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> The exact time and the exact place are uncertain now, obscured by the haze of a distant past. What is known is that on that long ago day on a field of natural turf, a middle-aged sort whom everybody would learn to call `Coach' surrounded himself with a gaggle of youths and, having told them what a football was, delivered his first axiom. `Gentlemen,' he said, `mistakes'll kill ya.'
>
> --**New York Times**, 22 October 1985

The most pernicious doctrine ever laid on the public administration is the doctrine of efficiency, a doctrine that appears to be so much a matter of common-sense as to be beyond debate. In these days of economic uncertainties, norms of efficiency have ascended to the first rank on organizational preference orders, public and private. And if common sense is not enough of a warrant for such action, we have the weighty pronouncements of economists who assure us that we must be efficient if we are to avoid disaster.

But, in fact, to follow their pronouncements is to court disaster -- and this is the claim we advance in this paper. Stated alternatively, we need to set aside norms of efficiency and optimality[1] and replace them with norms of reliability. The former rest on foundations of optimism, the latter on pessimism; and the difference is that which distinguishes success-oriented management from a failure-avoidance management.

In the pursuit of our claim, which we shall begin to unpack shortly, we deliberately minimize the criterion of economic efficiency, especially as directed by economists. We do so for several reasons:

(1) Standard neo-classical economics is a normative enterprise. It legislates proper rules of conduct. Its body of knowledge is based not on empirical generalizations (findings) but on axiological deductions from postulates that are by now axioms of right.[2] Economists were not, however, standing with

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[1] It is no accident that we connect optimism with optimality. Both owe their derivation to the Latin <u>opti-mus</u>, meaning best. According to the Oxford English Dictionary, "Optimism was originally a name given to the doctrine propounded by Leibnitz, in his <u>Theodicee</u> (1710), that the actual world is the `best of all possible worlds'; being chosen by the Creator out of all the possible worlds which were present in his thoughts as that in which the <u>most good could be obtained at the least cost of evil</u>." (Emphasis added) More generally, optimism is "applied to any view which presupposes the ultimate predominance of good over evil in the universe." It is a "disposition to hope for the best or to look on the bright side of things; a general tendency to take a favourable view of circumstances or prospects. (OED)

[2] This point was made long ago by Wesley C. Mitchell, now remembered as the "first empirical economist" and the "father" of business cycles:

"...[economists'] habit has been to set up simplified conditions in their imaginations, and draw conclusions about what would happen in an unreal world--conclusions that cannot be refuted by an appeal to actual experience.

One of the besetting sins of economists is failure to recognize the difference between an hypothesis and a theory. They forget Mill's warning that "The ground of confidence in any

Moses on Sinai. When, therefore, they legislate efficient decisions, the worth of such a value is open to debate. The situation would be quite different if economists treated their axioms as premises that must be questioned; we would then have a store of knowledge that would include empirically warranted praexiological rules. But when our colleagues tell us that if the world does not operate as their models describe, the world is wrong, we know we are in the universe of moral discourse.[3]

(2) Even when one accepts the norm of efficiency, it makes little sense to strive for it until one has a measure of effectiveness. The latter has to do with the distance between planned or anticipated outcomes and actual outcomes. It is just plain dumb to try to make an ineffective organization efficient. But it is not dumb to ask of an effective organization whether the same level of performance can be had at less cost. It is not often that we see demands for efficiency predicated on demands for effectiveness, despite frequent resort to cost-effective tests. Calculating odds with respect to alternatives is one

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concrete deductive science is not the a priori reasoning itself, but the accordance between its results and those of observation a posteriori."

"Facts and Values in Economics," Journal of Philosophy 41(1944): 217. See also "The Rationality of Economic Activity," Journal of Political Economy 18(1910): 97-113, 197-217; "Human Behavior and Economics," Quarterly Journal of Economics (1914): 1-47.

[3] This, incidentally, is the only domain where subjective certainty is preferred to objective certainty.

thing; it is quite another to apply efficiency criteria without an empirical demonstration of effectiveness.[4]

(3) Insofar as the management of organizations is concerned, norms of efficiency or optimalization raise the probability of error. They may even assure it. The tighter the system, the leaner it is, the more "optimal" its decision processes, the more it is prone to malfunction. To operate with the absolutely minimal number of persons, machines or units that could possibly be employed in the performance of a task, is to strip away all of the protective redundancies of any organization. It becomes error-intolerant: the failure of a single part can endanger the entire system; as when the breakdown of a switching circuit blacks out an entire region; or one flawed act produces Bhopal; or a minor parts failure results in 3 Mile

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[4] Curiously, the common language meanings of efficient and effective are quite similar and are used almost interchangeably by the Oxford English Dictionary. Efficient is defined as "making, causing to be; that makes (a thing) to be what it is; chiefly in connexion with cause," while effective is defined as "that which is concerned in the production of an event or condition," or, alternatively, as "an efficient cause." However, in economics, efficiency has come to mean "the use of economic resources in the most effective way" (Paul A. Samuelson and William D. Nordhaus, Economics, Twelfth Edition, San Francisco: McGraw-Hill, 1985, pp. 903-904), or the "best use of what is available to attain a desired result." (William H. Spencer, Contemporary Economics, Third Edition, New York: Worth, 1977, p. 745) Technical efficiency exists when "a production system--a firm, an industry, an economy--is achieving maximum output by making the fullest utilization of available inputs." (Spencer, p.745) Economic efficiency "requires the choice of a least-cost combination of inputs for a particular output level from among the technically efficient alternatives." (Richard S. Ekhaus, Basic Economics, Boston: Little, Brown, 1972, p. 452) Here, we understand efficiency in the latter sense and use it interchangeably with optimality.

Island. As we shall show, when NASA shifted to the criterion of efficiency, it virtually guaranteed the destruction of Challenger. In complex organizational systems, both soft and hard, simple mishaps so often produce catastrophe: where, however, norms of reliability displace those of efficiency, the organization becomes error tolerant and danger lessen.

A Fool's Errand?

In these days of austere cut-backs in the public administration, it may appear to be a fool's errand to warn against the norm of efficiency. But we do so precisely because prevailing doctrines are so dangerous. They belong to a world without friction, a world without bugs; one in which no errors are made and second order effects are always benign. We do not live in such a world. For this reason, normative organizational and management theories that assume zero tolerances are, at best, Utopian. When applied to the organizations that serve us, they weaken them. They breed "institutionalized self-deception;" they induce a dogma that precludes experimentation and therefore banishes "institutionalized disappointment;" and their optimistic, success-oriented management strategies do not allow for the constructive features of error detection and correction systems. Life, evolutionary theory tells us, advances only because of error; this is exactly the case for organizations.

Misplaced and dangerous optimism is not limited to only one sector of the public administration or to certain types of organizations; it is virtually ubiquitous. Evidence of its presence can be found at all levels of organizational structure and function: The design of the common gasoline tanker truck, e.g., is predicated on the assumption that nothing will go wrong in traffic; they are constructed of the lightest aluminum that can be legally used, in the interest of efficiency, of course. What we need to note here is that such tankers have more than five times the death rate in crashes than other trucks.[5] Or we will read that Chrysler, following the "efficient" Japanese practice which eliminates parts inventories, installs an assembly line that is optimal; inventory is eliminated. A week after this article appeared in the New York Times,[6] Chrysler suffered a strike that idled 21,000 workers at plants which had not been struck because a parts inventory no longer existed. That cost the company tens of millions of dollars.[7]

During the Vietnam War

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5 "Disaster Just Waiting to Happen," Los Angeles Times, 5 March 1982.

6 "Chrysler: New Van and Plant," New York Times, 29 October 1983.

7 "Chrysler, UAW Reach Agreement," Detroit Free Press, 6 November 1983.

> ...American soldiers and civilian officials were spurred on by a myopic sense "candoism"--the conviction that they could achieve anything anywhere. Their belief in their own omnipotence was stimulated too, by pressures from their superiors in Saigon and Washington. To adopt a negative attitude was defeatism, and there were no promotions for defeatism. In contrast positive reports were rewarded, even if they bore little resemblance to the truth.[8]

The cost of this attitude is by now well known.

The most important fact that can be known about an organization, any organization, is that it is error-prone. Mistakes are made; failures occur; and carelessness, or fear, or incompetence, or fatigue, or greed, or a host of other factors, contribute to error. We know, beyond any doubt, that there is noise in every system. There are no exceptions.

Now we can choose to hide from this fact, but it will be to no avail. At one time or another, faults will make themselves evident. Many will be nuisances, easily disregarded; others will strain the organization, but are tolerable; and there are those that can and do result in disaster.

As the sphere of government activity has expanded in the twentieth century, public organizations have been made responsible for the solution of increasingly difficult problems, making error both more probable and more costly. Our success rate has not been noteworthy. Whether one considers federal efforts to relieve poverty and urban blight, state attempts to control toxic waste, or local job training efforts, failures are conspicuous. Nuclear reactor accidents appear now to result from

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8 "Required Reading," New York Times, 23 September 1983.

organizational as much as from mechanical malfunctions. Failure rates are also affected by increases in the size of organizations and the seemingly irreversible trend toward tight coupling. First and second-order effects of error and failure seem to grow less benign, producing injury neither society nor any given organization can afford.

When we do seek to improve organizations, with few exceptions, recommendations for improvement invariably focus on improving efficiency and "managing for success." It is hard to find design proposals which derive from searches to uncover sources of error and which seek to protect against those which are judged to be system or program threatening. But if failure/error is not self-consciously searched out, it is not likely to be removed. Alas, our tendency is to the contrary: failures are suppressed and bearers of bad news punished. The operating rule seems to be that "it is better to insist you did nothing wrong than to learn from your mistakes."[9] The fate of "whistle-blowers" warrants the accuracy of this remark.

When, however, the threat of error is taken seriously, management attitudes must become pessimistic. The idea is to protect against error; to render it less probable; and to insure reliability of performance even when failure does occur. The

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[9] Jack Cloherty, " The Culpability Trap," The Washington Monthly, February 1984.

design and implementation of redundant organizational components has been one response.[10]

But there is more to a failure-containing management mode than redundancy. If one acts on the fact that organizations are error-prone, that all of its actors (man and machine) are risky, and that zero tolerance is a real-world illusion, the logic of that position requires close attention to "vital functions." Any really rational management would clearly understand that to inhibit the failure of vital functions is to increase the probability of success. The idea is to expose the potential for error before it can occur. In engineering, this type of attack is known as "fault-analysis."

Fault Analysis

That the structures and procedures of modern organizations are indebted to the field of engineering holds little news value for even the most casual observer, let alone the serious student of organization. Whether the aim has been to improve production efficiency through scientific management or to make "good" decisions about increasingly complex problems through M-I systems, business corporations and public bureaucracies alike have borrowed heavily from engineering;--its language, concepts,

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[10] On the theory of redundancy as applied to the public administration, see Martin Landau, "Redundancy, Rationality, and the Problem of Duplication and Overlap," Public Administration Review 29(1969): 346-358.

and analytic tools. Moreover, organizations operating in highly technical domains have by necessity to adjust their designs to the imperatives of their technologies. Despite these transfers, however, it remains noteworthy that we adopt the synoptic and deterministic aspects of engineering and neglect its treatment of component and system failure. This is all the more puzzling when one considers that over the past thirty years an entire engineering discipline devoted to increasing reliability has developed. Reliability has now become another parameter to be included from the very beginning of the engineering design process.

Concern for reliability in engineering began to assume paramount importance because of the extraordinarily high failure rate of military electronics systems.[11] In 1952 the joint military-civilian Advisory Group on Reliability of Electrical Equipment was established for the specific purpose of reducing failure rates. Its initial report stressed the

> need for new equipment to be tested for several thousand hours in high stress cyclical environments

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[11] Patrick J. O'Connor, Practical Reliability Engineering, 2nd Edition (New York: John Wiley and Sons, 1985) p. 10. However, it appears that even in engineering the value of reliability is not entirely understood yet. O'Connor comments: "Engineering education is essentially deterministic, and does not usually pay sufficient attention to variability. Yet variability and change play a vital role in determining the reliability of most products." (O'Connor, p. 1) And Henry Petroski, professor of civil engineering at Duke University notes that as things get more mundane, "they are built less conservatively." And the sure indication that conservatism had too little influence on the design of such structures as the Mianus bridge in Connecticut is the fact that they are often non-redundant. ("When Public Structures Fail," New York Times, 11 August 1983)

> including high and low temperatures, vibration, and switching, in order to discover the majority of weak areas in a design at an early enough stage to enable them to be corrected before production commenced.[12]

The Advisory Group operated on the belief that

> Complex systems and the components used in them included too many variables and interactions for the human designers to cope with infallibly, and even the most careful design reviews and disciplines would not provide sufficient protection. Consequently it was necessary to make the product speak for itself, by causing it to fail, and then to eliminate the weaknesses that caused the failures.

In fact, by 1965 the Department of Defense had made mandatory the integration of a program of reliability engineering with the traditional activities of design, development, and production; a decision that in those days should be reviewed and adhered to scrupulously.

In engineering, reliability is related to quality control, but is expressed as a probability in terms of time; specifically, it is the "probability that an item will perform a required function without failure under stated conditions for a stated period of time."[13] Although reliability engineering began in electronics, it has spread to other domains, and now encompasses an array of specific techniques, including its own branch of mathematics, management techniques, forensic engineering, and the like.

We use "fault analysis" as an umbrella term for these various techniques. Of the techniques available in engineering,

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[12] O'Connor, p. 9.

[13] O'Connor, p. 4, 10.

we learn the most and can make the greatest transfer to the domain of public organizations from Failure Mode, Effects and Criticality Analysis (FMECA); Fault Tree Analysis; Parts, Materials, and Processes Review; Human Reliability Review; and Critical Items List. FMECA is

> the most widely used and most effective design reliability analysis method....The principle of FMECA is to consider each mode of failure of every component of a system and to ascertain the effects on the system of each failure mode in turn."

Fault Tree Analysis

> starts from consideration of system failure effects, referred to as "top events." The analysis proceeds by determining how these can be caused by individual or combined lower level failures or events. It differs from FMECA in being a strictly top down approach and in considering multiple failures as a matter of course.[14]

In Parts, Materials, and Processes Review (PMP) all new parts and processes called up in the design are identified and assessed or tested before their actual application, and Human Reliability Review deals with the probability that human fallibility can produce a system failure. The Critical Items List is a summary of items shown by other analyses to be likely to have an appreciable effect on system reliability. Its purpose is to highlight critical items and summarize the actions taken to reduce the risks. The now popular term "criticality" derives from fault analysis.

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[14] O'Connor, p. 156-7, 163.

Fault Analysis As Attitude

Serious and rigorous fault analysis is a function of an institutional leadership that understands the importance of "institutionalizing disappointment." To institutionalize disappointment is to open the organization to self-criticism, and to discount expectations. On the assumption that any plan, policy, strategy, or program is fallible, perhaps prone to serious error, procedures are established which seek to identify potential failure. In fault analysis systems, these are usually in the hands of independent experts who, in disinterested manner, approach a plan or a design for the exact purpose of uncovering failure, and to establish the consequences of failure for the program. In this way, catastrophe and nuisance are separated. To honor its purpose, fault analysis must be strictly objective, grounded empirically, and concerned only with the effective operation of that which is under scrutiny. Institutionalizing disappointment works against the line, so to speak; it checks the authority of incumbency in order to find weaknesses that may have been overlooked for any number of reasons. To adopt this perspective compels a redirection of attention toward sources of failure and their consequences. In organizations, as in engineering designs, failure results from a variety of factors: design flaws; limited knowledge and experience; overload; stress; secular changes in operating conditions; obsolescence; human error, including judgmental mistakes and inadvertent lapses; complexity; and it also occurs randomly (i.e., at times that are unpredictable, even if causation can be established). Such problems are compounded because any single failure can have multiple causes, either at any one time or in sequence over time.

What can be exposed, however, is the type of flaw which is devastating in effect, that which must be assigned the highest criticality because it can cost the entire program. It is at such a point that appropriate redundancies can be added. That is why there are three inertial navigation systems in a Boeing 747, and why there are two human pilots; a third is automatic.

While our interest here is in preventing serious and costly error, and reducing the risk of catastrophe, it should be clear that for any program "there is a theoretical optimum expenditure on reliability in relation to the subsequent benefit."[15] Nevertheless, investment in reliability as opposed to efficiency is the most economical approach when full life-cycle costs are

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[15] O'Connor, p. 15. In a discussion of telephone switching equipment, Willett observes that "Software deficiencies and coding errors will always exist in a large system. It is not cost effective and probably not possible to test a system to the point where all problems have been found and removed. What is important is that service-affecting incidents are kept to a minimum, and that any such occurrences are analyzed for cause. Program corrections or enhancements are developed thereupon, when appropriate." R. J. Willett, "Design of Recovery Strategies for a Fault-Tolerant No. 4 Electronic Switching System," Bell System Technical Journal, 61 (1982): p. 3038.

calculated.[16] Even where budget restrictions are important, this will hold.[17]

Organizational Self-Deception

In most organizations, decision centers rely on the authority of incumbency. But there are no organizational decisions that do not contain high empirical content. If empirical assumptions are not subject to criticism, weaknesses, flaws, and faults cannot be exposed and cannot be corrected. Organization codes then become dogma. That is why a cogent line of criticism is as valuable as a reasoned consensus. The ground is much firmer, and the program much more secure, when proposals are subjected to fault-analysis. Indeed, competitive, objective,

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[16] The cost of the Challenger disaster has been conservatively estimated at $3.2 billion. ("Ground Shuttle Until Seals Are Fixed, Space Chief Says," Los Angeles Times, 12 March 1986). Does it seem probable that error detection and correction activities which might have prevented the disaster would have cost more than this? O'Connor notes that he is unaware of "any programme in which experience indicated that too much effort was devoted to reliability or that the law of diminishing returns was observed to be operating to a degree which indicated the programme was saturated." (O'Connor, p. 321)

[17] For economic application of resources in reliability improvement we may use the Pareto principle of the "significant few and the insignificant many," where we attempt to identify those causes that produce the largest number of failures, thus solving the largest proportion of the overall reliability problem with the most economical use of resources.

According to O'Connor, "Much written work appeared on the costs and benefits of reliability, showing that resources spent in the early development led to reductions in in-service costs which more than repaid the reliability program expenditure. The concept of Life Cycle Costs (LCC) was introduced." p. 10, 296.

and competent criticism is the essential feature of a science, and of a scientific management. Such managements institutionalize disappointment and they do so to protect against institutionalized self-deception. For organizations to deceive themselves is neither rare nor random. Charles Frankel, Assistant Secretary of State in the Johnson Administration, concluded that self-deception was not simply a passing problem, but a permanent condition facing all organizations. Accordingly, he observed, public institutions need their own internal instruments of self-criticism if only to protect against self-serving reporters, information distortion, and the censorship of monopolistic gatekeepers:

> When information and advice flow upward through ever-narrowing channels, the paneling on the walls and the rugs on the floor of his office do not protect the man at the top from living in an isolation cell.[18]

Parenthetically, this phenomenon can reach to the highest levels of government. So Robert Gilpin wrote of the Eisenhower Administration:

> ...the President and Mr. Dulles were unwitting prisoners, in their lonely isolation at the top of the government pyramid, of the special selection of knowledge and attitudes which came to them through official channels....They had no alternative against which to measure the partisan quality of this advice or its scientific inadequacies.[19]

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[18] Charles Frankel, <u>High on Foggy Bottom</u>, New York: Harper and Row, 1968, p. 93.

[19] Robert Gilpin, <u>American Scientists and Nuclear Weapons Policy</u>, Princeton, N.J.: Princeton University Press, 1962, p. 382.

Or, one has only to read the Stockman memoir to understand that decisions can be made to stand on the foundations of deliberate deceit.[20]

When such deception prevails, the bearer of bad news is in danger. The atmosphere itself demands that bad news be suppressed. Tom Wicker of the New York Times tells of a party at which he met Dean Rusk. It was in 1966-67; Rusk was Secretary of State; and the United States was enmeshed in Viet-Nam. That morning, the Times reported that Buddhists had taken control of the radio station in Hue. On reading the report, Rusk called the consul in Hue: the consul denied the event. Whereupon Rusk, at the party that evening, denounced Wicker and the Times for its lying stories. Some weeks later, Wicker was in Hue and met the very same consul. He asked whether or not the station had been taken as the Times reported. The reply was affirmative. Why did he not so inform Rusk when he was called. And the answer came: I could tell from the character of Rusk's request that he did not want for the station to be taken. Smart consul that: he might have been fired.

It was different in the Roosevelt Administration. For Roosevelt, the first task of any executive was to guarantee a reliable and effective flow of information, positive or negative. Accordingly, he checked official channels against the unofficial; he encouraged competition amongst agencies; he kept

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[20] David Stockman, The Triumph of Politics: How the Reagan Revolution Failed, New York: Harper & Row, 1986.

jurisdictions overlapping; he pitted public against private sources; and he would use one source of information, evaluation, or analysis, to challenge another.[21] To many critics of his management stance, this occasioned a messy and sloppy administration. But we have come to understand that its point was to protect itself against organizational self-deception. There are, of course, managements that operate on the basis of deception but, as we have learned, nature doesn't treat them too kindly.

NASA and the Challenger

Now we come to NASA and the tragedy of the shuttle. On June 11, 1986, the New York Times carried an interview with Richard P. Feynman, Nobel Laureate in Physics, and a member of the Rogers' Commission. Feynmen, who wrote a special appendix to the Commission report, presented a picture of an organization that continually fooled itself; and of officials who continually fooled themselves. They did not want to hear the truth, he stated. They ignored warning after warning, even the clearest signs that something was wrong. Their optimism was of such high order that when erosion of the "O" rings had been detected after earlier shuttle launches, a condition that was not supposed to occur, they dismissed it out of hand. Such optimism could not

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[21] See Arther M. Schlesinger, Jr., The Coming of the New Deal, Boston: Houghton-Mifflin, 1959; and Harold Wilensky, Organizational Intelligence, New York: Basic Books, 1967.

even be contained in their testimony before the Rogers' Commission: as when the deputy manager of the Marshall Space Flight Center testified that the probability of a catastrophic failure of the booster rockets was 1/100,000. These, however, were funny numbers. As Feynman says, "they were making up numbers not based on experience. NASA's engineering judgment was not the judgment of its engineers." The real numbers were more like 1/1,000.

But unlike the American consul at Hue, there were engineers willing to carry bad news. For this they were initially demoted. This is exactly what happened to those at Morton-Thiokol who, on the eve before its destruction, demanded that Challenger's launch be postponed. It was the "O" rings they warned about; and it was the failure of these rings that destroyed Challenger. It took sharp reaction from the Rogers' Commission to get them reinstated.

Here we have a striking illustration of organizational self-deception. One may ask, what happened to that great, powerful, scientifically oriented, and beautifully managed organization that put men on the moon? The answer, alas, is not hard to come by.

Despite the fact that Apollo was a crash program, NASA's management strategies in the 1960's were, in the main, pessimistic. The drive to the moon was administered protectively, to prevent failure. Its posture was failure-avoidance. Fault analysis; parallel development of alternative plans, designs, and technologies; independent checks and tests; redundant supports for all critical components and processors; all of this and more were standard operating procedures. As part of its design and construction process, failure-avoidance was a critical feature, as one reliability engineer for a NASA subcontractor observed:

> Central to the design reviews, even in the early conceptual reviews, was a carefully documented program of "failure-mode and effects analysis." Engineers would attempt to determine the manner in which things might fail and then assess the effect of such failures upon mission success and crew safety.[22]

In Apollo, reliability and effectiveness replaced efficiency as the foundation of administration.

And still there were failures. One need only recall the ground fire in the Apollo command module which, in 1967, claimed the lives of three astronauts. This was the result of a terrible negligence on the part of the major contractor. But NASA did not fool itself. James Webb acknowledged NASA's error, attributed it to inadequate information from the field, and moved decisively to correct the weakness. While Webb was Director of NASA, management policy was flexible and quick to change in response to problems; it is to the point that there were four major reorganizations during his six year tenure. The motivating idea was to constantly adjust the process of management to the institution's task, not the other way round. Toward this end, information channels were ever-widening, not narrowing, and if

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[22] Letter to the Editor, John A. Rice, Sr., Los Angeles Times, 11 March 1986.

anything, NASA's leadership was deluged with both good and bad news. It was the bad news that was important because this signaled the potential for failure. Nothing is ever perfect, and neither was NASA of the `60s. But it is most important to note that all critical decisions, including launch, were independently reviewed by a special top-level unit outside the line--the Office of Organization and Management.

For the space shuttle, NASA reversed its strategy. There is not the space to indicate all of the reasons why, but one major factor derives from the fact that NASA coped with its development difficulties and delays by attempting to maintain a "low political profile." This translates simply into efforts to keep its troubles under lock and key. The one way to really attract attention was to report costly overruns. To avoid this, NASA's primary concern was to control cost and to keep to budget. From here, it was a short march to a "success-oriented management"--a phrase, it should be emphasized, that NASA officials repeatedly used. This strategy is, of course, optimistic: it assumes that things will work out. What it really meant, as one NASA engineer put it, "is that you design everything to cost and then pray."

What of the effect of this strategy? As a special committee of the National Academy of Engineering later reported, it was precisely to eliminate the failure protection systems that had been so painfully built by previous managements. It was to eliminate parallel redundant development, analysis, and test;

"keeping expenditures to the absolute minimum." And what did it get NASA? It got "deferrals of difficult work, embarrassing accidents, expensive redesigns, weakening of specification, <u>and the illusion that everything was working well.</u>" As one might expect, overruns were not reduced, they were simply concealed.[23] It also got Challenger.

Through to that most lamentable of flights, NASA pursued its optimistic strategy. Its management, so determinedly success-oriented, repeatedly legislated its own facts. Assuming success, it reduced testing and eliminated vital redundancies. It even decided not to build spare parts for its engines. It did things that were actually stupid: it began to bond heat protecting tiles to the shuttle before they had been tested for vibration and temperature. Should we then be surprised that shortly afterward, half of the bonding crew was busy applying tiles while the other half pulled them off.

Von Neumann once explained why every effort must be made to detect error as quickly as it occurs; why it is necessary to isolate faulty components as quickly as possible; why it is necessary to design in such a way as to make error conspicuous; and why it is necessary to provide for error signals, especially as regards vital functions. The reasons have to do with the

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[23] We note that original estimates for launch costs were $10.45 million ($40 million adjusted for inflation in today's dollars) per launch and $100 per pound to place objects into earth orbit. The actual figures reflected in practice were $279 million and $5,264 respectively. ("Fletcher Backs New Shuttle but Balks at Mission Plans," <u>Los Angeles Times</u>, 42 April 1986).

properties of designed systems. Here, however, we simply observe that it is so much more difficult, and costly, to diagnose errors when a system multiplies errors.

But, as a case in point, Feynman tells us that instead of testing separate components, as is both usual practice and in concert with Von Neumann's injunctions, NASA built the entire engine first--making it difficult either to test components or to repair them. So, "malfunctions [were] laboriously traced to flaws that might have been detected earlier individually. Instead, every time a part failed, an entire engine was jeopardized."

We need not go any further. The story is public. Despite demands to the contrary, which began to be pressed in the late 1970's, NASA retained its optimistic management stance to the bitter end--of Challenger.

Shortly thereafter, the headline writers of the nation's leading newspapers and news magazines had a field day. The titles they used are most revealing: NASA CUT 70% OF STAFF CHECKING QUALITY; TRAPPED IN THE NASA-SPEAK MACHINE; NASA CUT OR DELAYED SAFETY SPENDING; NASA HAD WARNING OF RISK TO SHUTTLE IN COLD WEATHER; A FATAL ERROR OF JUDGMENT; SHUTTLE OFFICIALS DENY PRESSURING ENGINEERS; EVIDENCE OF DESIGN FLAWS; NO CHEERS FOR NASA; and so many more. The articles, columns, and commentary are so sad to read. Sad, because in February 1978, the chairman of NASA's safety advisory board warned that one of the most dangerous situations NASA confronted was that of the launch schedule driving the agency to "quick fixes". Scant heed was paid to this caution; and when Morton-Thiokol engineers insisted that the launch be postponed, a high NASA official, so often quoted, was prompted to protest: "My God, Thiokol, when do you want me to launch, next April?" Needless to say, Thiokol's bad news was never delivered to NASA`s Administrator for Space Flight. His was the final decision to launch, a decision made in ignorance.

Lest we be too quick to conclude that NASA has now learned from the Challenger debacle and will re-institute its formerly effective fault analysis procedures, we note that Morton-Thiokol rocket engineers have already complained of being pressured by NASA to meet a July 1987 deadline for a projected launching at the sacrifice of safety concerns:

> We're going too fast....We don't even have time to evaluate test data before we're being asked to recommend something.[24]

Something seems to have been learned, however, if we judge from the number of times the next spacecraft launch has been postponed.

"Mistakes'll Kill Ya"

It is ironic, but no where has fault analysis been used as much as in professional football. Here, managerial pessimism and

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[24] "Experts Hit Pressure for New Shuttle," Los Angeles Times, 25 May 1986.

error-detection and correction systems have been institutionalized more successfully than perhaps anywhere outside of the scientific community.[25] Football may be a game of inches, but above all else, it is a game where success depends on the consistent and progressive reduction of error. Error, and its manifold synonyms, comprise a large portion of football's vocabulary. One commonly reads that the losing team failed to execute properly, deviated from its game plan, fumbled more or that its opponent was able to "capitalize on its mistakes." Not surprisingly, one study of professional football games finds that the teams with fewer turnovers than their opponents win about 90% of the time.[26]

The high probability of error is widely recognized in the coaching profession. Its importance is clear: only one team

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[25] The entire structure of science rests on the principle of redundancy. Scientific decisions are subject to a constant barrage of criticism, which take form as an objective institutionalized control procedure. Nothing will be admitted as a permanent feature of the scientific corpus of knowledge unless it can withstand such criticism. This is the cardinal element of the philosophy of science. Its methodological rules are not intended to make proof easy. The contrary is the case, and the reason why is quite simple. Scientific decisions, as all organizational decisions, must be protected against "optical illusion." For a discussion of scientific techniques as applied to public organizations see Martin Landau, "On the Concept of A Self-Correcting Organization, Public Administration Review 33(1973): 533-542.

[26] Of 56 sets of circumstances in the NFL in 1985--total victories by 28 teams and total losses by 28 teams--51 corresponded to the takeaway-giveaway figure: a net plus or net balance in takeways vs. giveaways when the team wins, a net minus or net balance when it loses. Thus, when a team coughed up the football more often than it took it away from the other team it lost the game 51/56 times. "Mistakes'll Kill Ya," New York Times, 22 October 1985.

wins any given game, only one team wins a national championship, and only one the Super Bowl. And no coach wins 100% of the time. And, since none of them enjoys the security of tenure or civil service protection, the desire to win compels close scrutiny of losses.

Close scrutiny or, as we say, fault analysis is not limited to the week following a game, nor to losing games. The most successful coaches are those who constantly subject every aspect of their plans and executions to close analysis. The process is never-ending, and it is iterative. Many (if not most) of the coaching profession see their task as teaching, the conscious aim of which is the elimination of mistakes.[27]

High potential for error attends every aspect of football. Wherever and whenever a decision is made, error threatens: when, e.g., recruiting new players, scouting an opponent; selecting pass routes; executing plays, and in the design of plays themselves.

The close attention to error which marks football, rests on a number of basic premises:

(1) No offensive or defensive strategy is without its vulnerabilities; these are discoverable and can be exploited by one's opponents.

(2) Every play is a combination of tradeoffs and

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[27] We are indebted to Coach Jim Sochor of the University of California, Davis for his extremely helpful comments and insights about the football coaching profession.

compromises. Thus, every play has particular weaknesses which can be discovered and exploited.

(3) There is a finite body of plays. While these can be grouped into families, any given play can be made to look like a very different play, both in its original set and in the way it looks as it unfolds.

(4) Plays fail because of errors. A play that is properly designed and executed will always work. Even when it does work, it will reveal some error.

Football strategies organize individual decisions and actions. Plays are designed to coordinate the movements of eleven individuals who perform specialized actions on the field; each play coordinates differently; each coordination scheme is a choreograph. But plays are not rigidly specified. They can't be because an opponent's respones cannot be predicted exactly. Thus, they also provide a set of decision rules intended to permit quick adjustment to a range of contingent actions both offensive and defensive. So, e.g., there are rules which allow quarterbacks, receivers, and running backs to adjust to unanticipated defensive alignments; allow discretion to whether to run or to pass; etc. Plays are often combined into a series. Decisions about which play to use in any particular situation depends upon field position, the down, distance to first down, time in the game, the score, and anticipated defensive alignments.

Plays are developed (invented) weekly; adjusted to each opponent. Some coaches, such as Walsh of the San Francisco Forty-Niners, construct game plans which lay out the first 30-40 plays to be used. When this is not successful, the plan also includes contingency rules which instruct as to the kinds of plays to be shifted to.

Errors, or course, occur in devising the game plan. They occur during the game, especially when coaches fail to make quick adjustment to changes in the play action of opponents. There are many sources of error: what is clear, however, is the constant effort to progressively reduce error. To achieve this, football teams engage in their own forms of "fault analysis," including, but not restricted to the following: Close examination of each game film, which includes film on each subset of players (defensive backfield, offensive line, etc.), to detect error, physical and judgemental, in both plays that failed and those that worked; opponents are scouted, their game films are examined carefully to capture their approaches and strategies; offensive plays are isolated, coded, and fed into a computer to improve analysis; such plays are classified in terms of when they are used, where they locate in the offensive series, where they locate on the field, the score when they were used, how often they were used, etc.

The same analytic procedures are performed to analyze the character of an opponent's defensive strategies.

In devising plays and game plans, many factors are taken into account: the existing repertoire of offensive plays and defensive alignments available to both teams; weaknesses in offense and defense; the health and capacity of players on both teams, especially those in key positions; the presence of particularly gifted athletes on either team, and the type of play that is executed consistently with the fewest errors. Once a play is developed, skull sessions seek to find flaws even as they serve to instruct players; practice is not just training, it is also testing--as is the running of the play against squads that defend on the basis of the strategies generally employed by opponents. In so doing, instruction and training merge into fault analysis.

The football game plan, like the structure of an organization, is a theory of how to accomplish a finite set of goals. It is based on a set of cause and effect assumptions. But in football, these are modified on the basis of experience. Failure (loss) remains its prime concern and strenuous a priori efforts are undertaken to protect against its occurrence. Hence, redundancy is built into team action, from game plans to plays, even to the components of plays; and especially at those vital points where a failure means a serious loss. That is why a quarterback has secondary and tertiary receivers; plays are typically called by coaches with one on the playing field and one high-up in the stands, thus securing a double perspective; reserves are always in hand; etc. It is also striking that in the game itself, constant correction occurs: blocking assignments are changed, pass patterns are altered, players with different physical skills are substituted; all to minimize failure. Fault analysis is an integral part of every professional football game played.

Concluding Thoughts

We conclude now by noting that in 1600 reactor years of operation, more since this essay was written, there has never been a nuclear accident in the United States Navy; not a single accidental discharge of radiation; not one death attributable to nuclear causes. There is a reason for this: the rule of the nuclear navy is simply "never gamble." And it doesn't.

A chief petty officer on a nuclear-powered vessel complains that while he is clearly competent, well-trained, and highly motivated, nobody trusts him. His engineering supervisor responds: We all make mistakes, all of us. But the probability that four, or three, or even two people who are knowledgeable and attentive making the same mistake at the same time approaches zero. That is why your work is checked.

Or, on the U.S.S. Carl Vinson, a huge nuclear aircraft carrier, a seaman reports to the Air Boss that he has lost a wrench he was using on deck. There are a dozen or so planes in the air. The Air Boss halts all landings, redirects the aircraft to land bases, and orders a crew of hundreds into a search formation to scour every inch of the deck. The wrench is found; and the next day there is a ceremony commending the seaman who had reported the loss. With a loose tool on deck, the jet intake of landing aircraft could easily suck it up, the engine explode, and havoc and disaster result. The idea is that error is not to be concealed; never.

Karl Popper once wrote that the application of scientific method to the administration of institutions means that the great art of convincing ourselves that we have not made mistakes, must be replaced by the greater art of accepting responsibility for them, of learning from them, and applying what we learn correctively.

These are not idle thoughts. Once the wonder of the world of public administration, the Tennessee Valley Authority is now a mess of trouble. In 1985, all five of its working nuclear reactors were out of service and it absolutely botched a $12 billion expansion program. Gone are the days of David Lillienthal and Gordon Clapp. TVA directors admit it is in a "management crisis." It surely is. The Watts Bar project, scheduled to commence operation in 1976-77, has still to be licensed. It has been torn down and rebuilt three times. There is great internal dissension in the agency. Its management has not been congenial to criticism, but its operating staffs have had to face the facts. For facing facts, and speaking truth to power, many have been harassed and demoted. As one senior engineer lamented, "management simply refuses to learn from its errors."

None of this is really surprising. Utopian managements, confident and optimistic, see no need for criticism; for independent checks, fault analysis, and bad news. Subjectively certain, they translate their wishful dreams into an objective certainty. And they have the authority to do so. When, thereafter, nature proves to be unkind, when its effects are confounding, such managements are left with little more than self-serving defensive postures and a resort to the insolence of office.

But managements which are skeptical, resistant to institutional self-deception, which are not easily deceived because they institutionalize disappointment, fare so much better. They cannot help but enlarge their repertoires of response--which is another way of saying that they learn. There are, however, great problems in establishing organizations with this perspective: they seem to defy our sense of strategy. It is easily observed that policies and programs, public and private, are invariably "sold." One does not sell too well on the basis of pessimism, except perhaps in the insurance business. In all other areas, we present our plans and introduce our proposals on a note of optimism, frequently making claims that are truly heroic. It is a curiosity that it is left to opponents to be pessimistic. Even that, however, appears to be diminishing, as we follow the course of presidential campaigns.

Optimism carries over into our images of good managers, particularly public managers. In the conventional wisdom, executives and managers are supposed to be doers; positive, certain, decisive, in control, and possessed of a confidence that inspires enthusiasm and support. Now consider the response to those who are pessimistic, protective, cautious, and subjectively uncertain: they emerge in the public eye as indecisive, risk-aversive, at best, thinkers not doers. God save us from doers: they have done enough harm. The point is, and we choose to follow the great Holmes here, that "every hour of every day, every day of every week, we wager our salvation on prophecies that are based upon imperfect knowledge." It is on this foundation that we must learn to manage.

A final postscript: the day after Challenger blew up, the U.S. General Accounting Office cancelled its investigation into why NASA was not meeting its schedule, why it was not launching fast enough, why it was not efficient.