

attempted following the submission of preliminary designs — or even earlier.

Studies have been made of the reliability of early estimates of (1) cost, (2) development time, and (3) physical and performance characteristics of new, advanced weapon systems. The results are striking. In the case of estimates made at the preliminary design stage, costs are typically underestimated by factors of 2, 5, 10, or in some cases substantially more. Development time is typically underestimated by 1 to 5 years. And the final system usually differs markedly from the predicted system both in physical and performance characteristics.¹¹ Usually, although not quite always, the estimates are optimistic — a bias one could expect from the premium on exaggeration by contractors in design competitions. But more serious than the bias (which could be discounted if it were systematic) is the wide range and scatter of the estimates. Choices at this stage must recognize these uncertainties. Precise technical and performance specifications at this stage involve self-delusion.

Premature specification makes it inevitable that many changes in specifications will have to be made as the system is developed. Detail also multiplies the number of changes in specifications that will be required, and obstructs the objective of getting a working model quickly into test. Excessive optimism in drawing up performance specifications can make the development so difficult that it must fail, or take much longer and cost much more than planned, or require a downgrading of the requirements.¹² It is not unusual for weapon system requirements to be so optimistic that several inventions or advances in the state of the art are needed on schedule if the development is to succeed. Prior to the successful test of the H-bomb, the development of the Air Force's first ICBM had been thwarted by requirements for payload and accuracy that proved infeasible. Only when these requirements were substantially relaxed after the successful H-bomb test could development proceed to the point where vehicles could be tested.

The need for changes in specifications would not matter so much if

¹¹ For example, more than half the aircraft developed since World War II ended up using different engines from those envisaged at the preliminary design stage. Aircraft expected to be supersonic turn out to be subsonic. Nuclear weapons expected to have a "yield" of x in fact have yields of $3x$ — or $.1x$, and so on. See A. W. Marshall and W. H. Meckling, "Predictability of the Costs, Time, and Success of Development," The RAND Corporation, P-1821, December 11, 1959.

¹² We will suggest later that instead of trying to specify all performance characteristics well in advance (x miles per hour, y C.E.P., z range, etc.), which places an intolerable strain on the art of prediction, the military Services would be well advised to indicate limiting values of such characteristics and acceptable trade-offs between them (in short, their "preference surfaces").