather than technical failure.

We begin with the assumption that whenever an engineer faces an ethical problem, something has gone wrong. There are at least three possible ways to explain what went wrong: a) the individual—someone (the engineer or someone else) acted inappropriately; b) the organizational—the organization lacks a satisfactory policy or

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procedure to prevent the problem or at least to make it a "no brainer"; or c) the technical—the absence of some device that would prevent the problem from arising (for example, a testing device eliminating the uncertainties that leave a decision to "engineering judgment").

These three ways of explaining an ethical problem are not mutually exclusive. Indeed, often, each sheds some light. What we identify as "the explanation" of a problem probably has more to do with the solution we think best than with how the problem arose. Where we think the problem is best handled by an individual, we emphasize individual conduct. Where we think the problem is best handled by changing the organization, we emphasize the role of practice or policy. Where we think the problem is best handled by bringing in a new machine, changing the physical layout of a building, or otherwise rearranging things, we emphasize the technical (usually without acknowledging the ethical dimension in any technical choice). And, where no one approach seems adequate, we are likely to describe the problem as "complex".

This article approaches certain problems of engineering ethics organizationally. We believe we can identify policies or practices that, by improving communication between engineers and managers, will avoid some of the ethical problems engineers would otherwise have to resolve as individual professionals. This is a work in "preventive ethics".

I. THE PROBLEM

What engineers do is important. A defect in the design of an airplane, a failure to maintain quality in the manufacture of a chemical, or even a mistake in operating a power plant can ruin a company, undermine trust in government, or kill hundreds of innocent people. Our comfort, prosperity, and safety depend upon feats of engineering which, because of their scale and complexity, are necessarily feats of management too. Anything in the relationship between engineers and managers that threatens the integrity of their work threatens as well our common well-being. The tendency for technical communication between managers and engineers to break down is certainly such a threat. The Challenger disaster provides two stories that will serve to illustrate how serious a threat—and to suggest the potential significance of what we will be doing in this paper.

Acting as a member of the Presidential Commission investigating the Challenger disaster, Richard Feynman interviewed managers and engineers in the shuttle program. He soon found that managers could differ substantially from engineers even about what seem readily determinable facts.[1] For example, Feynman asked both a middle-level manager and three engineers working for him on the shuttle's engines "what the probability of failure for a flight is, due to failure in the engines." The engineers all said about 1 in 200. Feynman's description of the manager's answer is too good to paraphrase:

> [The manager] says, "100 percent." The engineers' jaws drop. My jaw drops. I look at him, everybody looks at him and he says, "uh..uh, minus epsilon?"
> "OK. Now the only problem left is what is epsilon?"

> He says, "1 in 100,000." So I showed [him] the other answers and said, "I see there is a difference between engineers and management in their information and knowledge here..."[2]

The disagreement Feynman thus uncovered had nothing directly to do with the Challenger disaster. Failure of a *booster* O-ring, not the *shuttle's* engines, caused the disaster. The company responsible for the boosters, Morton Thiokol, had nothing to do with the shuttle from which the boosters would have detached after the first few minutes of flight. Neither these shuttle engineers nor their manager was an employee of Morton Thiokol.

Yet, the disagreement is relevant. Feynman asked his questions of these engineers and their managers only after finding that the managers and engineers working on the booster differed substantially in their assessment of the probability of the booster's failure. The differences there had come as a surprise. The probabilities were easily calculated (or, at least, everyone agreed on how to do the calculations). Once Feynman realized such differences existed, he wondered how widespread they were.

He began his interview with the shuttle engineers by asking about any disagreement between the engineers and their manager. The manager assured him there were none, explaining why by pointing out that he too had been trained as an engineer.[3]

Feynman did not ask the manager why his training as an engineer should guarantee agreement with the engineers he managed. No doubt the manager assumed that being able to understand technical information is enough to assure that he would understand it in the way others with the same technical training did. This assumption certainly seems plausible. What then explains the disagreement? Feynman suggests that the manager's misunderstanding was produced by a work environment, "a game, just as in the case of the solid rocket boosters, of reducing criteria and accepting more and more errors that weren't designed into the device."[4] Feynman does not explain *how* this process could lead managers to get simple facts wrong or *why* ordinary engineers were not affected in the same way. In truth, Feynman's suggestion does not so much answer a difficult question as identify the difficulty. We may get a better sense of the difficulty by considering an event crucial to the disastrous decision to launch.[5]

The night before the Challenger blew up one manager advised another to "take off [his] engineering hat and put on [his] management hat." This advice apparently led the manager, a vice president at Morton Thiokol, to *change* his evaluation of the risk of O-ring failure and approve the launch (knowing that the launch would not occur without his approval). The manager was himself an engineer who, earlier that day, had decided against the launch after receiving the unanimous recommendation of his engineering staff. The night-time reversal occurred under pressure from NASA but without any new information about the risks involved. "Putting on [his] management hat" seems to have changed the way he thought about the data before him. Here the gap between engineers and managers seems to have existed within one individual, an engineer-manager.

Feynman did not find this gap between engineers and managers everywhere in the shuttle program. For example, in avionics, "everything was good: the engineers and managers communicated well with each other..."[6] So, the gap is not inherent in relations between engineers and managers. It must open as a result of specific practices. Once it opens, management may (like Feynman's NASA manager) make decisions on the basis of something less than all information readily available. Insofar as full information tends to make decisions better (better by almost any reasonable criterion), management will have reduced its chances of making a good decision.

Good managers will, of course, want to avoid making decisions on less than the best information available. The research reported here is intended to contribute to that end. Our research group began with four related questions:

1. Can the communications gap Feynman discovered occur in other organizations employing engineers and managers?
2. Is there a readily usable procedure for identifying the communications gap before disaster strikes?
3. What can be done by engineers or managers in an organization to help prevent the communications gap from opening or help close it once it has opened?
4. What can be done by colleges and universities training future engineers or managers to help prevent the gap from opening or to help close it once it has opened?

II. RELEVANT LITERATURE

Descriptions of the manager's life in large organizations are common. Many touch on ethical problems a manager may face. Few do more than touch on them. An important exception is Robert Jackall's *Moral Mazes*, a particularly grim evocation of corporate life. His managers work in a largely amoral environment where technical knowledge seems largely irrelevant and satisfying the boss is the only criterion of success. Jackall discusses engineers only in the context of whistleblowing and without giving any indication that engineers might differ in any significant way from managers or other employees.[7] Still, if the managers he describes are even a rough approximation of the managers with whom engineers work, the communications gap between managers and engineers would be both common and difficult to eliminate.

Engineering is a profession. What does the literature explicitly discussing relations between managers and professionals have to offer? That literature is surprisingly small. Most of it seems designed for the personnel department (or, perhaps, for a generic MBA program). Albert Shapero's *Managing Professional People* is typical. Much is said about how to recruit creative professionals, how to keep them creative, and how to evaluate them. Shapero is especially good on such personnel questions as whether to keep salaries confidential and how to break in a new hire. There is even some useful advice about encouraging communications between professionals. But virtually nothing is said about what happens to the information, designs, and recommendations professionals generate. Shapero gives no hint that professionals and managers might disagree in the way those working on the Challenger did.[8]

The one significant exception we have found to this personnel-department orientation in the literature concerned with managing professionals is the work of Joseph Raelin, especially *The Clash of Cultures: Managers and Professionals*. The title itself suggests the important difference between Raelin's work and that of others writing about relations between professionals and managers. For Raelin, there can indeed be a "clash" between managers and professionals. Raelin explains this clash by the difference in culture between professionals and managers. Professionals have a code of ethics setting standards they must satisfy whatever their employer may think. Professionals, as such, always have loyalties beyond their employer. Managers, on the other hand, have no such divided loyalty. They are therefore much more susceptible to organizational pressures. Raelin therefore urges managers to rely upon their professionals for guidance in decisions with an important ethical component.[9]

Yet, even Raelin's work does not help us see very far into the gap between managers and engineers. Raelin's own discussion of the Challenger disaster ignores the fact that virtually all the managers involved in the Challenger disaster *were* engineers.[10] His emphasis on the ethical also seems misplaced. The disagreement between managers and engineers on the night before the shuttle exploded was not explicitly ethical. And the disagreement Feynman reports is over an easily calculable *fact*, the probability of failure.

My "Explaining Wrongdoing" takes a different tack, one closer to Feynman's.[11] It stresses the close relation between the work we do and the way we think. Since the work engineers do is different from that of managers, engineers may be expected to think somewhat differently. The exact differences will, however, depend on the specific working environment. "Explaining Wrongdoing" suggests that the working environment at Morton Thiokol (Feynman's "game") would have made a certain "tunnel vision" part of how managers normally thought about risk. Thinking like a manager rather than an engineer would, then, have meant giving less weight to engineering considerations than an outsider would think justified. The managers had, in effect, gone blind.

"Explaining Wrongdoing" (like Raelin's work) is a contribution to the literature on the relation between organizational structure and ethics. James Waters makes another suggestive contribution to this literature. Though Waters' chief example, GE's price fixing in the 1950's, does not involve a breakdown of *technical* communications, there was a communications breakdown. Waters argues that seemingly unproblematic aspects of the organization blocked the normal tendency of people to oppose conduct they judged illegal, unethical, or unwise.[12]

Technical communications seem far from ethics. Why then are we drawn to the ethics literature? The answer is that technical communications is often the vehicle for making ethics practical. Consider:

The cases commonly used to teach business ethics include a surprising number that seem to involve a breakdown in communications between managers and engineers of just the sort that concerns us. Among these cases are the Ford Pinto's exploding gas tank, the DC-10's cargo door, Three Mile Island, and BART. Though Waters' 1978 paper focuses on GE's price-fixing, he briefly discusses another workhorse of business ethics, the scandal over brakes Goodrich developed for the Air Force's A-7D project. Waters notes what is a common feature of the other scandals as well, the great difference in the way senior managers and the engineers directly involved interpreted crucial events, an apparent failure of middle managers to pass along important information.[13] Engineers saw serious problems where, apparently, management, especially upper management, saw nothing significant.

Our problem is connected with engineering ethics in the same way. Most of the scandals cited above can (and frequently do) appear in a course in engineering ethics. Our problem is, however, more than a problem for business and engineering. There is evidence of a similar gap between government managers and their engineers.[14] There also seem to be analogous communications breakdowns where no engineers are involved, for example, between army generals and their technical staff and between airline mechanics and their managers.[15]

Our problem's connection with business ethics is nonetheless important. Unlike the literature on professional ethics, the literature on business ethics is relatively rich in suggestions for preventing or eliminating the sort of communications gap that concerns us. For example, Waters makes five suggestions:[16]

1) remove ambiguity concerning organizational priorities (e.g. by a corporate code of ethics);
2) include concrete examples in directives concerning what is permitted or forbidden;
3) provide concrete steps for internal whistleblowers (e.g. ombudsman);
4) develop an appropriate organizational vocabulary (e.g. by organization-wide ethics training that includes discussion of specific cases likely to arise in the organization); and
5) launch regular ethical investigations similar to the annual audit.

Waters also remarks that the problems that concern him seem to arise in relatively hierarchical organizations, that is, highly compartmentalized organizations with a strict chain of command making it difficult for information to flow "horizontally" (from department to department) or "vertically" (around a particular manager).

Raelin's recommendations are similar to Waters'. The only important additions are:

6) mentorship to help socialize new engineers professionally; and
7) rewards for those who bring in bad news the organization is better off having (as well as the usual rewards that go to those who bring in good news).[17]

Similar recommendations abound.[18] But virtually missing from the literature is the suggestion that the *organization* should explicitly encourage professionals to adhere to their *profession's* code of ethics, provide in-house training in that code, or otherwise encourage loyalty to one's profession.[19] Even studies of professional diversity in the workplace are rare.[20]

We have so far omitted mention of two more categories of literature relevant here. One is the literature on managing innovation, especially the classic study by Burns and Stalker.[21] That literature seems to confirm the connection already suggested, between good ethics and good management.

The other category of relevant literature so far omitted should have been obvious to us from the beginning. The *Challenger* explosion was a man-made disaster. It was, however, very late when we discovered Barry Turner's classic work on man-made disasters. Much of his analysis focuses on breakdowns of communication, some quite subtle. Unfortunately, he has little to say about prevention.[22]

III. HYPOTHESIS

We began our research with the assumption that business (and government) tend to treat engineering as a "staff function" and management as a "line function." This seemed safe. The staff-line distinction has been a relatively stable feature of American business ever since the middle of the last century when America's first big businesses, the railroads, organized on the model of the U.S. Army, America's first big organization.[23]

In its pure form, the division between staff and line works like this: Engineers (and other professionals) are thought of as having special knowledge of how to do certain work (drafting, designing, checking, evaluating safety, and so on). They answer to a manager, but no matter how high they stand in the organization, no one (except perhaps a few assistants) answers directly to them. The engineers are not "in the chain of command." Managers, on the other hand, whether having technical knowledge or not, are thought of as having special responsibility for deciding what to do and how to do it. Managers answer to those "above" and command those "below." Engineers on the staff of a particular manager provide information, advice, and technical assistance.[24] Engineers are concerned with facts; manager, with decisions. A historian of technology recently summed up this "military model" of engineer-manager relations rather nicely (while assuming it to be an accurate description of engineer-manager relations today): "The organizational structure of engineering today does not encourage practitioners to ask questions beyond narrowly technical ones—much less to raise objections."[25]

While recognizing that practice is seldom pure, we assumed that the staff-line distinction would nonetheless produce a division of labor in which engineers tended to think about questions one way while managers tended to think about them another. In particular, we expected engineers generally to defer to managers, to present options and let the managers decide. We also assumed that engineers and managers would bring somewhat different standards of evaluation to their work. For example: Engineers, adhering to professional standards of success, would want to "do things right," even if the added expense or time required was substantial. The managers would instead adhere to company standards of success; they would want to "get things done"—in time and within budget—even if that meant cutting corners or taking substantial risks. We expected this difference in perspective to make the perspective of managers at least partially opaque to engineers and the perspective of engineers partially opaque to managers.

Last, we began with the assumption that the current literature on improving communications between managers and engineers was probably inadequate. The shuttle program had a complex system of consultation to assure engineering "input" at every step in making any important decision. That system included much of what the literature recommended. Information (or, at least, the paper it was printed on) moved upward relatively freely, with no one in a position to block it. Communications between engineers and managers still broke down on a grand scale. The result was a disaster no one wanted. Since the shuttle program did not seem to differ in any fundamental way from other undertakings employing large numbers of engineers, we assumed that the same thing could happen in any other undertaking of that sort.

Clearly, something more than NASA's complex system of consultation was needed.

These assumptions lead naturally to the following hypotheses:

1. That the boundary between engineer and manager would be relatively clear in most organizations—so that, for example, an engineer would know whether or not she had become a manager.
2. That engineers would be primarily concerned with safety and quality while managers would be primarily concerned with costs and customer satisfaction.
3. That engineers would tend to defer to management judgment, since management had ultimate responsibility for decisions (so that, for example, one way to improve communications between managers and engineers would be to find ways to encourage engineers to be more assertive in their dealings with managers).
4. That the more hierarchical an organization, the more difficult communications between managers and engineers would be and the more likely that a communications gap would open.
5. That we could develop a procedure for identifying a gap between engineers and managers if one existed.
6. That we could add to the stock of procedures to prevent a gap from appearing or to help close it once it appeared.

IV. METHOD

We early recognized that the empirical literature was inadequate for our purposes in three respects:

First, little of the literature specifically discussed engineers. Most of what did was too abstract to give any feel for how managers and engineers deal with each other day to day.

Second, the only works that did give such a feel were the congressional hearings, court cases, and investigative reporting that scandals generate. Engineers were, we assumed, likely to err on the side of safety and quality. Such errors may hurt corporate profits or even ruin a company, but they will not produce a public scandal. Managers, on the other hand, seemed likely to err on the side of profit or consumer satisfaction. Since such errors tend to threaten safety or quality, they are likely to create just the sort of disaster the public would be interested in. Thus the scandal literature, standing alone, seemed likely to be skewed against managers.

Third, engineers are seldom in a position to produce an interesting disaster by themselves. Managers have to be involved. When managers are involved, they will have to take the blame, whether they relied on their engineers or not. It would be their decision, however poorly they were advised. Engineering advice thus tends to be invisible—with one exception. When the disaster happens because the manager did not take the engineers' advice, the engineers' advice suddenly becomes visible. Why, everyone wants to know, did the manager not take *that* advice? It is, then, not surprising that the scandals getting the most attention are those where communications between managers and engineers broke down. When a manager correctly overrules an engineer, nothing newsworthy happens.

So, we could not rely solely on the scandals literature for an understanding of how managers and engineers *normally* work together. We needed to investigate directly how engineers and managers work together under more or less normal conditions (that is, without the selective hindsight disaster gives). This we did (see Acknowledgements, p. 208).

We developed one questionnaire for engineers and another for managers (see Appendices, pp. 210-212). We then tested the questionnaires at one company and made minor revisions, mostly clarifications in wording so that, for example, it was clear that we were interested in disagreements on "technical" rather than "personnel" matters. We then interviewed at three more companies. Only then did we add the starred questions, preserving the original numbering to make reference easier.

The questionnaire had four functions: 1) to tell us what the engineer or manager did, her daily routine and place in the organization's work; 2) to tell us what her relations were with management (if she was an engineer) or with engineers (if she was a manager); 3) to help us identify those practices that contributed to good communications and those that did not; and 4) to see whether we could identify a breakdown in communications of the sort Feynman found in the shuttle program. The questionnaire was designed to structure an open-ended interview lasting about ninety minutes.

Having developed the questionnaire, we contacted companies employing engineers. The smallest employed four engineers (two without degrees); the largest, more than ten thousand. Except for one construction company, all were engaged in manufacture. They ranged from companies with relatively benign technologies like electronics to a company with a relatively dangerous technology (manufacture of petroleum-based chemicals), from companies that are primarily parts suppliers to companies that produce primarily for end markets, from a company with one location to several large multinationals (one of which was closely held).

These companies were not chosen by chance. Our original budget kept interviewing within the Chicago metropolitan area. Even after the budget was revised to allow interviews at two locations beyond an hour's drive of Chicago, we were selective. We assumed that few companies would be willing to let just anyone interview their employees on company time. We therefore limited our contacts to companies where one of us had an "in".[26] The result of this mode of selection may have been a bias in favor of "good companies".

Perhaps for this reason, one sort of bias we expected did not occur. We expected some self-selection (even though we promised that our report would name the company only to acknowledge its help or to recommend one of its procedures). Agreeing to participate meant that the company had to think what we were doing was important enough to be worth the time we would take out of the working day of its managers and engineers. The company also had to feel comfortable having outsiders probe into day-to-day operations. Every company we asked to participate wanted to know what we were going to do before they agreed. It got to see our project proposal and both versions of the questionnaire. We made no effort to conceal our interest in ethics. Any company without a sense of social responsibility or without a clear conscience would, we thought, refuse. To our surprise, not one of the ten companies we contacted refused, insisted on control over what we published, or even suggested that it be allowed to comment before we published. All did, however, ask for a copy of the final report. (We, in fact, did give them all a chance to comment on a draft—to see whether our sense of their technical decision-making fit theirs.)

Once a company agreed to cooperate, we indicated that we were not interested in interviewing just any manager or engineer. We were interested in the "interface between management and engineering functions." We wanted engineers who dealt with managers and managers who dealt with engineers. We left it to the company to choose the managers and engineers to be interviewed. Their choice seemed determined primarily by who, among those who would be appropriate, could be available on the day we were to interview. Generally, we got to interview a manager and one or more engineers who worked together rather than two unconnected individuals. In a significant number of cases, there were last minute substitutions because "something had come up" (for example, an emergency at a distant plant or meeting date changed). Often, it seems, a company simply asked for volunteers from among those in the appropriate category. We never had a sense that we were interviewing from a "stacked deck."

Small companies had no trouble understanding what we meant by "manager" and "engineer". But, to our initial surprise, companies with large numbers of engineers did. In these companies, there was no single interface between the engineering and management functions. Two, three, or even four levels of organization might stand between employees regarded as "just engineers" and others regarded as "just managers". In such companies, we said we wanted to interview some from each level, beginning with "bench engineers" and ending with the first level of "just managers." For this reason, we conducted more interviews in large companies than in small.

All interviews were conducted at the company on company time and usually within a few feet of where the engineer or manager worked, either in a conference room or private office. The only people present during an interview were the interviewers and the interviewee. We did not use a tape recorder. Generally, we had two interviewers, one to ask questions and one to take notes.[27] Occasionally, the note taker would ask a clarifying question. The interviews began with introductions, an explanation of the interview's purpose, an assurance of anonymity for the interviewee, and a promise to identify the company only to thank it for its cooperation or to point out a procedure others might want to copy.

The interviewer then asked, "Manager or engineer?" This often occasioned a brief discussion useful in understanding how the organization thought about engineering. We abided by the individual's decision. This had one troubling consequence. Some "group leaders" (those who look after the work of 4 to 6 bench engineers) are treated as engineers while others with the same responsibilities in the same company are treated as managers. This is less troubling than it may seem. We were, after all, concerned with understanding our interviewees' work from *their* perspective. We have, however, taken one precaution against any bias this method might introduce. Whenever we quote a group leader while contrasting the perspective of manager with that of engineer, we indicate that the person quoted is not only an engineer or manager but also a group leader.

Once the interviewee decided that he was a manager or an engineer, the interviewers would work from the appropriate questionnaire (adding a spontaneous question now and then). Though we tried to get a copy of the questionnaire to each interviewee at least a week before the interview, about half the interviewees did not see the questionnaire in advance. Those receiving a copy in advance indicated that they had read it and given it some thought. A few had even made notes. Our impression is that those who had the questionnaire in advance tended to give fuller answers. Otherwise, the answers given by those who had the questionnaire in advance did not seem to differ from those who did not. No interviewee gave any indication that he had discussed his answers with a superior.

We interviewed a total of sixty engineers and managers. All but one were male (indicating, we think, how few women these companies employ in engineering work). These sixty represented all the major fields of engineering: mechanical, electrical, chemical, civil, and metallurgical. They included engineers in design, testing, and operations (both manufacture and construction). Not all were U.S.-trained. At least one had been trained in each of the following countries: Canada, the Netherlands, West Germany, East Germany, Poland, India, and Japan. Most of these had worked as engineers before coming to the United States. In the large companies, the most senior managers interviewed were middle-level; in the smaller companies, they were very close to the top of the company.

We had initially expected that engineers would have engineering degrees and managers would have management degrees. While most engineers in most companies were in fact "degreed", we occasionally came across an older "engineer" who had been "promoted from the shop floor". In one company, however, promotion from the floor was still common. That was also the one company in which we interviewed three managers who had neither been trained as an engineer nor worked as one. We sought out that company when we realized our initial sample of managers consisted entirely of former engineers (most with a baccalaureate in engineering whether or not they held an MBA or other management degree). Because the common wisdom is that "business schools, not engineering staffs, are [now] the favored sources of managerial expertise",[28] we were surprised at how hard it was to find a company with a significant number of managers of engineers who were not themselves engineers. We now doubt the common wisdom on this matter—at least for the management of engineers.

Our interviews cannot provide a complete picture of the way managers and engineers work together. What they provide is a part of the picture different from that given by the scandals or the existing management literature. Ours is a study of *technical* decision-making under normal conditions (or, at least, without the benefit of hindsight that a disaster brings).

The picture is somewhat fuller than our method of selecting companies and their absolute number would suggest. Just over a third of our interviewees (ten managers and eleven engineers) had worked for at least one other employer first. Several others had worked for another branch of the same corporate family (in Germany, Japan, or India). We encouraged these interviewees to compare their present employer with their previous one or their employer's practices here with its practices abroad. This gave us some insight into a kind of company not officially represented.

Some of the interviewees had worked for their present employer for several decades, long enough to see important changes in relations between managers and engineers. We encouraged those interviewees to compare past and present. These comparisons imparted some sense of history to what would otherwise have been a snap shot of the present.[29]

V. EVIDENCE

Our discussion of evidence has five parts. Part A compares the perspectives of engineers and their managers. Part B distinguishes three kinds of company according to the criteria emphasized in engineering decisions. Part C describes how engineering decisions are normally made, noting differences related to kind of company. Part D considers the effect an open-door policy, code of ethics, and other devices (including some not in the literature) have on how engineering decisions are made. Part E describes a breakdown in the normal process of decision that our questionnaire uncovered, an undramatic form of what led to the Challenger disaster.

A. Engineers and Managers: Some Differences

Question 11 on the manager's questionnaire ("Are engineers good management material?") and the identical question 12 on the engineer's were designed to encourage interviewees to compare and contrast managers' and engineers' ways of doing things. We also expected answers to question 5 on both questionnaires ("Is the company's management trained or versed in the company's technology?"), question 12* on the manager's questionnaire ("What questions should an engineer ask you to get the information he needs...?") and question 13* on the engineer's ("What questions should a manager ask you to get the information he needs...?") to provide useful information about differences between engineers and managers.

What we found was that the engineers and managers interviewed were virtually unanimous in the way they distinguished the engineer's perspective from the manager's. While both engineers and managers agreed that some engineers could be good managers, they also believed that engineers had to change (and that those who could not would not make good managers). Three sorts of change seemed to be involved (apart from learning how to do budgets, fill out personnel reports, and the like).

First, an engineer must pay less attention to engineering to be a good manager. "Letting go of the hands-on-the-bench engineering was," for one manager, "the most difficult part for me." Another (in a different company) made the same point: "An engineer [when he becomes a manager] must look at the picture differently and detach himself from the details of the job." An engineer (in the same company) made the same point: "Engineers that can't wean themselves from the engineering work make bad managers...You have to learn to let engineers do the engineering." The most negative comment about engineer-managers came from an engineer (in another company): "No, engineers aren't good management material—unless given specific training. Engineers have trouble giving up control over every detail."

The second way engineers must change to become good managers is related to the first. Not only must engineers give up control of engineering details, they must (as one manager put it) "develop a broader horizon and look at the big picture." For another manager (at another company), that broader horizon included learning "to think forward, think about others, think in terms of human resources." Connecting the first change to the second, another manager put it this way: "We have to move from reaching the conclusions to guiding the process which reaches the conclusions."

The engineers could not have agreed more. One suggested, "The engineer turned manager needs to appreciate what it takes to implement his project..., to take cost into account and...to track performance on a weekly basis." Another (in a different company) made the same point: "He must learn to handle responsibility and learn to get things done through his people. He can't do it all himself."

The third way the engineer turned manager must change is more fundamental than the other two. The manager must not only widen his horizon, he must change the character of what he does. "Engineers like to work with things," as one engineer noted, "[but] managing is more a matter of people than things." Or, as another engineer expressed it, "Socially adept engineers make good managers. Others should stay away from management." Managers made the same point. One recalled, "I had to become much more people sensitive." Another observed, "You have to build effective working relations with your people."

We did not (unfortunately) ask in what ways an engineer turned manager should not change. Nonetheless, we did receive some relevant responses, most from managers. Here again, there seemed to be a consensus. "[The manager] shouldn't lose his technical touch," said one manager. If he does (observed another in a different company), he will become "too superficial" and "no engineer goes to this type of manager for help." "Technical understanding," according to one engineer, "is crucial at times. What's needed is a fine balance [between technical understanding and holding on to one's engineering loves], and it is seldom found."

While most companies at which we interviewed provide some formal training for an engineer turned manager, either in-house or (more often) by paying tuition, the general opinion was that the training was not much help (except in handling personnel and technical business matters). A surprising number of both engineers and managers answered question 11a (for managers) or 12a (for engineers), "None" or "None, really," while others in the same company (often in the same department) reported such training. One engineer answered in a way that may explain this apparent disagreement. Having answered, "None to my knowledge," he added, "We have a management training program; but it seems pretty hokey, so I don't go to it." A manager in the same company gave an answer that at once suggests the vast scale of the company's efforts and the great difficulty of the undertaking. Having answered: "No transition training," he went on, "Well, we do have some supervisor development courses. And an MBA program. Role models. But that's about it. Nothing that really prepares an engineer for the transition." Perhaps an engineer (in another company) best expressed the underlying difficulty: "Engineers know their products but management is a trait."

For most managers we interviewed, the most helpful preparation for managing was early experience at the edge of management, for example, as group leader, together with a certain amount of informal coaching. Most managers seem to be trained "on the job". Those who can't change enough (or don't want to)—what one manager called "the scholar type"—never get beyond group leader. The rest get more and more management responsibility (and less time for engineering) until they become full-fledged managers.

The transition from engineer to manager is, then, not primarily thought of as the acquisition of technical knowledge an engineer can't expect to understand.[30] A manager may indeed know about matters an engineer does not because the manager gives his attention to matters an engineer does not (just as the engineer gives his attention to matters the manager does not). But the manager's knowledge is in principle as easy for the engineer to understand as it is for the (technically trained) manager to understand what the engineer knows. The good engineering manager differs from the bench engineer primarily in being able to do his engineering *through* other engineers. So, according to this common understanding of management, an engineer and an engineer-turned-manager should have no more trouble communicating their respective (technical) concerns to each other than one engineer or manager has communicating them to another.

This common understanding may explain both why we found so few non-engineers managing engineers and why those few were concentrated in production. Production is (according to our interviewees) that part of engineering where experience, rather than technical training, is most likely to be the decisive factor. Even so, we noticed unusual friction between production engineers and their non-engineer managers. At the one company that did have non-engineers managing engineers, one (college-trained) engineer told us, "I have to explain to my own manager in 'baby talk' since he is not an engineer. This is frustrating. I pull my hair out when he repeats my recommendation to his manager since he presents the recommendation incorrectly." One (college-trained) non-engineer manager confirmed this description (while giving the manager's side): "Sometimes engineers will spoon feed me. Then I'll tell them to hurry up. Or they'll water the information down—you know, talk about apples and buckets—then I'll tell them to talk about engines. Engineers often don't know how to talk to non-engineers."

What we derived from these interviews was not so much an impression of a breakdown of communications between engineers and their non-engineer managers as of an inauspicious thinning out of communication. A lot of important information seemed to be "lost in translation". We found something similar in the one company where many of the managers were foreigners struggling to perfect their English. Thus, one American engineer gave us this example (after making clear he thought his manager was a good engineer): "Let's say we discover a design change is needed on a local part. I might make the change myself and put it into operation and then tell my manager. This is just a simpler way to go. If I had an American manager, it would be easier to explain the fine details and involve him." Good technical communications is surprisingly fragile.

B. Three Kinds of Company

The companies at which we interviewed seem to be of two kinds: "engineer oriented" and "customer oriented". To these two kinds must be added a third, "finance oriented". While none of the companies at which we interviewed was finance oriented, we did hear about finance-oriented companies from several interviewees when they contrasted their present employer with a previous employer or the way their employer does things now with the way it used to do them. Finance-oriented companies seem to be different enough from engineer- and customer-oriented companies to be treated separately.[31]

An *engineer-oriented* company is distinguished by general agreement that quality is the primary consideration (or, rather, the primary consideration after safety). So, for example, in one such company, an engineer volunteered, "It is company religion to seek perfection." A manager in the same company was equally definite: "We have over-designed our products and would rather lose money than diminish our reputation."

Such companies do not ignore cost, but (as one engineer put it), "Cost comes in only after quality standards are met." They also do not ignore their customers, but they are likely to take pride in how often they say "no" to them. So, for example, one manager at such a company told us, "If a customer wants to take a chance, we won't go along." An engineer at the same company told us: "We do actually say no to customers...We refuse customer applications to exceed our ratings in spite of these often being big ticket items where money losses can be significant. We will negotiate with customers to move them within our specifications. We very rarely budge from this posture."

Such a company is not likely to maximize return on investment—in the short term at least. It can, however, be successful by another measure. Each of the four companies we identified as engineer-oriented had (they told us) a large and growing share of the markets in which it competed. Two were closely held; three (including one of the closely held) were large multinationals.

We do not call a company "engineer oriented" because engineers in fact run it. Like Morton Thiokol, all the companies at which we interviewed had engineers (or "former engineers") at all levels up to (and sometimes including) executive officers. Rather, what led us to call some companies engineer oriented is that their way of doing business closely fit the stereotype of engineers as concerned primarily with safety and quality (and of managers as differing from engineers in their greater concern with customer satisfaction and finance). The companies we call engineer oriented were therefore ones in which the engineers felt at home. What was surprising was that the managers in these companies seemed to feel exactly the same way.

Still, even in such a company, the expression "take off your engineering hat and put on your management hat" would not have been meaningless (even ignoring personnel matters). The engineers were likely to think the managers "more cost-oriented." Managers, on the other hand, could still contrast the engineer's tendency "to go into too much detail" with the manager's tendency to be "too superficial—[to] want only a 'go or no go' decision."

The contrast with *customer-oriented* companies is nonetheless substantial. For customer-oriented companies, customer satisfaction is the primary consideration (or, rather, the primary consideration after safety). "The main objective," as one engineer in such a company put it, "is meeting the customer's requirements." A manager in the same company gave this example: "If a particular batch can't meet specs, we might call the customer, tell him what we have and ask whether we should ship anyway." In place of the engineer-oriented company's *internal* standard of quality is the *external* standard of what the customer wants or is willing to accept.

In such a company, the engineer's concern with quality *regularly* comes into conflict with management's concern to satisfy the customer. Consider, for example, the question: Should we substitute a cheaper material for a more expensive one, making a part significantly less durable, if the part's probable life is still significantly longer than that of the machine into which it will be put? Both engineer-oriented and customer-oriented companies will have to answer such questions. In an engineer-oriented company, it will probably be understood as an engineering question, that is, as a question about how to define quality. In a customer-oriented company, however, it will probably be understood as a choice *between* engineering standards and management standards, that is, as a choice *between* quality ("lowering standards") *and* giving the customer what he wants ("a cost-effective solution" to his problem). So, even if the decision is ultimately the same, the dynamics of deciding will be different (in this respect at least).

The *finance-oriented* company resembles the engineer-oriented in having an internal standard of success, but resembles the customer-oriented company insofar as that standard is distinct from quality. For a finance-oriented company, certain numbers (for example, gross profit or return on investment) are the primary considerations. Customer satisfaction and quality are relevant only as means of maximizing those numbers. As one former employee of a finance-oriented company put it, "[The] attitude [there] was 'we get by with what the customer cannot detect.'"

Finance-oriented companies tend to measure success in tons produced, units out the door, or other *quantities* rather than in ways explicitly acknowledging quality or customer satisfaction. While one might expect engineers to prefer such hard measures to quality or customer satisfaction, all references to finance-oriented companies were negative or at best neutral. One manager recalled that "the production process [there] was driven by a 'units out the door' mentality which often inhibits quality and cost-effectiveness." Another manager recalled with obvious pain being asked to make small adjustments in test results (that is, as he saw it, falsifying the data) so that a product could be said to meet customer specifications and be shipped. The standard of success in a finance-oriented company seems to be much more foreign to engineers than that of a customer-oriented company.

Being a finance-, customer-, or engineer-oriented company is not, like being male or female in humans, a matter of being more or less permanently one or the other. We interviewed at one customer-oriented company that seemed to be consciously trying to become engineer-oriented. (The engineers reported these efforts with a tone of "at last," while the managers were plainly having difficulty adjusting to the new demand for quality.) We also interviewed at several companies that seemed to have gone from finance oriented to customer oriented within the last decade or so. We even interviewed at two companies which we assigned to the customer-oriented (rather than to the engineer-oriented) category only after considerable discussion. What made these companies difficult to classify was that one of their largest customers was pressing them so hard for quality that they themselves seemed to be uncertain whether they thought quality a mere means to satisfy a major customer or something good in itself.

The distinction between engineer-, customer-, and finance-oriented company is probably best thought of as a rough topology useful for organizing the data presented here or as specifying "ideal types" actual companies only approximate to varying degrees (with perhaps some departments or divisions in the same company belonging to one type while others belong to others). The distinction has no obvious connection with that other ideal type, "the technology-driven company." Most of the companies in our sample probably qualify as technology-driven.

C. Normal Decisions

Questions 3, 4, and 7 on the manager's questionnaire and questions 3, 4, and 6 on the engineer's questionnaire were designed to tell us who made the decisions and how they were made. Question 8 on the manager's questionnaire and question 10 on the engineer's questionnaire were designed to tell us whether the interviewee approved of existing practice. In fact, questions 8 and 10 (about how decisions *should* be made) often led interviewees to modify their description of how decisions *were* made. Occasionally, questions 12 and 12* (for managers) and 13 and 13* (for engineers) also led to such modifications.

ENGINEER-ORIENTED COMPANIES. Some of our interviewees initially described what sounded like a modern version of the staff-line division between managers and engineers. For example, one manager told us, "Managers nearly always make the decisions;" another, "Managers have the most weight." One engineer put it this way: "[The engineer] gives the best advice he can but it's their money." Another told us that, in case of disagreement, "The boss typically wins."

Such comments were, however, largely contradicted by what even these interviewees went on to tell us about decision-making in their company. For example, the same manager who told us managers nearly always make the decision also told us: "If an engineer has a good case, a manager seldom, if ever, would overrule—that is, if the engineer really feels it won't work. However, a manager might step in regarding costs, customer preferences, or some life cycle strategy—that is, something that is not absolutely engineering in nature." In the same vein, the engineer who told us the boss typically wins added, "I haven't experienced this."

What in fact emerged from our interviews was a process of "negotiation" (as one manager called it) much more reminiscent of an academic department than an army barracks. Engineers' "recommendations" were often indistinguishable from decisions. Managers generally "overruled" engineers' recommendations only when non-engineering reasons (such as cost or schedule) seemed to outweigh engineering considerations. Managers generally let the engineer do the engineering. And even when they "overruled" an engineering recommendation for non-engineering reasons, they did not literally overrule it. Instead, they presented the additional reasons to the engineer and sought the engineer's concurrence, either by winning him over with the new information or by seeking some compromise. Consensus seemed to be the mark of a good decision; outright overruling, something to be avoided at almost any cost.

This process of seeking consensus (a better term than "negotiation") seemed to rest on three assumptions: 1) that disagreement about any engineering or related management question is ultimately factual; 2) that where reasonable technically-trained people with the same information cannot reach consensus on a factual question, there is not enough information for a good decision; and 3) that, except in an emergency, putting off the decision until there is enough information (or a better understanding of the information available) is better than making a bad decision. Our interviews suggest that these assumptions are shared by engineers (and engineer-managers) at whatever kind of company they work. These assumptions are, however, likely to be more potent in an engineer-oriented company. There the priority given to quality gives engineering considerations a force which they cannot have where customer satisfaction or “the numbers” carry more weight than quality.

Whether such considerations as quality or customer satisfaction are literally factual is a philosophical question we may ignore here. What we mean by calling such considerations “factual” is simply that experience has taught those disagreeing about such matters to expect to settle their disagreements by further testing, other new information, or reconsidering information already available. For our purposes, what is important is that engineers and managers *do* expect to agree on questions of safety, quality, customer satisfaction, and cost even if they do not expect agreement on anything else.

The power of these assumptions can be seen in comments like the following. Asked whether he and his engineers always see eye to eye, one manager, having answered “no,” went on to explain: “There are different ways to approach a problem. Young engineers are often inexperienced and need to learn from their mistakes. There are no real differences, though, on matters of safety and quality—these are pretty much black and white.” Asked how much weight an engineer’s recommendation should have, he responded 100% and added, “I’ve always reached agreement with my engineers.” Another manager informed us that if a manager and engineer disagree over a major technical decision “engineers and managers go to a boss together...The boss then decides. But we haven’t had major problems here.”

Engineers sketched a similar picture. Asked how engineering decisions were made in his company, one engineer responded, “I’m handed a design and asked, ‘How do we produce this?’ Eventually I make a recommendation My boss, a supervising engineer, says yes or no. If he says no, he gives reasons. If I’m not convinced, there’s no stand-off; we just go out and test.” The “boss” seems to have no more weight in the decision than the engineer. The ultimate arbiter is another “test.” Another engineer, the one who said he gave the best advice he could “but it’s their money,” nonetheless reported that he and management “*always* see eye to eye *in the end*.” He had in fact never been overruled.

This process of reaching consensus seems to presuppose that engineers and managers have the same information. Since openness about technical and related business matters would seem to be crucial to reaching such a consensus, what engineers and managers at these companies report about technical communications is important. Questions 9 and 10 (on the manager’s questionnaire) and question 8 (on the engineer’s questionnaire) were intended to tell us how open communication of technical information was.

Managers at engineer-oriented companies were unanimous that *they* never withheld technical information from their engineers. Though evenly divided about whether their engineers ever withheld information from them, managers never indicated they thought their engineers’ conduct a problem. One manager’s answer may explain why. Having said his engineers do sometimes withhold information “to cover up a mistake,” he added: “Sometimes I need to ask questions to determine who made a mistake.” Another manager put the point more gently: “I believe that engineers never intentionally withhold information [, but every] person tries to put his best foot forward.” In an engineer-oriented company, the natural tendency of engineers to withhold embarrassing information seems a small impediment an experienced manager can overcome with a few probing questions, not anything likely to affect significantly the free flow of information.

The engineers saw things a bit differently. They generally agreed that their managers were open with them. Only one thought there "have been cases when the boss had information and did not give it—but never knowingly." On the other hand, *none* reported knowingly withholding information—except, significantly, in the company with foreign managers and American engineers. For one engineer, the problem was "the other way": "Usually...I provide too much detail to my superiors. I have had to learn brevity. But there is a fine line between too much and too little. I believe in open communications, and for that reason I don't hold back." Another engineer, while denying that he ever withheld information, did admit that "lots gets lost in translation."

In any organization, the ultimate test of openness is bad news. Our interviews at one engineer-oriented company provided an example of how bad news was handled. The example gives some insight into how such a company remains engineer-oriented even under the market's constant pressure to pay more attention to customers:

A manufacturer of motors for pleasure boats asked the company to make a part for the manufacturer's engine that would outlast the engine under normal operating conditions but would quickly wear out if the engine operated at full power for very long. A part adequate for extended operation at full power would have been much more expensive. Company policy was to make parts so that they would outlast the engine, however it was used. So, the engineer in charge recommended against making the part. After much back and forth along the chain of command, the engineer's superior decided to go ahead, explaining the decision in something like this way: "There is no safety issue even if the motor fails. There is no real quality issue either. Pleasure boats are *never* run at full power long enough for the part to fail. Hence, the part will be cost-effective for the use it will serve. I do, however, agree there is at least the possibility of legal liability here should the engine be misused. So, we must take care to inform the customer of our concerns in writing and require him to take full legal responsibility for the part."

A few years later, the customer sold out to someone who made towboats as well as pleasure boats. The new owner promptly put the engine on its towboats. The part would fail after only a few hundred hours of towing. Legally, the company was in the clear. But, since its name was on the part, it received some complaints.

We heard this story from both managers and engineers. We heard it not only in the department involved but in other departments as well. Each person who told the story treated it as a cautionary tale. The company had taken a risk it should not have. No one wondered whether the profit from the deal might have justified the risk or argued that satisfying the original customer excused it. The bottom line was that the decision had harmed the company's reputation. What could be worse than that? Here was an experience to learn from, not a skeleton to be locked away in a closet and forgotten. As one engineer predicted with evident pride, "We probably won't do anything like that again."

CUSTOMER-ORIENTED COMPANIES. Decision-making in customer-oriented companies is similar to decision-making in engineer-oriented companies. Once again we heard echoes of the staff-line division in interviews that eventually revealed a quite different process. For example, a manager who first told us "Engineers lay out options; managers choose" immediately corrected himself: "Well, managers choose when the decision involves risks or resources. Other decisions, purely technical ones, are really for engineers." Similarly, the same engineer who initially told us, "The manager decides" later told us, "If I don't like a decision, I would go to my boss. I could go to my boss's boss, too, but I never had to...Technical questions are talked out."

The search for consensus was again central to decision-making. One engineer at a small company described decision-making quite simply: "We operate by consensus." A manager in a large company described the process in greater detail: "Engineers have high weight on technical issues. The problem is integrating technical recommendations into company interest. Cost. Marketing strategy. Change in technology, etc. It's important that the engineer's recommendation get out beyond the immediate group. When he sees how his decision does not fit into the large picture, he's likely to rethink it."

Despite the basic similarity between decision-making in engineer-oriented and customer-oriented companies, we did notice four significant differences. Customer-oriented companies seemed, first, to assign greater importance to the engineer's role as *advocate*; second, to place more emphasis on non-engineering considerations in decision-making; third, to be more explicitly concerned with safety (even though the technology seemed no riskier); and fourth, to have more difficulty maintaining open communications. Let's consider these in order.

In most of the customer-oriented companies at which we interviewed, relations between individual engineers and managers seemed as good as at the engineer-oriented companies. Yet, the managers repeatedly stressed the need for engineers to "hammer" on their recommendations. One manager at a small company thought that "an engineer should be willing to go to the mat if he feels strongly that quality is violated." A manager at a large company agreed: "Engineers should never be content to see their professional judgment superseded. If there's a good reason for the manager's decision, the engineer should agree. If the engineer doesn't agree, something must be wrong. Everyone should keep talking."

The managers clearly thought of their engineers as advocates of a point of view which, though different from their own, had to be weighed against their own—or rather, integrated with it. There was no mystery about how the two points of view differed. According to one manager, "[satisfying] the customer's needs [involves] three factors...: quality (which is a technical matter), timing (which is a concern of sales); and specs/cost." The engineers spoke for the "technical". A manager at another company contrasted his role with the engineers' this way: "It has to be decided where the line is on a specification. For example, how 'perfect' does something have to be. I occasionally have to explain, 'Hey guys! It doesn't have to be absolutely perfect.'...The customer's needs are the most basic consideration." Another manager at this company gave the same picture but in a phrase familiar from the Challenger disaster: "The most important factors in company decisions are business issues: What does the customer want? What are his expectations? What can we do to optimize given time and quality requirements? Often, it's time *versus* quality. And then you have to decide which hat to wear—engineer's or manager's."

Engineers in most customer-oriented companies seemed to accept—or at least be resigned to—the conflict between technical and business considerations. As one engineer put it, "Cost issues are constraints I can understand." There was, however, one company in which the engineers showed no such resignation. This was the customer-oriented company that seemed to be trying to become engineer-oriented. Here, for example, one engineer told us: "Technical questions get short-changed to make schedule. 'We can do it better,' I say, but my manager says, 'No time.'" Another engineer said with evident disgust, "They'll sacrifice quality to get it out the door," adding, "Why not do it right the first time rather than taking a lot of time later to patch up a system?"

In engineer-oriented companies, "safety" and "quality" were mentioned in the same breath (when "safety" was mentioned at all). That, however, was not true in customer-oriented companies. In customer-oriented companies, safety had the same absolute priority as in engineer-oriented companies, but it was mentioned much more often. So, for example, the same engineer who said quality was sacrificed to get products "out the door," stressed that he "never felt safety was being sacrificed." Many engineers also told us that they should have the "last word" on safety (even though they did not claim the last word on anything else). Managers agreed, "It's okay to overrule an engineer's recommendation on a business issue. But on safety, exposure to dangerous materials, etc., the engineer should have the last word."

Given the importance assigned to consensus in customer-oriented companies, open communications should be as important in such companies as in engineer-oriented ones. Many of the managers seemed to believe so. Indeed, generally, they were more emphatic about being open with engineers than the managers at the engineer-oriented companies. Thus, one manager observed (in response to question 9), "I never withhold technical information. That's dumb." Another (at another company), "Never. That's dangerous." A third, "There's no need...We've got strict rules on use of information."

Yet, in each customer-oriented company where some managers answered in this way, others reported withholding information relevant to technical decisions. For example, one manager admitted: "I have withheld proprietary information, for example, relating to preparations for a joint venture that might mean using a different technology." Others, while denying that they had withheld information, reported superiors withholding information from them: "I should add," said one, "that engineers are often in the dark and are subject to last minute surprises: Our department last year was working on existing products, things that were familiar. We were not told about any new possibilities or any new product challenges. We were provided only with vague clues. I don't know why."

These managers also seemed more concerned about engineers withholding information from them than were their counterparts at engineer-oriented companies. Thus, one manager reported, "Engineers tend to give me a rosier picture than is factual just to continue getting my support. I try to counteract that by MBWA [Management By Wandering Around]. This is a lot more effective than formal performance reviews." Another manager at the same company stressed the dark side of such withholding: "Yes, but it only happens when they don't know enough to know what to tell. For example, now and then, a guy gets into trouble and thinks he can fix it himself. The result is I find out when it's too late to help—and I get burned too. That's happened a couple of times in my career." A manager at another company put it more succinctly: "Do they withhold information from me? When they screw up, yes."

Yet, other managers at these same companies denied that their engineers had ever withheld technical information from them. One manager was more cautious: "This is the toughest question on the list. I've occasionally had the feeling there was more there than I could see in the engineer's report."

Engineers gave an equally mixed report on communications For example, one engineer told us of a "recent survey" that indicated that "people believe upper management holds back information from the company," adding, "My current manager does not withhold information from me." An engineer at another company admitted to the "feeling" that his superior was withholding technical information. Yet, most engineers reported that they did not think their managers withheld technical information from them.

Interestingly, unlike engineers at engineer-oriented companies, engineers in some customer-oriented companies did report withholding information from managers. One observed, "I have, but I'm not sure it was necessary. I have withheld a theory or brainstorm until it was tested to verify it positively. I have delayed bad news in order to retest first." A group leader at another company admitted, "I sometimes don't tell my manager about a decision, if I am already quite comfortable with it."

Technical communication in customer-oriented companies thus seems to be somewhat less open than in engineer-oriented companies. Given how much these companies differed, the cause of that tendency is probably complex. Still, two factors are obviously relevant. First, the relatively greater importance of business information in decisions of customer-oriented companies seems likely to change the nature of withholding such information. Even if the same amount of business information were withheld in a customer-oriented as in an engineer-oriented company, its withholding would be more likely to threaten consensus in a customer-oriented company (where it would be a more important part of the big picture). Second, the greater emphasis on the engineer as advocate in customer-oriented companies may itself tempt engineers to engage in lawyerly tactics. But, whatever the cause, a customer-oriented company that wants to decide by consensus will, it seems, have to take more care to keep information flowing than an otherwise similar engineer-oriented one.

Perhaps this is the place to note that we found little in relations between managers and engineers resembling the ruthless gang culture reported in Jackall. What explains that? At least two factors may help to explain the apparent difference between what Jackall reports and what we report. One factor is that Jackall's description may be true only of companies that our method of selection was biased against. Our method of obtaining interviews seems to have selected in favor of "good companies." Jackall's method probably did not. A second factor helping to explain the difference between Jackall and us may be that what Jackall describes begins *above* the engineering departments in the companies at which we interviewed. Interestingly, we did find one (and only one) manager supporting this explanation (but without any example from his experience). A group leader responded to question 12* (in part): "Higher managers often become involved in company politics, however, and may compromise our engineering values. As managers go higher up [here], their engineering values become corrupted, in my opinion. No, I cannot think of any precise example, I am a blank right now. But, managers can become selfish. They want to be promoted and will enhance this prospect by focusing on high visibility projects that look good."

FINANCE-ORIENTED COMPANIES. We do not have enough information in our interviews to conclude anything about the normal decision-making process in finance-oriented companies. We do, however, have enough to offer four (related) hypotheses: 1) Because finance-related information tends to be centralized in a way customer-related information is not, engineers in a finance-oriented company will normally receive less information crucial to company decisions than in a customer-oriented company. 2) Because engineers receive less crucial information, their recommendations will carry less weight in finance-oriented than in customer-oriented companies. 3) Because their recommendations carry less weight in finance-oriented companies than in customer-oriented companies, finance-oriented companies will be less likely to try to reach consensus with their engineers. And 4) because finance-oriented companies are less likely to try to reach consensus with their engineers than customer-oriented companies are, they are more likely both to compartmentalize decision-making and to treat engineering as a staff function. As one manager remembered: "[At his old finance-oriented employer], a report couldn't leave the department without the co-signature of a manager....The engineering function can be muzzled by a heavy-handed management....Management's pressure on engineers sometimes results in low quality."

D. The Effect of Various Devices

The literature surveyed in Section II recommended a number of devices to improve communications within an organization in order to reduce the chance that the organization would do something wrong. What do our interviews tell us about those devices? We found nothing like Waters' "ethical audit" or Raelin's awards for bringing bad news. Though one company had a mentoring program for engineers of the sort Raelin suggests, no interviewee mentioned it. Our interviewees did, however, mention the following devices: a code of ethics, ethics training, open-door policy, ombudsman, and reduced compartmentalization (including such things as a technical promotion ladder paralleling the management ladder). Except for reduced compartmentalization, none of these devices was common to more than a few companies. Some occurred at only one. In general, the large companies were more likely to have adopted some of these devices than the small were; the customer-oriented companies more likely to have done so than the engineer-oriented. We shall briefly survey the evidence under three headings: 1) codes and related training; 2) appeals procedures; and 3) reduced compartmentalization. Our conclusion is that, except for reduced compartmentalization, none of these devices seems to have had much effect on technical decision-making. We also came across one formal procedure, independent technical review, not mentioned in the literature. We shall discuss that as well.

CODES. At four of the six customer-oriented companies we interviewed, some of our interviewees answered yes to question 4.b on both questionnaires: "Does your company have a code of ethics?" Most of those so answering were managers. Their answers were often qualified. And they often disagreed in important details. Consider, for example, these two answers from managers in the same company. "We have a *business* code of ethics—no gifts, etc." one told us, "but we have nothing called a 'code of ethics' for engineers, nothing that would, for example, provide guidance if someone orders an engineer to change test results." Yet, another manager at the same company thought not: "Well, there are policies on... e.g. entertainment. But no formal code—except [the CEO's] letters. Nothing written, for example, on how a technical rep should act in a customer's plant." In another company, one manager informed us, "Yes, we have a code of ethics. We're even going to get a lecture on it from the legal department tomorrow. But it doesn't affect engineering work. What matters is the 'spec book.'" Yet, another manager there (a group leader) answered, "I think we have one, but I'm not sure. I vaguely remember being given a pamphlet when I was hired that said something about all this."

If that is how managers described their company's code of ethics, what did the engineers say? Most either told us that their company had no code or responded in some such way as this: "No real corporate code, just individual standards. Maybe there's a code of ethics somewhere...but I don't know of it."

Since the corporate codes apparently have little to say about engineering decisions, any training in those codes could have little effect on those decisions. We are then in no position to judge the effect of appropriate ethics training on the way engineers and their managers make technical decisions. As far as we could tell, no company has a code appropriate for engineers.

No one at any company at which we interviewed mentioned a professional code as a guide to decisions; and, as far as we can tell, no company at which we interviewed had ever circulated or endorsed the code of any professional society. Our interviews gave us no insight into why that was. Our interviews did, however, suggest that one explanation should be ruled out. Engineers, it might be thought, did not mention professional codes because they had no sense of themselves as professionals. Yet, some of the engineers we interviewed clearly did think of themselves as professionals. For example, one engineer (a group leader at a customer-oriented company) answered question 12 (in part): "Managers of engineers should provide support, not control. Engineers work on their own. They like their work. They're professionals. Look at the engineers here. They work 45 hours a week, even though they are paid a 40 hour salary. They'll sacrifice to get the job done right. Where they work is too cramped, overcrowded, and dingy."

We may, it seems, be left with a mystery. If the corporate code of ethics has little to say to engineers about their technical decisions, and few seem aware of their profession's code of ethics, why do engineers so uniformly become advocates for safety and quality? The traditional answer of sociology has been "socialization" (in professional school or on the job). Our interviews tend to confirm this answer. For example, one engineer at an engineer-oriented company explained his commitment to safety and quality (in part) this way, "I learned that attitude as part of my professional training." He then added, "But...it is [the company's] attitude too." In fact, most interviewees who had an explanation for the emphasis on safety and quality referred only to company "norms," "spec book," or other detailed engineering standards developed within the company. And this was true even of engineers who made it clear that they had to contend with managers who routinely wanted to put customer satisfaction ahead of quality.

Our impression is that the engineers' concern with safety and quality is too ingrained for most of them to have a good sense of its origin. What they do have a good sense of is how pervasive such concern is in the company in which they work. This does not mean that, for example, managers are not more concerned with other things, but that even managers recognize safety and quality as central considerations. The company demonstrates this concern not so much through general pronouncements as through relatively strict adherence to thousands of minute specifications.

APPEALS. The small companies were so informal that recourse to the "top" seemed routine. As one engineer (in an engineer-oriented company) put it, "What would be the point of such a policy [an open-door policy]? I walk into the office of the president and vice president every day." But even this engineer thought it important to tell his immediate supervisor first: "A manager doesn't like to hear bad news from outside. So, I first tell him and get advice." Yet, even in the small companies, our interviewees could not recall taking a technical question directly to the top.

Given their informality, it is not surprising that the small companies seemed to have no formal appeals procedure of the sort discussed in the literature. The informality was enough. The formal procedures were available only in larger companies (and not always there). The most common of these formal appeals was "the open door policy." A subordinate dissatisfied with his superior's decision could take it to his superior's immediate superior who would hear him out, might make subtle inquiries, and might even change the decision if that seemed justified, all things considered.

Though this procedure could in principle be used for any problem, it was in fact much more likely to be used for "personnel" than "engineering" problems. One manager in a customer-oriented company described his company's open door policy in this way: "Engineers can go to my boss and complain. This happens sometimes, on personnel matters, primarily. It's never happened on an engineering question." An engineer gave a strikingly similar description of the appeal procedure at another customer-oriented company: "You can go to his superior. I've only done this once or twice, but more on personnel than on technical matters."

Only one company had something like a formal ombudsman. A group leader explained the procedure: "There is a formal path to use in such cases...It is a strong way to express your disagreement. It has not been used very often in my recollection. I can think of just one case in which an engineer used it. This was a case where a product was being tested. The engineer thought that the performance problem was due to a screw that was not tightened all the way to ground contact. I hadn't responded quickly enough to his recommendation, he thought. So, he used [this procedure] and I had to respond." The procedure involved filling out a form and placing it in a special box emptied once a day. The form is (he thought) delivered directly to someone in the general manager's office. The person against whom the complaint is made is then notified and has a certain number of days to respond.

Few engineers or managers at this company mentioned this procedure as a way to appeal engineering decisions (just as few engineers or managers made much use of any other formal appeal procedure). Why? Fear of reprisal may seem the most likely explanation. As one manager put it: "Most managers don't mind. But there are some around here who would do a guy in for going over his head." There are, however, two reasons to doubt this explanation. First, personnel appeals are *less* rare even though they seem at least as likely to lead to reprisals. Second, few engineers we interviewed expressed any fear of reprisals. As one group leader at the same company explained, "Yes, this can ruffle some feathers. But a manager who indulges in reprisals doesn't last long."

Perhaps, then, a better explanation for the relative rarity of appeals is simply that both engineers and managers work harder to reach agreement on engineering questions than on personnel questions. They work harder because they *expect* to reach agreement. Engineering questions are (as explained earlier) supposed to be "factual" in a way personnel questions often are not. As one manager explained why his engineer-oriented company did not need a formal procedure for technical appeals: "There's no appeal process. I can't imagine an engineer and manager not being able to come away with a solution." Given such expectations, going over a manager's head is likely to suggest a criticism of the manager's technical judgment, something much more likely to ruffle the feathers of an engineer-manager than a disagreement over a personnel matter.

There is other evidence for this explanation. Some interviewees reported an informal procedure easily mistaken for an open-door policy. The procedure had no name (and may in fact be no more than a natural byproduct of reduced compartmentalization). One engineer (at an engineer-oriented company) described it this way: "Policy is to discuss the [technical] problem with your boss. If you can't agree, the two go up to the next level or bring in more people who know about the problem. There's no written policy as far as I know. That's just how we do it." We found this procedure of "bringing in more people" in customer-oriented companies as well. For example, one engineer in such a company told us, "If I had a [technical] concern I didn't think was properly resolved, I would write a note to my boss restating it—with copies to lots of people, including [his boss's equivalent in the next department over]. Writing such notes is not all that uncommon."

This procedure of "bringing others in" seems to differ from an open-door policy in at least three important ways. First, it does not seem to be a formal policy in any company at which we interviewed. No one knew its origin. It was, as one engineer said, "just how we do it." Second, no interviewee suggested that bringing others in would "ruffle feathers" (while several suggested using an open door would). No one, it seemed, doubted the benefits of another perspective. Third, and perhaps most interesting, bringing others in seems to be a procedure even managers can use, for example, when their own arguments cannot budge an engineer from a recommendation they don't like. Asked when an engineer should have the last word, one manager (a group leader) responded, "Last word? You can always get a second opinion."

REDUCED COMPARTMENTALIZATION. For a century at least, one characteristic of engineering has been the large number of engineers involved in any significant project. The traditional way to approach an engineering project was for a senior engineer, the project manager, to divide the project into small parts, assign each part to a particular engineer (or engineering group), send them off, and then assemble the results as they became available. The engineers would not be encouraged to coordinate their work with one another. Coordination would be the manager's job. Engineers might not even know who else was working on their project. They might in fact have little idea how their little project fit into the overall work. Especially in a large company, very little information could flow directly between engineers. The project manager alone would know more than a small part of the overall work. Engineers would have no choice but to defer to his judgment.

Burns and Stalker called this form of organizing work "mechanical." They found many instances of it in the British companies they studied in the late fifties and early sixties. That highly compartmentalized way of managing engineering may still be practiced in the United States. One engineer we interviewed recalled work at a previous employer (more than ten years before): "There I would often be assigned a job by a P.E. I never saw and sent him a written report. Occasionally the report came back with written comments. Usually I had no idea what happened to it." Though this way of managing engineering may continue in the U.S., we found little evidence of it in our interviews.

We may distinguish two aspects of compartmentalization: vertical and horizontal. Vertical compartmentalization produces a strict hierarchy, with one manager having a certain number of subordinates, each of whom answers only to her. They cannot go over her head without her consent. Horizontal compartmentalization puts up barriers between individuals, groups, and departments on the same level. One engineer might, for example, have to ask his manager's permission before talking to an engineer in another department about a technical matter; or he might simply have no way to know who else is doing work he should know about.

As our discussion of appeals suggests, we found relatively little vertical compartmentalization. We did, however, find significant horizontal compartmentalization between major functions such as sales and design or development and manufacture (especially in the large companies). So, for example, one engineer in manufacturing complained that the engineers in development still "throw things over the wall to us"—that is, develop a product without consulting the manufacturing people about how it is to be manufactured. Sometimes the technically neat solution causes trouble in manufacture.

We found significant horizontal compartmentalization, but we also found that every company at which we interviewed was trying to reduce it. Answers to question 12* (for managers) and 13* (for engineers) suggest that managers, rather than engineers, are generally leading this effort. For example, one manager complained: "I want my engineers to see their job as involving more than technology. How should mills relate? Where does what we're doing fit into the [company's] future? They need to ask more integrative questions, e.g.'Who reports to whom?' or 'Who can hold their feet to the fire?'" A manager at another company gave a different list in the same spirit: "What don't engineers ask that they should? Cost? Quality? Time? Cycle time? Design for assembly? They are ready to run as soon as they see the specs."

The engineers, in contrast, tended to think their managers more likely to fail to look into the engineer's own compartment. For example, one engineer wanted his manager to ask, "How thoroughly did you analyze the problem? Did you shoot from the hip? How much data and factual evidence did you collect? Is it repeatable? If you had more time, what would you do differently? If you're wrong, what are the ramifications? What's your second best answer?" An engineer at another company gave a similar list: "Managers need to ask, How did you reach that decision? What information did you use? Did you cover all the bases? Substantiate. The question managers are least likely to ask is, Is this date realistic? Usually, I'm told a date to be done by, not asked when I can be done. Often the date isn't realistic. But no one seems to know that—until the deadline is close."

Overall, what we found was a highly fluid decision-process depending heavily on meetings and less formal exchange of information across even department boundaries. Managers seemed to have little control over what information would reach their engineers. Indeed, they seemed anxious to get their engineers to hook up with others on their own. Their only complaints were about remaining compartmentalization, especially the parochialism of their own engineers.

While we heard many complaints about remaining compartmentalization, we also heard a few arising from attempts to reduce compartmentalization. One example will be enough. An engineer (at an engineer-oriented company) answered question 13 ("If you had full control..., what would you do differently"): "I wouldn't show up at a field meeting with so many engineers we outnumber the customer." Such outnumbering was, it seemed, a common consequence of sending one engineer from each department likely to be involved in a particular project. The most common complaint of this sort was simply "too many meetings."

INDEPENDENT REVIEW. Several companies at which we interviewed had a "technical review" in which a project group, section, or department had to defend its proposal to a committee of experienced engineers (and managers) from elsewhere in the organization. These reviews seemed to vary considerably in formality (as well as in other respects). The most elaborate we found was the "HAZOP" (hazard and operability) study used by Amoco Chemical. Designed for a particularly unforgiving technology, HAZOP is probably too elaborate for most engineering undertakings. Even so, it provides a standard against which other companies can measure their own review procedures.

Amoco uses HAZOP to evaluate both proposed and existing installations. Since these two uses differ significantly, we shall discuss them separately, beginning with proposed installations. For a proposed installation, a department works out a complete plan (which, for Amoco, routinely includes having it reviewed by operations, maintenance, and installation who are supposed to work as carefully as they would if they, not the HAZOP study, were the last step before construction of the installation would begin).

Once a department has done all it can, including receiving approval (and funding) through the ordinary process, a HAZOP team will be appointed, including a leader and a secretary. The team should consist of engineers experienced enough to "look at paper and know what that implies [about how a plant will run]." (One manager set the required experience level rather high, at "20-30 years," but we interviewed one engineer with eight years experience who had already served as a HAZOP leader.) No one involved in the original design will be on the HAZOP team. Following a "formalized procedure," the team examines every aspect of the proposal, identifies possible flaws in the design, and makes recommendations as it sees fit. The secretary takes down all recommendations, ultimately sending one copy to those who developed the proposal and filing the other "downtown" (that is, at Amoco's corporate offices). This usually takes "1-4 months."

Once the HAZOP team has completed its work, a response team is appointed, including one (and only one) member of the original HAZOP team. Apparently, for some projects at least, the response team may consist entirely of managers. It is supposed to respond to each HAZOP recommendation. (There may be several hundred.) Its response will also be filed "downtown." Ordinarily all, or almost all, the HAZOP recommendations will be incorporated into the original plan. Any rejections must be justified in the written response. Once the review is complete, the project will proceed. (We received no indication what would happen if a recommended change put a project over budget.)

That is the procedure for HAZOP review of a proposed installation. HAZOP can also be used to review an existing installation. The chief difference is that the result of such a HAZOP review will be recommendations piled on one or another engineer's desk beside ordinary work orders with which they will have to compete. This seems to be HAZOP's Achilles heel. Several managers told us that, had Union Carbide used a HAZOP procedure to design its plant in Bhopal, "Bhopal" would not now be a household word. They could well be right. But, had HAZOP come into use only *after* the Bhopal plant had been built, a HAZOP study might only have produced a series of recommendations which, though accepted by everyone, would, at the time of the disaster, still have been sitting on the desk of an engineer too busy "putting out fires."

We nonetheless recommend something like a HAZOP review even for existing operations. While it cannot guarantee that everything recommended will be done, it seems likely at least to call attention to important flaws in existing installations. It can set an agenda. For most companies, perhaps, identifying serious problems in some such constructive way as this is at least half of assuring that the problems will be resolved relatively quickly.

E. A Breakdown in the Normal Communications

Company B (as we shall call it) is a large customer-oriented manufacturer. As at the other companies at which we interviewed, engineers and managers at Company B generally worked by consensus. Company B had no open-door policy, ombudsman, or other formal appeals procedure. While going over the boss's head was generally considered a bad idea, the company did have frequent "review meetings" at which technical disagreements could be aired. These seemed to provide an important forum for (what we have called) "bringing others in." Bringing others in was also done more informally. Like other large companies at which we interviewed, Company B was working hard to improve communications between engineering functions, especially between development and manufacture. And, like our other customer-oriented companies, Company B had a code of ethics with little relevance to engineering. Over all, then, Company B would seem to differ in no fundamental way from other companies at which we interviewed.

Yet, Company B clearly did differ. It seemed to have a communications problem much like that Feynman reported at NASA. The evidence for this claim may be divided into four categories. Company B seemed to differ from other companies we interviewed in: (1) the way managers and engineers felt about each other, (2) the amount of information managers withheld, (3) the prominence of "top-down engineering," and (4) the way management chose to encourage an important development project.

MANAGERS VERSUS ENGINEERS. Unlike most of our interviewees, those at Company B had little doubt about whether they were engineers or managers. Thus, one manager told us, "I was an engineer until a few weeks ago. [Then] I was promoted to Chief Engineer." Though his former job as Supervising Engineer also involved a good deal of managing, he did not then consider himself a manager. Another interviewee spoke with equal assurance even though his demotion had not changed his job at all: "I was a manager before a recent reorganization flattened the organization a bit. Now, I'm not, though I was a group leader before and after reorganization—with the same responsibilities as before."

Why were interviewees at Company B so much clearer than our other interviewees about whether they were engineers or managers? The answer is that Company B had made the distinction sharp and important. As one engineer explained, "[Company B] gives better benefits to managers than engineers." Another engineer made the same point, while suggesting one disadvantage of making the distinction so sharp: "Around here many things, including fringe benefits and office space, treat engineers one way and managers another. The differences between engineers and managers are emphasized. They are in separate camps." This engineer also referred to engineers-turned-manager as "former peers". We heard nothing like this at any other company.

WITHHOLDING INFORMATION. Engineers and managers at Company B seemed agreed that engineers did not withhold technical information at all or only did so for just long enough to double-check it. Their answers were similar to those at other companies—except that there was no mention of engineers trying to cover up mistakes. Managers at Company B were also like managers at other companies in being unanimous that they did not withhold technical information from their engineers. Where Company B really differed from other companies was in the answers engineers gave to that question.

The engineers were virtually unanimous in reporting that their managers *did* withhold technical information from them. For example, one engineer told us that he "had frequently felt that they didn't tell me the whole story." When we asked "When?" he responded: "Whenever I couldn't reach their conclusion on the same facts." Another engineer gave this list of technical information managers were withholding: "[Information] about cost. Proprietary information too. That is, either information that's not directly relevant to what I must do or is too sensitive to risk leaking." Another engineer added this example: "We are reasonably sure that there is a potential big overseas buyer for the [new technology we are working on], but no one is leveling with us about it. We are in the dark on this and I don't like it." Yet another engineer described a different sort of withholding: "Sometimes they want us to be under-informed, maybe so as not to prejudice us or they don't think we need to know how bad a problem it is—e.g. that we had the same complaint before and thought we fixed it. More often, it's not deliberate. They just don't see the relevance of the information, e.g., they have divided a problem into parts that are too small."

What explains this difference in the way engineers and managers answered the question about whether managers withheld information? It is worth recalling that at other companies we interviewed, the *managers* stressed how important it was for engineers to include business considerations in their engineering decisions. At Company B, managers *never* made this point. Instead, the engineers did. Indeed, the engineers at Company B seemed to accept the broad conception of engineering which managers at other companies were encouraging their engineers to adopt. But, at Company B, the managers did not seem to share that conception. They therefore withheld information which managers at other companies did not withhold. They withheld it simply because they did not think it relevant to technical engineering decisions and seemingly without realizing that their engineers did not share their conception of what engineers need to know.

TOP-DOWN ENGINEERING. By "top-down engineering" we do not mean typical management functions like setting a general development strategy, standard of quality, or even the timetable for a particular project. We refer to something much more specific, management's involvement in the details of engineering. At other companies at which we interviewed, both engineers and managers thought that managers should leave the engineering to the engineers. We heard that thought expressed at Company B too but with this difference: The target was not (as at other companies) primarily the low-level manager clinging to his "former love". The target was management generally, especially *upper* management.

Company B apparently has a history of "engineering from the top down." An engineer employed there for almost a decade recalled, "It used to be that engineers didn't count for much. The manager ruled or overruled. This happened too often in the past. We would be told, 'The data must be wrong.' Some management guys don't have an open mind, but this happens a small percentage of the time now. Engineers are being more encouraged. We've become more involved. There has been more delegation and that's good."

While that engineer stressed how much worse things used to be, others stressed how bad they still were. One told us, "If my recommendations fit a pet theory, then they are acknowledged. If not, I have to make one hell of an argument....There was this case with the seal...My manager said, 'If you think about it, this seal should really work.' But it didn't work. Then the idea was changed from let's see if it works to how much leakage is O.K. in using the seal. This adds to the costs and the risks, but we're going ahead with it anyway." Another engineer told a similar story: "[Recently,] we were looking at two nozzles for spraying fuel into a cylinder. We could get a 10% improvement with almost no cost one way; or a possible 20% improvement doing it another way, but at considerable cost in redesign and no guarantee it would work. [I recommended the 10% improvement.] Management, not my boss, but someone higher up, decided to go for the 20%."

The engineers at Company B were virtually unanimous, "Managers here still try to do too much of the engineering." We heard the same thing from two *newly promoted* managers. One described decision-making in his company this way: "Managers provide proper manpower and tools and work with engineers—except sometimes, when there is a management-driven decision. Then the manager gets into the engineering itself. That's bad." The other new manager described the appeal process this way: "There is no formal process. After all, technical disagreements are hardly ever dramatic. If I'm unhappy, I just keep trying to change my boss's mind. I try to wear him down. [But] sometimes the heat comes from on top. We are told, 'Consider this design. Look at it. Tell us in detail what you think.' Then the process feeds back up. These top-down things give us the most trouble."

What he meant by "trouble" became clear when he answered our question about what he would do differently if he had full control of engineering: "[There] are too many projects initiated by top management, from the vice-president on down. I would prefer this changed. It creates tension at lower levels because of the mode of introduction. People are told to do this, to do that, that this is what we need. This creates bad feelings and destroys creativity. These top-down actions can be very specific and detailed. They can take the form of designs and actual sketches. 'This is what we want.' All this is out of control, in my opinion."

Though the *new* managers complained about top-down engineering as much as the engineers did, the more experienced managers did not. They did, however, answer question 3 (about how decisions are made) in a way confirming what the engineers told us (and suggesting the managers were on the engineers' side). "Decisions are made top-down," one manager began, "[but] we would like to push decisions down the organization." Another made the same point: "[Engineers] play as big a role as we think they can handle. This is easier said than done. I try to push decisions as low as possible. But you can't delegate then not stay in touch. I like to have engineering decisions or firm recommendations made at the project manager, group leader, or bench engineer level."

UNINTENTIONALLY DISCOURAGING BAD NEWS. Company B has undertaken a major technological initiative upon the success of which its future may depend. The initiative is not simply a research and development project. The assembly line is being prepared simultaneously. Because the project involves a major leap in technology, many parts of the project are crucial to its success. Should any of these prove impossible to develop, or impossible to develop in time or economically, Company B would have nothing marketable for its large investment.

Both the engineers and managers we interviewed were involved in work on one or another part of this new technology (as well as on other projects of more immediate concern). The engineers (and new managers) mentioned work on this new technology frequently, especially when asked whether Company B took large risks. The experienced managers *never* mentioned the new technology One even denied that Company B ever took risks, even after we restated the question to include financial risks. We seem, then, to have uncovered a disagreement between managers and engineers at Company B similar to that Feynman reported at NASA. The engineers recognized risks the (seasoned) managers did not.

Of course, the similarity is not perfect. The risk at Company B concerned its financial safety, not anyone's life or health. Engineers differed from managers on what would seem to be a question of business rather than engineering. And, unlike the engineers at NASA, the engineers at Company B could still be proved wrong.

Such differences are, however, irrelevant now. Even if the engineers are wrong, Company B would still have a communications problem. As one engineer noted, "[There is] too much rumor around here....I wish the managers here would just admit the problems we're having with [the new technological initiative] and tell us how they hope to respond." Clearly, management's message was not getting through.

There are, however, at least two reasons to think the engineers are right. The first is obvious. Whether a new technology can work is itself a technical question about which engineers are likely to be better informed than anyone else. Or, as one group leader at Company B put it, "Guys at my level know all the problems. But there's a filtering process upward. Lots of things we don't tell unless asked." Insofar as the financial risk the company is taking is itself a function of that technical risk, the engineers would be likely to have good information even about the business risk involved.

The second reason to think the engineers are right that Company B is taking a big risk with its new initiative is that management itself took strong action to move the project along. Unfortunately, as we shall see, the action it took seems likely to have the opposite effect. The action also suggests how large a gap divides engineers and senior management.

Company B has called in a management consultant, whom we shall call "Doctor Feel-Good" ("DFG" for short). DFG has tried to spur creativity through a motivation program for managers and senior engineers. The engineers who told us of DFG's program made it sound like a series of pep rallies. Whatever the program was in fact, the engineers tended to think it silly—or an admission of management's desperation. DFG clearly was *hurting* engineering morale (just the opposite of what management must have intended). But, perhaps more serious, DFG also seemed to be damaging communications between engineers and managers, the very communications upon which any technological breakthrough would depend. "[The] effect of [DFG]," said one engineer, "has been to make engineers feel out of step when they report that something won't work."

The flow of bad news upward has at least been slowed. Senior management may well be the last to know how bad things are; they may not find out until it is too late to do anything about it. Perhaps our interviews already show the filtering process at work. Though the engineers talked openly about the technical bottlenecks, shortage of staff, and the business risks, experienced managers did not. They were (it seemed) positive about what they were doing. If they were no more open with their engineers and fellow managers than they were with us, it is easy to see how they might be helping to create, however unintentionally, an environment in which even engineers would feel pressured to tone down bad news. As time went on, these managers, and those above them, would be more and more cut off from what the ordinary engineer knew.

Here is Feynman's "game"—with this difference. The disaster is yet to come and may never happen. The company may yet "luck out". But, even if disaster strikes, it will not produce a public scandal, only a lot of red ink or, at worst, the ruin of a good company.[32]

VI. CONCLUSIONS

Our first hypothesis was that the boundary between engineer and manager would be relatively clear in most companies because the staff-line mode of organization would force the distinction to be made clear. In fact, we found almost no trace of the staff-line distinction. What we found in its place was something much more like the distinction made in universities between faculty and administrators.

In most universities, senior administrators (president, vice-presidents, and deans) hold faculty appointments. Many still do some teaching. Ordinary faculty, on the other hand, do considerable administrative work, whether as department chair or through various departmental, college, or university committees. Faculty differ from senior administrators only in degree (though "administrative staff" are more like what engineers call "technicians"). Some ordinary faculty may be paid more than any administrator, even the university president.

In most companies at which we interviewed, the distinction between engineers and managers was similarly one of degree. A (bench) engineer was an engineer who spent most of his time at his bench (like an "ordinary faculty member"). A (pure) manager was an engineer who no longer did any engineering himself. Especially in large companies, there might be several grades of engineer-manager. In general, the distinction between engineer and manager did not seem to determine pay, benefits, or weight in technical decisions.

The one company that seemed to make the distinction between engineer and manager as sharply as we originally expected did not seem to have any more of a staff-line organization than the other companies at which we interviewed. Yet, though only for accounting purposes, the sharpness of the distinction seemed to hurt relations between its engineers and managers, making engineers feel as if they and managers belonged to "separate camps". This bad feeling may have contributed to the poor communications we found there.

Our second hypothesis was that engineers would be primarily concerned with safety and quality while managers would be primarily concerned with costs and customer satisfaction. This hypothesis was generally confirmed but in a way suggesting the concerns overlap more than commonly thought. Managers in most companies usually took more account of costs and customer satisfaction in their *initial* response to an engineer's recommendation than engineers *initially* did. In all companies at which we interviewed, however, decision was generally by consensus, not by management fiat. Decision by consensus required managers to inform engineers about considerations of costs and customer satisfaction they may have overlooked. No doubt as a result of that, most engineers we interviewed had a much better appreciation of such business matters than we expected. Even allowing for the fact that most managers we interviewed were trained as engineers, decision by consensus seemed to have a corresponding effect on managers. They seemed to have a better appreciation of engineering considerations than we expected. *Decision by consensus itself appears to be an important means of maintaining good communications between engineers and managers.*

Our third hypothesis was that engineers would tend to defer to management judgment, since management had ultimate responsibility for decisions. This hypothesis derived from our assumption that engineering would be treated as a staff function (with no responsibility for decision) while management would be a line function. Yet, the hypothesis was in fact independent of that assumption. It could have been confirmed even if (as it turned out) engineering was a line function. Engineers could still have routinely deferred to management.

Our findings here are therefore significant in their own right. Deference to management was *not* what was expected of engineers. Quite the contrary. Engineers were expected to "go to the mat" on any question of safety or quality they considered important. Even managers who expressly reserved the right to overrule an engineering recommendation emphasized the need for engineers to "hammer" at them anyway. Engineers themselves expressed no deference to management on questions of *safety*. There they expected their recommendation to be "final." Only on questions of quality, customer satisfaction, or cost were they willing to let management have the last word—and even then, they were willing to give management an "ear full" first. Here again the analogy with decision-making in a university (where faculty "advise" but expect to have administrators take their advice) seems much closer than decision-making in the military (where officers "command" and "subordinates" are expected to "obey").

Our fourth hypothesis was that the more hierarchical organizations were more likely to suffer a communications breakdown than the less hierarchical. This hypothesis, like the previous one, had been derived from the assumption that the companies at which we interviewed would have a traditional (quasi-military) hierarchy. Though their tables of organization made them look as hierarchical as we assumed they would be, none of the companies at which we interviewed was in fact organized in that way. The small companies were too personal for formal hierarchy to matter much. Even in the large companies, the use of consensus and bringing other people in meant that individual managers could not control information or access in the way they would have in a traditional hierarchical organization. (And, in addition, the managers generally did not want to.) Even the communications gap we found in Company B did not result from hierarchical organization but from a combination of other factors, including too narrow a definition of engineering considerations, too much interference from the top in the details of engineering, a failure to consult directly with those most likely to know, and the use of motivational techniques likely to discourage the reporting of bad news. The absence or presence of a code of ethics or formal appeal procedure seemed to have little part in technical communications between managers and engineers.

Our fifth hypothesis was that we could develop a procedure for identifying a communications gap between engineers and managers if one existed. We now have some support for this hypothesis. Our open-ended interview identified what seemed to be a serious communications gap at one company ("Company B"). The interviews also provided us much useful information about how engineers and managers generally work together.

Our sixth hypothesis was that we could add to the stock of procedures for preventing a communications gap or at least to procedures for helping to eliminate such a gap once it has appeared. We came across two, the informal "bringing others in" and the formal technical review.

VII. RECOMMENDATIONS

We believe our research justifies the following recommendations:

1. *Companies should try to soften the distinction between engineer and manager as much as possible.* Too sharp a distinction (as in Company B) seems to create resentment that can interfere with communication. Providing for a promotional ladder for bench engineers parallel to managers may help to reduce the feeling that managers are "above" engineers. Managers, especially, seem to welcome the possibility of bringing in a *senior* engineer (that is, a "technical person" with rank equivalent to "manager") when they disagree with an engineer's recommendation. Companies should also look for other ways to treat engineers and managers as professional employees, differing only in specific function and responsibilities (for example, by avoiding differences in benefits based on classification as "manager" or "engineer").

2. *Engineers should be encouraged to report bad news.* Communication is most likely to breakdown between engineers and managers when procedures or other aspects of the work environment discourage engineers from reporting bad news (for example, design problems). Top-down engineering may be justified at times, but it should be accompanied by on-site visits with the bench engineers doing the work ("management by walking around"). Senior management needs to remember how much bad news is likely to get filtered out by several layers of management. Senior managers should also be wary of motivational techniques that discourage bad news or otherwise inhibit the give-and-take that is a precondition of decision by consensus working well.

   While on-site visits, especially informal surprise visits with bench engineers, can undercut the authority of mid-level managers, that is not a necessary consequence. Undercutting can be avoided by *open* discussion of the rationale for the visit, emphasis on the helping (rather than the controlling) role of managers, and (when a problem is discovered) a focus on solving the problem rather than finding someone to blame.

3. *Companies should check now and then for signs of trouble in relations between managers and engineers.* Such trouble may not be obvious to managers inside the company even if it is obvious to the engineers there. How many subordinates will tell a superior more bad news than he asks for? One way for senior management to discover trouble is to meet informally with small groups of bench engineers. Another way is to have outsiders interview engineers and managers in the way we have.

4. *Companies should encourage both engineers and managers to settle technical disagreements by informally bringing other experts in.*[33] Companies should also consider adopting an open-door policy, ombudsman, or other formal appeals procedure. Though such formal procedures will seldom be used to settle technical disagreements between managers and engineers, they nonetheless seem to help establish an environment in which even technical information flows more freely.

5. *Companies should look for formal procedures that will bring out bad news that might otherwise be missed.* The most effective procedure of this sort we came across was Amoco Chemical's Hazard and Operability (HAZOP) study.[34] Though this procedure is probably too elaborate for most companies (that is, those with a less dangerous technology), it may provide a useful ideal against which any company can measure its own technical review procedures. Of particular value, we think is: a) that the reviewing body consists entirely of engineers who, though having the appropriate experience, have had no part in developing the plans (or process) they evaluate (and so, no built-in conflict of interest); b) that the plans have to stand on their own (the drafters not being there to defend them); and c) that all recommendations are put in writing, that rejecting a recommendation requires a written justification, and that both recommendation and rejection are kept on file (thus assuring later accountability). Such an independent review gives everyone directly involved in a project considerably more incentive than they would otherwise have not to play down bad news in the early stages of a project. At a minimum, however, we think companies should encourage engineers to put their doubts in writing and circulate them among all those concerned.

6. *Companies should not expect a general code of ethics to have much impact on engineering decisions.* Any company wishing to make safety or quality more central in its engineering decisions will probably have to do so through specific technical specifications. It may also find training engineers in their profession's code helpful, since these codes are generally more specific about problems engineers face than is a general business code. Such training may also confirm engineers in the belief that their employer wants them to be advocates for engineering standards.

7. *Companies should try to improve the way they use bad news.* Companies cannot learn from their mistakes if they do not remember them. In particular, companies should consider including information about how parts have failed in technical manuals (or data bases) engineers use or, at least, bring engineers together from time to time to discuss failures they have learned from.

8. *Technical engineering courses should include more about the place of cost, manufacturability, and other business considerations in engineering.* One manager in fact told us that, except for the graduates of co-op programs, engineers fresh out of college were poorly prepared to think about the range of considerations routinely part of good engineering. There seemed to be general agreement that engineering education is now too narrow.

9. *Engineers should be trained to make a case for their recommendations.* Ability to present data clearly, orally or in writing, and the ability to make arguments from the data, seem to be essential to participating effectively in decision by consensus. Right now, engineers seem to have to learn these skills on the job. They are, however, skills any school of engineering can teach.

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NOTES AND REFERENCES

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4. Feynman, 34.
5. For a good technical description of the "game" Feynman refers to, see Bell, T.E., "The fatal flaw in Flight 51-L", *IEEE Spectrum* (February 1987): 36-51. Compare Bella, D. A. "Organizations and Systematic Distortion of Information", *Journal of Professional Issues in Engineering* **113** (October 1987): 360-370
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17. Raelin (1986), 246-263.
18. See, for example, Argyris, C. and Schön, D. (1988) "Reciprocal Integrity: Creating Conditions That Encourage Personal and Organizational Integrity," in ed. Suresh Srivastva et al., *Executive Integrity*, Jossey-Bass, San Francisco, pp. 197-222; and Ottoson, G. E. (1982) "Essentials of an Ethical Corporate Climate," in ed. Donald G. Jones, *Doing Ethics in Business*, Oelgeschlager, Gunn and Hain, Cambridge, MA, pp. 155-163.
19. The only exception we found is Gordon, B. F. and Ross, I. C. (1962) "Professionals and the Corporation," *Research Management* **5** (November): 493-505.
20. Perhaps the most noteworthy exceptions are the very tentative studies by Victor, B. and Cullen, J. B. (1988) "The Organizational Bases of Ethics Work Climates," *Administrative Science Quarterly* **33** (March): 101-125; and Wilkins, A. L. and Ouchi, Wm. G. (1983) "Efficient Cultures: Exploring the Relationship Between Culture and Organizational Performance," *Administrative Science Quarterly* **28** (September): 468-481.
21. Burns, T. and Stalker, G. M. (1966) *The Management of Innovation*, Tavistock Publications, London. I should like to thank Peter Whalley for pointing this book out.
22. Turner, B. A. (1978) *Man-Made Disasters,* Wykeham Publications Ltd., London, especially, pp. 17-30, 57-67, 120-125, and 189-199.
23. Smith, M. R. ed. (1985) *Military Enterprise and Technological Change,* MIT Press. Cambridge, MA., esp. pp. 11-14 and 87-116.
24. This, of course, is not the only way in which to use the terms "staff" and "line" in business. Most frequently, perhaps, these terms are today used to distinguish between the historically oldest functional units of a business (production and sales) and the more recent (personnel, legal, accounting). On this version of the distinction, engineering might be either a staff or line function (depending on the history of the company). Often too, the staff-line distinction is used to contrast those functions which contribute (more or less) directly to the bottom line ("profit centers") with those that contribute only indirectly ("service functions"). On this version, some engineering functions (for example, operations and perhaps research) would be line functions while other engineering functions (for example, quality control or safety) would be a staff function. This diversity in the way the staff-line distinction is today made may itself signal that the original use no longer fits most American businesses.
25. Williams, R. (1990) "Engineering's Image Problem," *Issues in Science and Technology* **6** (Spring): 84-86.
26. The companies selected had business connections with one of the corporate members of our panel, with one of our two ethics centers, or with our sponsor (or even with some combination of these).
27. We had one interviewer on only three occasions, one for a whole day when there was no other way to schedule the interview and twice for part of an afternoon when one interviewer had to leave early.
28. Williams, 84.
29. For more information about the characteristics of those interviewed, see Appendix III.
30. It is perhaps worth noting that no one mentioned a commonplace of academic criticism, the need for engineers turned managers to learn to live with ambiguity. What explains the silence of our interviewees on this point? One possibility is that, as practitioners, they have already had to get used to ambiguity. Another possibility is that the crucial transition is not between engineering and technical management but between technical and nontechnical management. Here is a question inviting further research.
31. No member of our working group is altogether satisfied with the names we gave to these three kinds of company. Our only defense is that, after far too much discussion, we could not do better.
32. For an apparently analogous case ending in a half billion dollar write-off at General Electric, see O'Boyle, T. F. (1990) "Chilling Tale: GE Refrigerator Woes Illustrate the Hazards in Changing a Product—Firm Pushed Development of Compressor Too Fast, Failed to Test Adequately," *Wall Street Journal*, Monday, May 7, p. 1 ff.
33. See above, p. 196.
34. See above, pp. 198-199.

APPENDIX I: QUESTIONNAIRE FOR ENGINEERS

0. Explain project. Assure anonymity. Then ask: Are you an engineer or a manager?

1. What is your professional background?
   a. How did you come to work here?
   b. What does your company do? Example?

2. What do you do here?

3. How does your company make engineering decisions? Can you give an example?
   a. What part do engineers play in important design and operation decisions here?
   b. What part do managers play in important design and operation decisions here?

4. What are the most important factors determining company decisions on matters of engineering?
   a. Does your company take large risks in its technical decisions? Why?
   b. Does your company have a code of ethics?

5. Is the management of the company trained or versed in the company's technology? How current do you feel they are?

6. Are your engineering recommendations being acknowledged in such a way that you receive assurance that they have been received and will be acted upon in accordance with your statements? Explain.
   a. What review process is in place for an engineer's concern?
   b. Do you have, and participate in, a process of technical design review with your peers? With management on critical design specifications?

7. Do you think there are any communications problems between your supervisor and his supervisors? Examples?
   a. Do you ever find it necessary to withhold information from your superiors? If so, explain?
   b. Have you ever felt that your superiors were not telling you the whole truth? If so, explain.

9. Have you ever felt that safety or quality were being sacrificed for reasons with which you did not agree? If so, explain.
   a. What would you do if you thought safety or quality were being sacrificed?

10. On what issues do you think professional engineers should be content to see their judgment superseded? On what issues should the engineer's judgment be the last word?

11. If you don't like what your immediate superior is doing, what can you do about it?
    a. Does your firm have a formal open door policy? Is it used to appeal technical decisions? How does it work?

12. Are engineers good management material? Why or why not?
    a. What transition training or coaching is provided for an engineer promoted into management?
    b. In what important ways must a promoted engineer change?

13. If you had full control over the engineering work in your company, what would you do differently? Why?
    a. Are your engineering recommendations being affected by considerations or pressures that deny you the opportunity to provide the optimum solution to some problem?

13* What questions should a manager ask you to get the information he needs to make the right decision? Which, if any, of these questions is a manager least likely to ask?

14. Are there any questions we didn't ask that we should have? Anything you want to add to what you have already said?

APPENDIX II: QUESTIONNAIRE FOR MANAGERS

0. Explain project. Assure anonymity. Then ask: Are you an engineer or a manager?

1. What is your professional background?
   a. How did you come to work here?
   b. What does your company do?

2. What do you do here?

3. How does your company make engineering decisions?
   a. What part do engineers play in important design and operation decisions here?
   b. What part do managers play in important design and operation decisions here?

4. What are the most important factors determining company decisions on matters of engineering?
   a. Does your company take large risks in its technical decisions? Why?
   b. Does your company have a code of ethics? What part does it play in your decisions?

5. Is the company's management trained or versed in the company's technology?
   a. How current do you feel they are?
   b. Should managers have a technical background?

6. Do you and your engineers always see eye to eye on technical questions? If not, when not? What happens?

7. How much weight does an engineer's recommendation have?
   a.Does an engineer's technical expertise weigh as heavily as management considerations in making decisions?
   b.What review process is in place for an engineer's concerns?

8. On what issues should professional engineers (or staff) be content to see their professional judgment superseded? On what issues, if any, should the engineer's judgment be the last word?

9. Do you ever find it necessary to withhold technical information from your engineers? If so, explain?

10. Have you ever felt that your engineers were not telling you the whole truth? If so, explain.

11. Are engineers good management material? Why or why not?
    a. What transition training or coaching is provided for an engineer promoted into management?
    b. In what important ways must a promoted engineer change?

12. If you had full control over the engineering work in your company, what, if anything, would you do differently? Why?
    a. Are your recommendations now being affected or colored by considerations or pressures that deny you the opportunity to provide the optimum solution to some problem?

12* What questions should an engineer ask you to get the information he needs to make the right decision? Which, if any, of these questions is an engineer least likely to ask?

13. Are there any questions we didn't ask that we should have? Anything you want to add to what you have already said?

APPENDIX III: INTERVIEWEE CHARACTERISTICS

TOTAL INTERVIEWED

Customer-Oriented Companies (6)

Engineers	Managers	Total
3	1	4
3	2	5
2	6	8
3	3	6
5	4	9
3	4	7

Engineer-Oriented Companies (4)

Engineers	Managers	Total
0	1	1
3	4	7
3	4	7
4	2	6
29	**31**	**60**

(This table does not include three background interviews with managers not directly involved with engineers. The company listed with 0 engineers had a dozen or so engineers; but we only interviewed their manager in the first trial of the questionnaire.)

EMPLOYMENT HISTORY

	One Employer	Two or More Employers
Engineers	18	11
Managers	21	10

Years with Present Employer

	0-3 yrs.	3-9 yrs.	10-19 yrs.	20+ yrs.	unknown
Engineers	5	11	8	0	5
Managers	3	8	4	10	6

(The range for engineers was from 1-18 years; for managers, 6 months to 39 years.)

FIELDS OF ENGINEERING

(determined by degree or, in its absence, by work experience)

Civil	Chem.	Elec.	Mech.	Meta.	Unspecified
2	4	12	20	6	7

(In addition: One engineer (not counted above) claimed degrees in both mechanical and electrical; and two others (also not counted above) claimed a B.S. in Construction Engineering, a close relative of Civil. Of the remaining six interviewees, two had degrees in chemistry (and were working as chemical engineers) and one had an associate degree in quality assurance. The three non-engineer managers would bring the total to 60.)