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THE COST/BENEFIT MONSTER

When Robert McNamara served as U.S. Secretary of Defense, he introduced the concept of establishing a quantitative cost/benefit ratio as a prerequisite to justifying any new program. This mystic monster has been enshrined within the Pentagon's pantheon ever since and has justified decisions ranging all the way from rational to horrendous.

Of course, McNamara did not invent the concept that it would be nice if things were somehow worth what you paid for them. In his *Essays*, published in 1580, Montaigne warned against undertaking activities in which *le jeu ne vaut pas la chandelle* (the game is not worth the candle). But in pre-McNamara days, decisions were based on more or less intuitive judgments. For example, the Navy might be asked which they would rather have, one more aircraft carrier or three more attack submarines. Since the answer to this question is "It all depends on the circumstances," intuition—or even coin tossing—may well be the best solution; however, Mr. McNamara bravely asserted that it must be possible to reduce the benefit of any program to a specific dollar value that could then be compared directly with the cost.

Actually this does not work too badly in simple situations involving items in quantity production or minor modifications of such items. Suppose the problem is whether to issue the troops a new raincoat that costs more than the current issue but is more durable and thus expected to last longer. Clearly, if the coat costs twice as much and lasts three times as long, the bargain should be snapped up. If, on the other hand, it costs twice as much and lasts only half again as long, then *le jeu ne vaut pas la chandelle.*

But when the decision regards the development of a major new combat system, a new radar, a cruise missile, the MX system, or the like, things get a bit more difficult. First of all, one does not and cannot really know the cost of something that has not yet been developed. The number of major systems that have grossly overrun the initial cost estimates is notorious. This is so not because people are stupid but because they have been asked to do the impossible. They have also been encouraged to lie, since a low initial estimate increases the possibility of the program being supported, and there appears to be no real punishment imposed for subsequent overruns.

So the numerator of the cost/benefit ratio is not well determined for a major development program. However, it is the denominator, the benefit, that causes the real trouble in quantification. How much is it worth to save a thousand or a million lives? What value should be placed on preventing starvation for a million residents of India? Quite possibly nothing at all or less than nothing if the end result turns out to be an equivalent increase in the number who will die in next year's famine. All you can be sure of is that if you do find some rationale for establishing numerical values, it will look silly to you 20 years later.

Since the proponents of a new program have every incentive to understate prospective costs and overstate alleged benefits, it is not surprising that horror stories of huge cost overruns and inadequate performance are a daily feature of our newspapers. The opposite case, where costs are initially estimated too high and benefits not sufficiently recognized, usually results in not undertaking the program, and this action does not make a news story. But, it is quite possible that these cases do at least as much harm in the long run as the more visible cases of overrun programs. For example, the government has provided only token support for the development of renewable energy sources to replace petroleum. This fact may prove quite literally fatal to future generations.

There is one program, the Transit navigation satellite system, which has been under development or in being for something over 20 years, that illustrates quite remarkably the danger of basing decisions on an estimate of the cost/benefit ratio. In what follows, I will discuss things that have occurred during this 20-year period that grossly affected the cost of the system and its usefulness and that were unforeseeable at the start of the program.

The Transit satellite itself was sufficiently like things that had been built before so that it was quite possible to estimate a cost within a factor of 5. Even the launch costs were moderately well known except for the probability of success of a given launch, which in those early days appeared to be rather low, as based on the experience of the Vanguard program. However, the huge uncertainty that totally dominated any cost estimate for a prolonged operation of the system was the question of what to assume for the mean-time-to-failure of a successfully launched satellite. During the first year, when the program was still under Advanced Research Projects Agency (ARPA) sponsorship, ARPA requested an estimate of the mean-time-to-failure of the Transit satellite from an organization officially in the business of making such estimates. Based on the general complexity of the electronics and the experience of such equipment throughout the military, they came up with two weeks as a realistic mean-time-to-failure. If this number had turned out to be valid, the maintenance of the Transit constellation of four satellites would have required something over a hundred launches a year, and it is certain the program would never have been supported. In truth, and against all expectations, the mean-time-to-failure has turned out to be closer to 14 years, requiring well under a third of a launch per year. So, from this factor alone, the initial cost estimate could be off by a factor of 300.

More surprising is the situation with regard to user equipment. The first navigation equipment installed in Polaris submarines cost about $250,000. Commercial equipment is now available for $4000 or $5000. A factor of 50 reduction has occurred during a period when the cost of most things has been grossly increased by inflation. The main reason for the reduction in the price of the Transit receivers is that a substantial part of the receiver is an electronic computer, and the remarkable reduction in computer costs as a result of new manufacturing technology is very well known. Combining these effects, it is easy to see how a cost estimate for the maintenance of the Transit system for a 20-year period, and equipping of a substantial number of users, could easily have been high by a factor of one or two hundred.

Bad as this is, a benefits estimate was even more difficult to quantify. NASA, which studied the possibility of a navigation satellite system very seriously in its early days, chose an interesting approach to finding an answer to what such a system would be worth. They circulated a questionnaire to ship owners and airline companies asking them what they would be willing to pay for a magic black box that would tell them their position at all times by receiving transmissions from satellites. This assumed that a system is worth what people are willing to pay for it. It also assumed that, in response to a questionnaire, what people claimed they would be willing to pay would bear some relationship to the truth. The fact is that in those early days, no one really believed there would be a navigation satellite system and therefore did not take the questionnaire very seriously. It is also possible that they were afraid to put down a large number for fear they would be asked to support the development financially. For whatever reason, the answers varied from about $50 to about $200. It is, of course, on the face of it, preposterous that a man should be willing to pay in the multimillions of dollars for a ship and yet be unwilling to pay more than $200 for a device that could prevent it running on the rocks. But this was the answer that NASA obtained, and the agency immediately concluded that Transit would have no commercial use because of the computer and the consequent high cost of the user equipment. It is an interesting sidelight that one of the airlines that responded to the NASA request installed tremendously expensive inertial navigation systems in its transatlantic planes two years after asserting that it had no navigation needs worth more than $200. Ultimately, NASA abandoned its attempt to establish a navigation system meeting all the requirements that resulted from its questionnaire of potential users.

In the meantime, the Transit system had the great good fortune of having a rich customer, the Polaris program. The Polaris developers knew perfectly well that they had to have accurate positions in the broad ocean area under all weather conditions and that their superb inertial system required periodic updating at sea. They were willing to pay almost any price for this crucial information, and their support for the system never faltered. Meanwhile, very slowly (navigators are very conservative people), the word spread that Transit actually worked. The first civilian users were the oceanographic research ships. The oceanographers were unstinting in their praise of the system's performance. In fact, Maurice Ewing wrote to the Laboratory: "I congratulate all of you who have made this navigation system possible as the most important contribution to oceanic research that has been made during my career."

Gradually, other oceangoing devices (such as oil-drilling platforms) that had a need for precision location acquired Transit receivers. General commercial shipping followed. A surprising development was the speed at which the San Diego tuna fishing fleet equipped itself with receivers. Two factors were responsible. One is the fact that a school of tuna dives to the bottom in the evening and spends the night essentially anchored. In the morning, it comes to the surface and resumes feeding. The boats cannot anchor; it is too deep. But, if they can return in the morning to where they were when the fish dived the night before, they can pick up the school again. With Transit, they can do exactly that. The second, totally unlooked for, advantage is that the presence of a Transit receiver is accepted as evidence that the boats have not violated anybody's 200-mile limit.

But the most surprising and unlooked for development of all is the number of receivers that are in use, not for navigation at all, but for surveying. The Western European countries have recently completed a new survey of Western Europe. Used in the survey mode, on land, with an average of a number of fixes, an accuracy of one to two feet is achieved. International boundary disputes are settled by Transit surveys. For example, the line down the North Sea separating Norwegian from Scottish waters was positioned by Transit surveys. And, in view of the density of oil on this fortunate sea bottom, I have been told that the position of this line is worth about a million dollars a foot.

It is clear that no one, 20 years ago, could have foreseen the possibility of achieving the kind of accuracy that has made such uses routine and — pardon me — cost effective.

This is the second in a series of articles on R&D management by Dr. Kershner, APL Principal Advisor for Space Systems.