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Programmed to Fail:

The Rise of Central Planning in Defense Acquisition, 1945-1975

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Approx. 90,000 words

Contents

Introduction

> … each new generation of weapons costs several times more than the one it replaces, and the lifespan of new weapons systems is becoming shorter year after year.
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> Neil H. McElroy
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> "Semiannual Report of the Secretary of Defense," 1958

In the years after World War II, a ticket to the movie theater cost only 25 to 50 cents. Fast forward 70 years and movie tickets cost a whopping 10 to 20 dollars. That's a pretty big increase, but we've seen similar magnitudes for groceries, gasoline, and other everyday purchases. Wages have also grown about the same amount, perhaps a little faster.

Now imagine if all other prices remained the same except the price of movie tickets. Rather than costing 10 to 20 bucks, the same movie ticket now costs you anywhere between 100 and 500 dollars. Sure, the seat now reclines, the picture and sound quality is better, and so forth. Still, forking over hundreds to see a movie? Something must be wrong! And yet that is exactly the kind of cost increases we have experienced in the acquisition of weapon systems. The difference between spending tens and hundreds of dollars is the difference generated by price growth at 5 percent a year and 10 percent a year.[1]

Since World War II, the cost of U.S. weapon systems has rapidly accelerated. For example, the F-86 Sabre jet fighter aircraft cost just over $200,000 on average for each of the first 500 units. It dominated the skies over Korea after its introduction into operations in 1949. Five years later, the comparable cost for the F-100 Super Sabre was about $750 thousand, and in 1960 the F-4B cost over $2 million. Introduced in 1976, the F-15 cost over $11 million, and forty years later, the "bargain buy" F-35A cost $113 million.[2]

Procurement costs for fighter aircraft in the U.S. have on average grown at roughly 10 percent each year.[3] Compare that to prices in the economy at-large, which grew 3 percent annually.[4] Over 70 years' time, the difference is staggering. Whereas average prices have grown by a factor of eight, fighter aircraft costs have grown by a factor of over 600! In other words, it requires 75 times more real resources to buy an aircraft. A similar story is repeated in ships, helicopters, munitions, land vehicles, and missiles. In fact, the cost of weapon systems have grown at a similar rate or faster than healthcare and college tuition, two sectors which receive tremendous public attention due to their skyrocketing prices.[5]

For healthcare and education, higher prices haven't necessarily led to lower consumption. Their share of total spending has cut into other sectors. Healthcare spending, for example, has grown from roughly 5 percent of gross domestic product (GDP) in 1960 to over 17 percent in 2013.[6] Over the same time, spending on the Department of Defense fell from 8 percent of GDP down to near 3 percent.[7] Because the economy has expanded, the diminished share still represents modest growth in real defense spending. However, with system costs growing much faster than defense funding, weapons inventories have shrunk.

The Air Force's active inventory of aircraft dropped 60 percent in the twenty years after 1955.[8] Between 1990 and 2019, the Air Force's tactical aircraft fell again from 3,206 to 1,731, and the number of bombers fell nearly 80 percent.[9] A similar trend is apparent for U.S. Navy ships, falling from roughly 800 ships during the Vietnam War to over 500 during the Persian Gulf War, down to only 275 in the year 2019.[10] As for the Army, it inventoried nearly 9,000 helicopters at the end of the Cold War. Twenty years later, the figure fell to just 3,500.[11]

Higher weapon system costs and lower inventories has been the price of achieving great increases in system performance. The F-35A, for example, has stealth features, advanced electronics, and other capabilities that could make it worth the cost. The same is true, of course, for other high cost sectors. Healthcare has seen substantial improvements in prescription drugs, surgical procedures, and much more. Similarly, colleges have more “student life” amenities and nicer lab equipment. Adjusting for these quality improvements is a difficult task, fraught with uncertainty. Yet for some weapon systems, higher technology content has not necessarily led to increased performance, as evidenced by the F-35’s automated logistics system or the launch and arresting mechanisms on the *Gerald Ford* aircraft carrier.

While an exact index of military cost effectiveness is unavailable—and indeed impossible to devise—perennial efforts to reform the defense acquisition process have made clear that its performance is unsatisfactory.[12] In the minds of almost everyone involved, weapon systems cost too much, take too long, and when they are fielded, underperform in almost every characteristic compared to expectations. Past reforms, however, failed to turn the tide. Instead of looking for new solutions, reforms have oscillated within a narrow range of tried-and-true best practices. Experts largely agree on acquisition best practices dating from at least the 1970s, including requirements stability, realistic cost estimating, a “fly-before-you-buy” approach, and so forth. As a result, Frank Kendall speaks of acquisition “improvement” rather than reform. Norm Augustine concluded that “Management 101” is needed rather than new techniques.[13] Harvey Sapolsky advised that we “skip acquisition reform” this time around.[14]

Many experts believe the problem exists not so much with acquisition theory as with the acquisition workforce. In a compendium of 31 expert views submitted to Congress in 2014, over two-thirds pointed to weaknesses in workforce training and incentives leading to the poor execution of well-known best practices.[15] In the consensus view, policies devised during the industrial era need only minor tweaks; the remainder is a proper application of incentives.

One of the foundational works in the consensus view is the 1962 classic *The Weapons Acquisition Process: An Economic Analysis* by Merton Peck and Frederic Scherer. The researchers present two recurring themes: the constant presence of uncertainty and the non-market nature of decision-making. The two themes are indeed proper for any discussion on weapons acquisition, and will in fact reoccur in the following chapters of this book. However, this book applies a different understanding of uncertainty and the market which favors the bottom-up over the top-down, experimentalism over analysis, and a bias toward action rather than concurrence seeking.

Uncertainty

For Harvard researchers Peck and Scherer, uncertainty meant the degree to which contemplated outcomes are unpredictable. The relevant measures of prediction are cost, time, and quality. A distinguishing feature of weapon systems is that when a technical objective is identified, the estimated time and cost to achieve it might not even be in the ballpark of what it really takes. Uncertainty, therefore, was something to be minimized. Success was measured by achieving contemplated outcomes as planned.

The treatment ignores important aspects of uncertainty. Are the program objectives the correct ones? Can technical direction be modified when new knowledge is gained along the way? How quickly can the acquisition system adapt to changing circumstances? When is uncertainty so great as to recommend a diversity of options rather than a single-best choice? These questions stand outside the narrow definition of uncertainty, or the predictability of cost and time for a pre-conceived course of action.

Fixing a course of action makes sense when technology development is viewed as a linear process. The prevailing belief at the time was that engineering solutions could be mathematically derived from the natural laws of science. All that remained was a rigorous analysis to find what was already present in the theoretical model. In this view, the world was a closed-ended system of objective and deterministic phenomena. It made a small group of the best minds well suited to make the important decisions from the top, leading to a “requirements-pull” approach to technology development.

Over the course of the 20th century, evidence began to build that the “Newtonian” view of nature only worked for a small class of circumstances. In most cases of significance, predicting what will happen before experimental evidence becomes available is impossible. For example, U.S. scientists during World War II assumed that radar detection range increased linearly with frequency, leading them to a choice of 1.25 centimeters for aircraft side-looking radar. The choice was unfortunate, as later discovered by British scientists who performed realistic tests. It turned out that range was substantially improved at slightly lower and higher frequencies due to the unexpected effects of atmospheric attenuation. It turned out the function was not linear, as the U.S. scientists presumed in their simplified models.[16]

The 21st century is now dominated by a different paradigm of uncertainty. We live in an open-ended system of subjective and stochastic phenomena. Small—even unnoticeable—prediction errors have enormous consequences due to nonlinearity. Complex behaviors emerge from simple iterative rules, and in every case of significance have been traced to bottom-up architectures, such as found in "combinatorial innovation." For complex adaptive systems, uncertainty is not a problem to be contained. It provides opportunities for higher-level behaviors. The view leaves space for novelty and diversity. It suggests the wisdom of trial-and-error experimentation; of a "technology-push" approach to complement the "requirements-pull."

The result of complexity is that knowledge about what is likely to be successful is either unavailable or tacitly held by participants. Peck and Scherer deliberately defined uncertainty in the narrow sense because they rejected "fuzzy" notions of subjectivity. We should not reject an idea, however, just because it makes our problem more difficult. As thinkers like Michael Polanyi and Friedrich Hayek understood, a large fraction of scientific and economic information cannot be articulated or aggregated into statistics. It is dispersed across participants. Indeed, if we accept that no one person has but a small part of the total knowledge required to make decisions, and that each one of them has overlapping and even conflicting views of technical or operational feasibility, then subjectivity is a fact of life. The problem then shifts to how local pieces of knowledge can be most effectively coordinated to find out what is successful.

By contrast, Peck and Scherer saw uncertainty as a bug rather than a feature. As a result, they were committed to an optimization approach. Yet such analyses cannot discover anything that was not already provided in the assumptions. The abandonment of tacit knowledge limits the discovery of new technologies by constraining the search to what is known today. The antiquated view of uncertainty, with its emphasis on cost growth rather than the genuine discovery of knowledge, continues to pervade defense acquisition policies in the 21st century.

Non-market characteristics

The unpredictability of outcomes was seen by Peck and Scherer as unique to weapons acquisition; commercial firms encountered nothing close to the uncertainty of weapon systems. They pointed to the intensity of research and development as a good proxy for expected uncertainty. Even in research-oriented commercial industries like scientific instruments and chemicals, the researchers found that R&D expenditures amounted to only 5.4% and 2.9% of 1956 sales, respectively. By contrast, firms participating in the aircraft and parts industry put 19.1% of total sales towards R&D.

Times have changed. For the commercial firm Alphabet—which holds Google—R&D expenditures were 15.7% of sales in 2018.[17] Many of their projects are moonshots, both risky and highly uncertain. Compare that to the largest defense seller in the world, Lockheed Martin, which safely spent 2.4% of its sales on sure-fire internal R&D.[18] Modern tech giants also have incredible scale to achieve major programs. Amazon's 2018 R&D expenditures, for example, rivaled the entire fiscal year 2019 RDT&E appropriation for the Army and the Navy *combined*.[19]

Commercial firms in the 21st century don't just spend a great deal of cash on research and development. The nature of their business has changed substantially. No longer are commercial firms characterized by repetitive manufacturing of tangible goods. They no longer produce known things using known methods, where a bulk of the value comes from deploying physical capital, routine labor, and raw materials. Business value is now in the creation of intangible assets such as software, databases, platform design, supply chains, employee training, and business processes. These are precisely the qualities of investment that add value—and also uncertainty—to weapon systems. Over the years, commercial firms have charged ahead of defense firms in many important areas of technology development. Still managed by industrial era concepts, the Department of Defense struggles to keep pace with the rapid innovation happening in the market economy.

It was widely assumed in the 1950s and 1960s that technology development required government funding to large monopolistic firms. Famed economist John Kenneth Galbraith believed that the biggest firms would continue racing ahead in technology.[20] Galbraith, like other industrial era thinkers, could not conceive of small firms disrupting large incumbents. Yet experience has now shown cycles of small firms creating exciting technologies and growing rapidly, only to be disrupted themselves by a different set of firms. In the 21st century, technological disruption has become cliché.[21] Firms try to disrupt themselves.

It is now clear that uncertainty is not a defining characteristic of weapons acquisition. The uncertainty associated with the post-industrial economy has not caused market failures, but rather market innovations.[22] However, non-market decision-making—characterized by central planning and resource allocation—remains important. Centralized control is still alive within firms. They are "islands of consciousness" in a sea of market exchanges. Yet even the largest firm is relatively small compared to the overall coordination happening through exchanges.

The defense marketplace has greater non-market aspects because the government not only regulates the industry, it actively participates as the industry's only buyer. Back in the 1940s and 1950s, however, the government buyer was really fractured into multiple independent agencies that both cooperated and competed with one another. The Navy's Bureau of Ships relied on market-like exchanges with the Navy's Bureau of Ordnance for the armament of its ships, while the Bureau of Ordnance competed against the Navy's Bureau of Aeronautics to develop missiles.

Throughout the 1950s, government in-house organizations retained a significant technical staff. It helped them develop systems and evaluate the output of contractors. Even though the government made more technical choices internally—indicating the non-market nature of defense—it was pluralistic and competitive.

Central allocation didn't fully replace market-like exchanges until Robert McNamara's managerial revolution of 1961-1968. The in-house bureaus and technical services, crucial for generating the knowledge to become a smart buyer, were almost totally abolished. Weapons acquisition focused on planning the total defense program from the top. Basically all detailed work was outsourced to a single prime contractor through a dedicated program office. While such increased use of contracts may appear to have made greater use of market mechanisms, they were in fact an extension of the central allocation scheme. The entirety of the defense ecosystem then came under control of a single resource allocation mechanism that continues to exist well into the 21st century, the Planning-Programming-Budgeting System.

Summary

This book attempts to fill a gap in the literature on weapon systems acquisition. Whereas Peck and Scherer, and indeed nearly all other major works, remained committed to an optimization approach of resource allocation from the top-down, this book explores the concepts behind a diversification and selection approach focused on exchange from the bottom-up. In exploring new reforms for a post-industrial world, it is necessary to first understand the history. The following is dedicated to resurrecting the debates occurring between World War II and the 1970s, the period when the modern acquisition system grew into maturity. It finds how important thinkers dissented to the consensus view including Armen Alchian, John Boyd, Hyman Rickover, and many others.

This book is primarily a history and synthesis of ideas. It finds substantial precedent for an alternative paradigm to weapons acquisition that follows two related concepts. First, liberal concepts of individualism, property rights, subjectivity of cost, and rules-based order are crucial to any reorganization away from top-down allocation. Briefly, effective outcomes require the alignment of decision rights and production knowledge. Second is the multi-disciplinary studies of complex adaptive systems, which provides a scientific foundation for self-organization, emergent order, and resiliency. Here, we gain an intuition for why rivalry and redundancy are essential to technological progress.

While the historical framework integrates many concepts, it frequently draws the reader's attention to the central role of the budget process. The output-oriented budget implemented by Robert McNamara under the banner of the Planning-Programming-Budgeting System (PPBS) represents a major break from the liberal institutions of the United States. In the place of pluralism and exchange, the PPBS creates a central plan for future action.

The PPBS remains the most important barrier to achieving the intended effects of acquisition reform. Re-installing a traditional budget based on organization and object avoids the lock-in effect of central planning. It allows managers to take advantage of real options, incorporate intangibles into decision-making, and pursue "non-consensual" projects which, as tech entrepreneur Marc Andreessen has found, are the only ones that have a chance of big returns. Perhaps most importantly, the traditional budget process helps align authority, responsibility, and accountability, which is currently dispersed across numerous layers of bureaucracy.

This book argues that failure is built into modern defense acquisition. Attempts to detail financial plans by program output has corrupted the decision-making process. Hundreds of requirements are levied from all corners of the bureaucracy. Dozens of approvals are required to authorize funds. Years pass before the program can proceed, and once it does, plans become locked-in for five, ten, or twenty years into the future. The programming aspect of the budget is the ultimate source of rigidity in acquisition. Hence, the book is titled *Programmed to Fail*.

The first chapter of the book explores the administrative unification of the War and Navy Departments in the years after World War II. It shows how the prevailing attitudes at the time favored centralized planning and reviled competition. The chapter features the first Secretary of Defense, James Forrestal, a man who found himself increasingly broken by his attempts to slow the encroachment of centralization.

The program budget is discussed in the second chapter, proclaimed by its advocates to be the most important tool for unified decision-making. In 1954, administrative expert Frederick Mosher documented the implications of a program-oriented budget. Though he convincingly argued how programming presents many difficulties and should have been abandoned, he was later swayed by its proponents—at least in the special case of defense acquisition.

The third chapter introduces systems analysis, a set of mathematical techniques intended to solve questions of program choice. Developed primarily at RAND, systems analysis attempted to predict future technologies and the cost of their achievement. A separate contingent of RAND analysts led by economist Armen Alchian countered that technological uncertainty was too great for a systems analysis to recommend the single-best choice. Instead, they advocated for a diversification approach to R&D, relegating optimizations to more well-defined areas of procurement and operations.

The twin concepts of the program budget and systems analysis were only partially installed in the 1950s. It wasn't until 1961 that they became the foundation for a defense management revolution under Robert McNamara. The fourth chapter examines the rise of the Planning-Programming-Budgeting System, and puts it in the context of the broader debate on socialist planning. The chapter features insights from Friedrich Hayek on the problems of unified resource allocation, Karl Popper on learning by trial-and-error, and Harvey Sapolsky on the myth of scientific management.

The fifth chapter explains how the PPBS led to the demise of in-house technical staffs under the Navy bureaus and Army technical services. In their place, program offices with a single prime contractor put an emphasis on contractual agreements. It features critiques of defense contracting schemes by RAND analysts William Meckling and Oliver Williamson.

The sixth chapter focuses on the defense innovation process. It describes the daunting prospect of starting a new program and the linear stage-gate model of technology development. It examines European and Soviet innovation policies as described by Robert Perry and Arthur Alexander. A case study of the lightweight fighter program, led by John Boyd and the fighter mafia, is used to demonstrate how fragile and unlikely non-consensual developments are in U.S. acquisition.

The seventh chapter follows John Boyd's work as it moved from aircraft design into complexity studies. The chapter explains how the reductionist view of science has been replaced by a richer understanding of the inherent uncertainty built into our universe. It explains how order emerges from the bottom-up, not only in the economy and society, but in all complex physical phenomena. While military operations have started to reorient themselves to a complex adaptive systems view, the acquisition process remains trapped in the realm of linear thinking.

Competition is the focus of the eighth chapter. It describes how economic rivalry acts as a procedure for discovering knowledge that wouldn't otherwise be available to a central planner. It features arguments by James Schlesinger and his mentor, Roland McKean, a founder of the PPBS who nevertheless concluded that centralization contributed to layered decisions, group-think, and ineffectiveness. Also featured is David Soergel on state-planned technology and Martin Landau on the high-reliability organizations.

The ninth chapter looks into the uses of cost analysis in the Department of Defense. For industrial era thinkers, cost accounting revealed the value being generated in the production process. However, as the economy moves away from reproducible goods and towards intangible asset creation, money outlays become less indicative of the opportunity cost of alternative actions. It features insights from James Buchanan and Fredrick Brooks on how accounting data cannot be aggregated for use in specific decisions.

The tenth and final chapter explains the role of culture in transformative economic activity. Meaningful decentralization first requires building back up the technical competence which used to reside with the government. Admiral Hyman Rickover is featured for his emphasis on in-house technical staffs and a long tenure for program managers. Otherwise, managers would not have the knowledge or incentives to exercise wise discretion over advanced technology developments.

For more than 70 years, the pendulum of acquisition reform has swung within the narrow boundaries of industrial era thinking. As Colonel Peter K. Eide quipped in 2011, “The more things change, acquisition reform remains the same.”[23] The blame now lies with the acquisition workforce. However, we should consider how after so much time, perhaps it is not the acquisition workforce that should be found blameworthy. The following pages will provide a missing narrative to the rich history of thought in weapon systems acquisition.

1. Unification

> Who is to blame if the economic tail wags the political dog? It seems unfair to blame the evangelical economizer for spreading the gospel of efficiency. If economic efficiency turns out to be the one true religion, maybe it is because its prophets could so easily conquer.
>
> Aaron Wildavsky
>
> "The Political Economy of Efficiency," 1966

As final preparations were being made for the D-Day landings in Normandy, a seemingly distant proposal for post-war organization drew high-level attention back in Washington D.C. General George C. Marshall set the pieces in motion on November 2, 1943, when he submitted a memorandum to the Joint Chiefs of Staff "relating to the single department," or the administrative unification of the War and Navy Departments.[24] Marshall had already centralized the command structure of the War Department in March of the previous year.[25] He wanted a similar reform for the overall military structure, complaining how a "lack of real unity has handicapped the successful conduct of the war." Coordinating boards staffed by Army and Navy advocates, like the Joint Chiefs of Staff for military operations or the Army-Navy Munitions Board for supply, had proven a "cumbersome and inefficient method for directing the efforts of the Armed Forces."[26] Recent combat experience overwhelmingly supported the idea for unity of command in theater; the idea appeared to logically extend into broader organizational matters of supply.

1.1 The Woodrum committee

In response to Marshall's proposal for unification, Representative Clifton A. Woodrum formed a select committee.[27] The committee hearings that came to bear his name got started on April 25, 1944, a little more than a month ahead of the D-Day landings. One of the first witnesses before the Woodrum committee was the Secretary of War, Henry Lewis Stimson. He testified that only a unified military leadership could establish efficiency:

> "In warfare it is a long standing and thoroughly attested principle that no voluntary cooperation of independent forces can achieve the effective results produced by a single authority in such planning, supervision, and control. Consequently, there have been in this war, in spite of the earnest efforts of the military leaders of the two services at cooperation, many duplications of time, material, and manpower, with the loss of effectiveness, resources, and power which such duplications inevitably produce. Such duplications will doubtless be brought before you by the officers from all the services who will follow me."[28]

Several men from the Army and Army Air Forces indeed followed Stimson with supporting details. They described, as Chairman Woodrum put it, "quite a number of illustrations of overlapping and duplications that were clearly caused by the two services and which could clearly be obviated by consolidation." For example, Assistant Secretary of War Robert A. Lovett mentioned the adjacent airfields at Anacostia and Bolling Field. One was operated by the Army Air Force and the other by the Navy. He said that "there was two of everything there."[29]

Examples of duplication in manpower and materiel in fact abounded. The Army found such instances tantamount to waste and abuse. A unified defense organization, Lovett believed, would create substantial benefits. Based on his experience, he concluded that:

> "Unification should eliminate the substantial duplication in personnel dealing with procurement and contracting, inspection services, and so forth… Saving should result from establishing uniform specifications where possible and avoiding the multiplicity of items which differ only slightly… Consolidation of certain research and experimental establishments with their properly specialized divisions should result not only in substantial savings in physical facilities but also, by the elimination of duplicating projects, should permit in

peacetime the concentration of more funds on pure scientific research… Economy should result from consolidation and coordination of production and engineering supervision."[30]

The War Department succeeded in cataloging existing inefficiencies. They even went so far as to name some technical solutions such as uniform specifications. Specifications, however, certainly had to differ at some level. How large were the potential gains and what negative unintended consequences might result? Presuming that technical solutions led to large efficiencies, it wasn't clear that they could not be carried out in a decentralized framework.

The key assumption made by the Army and many others at the time was of the overwhelming benefits of consolidation. Representative Melvin J. Maas challenged Lovett on the assumptions. "I wanted to get that from the Secretary," Maas said, "how he thought we would improve our war effort and get any economy by merely lumping all the procurement." Lovett, however, thought he had already thoroughly covered the question. He left it there.

Brigadier General J. McAuley Palmer provided even less insight to committee members. As adviser to the Special Planning Division and confidant of General Marshall, Palmer made the opening statements for the War Department. Presumably he would have studied the details and implications of unification. Yet after asserting the necessity of a single administrator to stamp out duplication, Palmer admitted that he had not studied the matter, and further, that it should not require study. "I have not given the matter very much study," Palmer testified while under questioning, "and it has always seemed to me the object [unification] should be accomplished without going that far. I must confess I have not studied the matter fully."[31]

Somewhat more concrete was Lieutenant General Joseph T. McNarney, Marshall's deputy and chair of a reorganization committee in the War Plans Division. He brought a proposed organizational chart that nicely showed the clear chain of command from the President down to the Secretary for the Armed Forces, and from him to three Under Secretaries for Army, Navy, and Air. "I would add to the three armed services which are united in this single department," McNarney explained, "a fourth element, directly under the Secretary for the Armed Forces, which would consist of the common supply services."[32]

McNarney's chart, excluding the Navy, closely resembled the actual organization of the War Department since 1942. To limit the number of units reporting directly to the Chief of Staff, General Marshall raised his office and created three new commands. All combat units were grouped into either the Army Ground Forces or Army Air Forces, and the various technical services were consolidated into the Army Service Forces.

In order to coordinate the three commands with respect to resource allocation and operational planning, Marshall created the Operations Division (OPD). However, because each command had its own staff better suited to the task, the OPD became displaced. The OPD focused on monitoring theater planning and making only those decisions which bubbled up to the top.[33]

McNarney's plan had a similar mold. The focus of planning and direction would come from the staffs of the three Under Secretaries, tied together by the Secretary. The Common Supply directorate represented the Secretary's ability to finally eliminate duplication. Despite the seemingly limited role for the Secretary, McNarney made clear that the plan would reverse the current bottom-up planning process:

Mr. Wadsworth. "Today, as I understand it, the planning as you have described it, starts from below and moves upward?"

General McNarney. "Yes, sir."

Mr. Wadsworth. "You visualize the planning being made at the top and coming down?"

General McNarney. "That is correct. I believe the recommendations as to what our national military policy should be, as to the scientific allotment of our forces, as to a single war plan which provides for the most efficient use of our three armed services and as to the budgetary requirements to carry out our national military policy to include our strategic deployment and provision of forces necessary to implement our war plans, must necessarily come from the top."

Mr. Wadsworth. "Today we have no statutory top?"

General McNarney. "That is correct, sir."

Before the war, responsibility to Congress did not come from the top of the military hierarchy in every case. Congress appropriated budgets directly to individual technical services involved in production and supply, whose chiefs defended their budgets independently. This source of autonomy allowed the technical services to flout coordination from the general staff.

McNarney urged Congress to unify budget authority under the Secretary for the Armed Forces, who would allocate the budget downward based on the recommendations from the service chiefs. Centralizing the budget would remove two obstacles to unified planning. First, it provided a single authority with the power to eliminate duplication across the Under Secretaries, such as at Anacostia and Bolling Field. Second, it destroyed the independence of the various technical services, making them reliant on military staff approval. "One very great thing," McNarney said of unification,

> "… is that it would unify the Budget. Now, the Army and the Navy submit separate budgets. They are not coordinated by any single agency. They are what each one of the services feels that they must have. The control of money, of course, is what not only makes military forces work but it makes the world go around. That is one great unification."[34]

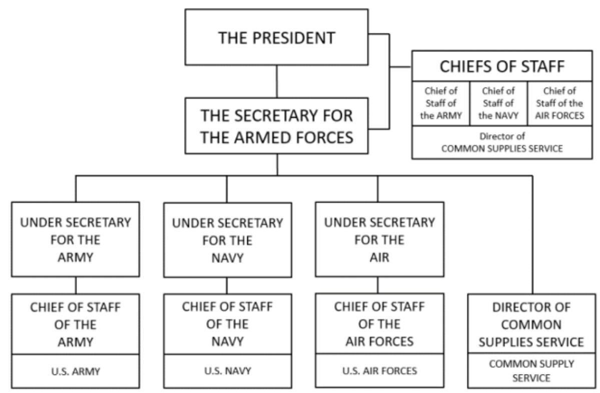


Chart presented by Lt. Gen. Joseph T. McNarney to the Woodrum Committee on April 25, 1944. The McNarney plan reflected the actual organization of the War Department during the war. Reproduced figure.

1.2 Alternative views

On April 28, 1944, after three full days of testimonies from the War Department, the Navy finally had its first witness before the Woodrum Committee. Although the Secretary of the Navy, Frank Knox, might have been expected to lead the discussion, he died that very day of a heart attack. Despite the loss, the Navy found a strong advocate in the Under Secretary of the Navy, James V. Forrestal, "a man of modest physical presence, reticent, and burdened;" a man who "struck one as constantly absorbed in thought."[35]

The Navy's "very real fear" about unification, Forrestal later wrote in his diaries, was of the Army's intent to make the Navy "merely another arm" for itself, as the Army Air Forces had been.[36] His fears may not have been exaggerated. For example, General Marshall reportedly told Admiral Earnest J. King that "I am going to see that Marines never win another war."[37] Further, the Air Force expected post-unification control of naval aircraft. Forrestal admitted that he "could not agree to anything which would involve the destruction of the integrity of the Navy."[38]

As the one man more responsible than any other for "buying" the wartime Navy, Forrestal had an intimate understanding of public procurements and a keen intuition about how complex organizations work.[39] He had no illusions about the difficulties of administering operations on the scale which the war required. Forrestal advocated for a decentralized approach:

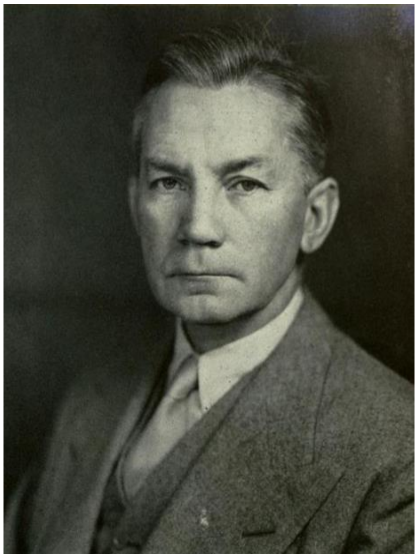
> "I would like to emphasize, as far as my opinion is concerned, and I offer it in all humility, that there are no easy solutions to a problem with so many facets as this. However it may be organized, the military effort will inevitably involve multitudinous forms of planning, procurement, production, transportation, communication, training, supply, and actual fighting. The problem is how to coordinate all of these grand divisions and all of their subdivisions.
>
> "There is one analogy which occurs to me out of my own experience in business. In the early years of this century following the formation of such great business enterprises as the United States Steel Corporation, the General Electric Co., and other large industrial concerns there was a vogue of consolidation. To some extent this was repeated in the 1920s. Some of those were successful, and General Motors is one I have in mind, and some were not. By and large, I believe that the economies gained through consolidation of administrative functions obviously seem bound to produce great savings, and therefore greater profits to the shareholders of the new combined enterprise; in actual practice it is frequently discovered that these probabilities that seemed so clear on paper were often difficult to transform into reality. You will recall that one architect of railroad consolidations, I believe it was Mr. James J. Hill, finally decided no one man could run more than 10,000 miles of railroad.
>
> "I think any executive of a great corporation resulting from consolidation will tell you how difficult it is to preserve the vitality and initiative of these units of the combination which, as separate entities, have those qualities. Once swallowed in the amorphous mass of a vast and new organization, they are apt to be hamstrung by the very inertia of size.
>
> "The point I am making simply is that size is no guaranty of efficiency. From my own experience in a small segment of the national war effort, I know how difficult it is to maintain contact with the individuals throughout the organization who really do the work. Organization charts are very fine things but they are of no value unless human beings, who have to make them work, have the necessary qualifications. Personally, whether in business or government, I would rather let the chart follow experience than the reverse."[40]

Forrestal made a number of important insights that countered the assumptions in McNarney's charts. First, he realized that local knowledge in complex organizations cannot be adequately centralized. Success required "multitudinous" plans and processes. The difficulty was ensuring all the parts pursued a common end.

Second, he pointed out the bias of overestimating the benefits of consolidation through economies of scale and underestimating the limits to the size of administration. Forrestal knew better than most. In his years on Wall Street, he earned the name "boy wonder" after he orchestrated his firm's takeover of Goodyear and Dodge.[41]

Third, and most importantly, Forrestal distinguished between seen and unseen costs. Consolidation may reduce the seen costs of duplication and overlap, but it may also reduce the unseen "vitality and initiative" of operational units. Continuing his antithetical arguments that re-cast duplication as a virtue, Forrestal again humbled himself before a select committee inclined toward unification:

> "There are certain things in the field of procurement where duplication has been, in my opinion, and again I say it very humbly, extremely wise. I think in certain elements of ordnance, and certainly in aircraft, the fact that there was a friendly competition in the types of aircraft gave the Navy dive bombers, and I do not believe we would have had dive bombing as either a material or as an art without it. Whether it is good or bad is a matter for the professional men to say, but I think the fact remains that without that competition you would not have developed the air-cooled engine to the extent we have. I am confident the Army would not have completely ignored the development of an air-cooled engine, but the fact remains the Navy believed in, sponsored, and pushed the development of that engine, and today I think it is fair to say that it is carrying and fighting a very large part of the war."[42]



James V. Forrestal,
Under Secretary of the Navy.

Forrestal again hammered the point of the unseen costs to defense unification, that many weapon systems, and military arts enabled by them, would go undeveloped. And this time Forrestal struck at the heart of the matter. Instances of so-called duplication had really taken different approaches, often based on conflicting concepts of war or technology. The Navy "believed" in dive-bombers and air-cooled engines whereas the Army Air Forces did not. The resulting success is less relevant than the fact that different opinions were not only heard, but fully pursued.

The unified direction proposed by the Army meant selecting the single best opinion or approach. However, under the fog of war and technological uncertainty, prudence suggests taking a diversity of approaches that only appear inefficient in the traditional business sense. A subsequent statement by J. Carton Ward, Jr., President of Fairchild Engine and Airplane Corporation, expanded on the idea of unseen costs. He found competition within government procuring agencies created desirable outcomes, particularly in naval aircraft. The supposed duplication put the U.S. on a strong footing:

> "During my service abroad on these several missions I found that none of the countries, to whose records I had any access, had what I call a strong naval air arm that would compare with what has been developed in the United States. In discussing problems with some of the naval officers of these countries it was their point of view that, as they were set up in their respective governments' procurements, they were generally dominated by the point of view of the biggest procurer of planes, which was the Army; so that the peculiar and specialized requirements of naval weapons was given a low place on the agenda.
>
> "The result has been I think, as you gentlemen know, that the British Navy today is relying heavily upon American developed naval air weapons."[43]

The committee members appreciated the arguments for decentralization and competition. Representative Dewey Short summarized the view. "As an example, neither the Army's football team nor the Navy's football team would have been as good a team if they had not had the other team to oppose. It is that healthy competition that develops it."[44] Likewise, decentralized procurement agencies created competition on the demand side that stimulated a diversity of innovation in ways a single monopsony buyer could not.

The view turned an earlier football analogy sideways. The problem, particularly for conducting "triphibious" warfare, appeared to be one of attempting to coordinate specialized military players by consensus rather than direction. Representative Maas characterized it in the following way: "If Yale produced only ends and Harvard only quarterbacks and Minnesota produced only guards, what kind of a football team would we have? And yet that is the way we are trying to fight the war."[45] Did the United States have one military team, or two, or more?

1.3 A bureaucrat's perspective

Striking back from the pro-unification camp nearly three weeks later was Harold D. Smith, Director of the Bureau of the Budget. As a lifetime bureaucrat, Smith could put meat on the bones of the Army's position for a single administrator. He answered two unresolved questions.

First, why would a centralized organization employ technical solutions more efficiently than the current bottom-up process? Smith didn't just want a unified budget; he wanted to reclassify the budget appropriations as well. In the earlier practice, budgets only exerted control over organizations, such as the Army Ordnance Department, and classes of objects to be bought, such as personnel, contracts, and construction. Budgets did not provide unified control over plans and activities, just the means through which they would be accomplished. Smith's recommendation had budgets submitted by program, allowing a single administrator to spot duplication and measure the cost effectiveness of military outputs.[46] The idea of linking plans with programs with budgets was an extension of previous budgetary reforms from the turn of the twentieth century.[47]

Second, why couldn't a board of participants from the Army and Navy coordinate the program budget? Smith saw that board members, who tried to maximize their service's interests, acted as both advocate and judge regarding the distribution of resources and projects. Budget Director Smith testified that "The boards have suffered from lack of authority and from the natural tendency of the board members to function primarily as the agents of their respective services rather than as representatives of an over-all point of view… the boards seem bound to develop even more into polite trading mechanisms."[48] In other words, the boards would transform into "horse trading" pits where the services divvied up resources.[49] Inter-service compromises were largely viewed as inferior to the decisive action of one side alone. A single administrator would avoid the rivalrous pitfalls of the boards.

After hearing 28 witnesses between April and May 1944, the committee refused to take immediate action on military unification. Chairman Woodrum wrote, "The committee does not believe that the time is opportune to consider detailed legislation which would undertake to write the pattern of any proposed consolidation, if indeed such consolidation is ultimately decided to be a wise course of action."[50] Though the topic was tabled, it succeeded in receiving the high-level attention the Army desired. Two major reports presented just months after the war's end would frame the discussions to come.

1.4 Postwar proposals

Closely following the end of combat, Major General Lawton Collins presented the official War Department position regarding unification on October 30, 1945. He explained that the plan was a reworked version of what General Marshall and the Army had been working on since 1942. Indeed, it was the culmination of decades of organizational theory along two interrelated threads. The first thread came from public administration theory, introduced to America by a young Woodrow Wilson in 1886. It was based on German concepts of neutral experts, clear lines of authority, and hierarchy. Bureaucracy, at the time, rang thoughts of efficiency.

The second thread came from the botched operations of the Spanish-American War, particularly the state of confusion in Tampa Bay during the Army's disembarkation. In response, Secretary of War Elihu Root advocated the general staff concept used by the Germans in his 1902 Semiannual Report. The general staff was a reaction to the difficulties of administering increasingly large organizations in a straight-line hierarchy. The top administrator had to synthesize so much information to tie the disparate pieces together that he required a staff to help plan and coordinate. In fact, the general staff implemented in February 1903 subsumed the technical services as "special staff organs."[51] Yet until the 1942 Army reorganization, the general staff was largely on the losing end of a struggle to wield their legal authority over the autonomous technical services.

McNarney's organizational plan presented at the Woodrum Committee exhibited a neat hierarchy, but did not provide the Secretary for the Armed Services a large staff of his own in order to effect economies and improvements.[52] The fact that it closely resembled the actual Army organization during the war turned out to be a major defect, an internal study found. The Patch Board concluded that staff planning from the top, like the OPD, "should not again become devitalized as it had during the war… The old theory that a staff must limit itself to broad policy and planning activities has been *proved unsound* in this war."[53]

As a result, the Collins plan moved the focus of the staff from the service Under Secretaries to the Secretary himself. The Secretary's large staff would consist of "functional" Assistant Secretaries who, in addition to making general policy for the services, would supervise military operations, research, procurement, and hospitalization.[54] The role of the service Under Secretaries, however, became unclear with many of their administrative functions being shared with the Assistant Secretaries. The organizational concept would later become known as the "active" or "functionalist" view of defense management.

A Navy report on military organization was released on September 30, 1945, a month before Collins. It was presented to then Secretary of the Navy Forrestal by his friend Ferdinand Eberstadt. While the report that came to bear his name disapproved of unification, it at the same time approved the need to centralize decision making.

The Eberstadt report found that competition often created duplication and other problems, stating that "there was a significant absence of centralized control."[55] In this respect the Navy did an about-face from little over a year ago; the inefficient and duplicative aspects of competition were stressed over its effective and innovative aspects.[56] However, the report viewed the primary method for coordination coming not from a single point of authority, as with the "active" view, but from a political process. He envisioned an organization where service representatives voluntarily coordinated their plans and programs. The boards and committees would serve largely the same functional roles as the Assistant Secretaries, but with democratic deliberations.

Eberstadt wanted to keep the focus of staff work at the service level, as had been the case during the war. The service staff officers would wear "two-hats" by also serving on joint boards. Compared to unification, the report found how voluntary coordination "is more in line with the principles of our Constitution, our customs, and our tradition."

Perhaps curiously, the Eberstadt report also supported a unified program budget. It directly quoted Budget Director Smith's testimony from the Woodrum Committee.[57] The Eberstadt report found merit in a mechanism for unification precisely because it too saw the logic in eliminating waste and duplication. However, budgetary reforms were not yet emphasized by the Navy. In time, the evolving view of unification as a political process became known as the "passive" or "generalist" view of defense management.[58]

On May 31, 1946, the feuding Secretaries of the Navy and War wrote a joint letter to President Harry S. Truman about their compromises. In it, Forrestal wrote that "The Navy favors unification but in a less drastic and extreme form." He recognized "the need for a greater measure of integration than now exists," but not a "single military department."[59] The Navy could tolerate unification if it left intact the Navy's integrity.

1.5 National Security Act of 1947

Congress largely favored Eberstadt's "passive" view, writing much of it into law in the landmark National Security Act of 1947. Only on unification itself did the act strictly side with the Collins plan over the Eberstadt report, though other provisions made it unification in name only.[60] The unified National Military Establishment would operate under the "general direction, authority, and control" of a single Secretary of Defense. It charged him to "eliminate unnecessary duplication or overlapping in the fields of procurement, supply, transportation, storage, health, and research."

Despite the apparently broad mandate given to the new Secretary of Defense, the act limited his administrative powers by reserving for the services all powers not expressly provided. The services "shall be administered as individual executive departments by their respective Secretaries and all powers and duties relating to such departments not specifically conferred upon the Secretary of Defense by this Act shall be retained by each of their respective Secretaries."[61] As the Navy wished, the Secretary of Defense would take a coordinating role. He had little power to eliminate duplication. The Marines avoided becoming "merely another arm" of the Army, and the Navy retained control of its naval aircraft. Moreover, with promises of harnessing business efficiency concepts, the Air Force was able to break away from the Army to create a third service.

President Harry S. Truman signs the National Security Act, 26 July 1947.

President Truman at first sought to appoint the Secretary of War, Robert P. Patterson, to become the first Secretary of Defense. Patterson refused due to his perception that the position lacked the power to effectively administer the services.[62] Truman then somewhat ironically asked Forrestal, who accepted the position and was sworn in on September 19, 1947.

A pivotal test for the new Secretary of Defense came in 1948 with the development of the first unified budget for fiscal year (FY) 1950. Forrestal's advisors were horrified that he had not intended "to exercise any personal judgement over the 1950 budget."[63] McNarney, who then headed the Secretary's budget advisory committee, wrote a memorandum to Forrestal imploring him to establish priorities for resource allocation.[64] Forrestal's initial reluctance to provide coordination over the budget increasingly fell at odds with Eberstadt, who came to believe that the Secretary must use the budget as "one of the most effective, if not the strongest, implement of civilian control."[65]

1.6 Forrestal's challenge

The FY 1950 budget process demonstrated that coordination between the services using a unified budget required greater involvement by the Secretary than the "passive" view permitted. Each of the three services submitted requests on August 16, 1948, larger than the entire defense budget from the previous year. For example, the percentage increases over FY 1949 authorizations for the "Construction" appropriation were 720% for the Army, 826% for the Navy, and 837% for the Air Force. The Army requested an increase in the funding for the National Guard from $197 million in FY 1949 to $1,298 million in FY 1950, a 659% increase.

Early attempts at program budgeting and assigning ordinal ranks to the resulting programs revealed duplication and excess. Ranked 15th in the Navy's "indispensable" category for domestic items was the purchase of 53 acres of land for the Naval Academy. Ranked 49th was $5 million for expanded facilities at the Naval Academy. Ranked 233rd in the "necessary" category was $3.3 million for "rehabilitation and renovation" of the Naval Academy.[66]

"Padding" budget requests through inflated or duplicative estimates highlighted the failure of the Munitions Board and the Research and Development Board to determine program costs and priorities. General McNarney pointed to 35 different guided missiles of all types being developed by the services. He blamed the Research and Development Board for the "most fundamental of all deficiencies."[67]

It quickly became apparent that the boards' attempts to generate economies failed to achieve stated goals. The Research and Development Board sought to accumulate information on all R&D projects proposed by the services to develop an integrated program. 18,000 project cards were received but many did not indicate funding levels, and when they did, they were inflated. Different accounting standards and reporting requirements also made it impossible to compare what was actually spent on similar projects. Further, by the time the Board received the project cards, nearly one-third were completed, canceled, or superseded.[68] The Board came to "rubber stamp" most projects because its members preferred not to argue against project advocates with better information.[69]

Similarly, the Munitions Board encountered limits to rationalizing production and supply. Material specifications could not easily be standardized and aggregated into bulk orders. One observer noted how well large purchases of standard equipment worked in reality: "Motorized cranes and shovels on rubber tires are assigned to the Army, and identical cranes and shovels mounted on caterpillar tracks are assigned to the Navy. This makes sense to no one, least of all to industry."[70] The "ridiculous assignment" occurred because bulk-buy discounts also required additional layers of management to match the nuance of specialized operations. The Munitions Board staff doubled between 1949 and 1950 due to the increasing number of procurement decisions it had to make on behalf of lower echelons.[71]

While overseeing early developments in unification, Forrestal could not convincingly articulate the logic for decentralized competition. He struggled against widespread belief in rational management that focused on centralized planning. Forrestal pushed back against what he saw to be misguided idealism:

> "My chief misgivings about unification derived from my fear that there would be a tendency toward over concentration and reliance on one man or one group direction. In other words too much central control—which I know you will agree, is one of the troubles with the world today. A lot of admittedly bright men believe that governments, history, science and business can be rationalized into a state of perfection."[72]

As historian James Roherty described Forrestal, he "consciously sought to rely on the merits of a measure of 'disorder' at lower levels; the structure would not stand or fall on its organizational symmetry."[73] Yet Forrestal never clarified the link between "disorder" and military economy. Instead, he often invoked anecdotal experiences from Wall Street or the war as justification. For example, Forrestal pointed to the fact that the German military suffered from an over-application of central command. He found that during the war, the Germans used

> "a single and personal source of decision. It did not work successfully in the German war staff, in the German Government or, as the records of Albert Speer's testimony show, in German war production… The Germans, to some degree, were the victims of overplanning for

> the last war. That planning was probably more precise and more nearly complete than in the history of any other nation. But the unplanned American economy, once the issue was joined, was able to far outstrip them."[74]

Forrestal's thinking on the troubles of rationalizing government and the benefits of disorder remained abstract, lacked constructivism, and focused on his opponents' errors. As Richard Bellman of RAND Corporation would later write, "For those who are interested in becoming prophets with honor in their own time and in their own country, there is a fundamental principle which we may call the Principle of Optimism: *Never make negative predictions*."[75] Forrestal's obstruction to the positive attitude of his opposition would stain his reputation and ruin his health.

1.7 A curious change

Despite his colorful statements against centralization, Forrestal started working to increase the Secretary's control over the rivalrous services. In his first annual report, Forrestal recommended that the "statutory authority of the Secretary of Defense should be materially strengthened… by making it clear that the Secretary of Defense has the responsibility for exercising 'direction, authority, and control' over the departments and agencies."[76] To more ably make informed decisions on service programs, Forrestal established the Weapon Systems Evaluation Group in December 1948. It was to provide independent advice on resource allocation.[77]

Forrestal's efforts did not secure him enough clout to resolve inter-service standoffs, reportedly leaving him weeping at his desk.[78] President Truman, who remained close to such developments, asked Forrestal to consider Louis Johnson as a replacement in December 1948. On March 1, 1949, Truman asked Forrestal to resign.[79] It could have been in connection to a number of issues, including allegations of mental health issues or a meeting with Presidential rival Thomas Dewey. Truman gave him until June 1, but Forrestal wanted out by the end of the month.

With the end of his public service close in hand, an exhausted Forrestal testified to the Congress. He now supported an amendment to the National Security Act seeking to significantly increase the power of the Secretary's office. Forrestal applauded the "economies" generated by "the consolidation of procurement," saying he lacked the power to take them further without an Under Secretary, a "sufficient number" of Assistant Secretaries, and a military staff of his own. Forrestal felt he had to explain such a complete reversal of opinion on his part for what may have been the last time:

"I would like to address myself briefly to what I believe may be the chief objection raised to the proposed amendments; namely, that these amendments would vest in the Secretary of Defense too great a concentration of power… After having viewed the problem at close range for the past 18 months, I must admit to you quite frankly that my position on the question has changed. I am now convinced that there are adequate checks and balances inherent in our governmental structure to prevent misuse of the broad authority which I feel must be vested in the Secretary of Defense."

When asked to describe those checks and balances, all Forrestal could muster was "I think the President and the Congress are the two great components in that system."[80] Forrestal almost immediately diverted questions to his legal assistant Max Leva. Four days later, on March 28, 1949, Louis A. Johnson was sworn in as the second Secretary of Defense.

Forrestal died on the top floor of Bethesda Naval Hospital on 22 May 1949.

Forrestal's mental health quickly deteriorated. His concerned friends flew him to Robert Lovett's winter home in Florida for rest. Forrestal, however, insisted the beaches were covered with hidden microphones. On April 2, he was flown back to Bethesda, Maryland, where he checked into psychiatric treatment. Within two months, he died.[81]

The life of James V. Forrestal had something of a cinematic aspect to it. From his stellar rise on Wall Street and in Washington to his downfall precipitated by tragic character flaws, the story is completed with rumors of Forrestal's assassination by secret conspiracy. The irony of centralization's leading opponent becoming its champion is repeated in defense by numerous policy makers. Another example of this pattern came from Forrestal's friend, Ferdinand Eberstadt. By trying to preserve the identity of the decentralized services while advancing civilian control, Eberstadt sought to centralize the budget. If the experience of the FY 1950 budget helped change Forrestal's thinking on unification, it also affected Eberstadt's.

2. The Program Budget

> … in my mind, I equate planning and budgeting and consider the terms almost synonymous, the budget being simply a quantitative expression of operating plans.
>
> Robert McNamara
>
> Congressional testimony, 1961

Ferdinand Eberstadt was born in 1890 to German immigrants living in New York City. Those who knew him growing up called him “Manny,” or, “little man,” because of his slight figure. However, during his years at Princeton, Eberstadt earned a new nickname, “The King,” due to his strong personality and numerous campus activities. It was at Princeton that Eberstadt forged a lasting relationship with James Forrestal, the man who brought him into the civil service immediately after the Pearl Harbor attacks. During World War II, Eberstadt earned respect throughout Washington for his sharp mind, tireless work ethic, and perhaps above all, for his connection to the Controlled Materials Plan.

The first wartime task Forrestal assigned to Eberstadt was a study on the Army-Navy Munitions Board organization. The effort propelled Eberstadt into the role of its chairman, and brought him into conflict with the civilian War Production Board (WPB). He saw the Munitions

Board's primary duty as determining military requirements for production, which required an effective material allocation system.

David Novick at the WPB had been working on such an allocation system based on plans from the First World War. The Production Requirements Plan (PRP) got underway late in 1941, calling for each manufacturer to estimate their total requirements for scarce metals. The PRP's "horizontal" method of control had WPB offices deal directly with every manufacturer regardless of its place in the production chain. Further, each estimate was broken down into various types and shapes of metals, leading to a "tremendous inflow of paper."

Because the estimates made no reference to the ultimate purpose it served, the WPB found that it had no basis on which to prioritize allocations. The "impossibility of selective cuts" broke the link between policy and allocation. It drove manufacturers to inflate their estimates in anticipation of across-the-board cuts. The director of the WPB's Copper Division said that the PRP was a "silly plan… whereby a claimant for material would dream up what he would like to have and put in a claim for it." The total requests for copper totaled nearly three times the world's supply.

Eberstadt quickly saw how the WPB attempted to administer the entire allocation mechanism rather than providing top-level policy. As early as March 21, 1942, Eberstadt made his displeasure with the PRP clear. By May 28, he had gained approval from Forrestal to study the matter.

Ferdinand Eberstadt working for the War Production Board, October 1942.

2.1 The Controlled Materials Plan

In collaboration with numerous WPB staffers, Eberstadt put forward the Controlled Materials Plan (CMP). The CMP was a "vertical" allocation mechanism where the WPB allocated large blocks of materials to major claimants, such as army, navy, aircraft scheduling, lend-lease, and various civilian departments. The top-level claimants would in turn divide the materials among their subdivisions, themselves prioritizing across prime contractors, and so forth down the production chain. Estimates for materials flowed upward, classified by program, providing each level of the production chain the necessary information to prioritize its downward allocations.

On November 2, 1942, Eberstadt formally presented the CMP to the Congress and its implementation quickly generated efficiencies. Forrestal later commented that "these programs, destroyer escorts and landing craft, in my opinion, could not have been accomplished—neither could have a good many others—without Eberstadt's Controlled Materials Plan." Though Eberstadt could not claim sole authorship of the CMP, he more than any other was its "Godfather."[82]

The CMP clearly reflected the principles of public administration that Eberstadt learned at Princeton.[83] From 1909 to 1913, Eberstadt attended Princeton just as Woodrow Wilson's influence on the school and the nation accelerated. One of Wilson's most important scholarly contributions was to separate policy, or the "broad plans" of an organization, from administration, or the "detailed execution of such plans."[84] Wilson sought to clearly separate politics from administration because he wanted to bring the "nearly perfected" techniques of German bureaucracy to the U.S. without threatening constitutional democracy. The goals and objectives of government would still be determined democratically, Wilson argued, but the detailed execution would be performed according to scientific principles of administration.

The CMP is properly viewed in the context of the dichotomy between policy and administration, though it was policy generated within the administrative hierarchy and not from above. The CMP allowed the War Production Board to determine broad policy by allocating resources across major government claimants. The concept rested on the fact that there existed a one-way direction from setting goals to executing goals; that planning programs could be performed outside the context in which programs are accomplished. It also rested on each claimant having mutually exclusive activities in order to avoid duplication or overlapping responsibilities. While the CMP created some inefficiencies—including a bias against small businesses at the bottom of the allocation mechanism—it greatly improved on the existing PRP by decentralizing the administrative detail without losing the information to set meaningful policy from the top.

It is difficult to underestimate the impact of the Controlled Materials Plan not only on Eberstadt's reputation, but on how Americans viewed central planning.[85] If the Great Depression proved that markets failed, then the war effort and the CMP proved that central planning worked.[86] In many ways, the CMP provided a template for budgetary reform.

David Novick later wrote how the CMP was a particular instance of the program budget, tying together inputs and outputs through program elements.[87] Whereas peacetime program budgets allocated dollars, the CMP allocated scarce metals and tooling. Though Eberstadt made reference to the program budget in his 1945 report, the question of unification loomed larger. When asked to lead a study in 1948 on defense organization, Eberstadt gave the program budget a central role.

2.2 The Hoover Commission

President Truman commissioned Herbert Hoover to lead a study on the administration of the executive branch. Hoover then appointed Eberstadt to lead a "Task Force" devoted to defense on May 21, 1948. Yet the two men did not see eye-to-eye on an important matter. While Hoover intended to install functional Assistant Secretaries across the departments, Eberstadt saw them as a threat to the Navy. For Eberstadt, the democratic aspects of the board and committee structure seemed the only way to safeguard the Nany's land and air forces.

Eberstadt was convinced that the boards' failing was not one of organization, but flows of information. He found that board members could not develop military plans without reference to programs and costs. Budget appropriations only provided resource control in terms of organization and object of payment; they did not provide the control of military programs and functions. Like the CMP, the budget needed to be classified in a way that helped it set policy from the top.

In 1945, the Eberstadt report gave only brief mentions of the program budget. The report emanating from the Eberstadt Task Force on November 15, 1948, devoted more pages to budgeting than all other aspects of the Secretary of Defense combined. It explained that the budget process was the Secretary's primary means for establishing efficiency:

> "The National Security Act recognized the importance of the budget function and, in effect, made it the principal means by which the Secretary of Defense carries out his duties to establish policies and programs, to exercise direction and control, and to take appropriate steps to eliminate duplication and overlapping among the departments…
>
> "In the exercise of his power over the budget—by far the most important instrument of general management and control in the Secretary's hands—the Secretary will require stronger agencies of administration and review."[88]

Eberstadt believed that the budgeting system had "broken down." He argued that centralized plans could be accomplished through budgetary administration and review, without the need for administering operations themselves. It did not require functional Assistant Secretaries to exert the power of the Secretary. Instead, the program budget provided "the necessary information to key points at such time intervals that the necessary decisions can be made at each level in the complex chain."[89] With greater powers provided to the Secretary over the budget, Eberstadt hoped for the continuing viability of the democratic boards and a strong role for the service secretaries.

Eberstadt's Task Force did not seek to substantially grow the Secretary's enumerated powers despite making a stronger central authority its number one recommendation. Central authority, it was argued, could be exerted by the Secretary by establishing programs that reflected military objectives. With the military programs tied to resource control through the budget, the Secretary's policy plans would constrain the administration of the services.

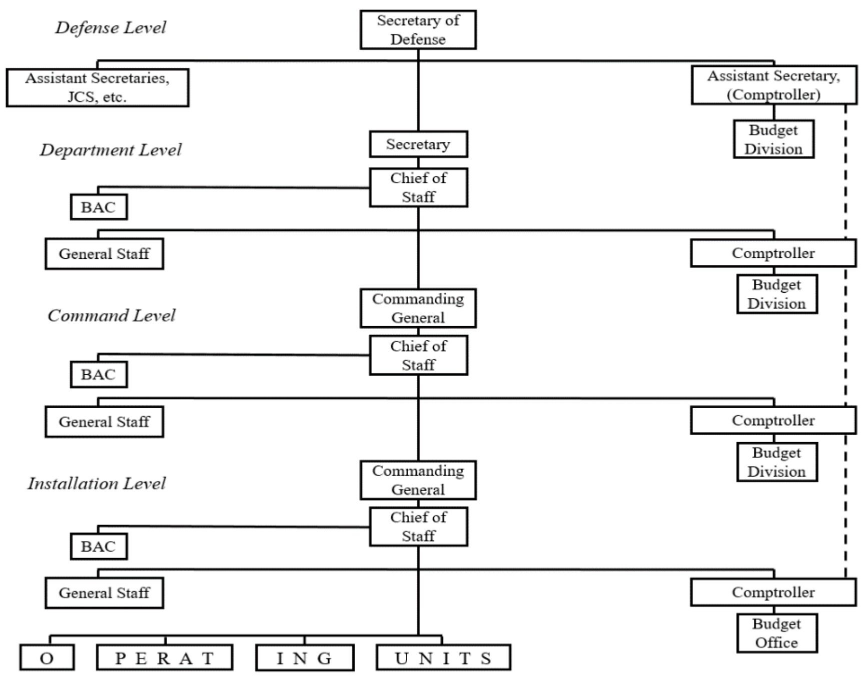
The Secretary must necessarily stand above the services to establish programs, but in the scheme, he does not need power to actively administer. Performance to the budget ensures the pursuit of centralized objectives. For Eberstadt, the Secretary of Defense should not need much more than "the power 'to exercise direction and control' over the preparation of military budget, instead of his present right simply to 'supervise and coordinate.'"[90]

In its own report the Hoover Commission agreed with the urgency of a program budget, and in a bit of marketing renamed the concept the "performance budget." The report recommended more than budget authority, which was all Eberstadt believed the Secretary needed. The Hoover report made its top recommendation that "full power over preparation of the budget and over expenditures as authorized by Congress be vested in the Secretary of Defense."[91] Power over expenditures meant the power to make decisions at the operating level. It meant deciding how programs would get accomplished. Eberstadt, however, did not believe that administrative powers were necessary for the Secretary to achieve his policy objectives.

Hoover wanted to take all statutory authority previously dispersed across the various boards and three services and vest it in the Secretary of Defense. The Secretary would then use the services to exercise his line authority and the board functions as his staff authority. With all statutory powers vested in the Secretary of Defense, he could adjudicate authority to the Service Secretaries and Assistant Secretaries as he saw fit. Further, the model maintained the vaunted unity of command concept, where all authority and responsibility flowed through a personal authority.

Eberstadt personally saw to writing the budget reforms into legislation. He proposed a new Title IV with the optimistic name, "Promotion of Economy and Efficiency Through Establishment of Uniform Budgetary and Fiscal Procedures and Organizations." Without representation from either the Army or the Air Force in its preparation, and little debate before Congress, Title IV was added to the National Security Act. It created an Office of the Comptroller, who doubled as an

Assistant Secretary of Defense (ASD). The Comptroller was charged with budgeting, accounting, progress and statistical reporting, administrative organization, and managerial procedures. The act provided for parallel comptroller offices in each of the services. Eberstadt was pleased that Title IV avoided the "long and sometimes acrimonious" debates before Congress. In his view, there was "an extraordinary, and almost complete unanimity."[92] The passage of Title IV, however, proved only to compound the existing confusion of authority and responsibility in defense organization. It began an on-and-off struggle between the military chiefs of staff and the civilian comptrollers.



Reproduced figure from Frederick C. Mosher (1954), titled "Organization for Budgeting in Army and Air Force." Note the separation of the Comptroller's office from the Budget Advisory Committee (BAC) and General Staff which provided the substance of the budget.

While the Comptroller reported through the Chief of Staff, he was also responsible to the Assistant Secretary of Defense (Comptroller) as represented by the dashed line of authority.

2.3 A budgetary examination

In a book entitled *Program Budgeting: Theory and Practice*, Frederick C. Mosher analyzed the Title IV budget reforms. By the time of the book's publication in 1954, the forty-year old Mosher already had a prolific career as a scholar-practitioner. Mosher was born into public administration "royalty." His father was a respected administrative scholar and school dean. Mosher's practical experience came from working for the City of Los Angeles, the Tennessee Valley Authority, and the Army Air Forces. His scholarly pedigree came with a Harvard diploma, a Syracuse professorship, and a role as lead editor for the *Public Administration Review,* during which time he published *Program Budgeting.*[93] Mosher emphasized the fundamental changes brought on by the budget reforms:

"[The performance budget] represents a quite radical departure from previous practice and previous ways of thinking. It is simply that when we budget and authorize funds we are providing for things to be *done* rather than for things to be *bought.* Moneys are furnished for activities and functions rather than for purchases and payments. Almost our entire experience and heritage in governmental financial control is the other way around. In a sense, this amounts to substituting ends for means as the focal point of financial planning and control.

"For example, performance budgeting might require that funds for basic training be estimated on the basis of the total numbers to be trained and the over-all cost of training each man, in contrast to previous practices of assuming the training goal, then adding up the salary, supply, and contractual costs to reach the goal. Congress would thus exert control on the number trained, the quality of training, and the total cost per man, rather than on the number and salaries of positions filled.

"The difference is not merely one of technique and method; it is a basic departure in way of thinking. It is not surprising that the performance budget has not been accomplished overnight. Not only must new estimating methods and control techniques be developed; the very minds of the citizen, the Congressman, and perhaps most of all, the administrator must be trained to think in different terms. For all of our history—and long before it—we have conceived of financial management in the accounting terms of items to be paid for rather than of programs to be accomplished."[94]

Mosher highlighted how program budgeting changed the nature of decision making from the top. It expanded financial control from broad resource classifications to technical direction. The increased power of the budget also transmitted greater authority to the comptroller.

Mosher explained how program budgeting became associated with the comptrollership. In the medieval period, the comptroller primarily referred to the government function for keeping "a copy of a document to check against the transactions of a treasurer or other official." American businesses picked up on the concept toward the end of the nineteenth century due to their increased "emphasis upon cost, dollars, careful planning, and allocation of resources."

For providing centralized management over increasingly large scale operations, the comptroller was a "made-to-order" answer. First, the comptroller relied on facts and figures rather than personal interest. Second, the comptroller's office was already the focal point of all resourcing information.[95] As scholar David R. Anderson wrote in 1949:

"From the standpoint of the sound business organization it would seem almost self-evident that the chief accounting officer is the logical person to assume responsibility for providing management with the information it needs to plan and control operations. It is his duty to construct and maintain the basic records of the business, in which the results of all operations are recorded and summarized; and, because he has no line-operating responsibility, he is in a position to report and interpret objectively the data available in those records."[96]

Comptroller duties in the business sector varied "all the way from simple responsibility for the accounts and records to those of a senior operating executive." The expanded functions of management, policy, and planning were often associated with the term "controller" instead of "comptroller."[97] For example, the business controller concept implemented at General Motors in the 1920s used program budgets to plan resources by car model five years into the future.[98]

The controller became a fast track to top management. As a controller at Ford, Robert McNamara experienced a stellar rise to become corporate president just before his appointment to Secretary of Defense in 1961.[99] Mosher explained how controllership made its way to the government and highlighted some potential problems:

"Controllers grew up to meet the demands of increasing complexity and bigness in private enterprise. In that realm, they have proven useful. The defense of the United States has often been called the biggest 'business' in the country. In fact, each of the military departments is bigger, by almost every measure, than any private enterprise. Therefore, so the logic runs, they should have a controller.

"The flaw in this reasoning is that… the controller epitomizes, in an organizational sense, the supremacy of objective facts and figures in business management, and the recognition, as the ultimate criterion of success, of the profit and loss and balance statements. Where objectives and accomplishments can be *technically measured,* there is reason to juxtapose or even identify the technique with policy and program determination. But where they cannot be, such a relationship may well constitute a triumph of technique *over* purpose.

"In less cryptic terms, such an application of the controller concept may contribute to: the elevation of subsidiary purposes, which are measurable, over primary purposes, which are not measureable; the emphasis in program and performance upon activities where a 'showing' can be demonstrated and proven by 'facts and figures'; the application of techniques to situations

> and problems for which they were not designed and are not suited; the incentive to show short-range economy in lieu of long-range effectiveness."[100]

Controllership sought the scientific management of complex operations using facts and figures to optimize business plans. The concept assumed the controller could not only collect relevant facts, but he could interpret them and direct policy improvements based upon them.[101] While traditional comptrollers had a foundation in accounting and record-keeping, the expanded business controller also served as policy-maker with quick access to the top administrator. In the role, the controller's ability to administer is in direct proportion to the suitability of program performance to technical measurement. When programs can run on a profit and loss basis, or where "returns" on capital expenditures can be calculated, then the controller may have suitable information to administer operations. However, the difficulty of measuring the value of government programs means that the controller has only unsatisfactory metrics, which, if they were strictly measured against, may lead to unintended consequences. Ultimately, an improper use of the controllership would harm the organization's true interests, which are imperfectly approximated by controller metrics. The view is summarized with the truism of how no unit that has seen combat has ever passed a readiness inspection.

2.4 The comptroller

In many ways, the authority of the controller and the program budget are intimately tied. The controller's authority over the program budget is the springboard for his authority over programs and plans. Mosher wrote that "The budget in government agencies, and particularly in the military, is the master "controller" (used in the generic sense) of virtually everything that is done."[102]

The practical authority of the controller to shape policy then depended on his ability to shape the substance of the budget. At the time of Mosher's writing, the full business controller concept had not yet made its way to defense. Mosher often noted, particularly for the Army, that the comptroller's jurisdiction did not extend to "amending the programs or policies which provide the substance of the budget."[103] Comptroller staff primarily concerned themselves with the procedural aspects of budgeting.

The comptroller's authority over the program budget presented an "inconsistency" to Mosher. He noted that the "planning and forecasting" functions associated with the budget differed entirely from the "essentially backwards-looking functions involved in almost all the rest of the organization. Accounts, records, audits, management audits, reports, and program analysis all have to do with what *is* and what *was*."[104] Mosher reasoned that if the budget was primarily a historical document that projected forward past rates of expenditures, then it belonged in the hands of the comptroller. If, however, the budget was primarily a future plan, then it belonged with the organizations responsible for executing the plan. Clearly, Eberstadt and Hoover intended the performance budget to reflect military plans.

Just days before the Title IV Congressional hearings, Don S. Burrows rationalized the program budget's ties to accounting in the *Harvard Business Review*.[105] Unlike Mosher, Burrows believed that government programs could be measured. He advocated the budget "as a measurement of government programs, similar to the use of the profit and loss statement as an index of the success of private enterprise… Every program has an end-product which is in some fashion measurable." He wrote that all program funding must be "justified" by explaining the "work units, the methods of computation, and the necessity for the sums requested."

Burrows argued that the comptroller must look to historical data to support future decisions. For the controller to have adequate information for setting realistic program performance targets, he needed competence in accounting to generate baseline expectations to measure against. Justified programs first required "an accrual method of accounting" to "establish costs on a program or activity." Program budgeting works only when there exists programmatic accounting. With both budgeting and accounting under his purview, the relevant question for the comptroller is whether he merely reviews budgets and checks-up on accounting progress, or whether he actively formulates budgets and controls expenditure decisions.

Eberstadt intended ASD Comptroller to exercise the full business controller concept, and further, believed it should represent civilian interests. Eberstadt lamented that "We hear many pious statements about civilian control… but not so much as to precisely how and where civilian control should be exercised." Eberstadt intended the budget as the precise point of civilian control using "continuous year-round scrutiny" from the "early planning stages through appropriations and expenditures." Mosher understood how budget reforms were closely linked to the question of civilian authority over military operations:

> "Civilian control cannot, in fact, be separated from the problem of unification. The rise in the power of the Comptroller of Defense *vis-à-vis* the Joint Chiefs of Staff may properly be considered from this standpoint, as may the position of the Comptroller in relation to the three military departments."[106]

Eberstadt made clear to Congress on which side he stood. "If everybody all along the line was responsible only to the Comptroller of the Department of Defense or to the Secretary," Eberstadt testified, the program budget "probably would have been easier to put into effect."[107] The programs intended by Eberstadt were not limited to matters of procurement, but military operations as well.

A compromise was struck during President Eisenhower's administration. The Secretary of Defense, assisted by the ASD Comptroller, provided a budget ceiling to each of the services. The services then had free rein over further allocations.[108] General Maxwell Taylor summed the process up well: "We put a sack worth about $40 billion in front of four very earnest men and ask them to split it up."[109] Within the services, Eisenhower allowed for the chief of staff to handle military commands and the service secretary to handle the technical and administrative services. The comptrollers, now solely responsible to their Service Secretaries, took a growing role over R&D and procurement decisions.[110]

At the recommendation of the Rockefeller Committee in 1953, Congress abolished the statutory boards. In their stead, the Secretary of Defense was provided nine functional Assistant Secretaries. While the Rockefeller Committee clearly did not intend the Assistant Secretaries to have legal authority over the service secretaries—they were to advise and assist the Secretary of Defense only—in practice they had direct influence over service decisions.[111]

As the end of his second term approached, Eisenhower campaigned to legalize the practice where Assistant Secretaries by-passed the service secretaries. In 1958, Congress passed a Reorganization Act that created the position of Director, Defense Research and Engineering (DDR&E), a civilian staff organization with line operating authority. The weapons procurement functions were placed under DDR&E and the military functions put into unified and specified commands answering to the JCS. The 1958 reorganization greatly diminished the role of the service secretaries.

2.5 Substance of the budget

Maintaining clear lines of authority and responsibility has long challenged complex organizations. The shift to program budgeting, however, injected additional confusion into the Department of Defense. Eberstadt took the lead on writing sections 401 and 402 of Title IV, which created the controversies over the organizational standing of the comptrollerships. He had help on the more technical aspects of comptroller functions in sections 403 onward.[112]

The help primarily came from Wilfred J. McNeil, who was Forrestal's fiscal director in the Navy. He later became ASD Comptroller for the next five Secretaries of Defense. McNeil's primary interest in the performance budget stemmed from his belief in the need for a more business-like Pentagon. To McNeil, that meant aligning financial responsibility with administrative responsibility. In other words, an administrator responsible for some military program should report to one higher authority and receive one source of funding from that exact same authority. The existing problem, as McNeil found it, was that budget appropriations had functioned in terms of object of payment, such as salaries, transportation, recruiting, facilities, and so forth. Not only did the budget appropriations conceal the goals and activities of the organizations, they placed arbitrary constraints on how managers spent funding.

The Navy's Bethesda hospital in Maryland became a notorious example. Hoover himself testified before Congress that the Bethesda hospital "receives allotments from 12 different appropriations and nowhere is its total cost shown."[113] Those 12 appropriations are further divided into hundreds of sub-appropriations. As McNeil recalled in plain language:

> "In years past the budget required a separate appropriation for water coolers; a separate appropriation for newspapers; separate appropriation for travel; separate appropriation for certain civilian hire; but nowhere could you tell what a function cost. Nowhere could you tell what the operation of a hospital cost. In other words, 269 pots of money it took to operate the hospital at Bethesda. A little money here for fixing a fence and a separate appropriation for this and that. To run the Task Force One to test the A-bomb out at Eniwetok, it took 189 pots of money."

McNeil recognized that in order for the director of Bethesda hospital to manage effectively, his medical organization should be funded through one primary appropriation. This provides Bethesda's director the financial authority to parallel his administrative authority. It also implied that medical care will be a primary program of defense. The classification of budgets by program, and alignment of organizations with programs, was the first step to McNeil's business goal.

The larger vision was to identify programs that segregate the technical services from the operating forces. "That by doing so," McNeil said, "you have a supplier-consumer relationship."[114] Ultimately, he wanted to establish a competitive system where the suppliers (technical services) would bill the consumers (military commands) for goods and services. The system sought to generate market-like prices.

As part of that system, any common stock used by multiple programs would be allocated to working capital funds. When stock is consumed for an operation, the working capital fund allows for a "clean-cut charge" to the proper programs. The organization also helped achieve efficiencies provided through single inventories and bulk-buy discounts. McNeil summarized the performance budget for the Congress in 1950:

> "After the determination of what constitutes a logical and identifiable program, there would be a logical and so far as practicable, uniform grouping of projects or budget programs by primary functions, with this grouping paralleling so far as possible the organization and management structure of the military departments. Next, there would be a segregation between capital and current operating categories. A further consideration in determining the programs to be adopted by one of the military departments was that those selected should lend themselves to comparison with similar programs of the other two military departments.
>
> "Management is handicapped when fiscal responsibility is diffused. The financing of an identifiable program from a single source of funds clearly fixes management responsibility, simplifies reporting and permits departmental management and the Congress more easily to determine costs and to evaluate programs."[115]

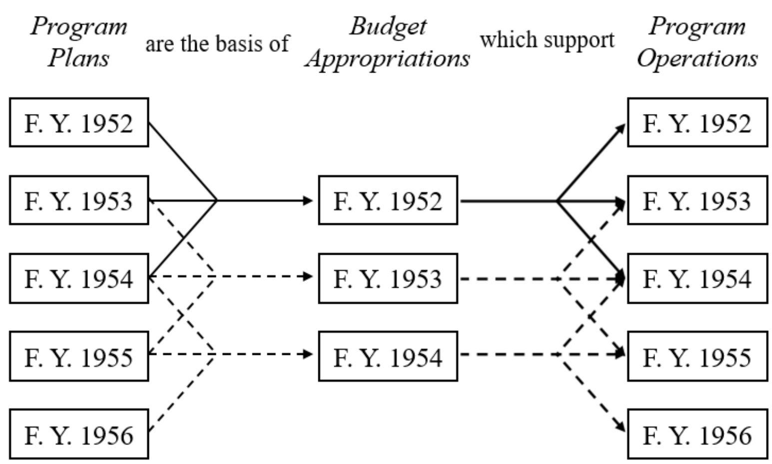
To McNeil, the performance budget radically simplified the budgeting process. Channels of money flowed alongside administrative channels. Even though the Navy secretary wrote that the program budget "involved a complete change in the pattern of appropriating," he expected it to provide "substantial improvements in the management of the Department."[116] When questioned on how much time and manpower the performance budget saved, McNeil said that during the change-over year it will create a "double load" because of "information coming through the channels in the old categories" as well as the new. However, the future should see great reductions in the time spent in the budget process.

It turned out that the double load of the change-over year did not go away because the budget never fully changed over. Mosher explained why the performance budget turned out to be "extremely difficult budgeting," and claims of its simplicity a "delusion." He identified two "inherent problems" of the performance budget: the problem of time and the problem of classification.

2.6 Problem of time

The problem of time in a performance budget is twofold. First, the up-front programming process forced another layer of planning on top of the traditional budget process. Programs had to be articulated two years in advance of funding receipt in order to accommodate the one year allotted to budget preparation and review. Mosher found that the added lead-time "makes program budgeting at the average installation virtually impossible for the simple reason that it does not have program information that far in advance."[117]

Second, it often takes several years for the agencies to spend authorized funding. "Budgets," Mosher explained, "by and large are requests for appropriations which in turn are authority to obligate funds." Obligated, or guaranteed, funds may take additional time to be spent. "Some of the funds will be spent during the budget fiscal year. Others," he continued, "will not be expended until one, two three, and in a few cases more years after the fiscal year." While the practice provides some "short-range advantage" by assuring at least partial program funding for the on-coming years, it also creates problems.



Reproduced figure from Mosher (1954) showing the problem of time associated with budgeting. Current and future program plans are the basis of budget appropriations which support program operations for several years to come. Note that the program plan for F. Y. 1952 is to be developed during F. Y. 1950, allowing a one year of additional time for the budgeting process.

When program budgets have long outlay periods, operational objectives become fixed for several years. The funding was authorized to a specific program task. It cannot be easily redirected to new or changing priorities. Moreover, when program elements are interrelated, the budget estimate for one program element constrains the estimates for the other programs. With systemic effects, the lock-in problem for one problem cascades to other programs. Mosher reasoned that "Much of the budget is beyond recall," particularly for programs that require long-lead times such as R&D and weapons procurement.

The problem of time forces program plans—the course of operations—to be set two years in advance of funding receipt, and potentially six or more years ahead of actual expenditure. The logic of the performance budget rested on the accuracy and integration of predictions. Program planning must incorporate “long range objectives and estimates of forces” in order to adequately account for the lock-in effect it will create on subsequent years. Mosher concluded that the performance budget was subject to greater “uncertainty and probability of error.”

2.7 Problem of classification

The problem of classification is another way of describing the misalignment of organizations and programs. Mosher made clear that the “avowed theme” of the performance budget was its effort to develop budget classifications based upon “identifiable functions, programs, and kinds of work, rather than upon organizational units and objects of payment.” Mosher examined a couple of important questions about the new budget classification. First, does it lead to an alignment of fiscal and administrative authority as McNeil promised? Second, is it proper for segregating capital from operational expenses?

First, the performance budget only aligns fiscal and administrative authority when lower-level organizations fulfill a single function in terms of the program structure. Mosher illustrated the point in connection to Bethesda hospital, the Hoover Commission’s “almost classic example of performance versus old-style” budgeting. He wrote that for the hospital to have one source of funds, the performance budget would logically necessitate medical care to be a primary program appropriation. The fiscal and administrative responsibility for Bethesda Hospital then flows through the Surgeon General in connection to the medical program. It would not flow through the military line of command.

In the case of Bethesda Hospital, a single function organization, the organizational structure and the program structure exactly paralleled each other. Yet the outcome of exact alignment is the exception, not the rule. Mosher pointed to the example of Fort Benning, whose commander is in charge of a multi-function organization. The commander should plausibly have all his functions funded through a single source. However, in support of its military operations Fort Benning also includes a medical facility. Here’s the crucial question Mosher posed. Does the head of the medical facility report through the Fort Benning’s commander and his military program, or through the Surgeon General and his medical program? If the former, the Surgeon General loses control of the medical care program, the total cost of which is not under his appropriation. If the latter, the commander at Fort Benning—a multi-function organization—begins to lose all control over his subordinates with each of them reporting to a different program and boss. Mosher demonstrated how the same issues in medical care extended to military personnel, training, installation support, and perhaps most of all, the technical services, whose operations supported nearly every identifiable military program.[118] The performance budget produced the same outcomes McNeil sought to eliminate, the diffusion of financial and administrative responsibility.

Second, the performance budget is at "cross-purposes" with separating capital and operational expenditures. Programs inevitably require both capital investment and operating expenditures. The situation leads to "knotty questions of definition." This is even true when programs are designed to segregate the two. For example, the budget appropriation "Major Procurement and Production Costs" included aircraft, ships, artillery, and guided missiles, but it also included "expendable" items such as ammunition. On the other hand, "the various appropriations for maintenance and operations cover a very large amount of procurement, including equipment items of long life expectancy and usefulness." Reorganizing the budget appropriations only led to contradictions in different forms.

The problem of segregating capital from operating expenses traced back to the multi-functional nature of organizations. Returning to Bethesda hospital, it was for budget purposes considered a single-function organization because it perfectly aligned with the medical care program. However, when the hospital includes both capital (such as medical R&D or equipment) and operating expenses (such as patient services), it turns back into a multi-functional organization. Segregating programs based on their capital or operating nature still forced multiple funding upon Bethesda hospital. Even where capital segregations are logical, Mosher concluded that the practice "directs the reviewers' attention again to an item-by-item and project-by-project analysis, only distantly related to program objectives."[119]

2.8 Effects on service organization

The consequence of misaligned structures for organization and program severely hampered effective administration. As has been shown, multi-functional organizations support several logical programs. Each service handled the problems in different ways.

The Navy chose to compromise the budget's program structure rather than carry out its intent. Navy programs were molded around the existing structure of its bureau system. Mosher wrote that "Each bureau was given one or more appropriations over which it has virtually exclusive jurisdiction… The fundamental basis, therefore, is organizational rather than programmatic; the result is a classification that is functional in the same degree that the organizational bureaus are functional." By interpreting programs along organizational lines, the budget perpetuated duplication across organizations.

The Navy's Bureau of Ordnance, for example, attempted to develop guided missiles by constructing high-speed aerodynamic studies carried out in captured supersonic wind tunnels from the Germans.[120] The Navy's Bureau of Aeronautics, however, believed itself naturally competent for such work and funded its own rocket and missile programs. Though molding programs around existing organizations retained the linkage between fiscal and administrative authority, which was McNeil's intent, it also permitted duplicative efforts.

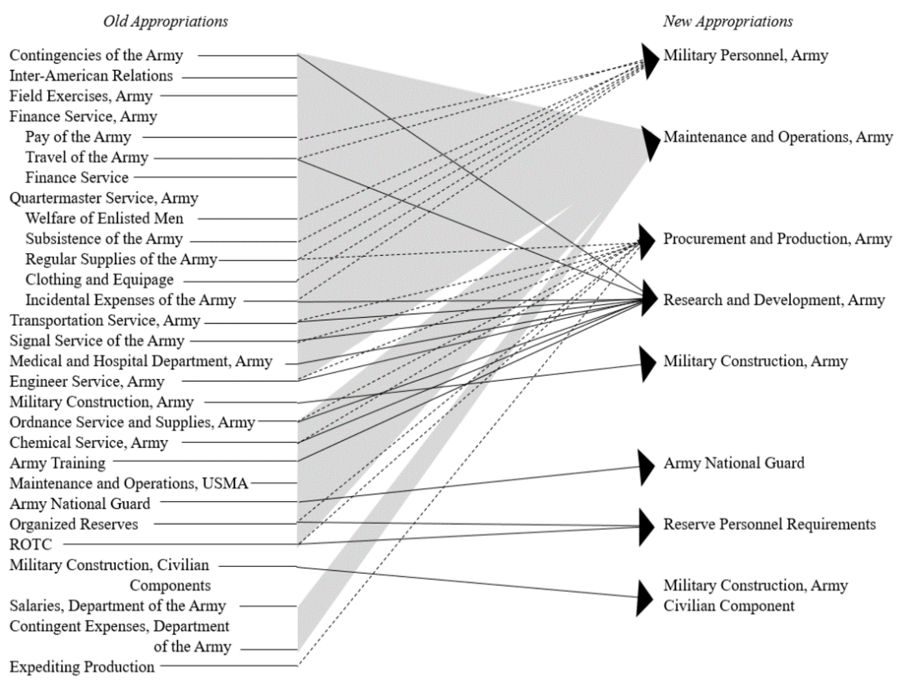
The Air Force looked to fully comply with the intent of the program budget. Not being endowed with an extensive technical service system, the Air Force defined its program structure with less regard to existing organization. Don S. Burrows remarked on four principles that served as the basis for the Air Force program budget. First, each appropriation served as a "grouping of self-contained programs so that fund adjustments to a program can be made without crossing appropriations." Second, to eliminate multiple funding, each "Air Force Station Commander will receive funds from one appropriation to support his station." Third, budget estimates will be presented based on program requirements using "specific cost factors and program units." Finally, the fourth principle segregated "capital procurement from operating costs."[121]

Mosher demonstrated, however, that the whole scheme relied on unifunctional organizations. Every budgeted project must be self-contained within an organization. And that served as the Air Force's organizing principle. As former Secretary of Air Robert Lovett explained, "The whole idea of the performance budget is to set up a unit that is going to cost so much, put some fellow in charge of it, and give him the authority and hold him responsible."[122]

The logical conclusion to making the program prior to the organization was the systems project office (SPO). All aspects of a project were handled by a single organizational unit. Yet Mosher had also showed that programs are at cross-purposes with segregating capital from operating costs. Because appropriations segregated R&D from procurement from operations, an aircraft program did not benefit from single funding. As the program matured, it was handed-off from one appropriation to the next. The result in the Air Force was strong central direction from the staff because the program was made prior to the performing organization. It led to a horizontal, or "flat," organization where the principal units included one layer of staff and one layer of SPOs.[123]

The Army, the last to develop a program structure, did so along Air Force lines despite having strong existing technical services. The effect was a misalignment of program and organization. Mosher wrote that "The technical and administrative services of the Army, in some respects the counterparts of the bureaus of the Navy, had formerly had their own clearly identified appropriations… Each technical service now receives funds from several different appropriations in which it had only a partial interest." Because each technical service only had a partial interest in each program, it required budget estimates at the general staff level to properly coordinate activities.

Unlike the Air Force staff which defined a program and created a SPO to fully acquire it, the Army staff preserved the multi-functional technical services. To do so, the Army staff had to receive input from below by organization, then translated it into a program structure for higher-level review. Finally, upon receipt of appropriations, the Army staff translated it back into organization and object for proper administration. The translations were largely done by statistics and "guesswork." Mosher wrote that "unless organization structure and program classifications are identical down to and including the operating level, there must be conversions in formulation from an organizational to a program classification."



Reproduced figure from Mosher (1954) depicting Army budget structure before and after the performance budget. Note that the old appropriations clearly delineated organization and object. Statistics and "guesswork" was used to force the old appropriations into the new. Based upon Department of the Army, "Pertinent Data on Revised Budget Structure Based on Fiscal Year 1952 Budget Estimates as Transmitted to Congress."

The new program structure finally gave Army staff officers the power they needed to control the unruly technical services. No longer did the chiefs from the technical services go before

Congress as independent pleaders for funds. The Army staff usurped the privilege. Mosher concluded that the "most important effect" of the performance budget had been to "lessen the independence and influence of the technical services, and, conversely, to strengthen greatly the position and the coordinating influence of the General Staff, *vis-à-vis* the budget."[124]

The ability of an organization to secure programmatic funds from those holding the purse strings, whether they are military staff officers or civilian comptrollers, depends on the strength of its case. That means building and defending a cost estimate based on the military requirements involved. Mosher worried about adverse effects from the process. He described how "the 'requirements' approach has implicit dangers, not alone that it may encourage inflated estimates but also in the 'pass-the-buck' psychology it encourages among budgeteers." "If carried to its dangerous extreme," he later explained,

> "this attitude might result in completely irresponsible behavior within the service. It is an attitude which might be expressed: 'This is what I need, even though I know it is impossible for you (Secretary of Defense, Bureau of the Budget, President, or Congress) to give it to me. However, it will not be possible to do my job without all of it. If you make any cuts, you assume full responsibility for any dire consequences which may result.'"

Mosher found that "the very expectation of budget review may encourage budget padding." When administrators expect higher levels to cut estimates, it is only "common sense and self-protection" that leads them to budget "padding" and "empire-building." Further, it gives the higher levels "an opportunity to make and proclaim cuts without real damage."[125] With the staff officers in control of the budget but dependent upon the line officers for information regarding program estimates, the line officers could act opportunistically by building in as much flexibility as justifiable. The same principal-agent problem went for higher levels of review, leading to calls for pushing the primary estimating responsibility to ever higher—and therefore more independent—levels of administration. Mosher concluded that

> "The budget plan and the program plan of a large agency may quite properly and necessarily *not* be the same thing. Their scope and coverage are almost certain to differ in some respects; their relation to time periods differs; the organization units and individuals primarily concerned for each may be different; the channels through which they proceed may well be parallel but not identical."[126]

His recommendations for an administrative budget along organizational lines went as follows: (1) each command or technical service should constitute an organic class in the budget; (2) each subcommand, a class at the second level; (3) each installation, a class at the third level; and (4) each activity at the installation, a class at the fourth level.[127]

2.9 A new culture

The impact of the performance budget was small at first and could only grow as fast as the military culture could change. The onset of the Korean War derailed the formulation of the first statutory budget during the spring of 1950. A series of "crash budgets" took precedent over careful programming which required two years of lead-time.[128] For several years after Title IV was enacted, the performance budget remained very much a "paper" plan. For the Army, where organizations and programs misaligned, some "scoffed" at it and passed budgets "whether or not the 'program' has caught up to it." Even the Air Force—which organized itself around the program budget through the SPO—was "still regarded by many, including some of its own staff, as being an opportunistic and largely 'unplanned' organization." For Mosher, the departure of the Air Force from its own programs suggested that the programming portion of budget largely remained "plans and hopes."[129]

In the end, Mosher had mixed feelings on program budgeting. In 1954, Mosher was skeptical but still believed that "budgeting and program planning must be intimately and frequently, if not continuously related, even if they are not married."[130] In 1956, Mosher argued that program budgeting, and the scope public administration itself, had crossed a threshold from which it could not return.[131] By 1967, he would write of the program budget that "I have been a supporter for about thirty years." Mosher did not take a stand against program budgeting in principle, just that it had been "oversold" and "misrepresented by its own advocates."[132] In fact, he looked upon programming as a central element for accountability to the public.[133]

Mosher later said that the program budget attained unique success in the DoD for two reasons. First, he believed that defense lent itself towards unifunctional organizations in terms of program structure. Such programming required the unifunctional SPO concept, which only became institutionalized in the Army and Navy after their bureau systems were formally abolished in 1962 and 1966, respectively. The SPO organization for weapons acquisition, Mosher argued, meant that "decisions could be, and were, almost totally centralized in the Pentagon."

Defense, however, provided a "pretty misleading" example for other governmental departments. It only applied the true program budget to "areas of weapons development and major equipment." Budgets for military operations, however, continued to have a fundamental basis in organization and object. In 1969, Mosher contrasted weapons acquisition from other Government objectives. "Inevitably the definition and classification of programs and subprograms will differ from the structure of the organizational hierarchy… there is no way one can design complex organizations without overlaps, competing perspectives, and interdependence."[134]

The second precondition to a successful program budget is competence in more advanced forms of estimating. While the traditional budget process added up salaries and expenses, the program budget required "cost factors" and "analysis of previous cost experience." Mosher noted how program budgeting required "essentially statistical, rather than accounting, skills and techniques." Those skills took many years of cultivation. By the 1960s, the DoD had a long history of statistical analyses, some of which Mosher believed attained "a high degree of accuracy."[135] He wrote that "Cost effectiveness studies had after all been going on in the military sphere ever since World War II and particularly in The RAND Corporation for most of the decade of the '50s. There was no such familiarity and experience in most of the civil activities of government."[136] As Mosher explained to Congress, "the nature and acceptance of program budgeting depends heavily upon the 'culture' of the organization."[137] Mosher's understanding of the budget process led him to foresee in 1954 that programming would foster the rise of a "new class" of specialism associated with statistics and cost effectiveness studies:

> "If the business concept [of controllership] is pushed hard by its supporters within and outside the departments, it could conceivably lead to an outright struggle for power and control between the military specialism and the accounting specialism. In such a struggle, there can be little doubt who in the long run would win. More likely is the gradual emergence of a compromise involving the absorption of a new type of specialism, more or less divorced from military command and planning channels, responsible for dollars, numbers, records, and budgets."[138]

3. Systems Analysis

> Little boys and matches neither logically nor inevitably lead to fires, but the probability is distressingly high, if it's your boy and house.
>
> Armen A. Alchian
>
> "A Proper Role of Systems Analysis," 1954

Centralization theoretically allows for efficient resource allocation. The central planner's tool, the program budget, seeks unified operations based on integrated long range plans. Yet the whole concept relies on numerous estimates about future states of the world. For example, programs depend on future military environments, enemy capabilities, technological readiness, and so forth. Moreover, there often exists many technical solutions to a program requirement, each of which has its own uncertainties as to cost, schedule, and performance attributes. Program budgeting, therefore, relies on a process for identifying the optimal course of action. It first requires defining the bounds of each estimate, and then systematically evaluating all relevant costs and measures of effectiveness.

The set of techniques used to inform programmatic decision-making is broader than that of statistics alone. It includes optimizations, marginal costing, game theory, and cost-benefit comparisons. The whole set of quantitative techniques became known as systems analysis.

3.1 Project RAND

The systems analysis approach was nurtured by Air Force General Henry H. ("Hap") Arnold. He wanted to improve military research by funding a "university without students."[139] Project RAND was first put on contract through Douglas Aircraft, and broke away as an independent corporation in 1948.[140] It attracted some of the most famous academics from a diverse set of fields.

Championed by RAND, the systems analysis approach was most fully adopted by the Air Force and the aerospace industry. The Wright Air Development Center began suggesting that contractors make their proposal as the result of a systems analysis study.[141] Industry proponents, such as Lockheed, suggested the practice become a requirement for all design and procurement decisions.[142] RAND analyst E. S. Quade wrote how "there seems to be a feeling in some parts of the Air Force that the systems approach may provide the complete answer to all questions of development, procurement, and operation as well as those of design."[143]

One ambitious Air Force officer that carried the mantle of systems analysis under General Arnold was Colonel Bernard Schriever. As a planning officer in bomber development, Schriever insisted on systems analyses that recommended the single best configuration.[144] Planning around an optimal design allowed for "concurrent" progress on development and production. With all pieces of the acquisition moving together, the greatest technological advancement could be achieved for the least cost and shortest schedule. Schriever brought the systems analysis concept to its summit by using it on a competitor to the strategic bomber's mission role, the inter-continental ballistic missile (ICBM).

During the budget drawdown of FY 1947-1948, the Air Force gutted its missile R&D budget in favor of bombers. Twenty-eight full-scale missile projects in 1946 fell to only three in 1950.[145] By that time, however, RAND Corp. and other industry studies began to show increasing feasibility for long range missiles to carry nuclear payloads. Starting in 1951, the Air Force provided limited funds to a relatively low-priority ballistic missile project, designated first "Project MX-1593" and later "Project Atlas."[146]

3.2 Atlas ICBM program

Believing that space technologies would dominate over the long haul, Schriever supported the ICBM concept. It led him into conflict over resource priorities with General Curtis LaMay who continued to favor strategic bombers. Project Atlas couldn't get fully underway until a change of leadership occurred with the inauguration of President Eisenhower. Trevor Gardner, special assistant for R&D to the new Secretary of the Air Force, also supported ICBM technologies. He initiated a committee of distinguished scientists and engineers to make recommendations. Under the leadership of John von Neumann, the "Teapot Committee" report found that an ICBM could be operational by 1960. That was only six years from the report's release in February 1954. But the committee warned that the accomplishment could only be achieved under the direction of a new agency "relieved of excessive detailed regulation."

Convair SM-65F Atlas #102, Site 11 New Mexico, 14 Oct 1962.

A month later the Air Force put Atlas on a crash basis. Three months later Atlas became assigned the Air Force's top priority. By August 1954, Trevor Gardner convinced Schriever, now a brigadier general, to manage the ICBM program by granting him sweeping authority.[147] Largely freed from time-consuming approvals involving nearly 40 military offices, Schriever could transcend the coordinating role of other program managers. He had the authority to manage the program to success.[148]

Systems analysis endorsed the use of a single prime contractor. While Convair had been the incumbent on Atlas, Schriever chose Ramo-Woolridge to take its spot in systems engineering and technical direction. Schriever relied on Ramo-Woolridge, an upstart company created by former Caltech physicists at Hughes Aircraft, to make sure that all parts of the program moved together and minimized the risk of specification change during integration and production.

The systems analysis approach generally pursued a single best system configuration resulting from a cost effectiveness study of alternatives. Schriever took the same approach with Ramo-Woolridge, selecting one design for the airframe (Convair), the propulsion (North American), the nose cone (General Electric), inertial guidance (Sperry Rand), and so forth. However, before Schriever could get underway the Scientific Advisory Board recommended a second parallel source of ICBM development using more conventional technology as a hedge against Atlas' possible failure.[149]

The genesis of the Titan ICBM, the Air Force's parallel effort to Atlas, actually lay with RAND president, Frank Collbohm. As historian David A. Hounshell showed, Collbohm was the only member of the Scientific Advisory Board to formally object to Schriever's systems analysis plan. In fact, RAND was initially asked to take the lead systems integrator role for Atlas before Ramo-Wooldridge, and Collbohm turned it down. Although the reason is unclear, Hounshell provided some clues as to his thinking:

> "From Collbohm's statements to von Neumann, we know that he believed there was a misfit between the air force's new religion of systems engineering and what Collbohm thought was the best way to get an ICBM built and fully operational. Also, Collbohm believed that RAND's undertaking such a task would not be consistent with his institution's fundamental mission for the air force.
>
> "Unquestionably Collbohm's views matched quite closely the ideas that Armen Alchian had been developing since the late 1940s about the importance of diversity in technological development; the critical differences between research, development, and procurement; and the inherent problems in employing systems analysis to optimize the performance of an advanced weapons system that had yet to be developed."[150]

RAND had a small number of economists who criticized systems analysis. They found it detrimental to the innovative process. Collbohm appeared to reflect those sentiments, despite the fact that RAND rose to prominence under the expectation that systems analysis could cure all project inefficiencies. Armen Alchian, not an engineer but an economist, led the debate within RAND about the proper role of systems analysis.

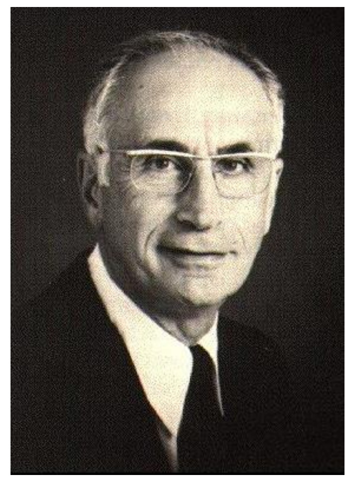
3.3 Uncertainty and evolution

In the years before the war, Alchian had been studying economics at Stanford. For his dissertation, he analyzed the effects of a general cut in wages on the economy. After six long years in the doctoral program, Alchian submitted his dissertation to his supervisors in 1942. He marked it "for your eyes only."

Normally, Alchian would have defended his work and received his doctorate. But with the U.S. having entered the war, the effects of general wage cuts took on a new importance. His supervisors informed the authorities, and in turn the U.S. Army Air Corps offered Alchian a job doing statistical evaluations. Though he had to wait another two years for his doctorate, Alchian recalled that his military service gave him time to wonder what it meant to be an economist.

After the war, Alchian took a job teaching economics at UCLA in 1946. It just so happened that RAND had opened up a few miles away in Santa Monica. Alchian's friend at RAND wanted to bring him on for part-time consulting, but they didn't have a role for an economist. By 1948, Charles J. Hitch was invited to lead a new economics division that at first consisted of only Alchian and himself.

Hitch had gained some notoriety before the war in mainstream economics. He asked whether firm managers actually followed the profit maximizing rule endorsed by economists. In other words, did firms actually set prices equal to the marginal cost of production or not? When Hitch did the field work, he discovered that managers priced their output at the average cost of production rather than the marginal cost.


Armen A. Alchian, after his time at RAND Corp.

For economists, the result implied that firms in the real world were leaving money on the table. If they simply priced output at the marginal cost, they could increase profitability and social welfare. Many interpreted the results as proof that markets generated inefficiencies. They explained how public managers would set prices at marginal cost. Due to fixed investments, marginal cost is usually assumed to be lower than average costs. If firms priced output at marginal cost, they would lower the price and increase the quantity supplied. It would create a tremendous boon to the consuming public.

Alchian remembered being drawn to the question not by his interactions with Hitch, but from a debate in the *American Economic Review*. Richard Lester argued that firms couldn't know enough about their costs and consumer demand to do the optimization. Fritz Machlup agreed, but responded that the profit maximizing procedure is a predictive construct of how firms reacted to change. "If that was the quality of analysis passing for economics," Alchian confessed after observing the debates, "I should have stayed in the military."

While discussing the controversy for his class, Alchian blurted out that Machlup and Lester should "Read Darwin!" He explained how "Competitive trial and error will evolve toward the fittest—whom economists characterize as profit maximizers." Word of his lecture got around, and a colleague asked Alchian to publish an article on it. Alchian initially "scoffed" at the idea, thinking it "all too obvious and trivial." To his astonishment, Alchian discovered that economists had simply "forgotten or ignored" the principles of evolutionary competition.[151]

In 1950, Alchian published his first and perhaps most famous paper, "Uncertainty, Evolution and Economic Theory."[152] It took a completely different approach to the profit maximization question. Alchian described how each action is associated not with a unique outcome, but with a distribution of possible outcomes. Alternative actions may have extensively overlapping outcome distributions due to uncertainty. A decision-maker usually cannot "maximize," but only choose between outcome distributions based on preference.

For Alchian, the filtering process of the economic system was more important than the decision of any individual. He directly compared the survival of firms in the economy to the survival of species in nature. "The economic counterparts of genetic heredity, mutations, and natural selection are imitation, innovation, and positive profits." Positive realized profits were the mark of success and viability in markets, not maximum profits. Those who suffered losses were filtered out of the economic system like a species gone extinct. Alchian explained:

> "As in a race, the award goes to the relatively fastest, even if all the competitors loaf. Even in a world of stupid men there would still be profits. Also, the greater the uncertainties of the world, the greater is the possibility that profits would go to the venturesome and lucky rather than the logical, careful, fact-gathering individuals."

With extreme uncertainty, the environment may "adopt" survivors out of sheer chance. This means that there was no specifiable way to optimize actions. But even in a world of unmotivated behavior and random outcomes, we will observe some successful actions. And when we evaluate those actions after-the-fact, they would appear as if they were devised with perfect foresight. They would have appeared to have maximized profits.

Alchian understood, however, that people had genuine motivations and outcomes were not entirely random. He advocated imitating successful ideas in the real world and trying out new variations. Some will become labeled innovators, while others become "reckless violators of tried-and-true rules." The only specifiable actions Alchian recommended to the human actor was to pursue "imitative, venturesome, innovative, trial-and-error adaptive behavior."

3.4 The decision problem

Over the next few years, Alchian applied his evolutionary ideas to the problems of weapon systems choice. The analysis of profit maximization had much in common with systems analysis. One of the primary advocates for systems analysis within RAND was engineer E. S. Quade. He later recalled how “It wasn’t until Armen Alchian, Jack Hirshleifer, and other economists tore my first system study apart that I became aware that economic theory had anything much to contribute to weapon choice.”[153] One paper in particular exposed the critical errors of systems analysis.

On January 27, 1954, Armen Alchian released a paper with Reuben A. Kessel entitled “A Proper Role of Systems Analysis.” It starts by reviewing Quade’s work. Quade discussed four existing problems that can be remedied by systems analysis:

> “(1) contractors seldom feel well compensated for development effort alone, hence systems analyses are required in order to avoid unprocured development; (2) resources are wasted when perfectly sound aircraft are developed and then not procured; (3) superiority of particular planes proposed by competitors could reliably be evaluated by the Air Forces; (4) there is too long an interval from research to production.”

The existing practice had been for Air Force contractors to assume development risk by investing their own funds. They had to prove their designs before securing a lucrative production contract. A system that didn’t make it to production risked financially ruining the contractor. In order to eliminate wasteful “loss leader” investments in R&D, systems analyses helped identify the specification with the maximum effectiveness for the least cost.

An already well known issue with systems analysis was the problem of the criterion, or the character of the values upon which alternatives are judged. Does the analyst want to maximize accuracy, or reliability, or damage, or something else? The numerous attributes inherent to complex systems often conflict such that an increase in, for example, accuracy usually comes at the expense of reliability and/or damage.

Alchian, however, did not pile onto the “criteria problem” and instead focused on clarifying the “decision problem.” He found the most basic problem in decision analysis to be whether a situation calls for a single best choice or whether a diversity of action should be taken. For example, if the Air Force is looking for a new bomber design, should it choose between turbo-prop engines and pure jet engines, or pursue both designs simultaneously? Alchian asked the critical questions:

> “For some problems, great gains will come from unique binding choices resulting from systems analyses; for others the gain will come from diversity of actions… In what situations is the latter principle of diversity preferable? And in what situation is the former appropriate?

Do systems analyses help us to answer these questions? Does it help us select the diverse or unique actions?"[154]

To answer his own questions, Alchian examined whether the implications of a maximization exercise equated with a decision or choice of action. He found that "If the assumptions were regarded as perfectly accurate forecasts and if the predictability of technological capabilities were known with perfect accuracy, then the maximization criterion, assuming one has the correct criterion, would reveal the optimal choice of action." In other words, if all estimates of future states of the world were perfectly known, including (1) the design and production feasibility of new weapons—questions of R&D; and (2) the enemies' capabilities, intentions, and environments—questions of procurement, then maximization along the correct criterion will lead to the optimal decision.

On the other hand, when forecasts contain uncertainty, "there is not available any generally accepted rule for rational behavior." The limitation occurs because outcomes correspond to a "probability distribution of costs under each type of choice."[155] To illustrate, suppose the Air Force evaluated two design proposals with the exact same performance. Design A costs $100M to fully develop and Design B costs $50M. If the forecasts of cost and performance were known to be perfectly accurate, the decision is clear. Design B wins. Supposing that Design B now also costs $100M, the Air Force will be indifferent between the two. However, if Design B employs a new team or technology, it may create uncertainty resulting in a distribution of potential outcomes. For simplicity, suppose Design B is equally likely to cost $50M as it is to cost $150M. Though the expected value is $100M, the same as Design A, the decision now depends on the decision maker's preference for risk. The more risk-loving the decision maker, the more he is willing to gamble that Design B will prove successful and accept that if it isn't, he will pay dearly. The more risk-averse the decision maker, the more he would be willing to pay for the assurance provided by Design A. In reality, both designs will likely have extensively overlapping probability distributions for each of cost, schedule, and performance estimates. Systems analysis, which relies on expected values from possible future states of the world, cannot provide the single best choice under conditions of sufficient uncertainty.

The fragility of the systems analysis approach to uncertainty was exposed early on. The first systems analysis performed by RAND in 1949 found turbo-prop bombers more cost effective than pure jet bombers. Displeased with the results, General LeMay changed the assumptions of the systems analysis. He discovered that the turbo-prop costs doubled while the cost of the pure jet bomber fell by half.[156] Systems analysis seemed to confirm the preexisting biases.

3.5 Separating R&D from procurement

When uncertainty reigned, Alchian believed that decisions pertaining to R&D should be separated from procurement decisions. The former requires determining the feasibility of new weapons. The latter requires determining the correct weapon to fight or deter the enemy. Alchian referenced a 1952 paper of his called "The Chef, Gourmet, and Gourmand." There, he wrote how "These two decisions are very different in their timing, in the information required, in their criterion of proper decision, and in their intended effects." He continued:

> "…since we suffer from predictive myopia in both eyes [the R&D and procurement decisions], we either can guess and then design what we hope will be the optimal, or, a good weapon—or, we can truthfully admit we don't know and obtain insurance by designing several alternative weapons, one for each possible contingency. The Research and Development effort is intended to create designs of new weapons which will form our confirmed and broad set of weapons available for procurement.
>
> "It must be recognized that R and D is directed toward providing a set of available choices rather than toward providing the one weapon that ex post best collates with the realized state of the world ten years hence. To assume that our foresight is adequate for this purpose is the error of not knowing how blind we really are. R and D not only advances us technically—it is also our only assurance of flexibility and wide range of choice in the future."[157]

Alchian believed that good R&D policy created a menu of available weapons that reduce the uncertainty of procurement decisions. With a menu of weapons, the procurement decision need only focus on its own uncertainties of operational environment instead of compounding uncertainties on top of those of R&D. In this way, procurement decisions gain from the availability of options emerging from realized outcomes of R&D decisions, minimizing the scope and magnitude of errors. He developed a useful analogy that formed the title of his paper:

> "Research and Development decisions are those of the Chef, who concocts new dishes and plans a menu of available alternative dishes, from which the Gourmet at a later time has the privilege of choosing in light of his tastes, companions, and income. A good Chef provides a broad menu—thereby assuring the Gourmet the opportunity to make the best selection. The

> difference between the Chef and the Gourmet must be kept strictly distinct. To confound the two is as disastrous in the military as in the restaurant business."[158]

Alchian's critical insight was the principle of insurance. He advanced an idea of insuring procurement and operations outcomes by fully developing a diversity of systems that could be selected from. Similar to how individuals pay a premium to insure themselves against natural uncertainties related to health, financial, and other risks, Alchian argued the military should pay a premium in R&D to hedge against weapon system uncertainties in procurement and operations.

The insurance policy that diversity provides is especially important when the costs to procure and operate a system are large relative to its R&D. To state it differently, diversification has higher R&D costs on average than a single best choice, but it also leads to better developments with less cost uncertainty overall. Perhaps most importantly, it lowers procurement and operations costs. The savings and increased utility of resulting weapons more than pays back the increased outlays in R&D.

Alchian, however, did not see the Air Force pursue the diversity strategy in R&D, leading him to fear that "we shall all soon cease to be economizing gourmets with a la carte menus and become expensive, undernourished table d'hôte gourmands." A table d'hôte is a fixed menu and a gourmand is a person who overeats. Alchian applied the analogy to the Air Force because many of its officers believed that pursuing the single best choice for a mission requirement allowed them funds left over to pursue even more requirements. Yet by having no alternatives to the single contractor once selected, the Air Force pre-commits itself to potentially sub-par developments and higher prices in procurement and operations. Escalating backend prices increasingly squeeze out R&D funding, straining diversity and creating a vicious cycle. As a result of the Air Force's desire to overeat it ends up undernourished. Alchian recognized that these gourmands would proactively suppress diversity for the sake of efficiency:

> "We, therefore, must recommend the development of a menu of several alternative weapons—guaranteeing that ignorant or malevolent critics will be able to show that a large majority of them were "useless" and "wasted" millions of dollars—but assuring ourselves flexibility in order to have safety and economy with optimal weapons in actual use."[159]

3.6 Exercising options

While diversification achieves insurance, it does not involve funding more projects based on systems analyses, as one might spread investments across financial asset classes. Diversification in management results from taking intermediate actions, each of which benefits from optionality previously gained. Alchian did not recommend pursuing the development of the top two, three, or more designs resulting from a systems analysis, only to wait and see which fully integrated system went from paper to hardware most effectively. Rather, he favored placing options at regular steps which allowed for reflection upon the information gained. As Alchian explained:

> "There will not result a specific *series* of particular steps which *must* be taken each year. The only firm decision now is the one applying to steps taken in the first year. Actions of succeeding years, while conditioned by the chosen moves in this year, are to be selected from the choices available in later years… In a nutshell, we seek a strategy for selecting actions as the need arises; we do not seek a particular series of actions to be committed to now."[160]

The principle of diversification conceived by Alchian unlocks the benefits of optionality. An option is a right without an obligation to a take future action depending on how circumstances unfold. Options provide the ability to defer decisions into the future, usually at a cost. Optionality in management recognizes that when organizations make investments they can: (1) change direction or funding levels before project completion; and (2) use project outcomes in a variety of ways.

By placing options throughout an investment project, through multiple paths, intermediate decision points, or both, managers can take advantage of information as it becomes available without pre-committing to one approach. The Manhattan Project provided an early example of the benefits of "real" options. Four major paths for developing fissionable material were taken in 1943, but it took a composite of a fifth path and two existing paths to achieve success. As researchers Sylvain Lenfle and Christoph Loch showed:

> "For the production of fissionable materials, a breakthrough came when it was discovered that a new process, thermal diffusion, could provide slightly enriched uranium, which would then feed the gaseous diffusion and electromagnetic processes for further enrichment. The parallel processes were unexpectedly combined into a composite process that finally achieved the desired performance."[161]

Had the program manager, General Leslie Groves, decided to pursue only the single best path, the atomic bomb may not have completed on time. However, it also turned out that a "diversity" of four paths would not have created the solution on their own had they taken the systems analysis approach. Without the option to start new paths *and* modify the course of existing paths, the atomic bomb may have not had such a timely completion.

The use of options was in fact pervasive in early Air Force developments. A 1963 RAND study found that of the Air Force's six most recent fighters, four ended up with different engines than originally planned, three with different electronic systems, and five with different airframes.[162] The examples highlight important implications of Alchian's work: (1) the information necessary to select the best weapon system is not available outside the process in which they are brought to test; (2) project controls should provide flexibility to take advantage of information as it arises by placing options at regular steps to reevaluate direction and funding; and (3) project outcomes create positive spillovers by solving problems on other, potentially unrelated, projects. Taken together, the implications call for a trial-and-error approach to program management as opposed to systems approach of systematically planning all steps before-the-fact.

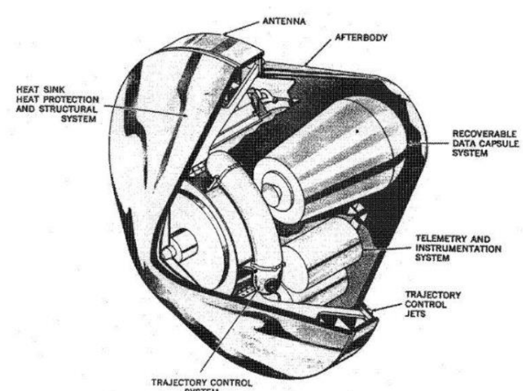
Like the general staff concept that relies on a one-way flow from policy to administration, or from planning to doing, the systems analysis approach relies on a one-way flow from science to engineering. If science is an exploration of the unknown and engineering is the application of scientific knowledge already gained, then concurrency in development and production tooling makes sense if scientific foundations exist. What remains relies on planning the engineering steps to bring the scientific knowledge into reality. Wernher von Braun, Chief of Army missiles in 1958, said "I believe an established missile program, like the Jupiter, has much more similarity with an industrial planning job than with a scientific project… I would say it was 90% engineering and 10% scientific."[163]

While systems analysts often believed that basic science requires duplication and overlap, engineering development and production tooling should not. However, even if development efforts can be characterized as engineering-based, it does not relieve them of fundamental uncertainties. In fact, the engineering discovery process often creates solutions that precede a fundamental scientific understanding. The Army, for example, conducted the Jupiter's "industrial planning" very differently from that recommended by systems analysis, to its own benefit as well as the benefit of the Air Force.

Harvard researchers Martin Peck and Frederic Scherer found that the Air Force Atlas ICBM program led by General Schriever had critical technical problems solved by the Army's Jupiter program. They showed how the engineering method used by the Army included trial-and-error processes that systematically searched for information without understanding all physical aspects before-the-fact:

> "There remained, as General Schriever noted, one critical problem—re-entry of the warhead into the atmosphere—about which little physical knowledge existed. When ballistic missile warheads re-enter the atmosphere at speeds up to 20,000 mph, shock waves with temperatures of 15,000F or more are generated. But just how these shock waves were formed, how they behaved in contact with various physical shapes, and how the tremendous temperatures would react with materials in a shock wave environment were all unknown.
>
> "In this respect Atlas was a "scientific" project. Even then, however, it turned out that the re-entry problem was resolved by [engineering] activities before a complete [scientific] understanding existed. The Jupiter IRBM nose cone problem was solved largely in an empirical manner. It was known from theoretical calculations that the nose cone had to resist certain general heats and shock waves. Guided by test data on rocket throat temperatures, one material after another and one shape after another were tried in the exhaust blast of a rocket engine until the most successful combination was found.
>
> "This nose cone illustration reflects a broader set of technical problems typifying advanced weapons developments. Fundamental scientific knowledge about the environments within which new aircraft, guided missiles, and space vehicles must operate has frequently been lacking during many developments of the 1950-1960 era. For example, science has yet to provide sufficient understanding of how objects behave in various supersonic and hypersonic environments to predict fully the problems which will be encountered in flight. All too often, these problems do not become apparent until a prototype vehicle is test-flown unsuccessfully. Then isolating the problem requires lengthy trial-and-error testing in which scientific theory may be of little assistance."[164]

Had not the Army pursued its own parallel path on ballistic missiles that rejected the systems analysis approach, the Air Force Atlas ICBM may not have proved successful. If a system requires all components to function and marry, then the Atlas would never have reached operational status until every single



Prototype design of the General Electric Mk-2 nose cone for the Atlas program. The blunt body concept shown above was scrapped for the Mk-6, which used a similar design to that of the Army's Jupiter IRBM.

component, including the nose cone, functioned. Had the Air Force chosen to break off nose cone engineering until they could generate the scientific knowledge of reentry, it isn't clear that the objective could have ever been accomplished. In technological progress, there exists a reflexive relationship between scientific and engineering discovery rather than a one-way flow of information from the scientist to the engineer.[165]

It will help to more fully illuminate the justification for the trial-and-error approach to augment diversification. Consider the attributes of a project estimate: cost, schedule, and performance. How do they vary with respect to uncertainty? As uncertainty increases, all three probability distributions are bounded at zero, but grow a "fat tail" toward infinity. Uncertainty then harms projects with respect to cost and schedule. The prospect of savings loom nowhere near as large as the risk of extreme cost and schedule growth. Conversely, uncertainty benefits projects with respect to technical performance. The worst that can happen is a lesson in what does not work. The best outcomes, however, can revolutionize technology. Such innovations create orders of magnitude more value than previous methods.

The primary objective of portfolio management in an uncertain environment, therefore, is to find ways to limit risk exposure to project cost and schedule, and, un-intuitively, to maximize risk exposure to system performance. Because of uncertainty, there are few projects that a central planner can afford *not to take part in.* This is in practice achieved by fixing cost and schedule targets and providing maximum discretion to the managers who may pursue a diversity of projects. On the other hand, if systems requirements are fixed, only minor performance gains can be sought unless there is a willingness to accept high cost and schedule risk.

3.7 Insuring weapons

Alchian identified an optimistic bias in industry emerging. It resulted from lock-in problem created by the systems approach, which selected the development, procurement, and operational support all at once. The selection was thus made entirely on estimates from contractors who had little incentive to provide realistic figures.

Traditionally, contractors would finance development overruns, or even the entire project, themselves. Winning systems led to large and profitable procurement contracts where they recouped the developmental losses. Development was therefore in a state of "hyper-competition" and procurement in a state of "hypo-competition," since there was no incentive for efficient procurement, only development.[166] Still, government procurement decisions could have a diverse menu of tested systems to select from, and the menu was financed in part by the contractors.

Systems analysis, however, intended to relieve the contractors of loss leaders by selecting the single best option ahead of time. This in effect meant deciding upon the best design, moving the state of hyper-competition from hardware developments to paper designs. As a result, contractors abused estimates because the most optimistic one in the design phase would win both development and procurement funds. J. L. Atwood, President of North American Aviation, summarized the Air Force's industrial environment:

> "There is a disproportionate premium attached to winning a design competition. It is the ticket of admission to the production show, but after all a design is just a list of promises based on calculations, which in turn are predicted on assumptions that can vary with the optimism of the producer.
>
> "Rarely if ever have there been any real penalties when the glowing forecasts of the design proposal were adjusted downward to the physical facts of the airplane. And it is then too late to change."[167]

Alchian's recommendation to avoid the lock-in problem was to start more R&D projects, make them pay, and break the relationship between developer and producer. "The way to weaken the importance of winning design competitions is simply to bring enough competitive designs through the development stage." Alchian essentially advocated replacing before-the-fact controls based on paper designs with after-the-fact controls based on hardware. Instead of letting the contractors take losses as they had before systems analysis, Alchian advocated getting contractors "to go into development work for what they can get as profits in development rather than a vehicle for obtaining production profits."

By making development pay, procurement contracts could then be awarded for efficiency in procurement, and need not be tied to the same contractor that developed it. Technical skills in development and production differed in form and function, and need not always be under the same roof. The increased development costs in support of diversity were returned by: (1) generating savings in procurement and operations—the far larger slice of the pie; (2) increasing the quality of systems available to procure; and (3) insuring against changing states of the world with functional alternatives ready for production. Alchian wrote:

"The insurance principle of diversified investments in development is superior to the principle of developing and procuring one flexible weapon. This assertion is refutable. But so strong is our conviction in this, that we strongly recommend this theorem as a basic part of the systems analysis. In all frankness, we are obstinately insistent that this is true for research and development decisions; we are of an open mind on the issue of whether or not it is true for procurement and other categories of decisions."[168]

Interestingly, Alchian leaves open the idea for the application of diversity to procurement, presumably where operational costs are particularly high or environments uncertain. This would push the primary benefits of optionality to operations and, potentially, increase relative procurement costs.[169] Alchian revisited the four rationales for systems analysis and flatly called all their implications "False." He wrote:

"1. Inadequate compensation for development work is the reason developers feel inadequately compensated. It's not because of some other technological or natural fact of life. Therefore the cure is not in using systems analyses, however desirable that may be for other reasons; the cure is to break the link between development and procurement and make development pay.

"2. Resources are not wasted when perfectly sound aircraft are developed and then not procured. In fact, such an outcome is a necessary result of an adequate development program. Failure of such an outcome is absolute proof of inadequate development.

"3. Superiority of particular planes cannot be ascertained by systems analyses; the ignorance giving rise to this inability is not the kind that systems analyses will remove.

"4. The time from research and development to production is not too long. This view confuses the time required to perform a task with the completion date. We want early completion dates, and this can be achieved despite lengthening the interval between development and procurement, if we can arrive at given states of technical knowledge even earlier…

"We may summarize our conclusions:

"1. Systems analyses are machines for generating implications of postulated initial information; they do not generate decisions.

"2. Under uncertainty, the criterion of decisions is not simple maximizations; the essence of the decision process is to affect the scope of random factors so as to give a "good" probability distribution of outcomes. The insurance principle is to decisions what maximizations are to analytic implications.

"3. Insurance requires diversity of investment—not variety of possible environments or flexibility of particular weapons.

"4. Optimal diversity in concrete situations cannot be ascertained. But institutional arrangements, wherein biases are created against diversity and toward identification of analysis with decision, are prima facie evidence of a system that yields suboptimal diversity.

"5. Stratification of the military problem into categories according to those in which diversity is economical and not optimal will facilitate an appreciation of purpose and usefulness of systems analyses."[170]

As the 1950s progressed, Alchian stopped spending as much time at RAND. However, he continued to support other RAND economists who worked on problems of military R&D. A 1958 paper by RAND economists Burton Klein, William Meckling, and Herman Mesthene continued where Alchian left off. The authors wrote how R&D is "a *search*, a process of discovery… R&D is not intended to buy airplanes or missiles; it buys *knowledge*."[171] The very act of performing a systems analysis before-the-fact implies having already solved all potential problems; the remainder is simply to administer the solutions without discretion. Put another way, R&D does not involve defining projects around future technologies because "to be able to predict an answer is tantamount to solution."[172]

The authors gave five policy recommendations to improve R&D: (1) the planning process needs to be simplified by defining work scope in the broadest terms; (2) there should be more authority in project offices to take advantage of knowledge discovery if and when it happens; (3) alternative approaches to difficult problems should be fully developed and brought to test; (4) financial commitments to a single design should be kept modest in the early stages of development; and (5) quick tests of all new equipment should be insisted upon as early as possible.[173]

The systems analysis approach, however, flies in the face of all five recommendations. The analogous points for systems analysis may go as follows: (1) the planning process needs to be well-defined to select the single best design; (2) project offices should require central direction to ensure optimality across the department; (3) only pursue the single best design for a particular mission, and fulfill multiple missions when possible; (4) financial commitments should be set aside up-front for the total expected costs of development and procurement; and (5) testing comes at the end and is only expected to result in minor modifications.

3.8 375-series regulations

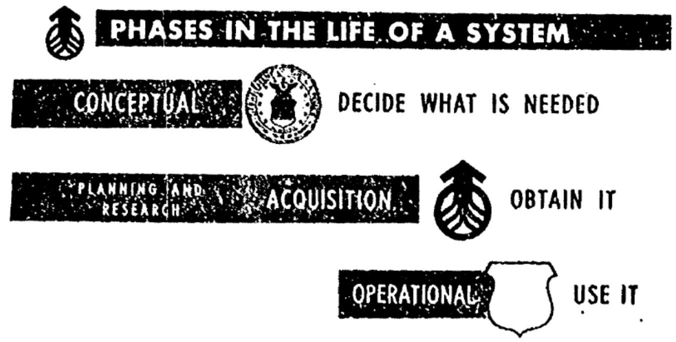
The diversification and systems analysis approaches, both with their own set of proponents in RAND, implied starkly different organizations and management techniques. RAND's schizophrenic attitudes were reflected by the DoD more broadly. For example, the 1950 Voorhees report found that small and diversified Army R&D programs provided "greatly increased strength with unexpected economy."[174] A year later, a different report scolded the Army staff for passively accepted programs from the technical services rather than aggressively formulating, coordinating, and evaluating an Army-wide program.[175]

The systems approach eventually won out because of the allure of scientific management. Despite problematic efforts like the F-102, the systems analysis approached claimed the Atlas program as proof of its efficacy. Using the Atlas model of systems analysis, the Air Force instituted the 375-Series regulations in 1961, institutionalizing the systems project office as well as its reporting and approval process controlled by headquarters staff.[176] As described to Congress, the linear steps to a procurement program were first, the staff officers "decide what is needed." Second, the systems project office is created to "obtain it;" and third, the combatant commands "use it." In deciding what is needed, the staff performed extensive before-the-fact planning, such as to "Identify responsibilities, tasks, and time phasing of major actions of each participant."[177]

To start any kind of work on a project, the budget had to be there. For the budget to be available, there had to exist a detailed "program definition" that spelled out exactly how the full system would be obtained, from research to development to procurement. In this way, the policy-making of headquarters staff truly determined the administration of the program. Planning translated to doing with little discretion required by the ones doing.

Yet even the 375-Series recognized uncertainty and that administration might require re-direction at a later date. Whenever discretion was required, it should run up the chain to headquarters, which would "Assure that all participants are provided with adequate, consistent, and timely decisions, guidance, and resource allocations."[178] While the form of centralization did not assure extensive barriers to diversity and optionality, it solidified an "institutional bias" that Alchian worried about.

375-Series chart shown to the Congressional Committee on Government Operations by Colonel Jewell Maxwell in August, 1962. It outlines a linear process of technology development. The Air Force Headquarters staff will "decide what is needed," the Air Force Systems Command sets up a project office to "obtain it," and the combatant commands "use it."



The 375-Series largely reflected the RAND approach to systems analysis that dominated over diversification. To some degree the skeptics, such as RAND president Frank Collbohm, were never skeptics of systems analysis in the way Alchian was. Collbohm, for example, wrote a withering critique of the "criteria problem" in systems analysis. He also protested Atlas in order to support a parallel development project. However, Collbohm fundamentally held faith that better designed analyses can generate efficiencies if "economic facts" can be "related expertly."[179]

By 1961, the systems analysis debate had a clear victor, the tenants of which were written down in a book proclaimed the Bible of the Pentagon. Collbohm verified that "RAND's general philosophy concerning costing and cost effectiveness studies… is reflected in the Project RAND report, subsequently published as a book, entitled 'The Economics of Defense in the Nuclear Age,' by Charles Hitch, now Assistant Secretary of Defense, and Roland McKean."[180] The book propelled Charles J. Hitch from head of the RAND's economics division to ASD Comptroller. In the book, Armen Alchian was relegated to a single footnote. His ideas were summarily dismissed by Hitch as "natural selection."[181] The systems analysis approach emerged from the 1950s largely unreformed, and when packaged with a revival of the program budget concept, would form a lasting institutional framework for defense management.

4. Planning-Programming-Budgeting

> The man of system… is often so enamoured with the supposed beauty of his own ideal plan of government, that he cannot suffer the smallest deviation from any part of it… He does not consider that the pieces upon the chess-board have no other principle of motion besides that which the hand impresses upon them.
>
> Adam Smith
>
> *The Theory of Moral Sentiments,* 1759

The postwar revolution in defense management found its roots squarely in RAND, but reflected a broader trend in public administration dating back in the U.S. to the late nineteenth century. If the logic of military unification derived from German concepts of bureaucracy and the general staff, then RAND's philosophy was derived from the German historical school of economics.[182] Essential to the German tradition is analytical holism and a rejection of the "fictitious individualistic assumption" of classical liberals. Because markets were identified with social and economic failures, particularly monopoly, a new class of expert was required to identify remedies using the administrative state. The economist as an American profession was built on men schooled in Germany, who solidified their expert status by creating university departments, prestigious associations, and new government bureaus on statistics and regulation. They proposed rational planning from the top as the singular solution to social problems.

To justify his supervisory role in society, the economic expert relied on the legitimacy of the scientific method. One top expert, Henry Farnam, compared the evolution of the economic sciences to the medical sciences. He found that surgery was once primitive and dangerous, but advances in science had made it most beneficial to society. Similarly, the economic expert had by 1910 enough scientific knowledge to make his reforms "more effective and less dangerous."[183] The analogy was repeated over 50 years later by Alain C. Enthoven, Assistant Secretary of Defense for Systems Analysis, who said "My general impression is that the art of systems analysis is in about the same stage now as medicine during the latter half of the 19th century; that is, it has reached the point at which it can do more good than harm."[184]

Even though he directed the Office of Systems Analysis from 1961 until 1969, Enthoven joined defense leadership at the relatively young age of 31. Before that, he joined RAND straight out of his doctorate program at M.I.T. in 1956. There, Enthoven became a protégé of Charles Hitch. He joined a team working on a defense resource allocation system based upon the methods of program budgeting and systems analysis. The system followed in the tradition of economic expertise that traced back to the War Industries Board of the First World War.

One prominent RAND analyst who played a major role in the efforts was David Novick, later called the "father of cost analysis." He also fancied himself the father of program budgeting in the federal government because of his personal involvement with the Controlled Materials Plan. With almost complete lack of regard for the existing debates, Novick wrote that the "CMP was a budgeting system, planning system, and a programming system to manage the nation's resources for war. I thought that, if we could adapt this same concept to the structure of the Air Force's planning, budgeting, and accounting, life could be very simple."[185] Carrying out his idea, Novick prepared a paper with a "real jazzy title," which in effect argued for the exact same principles that had been already legislated in Title IV of the National Security Act three years before.[186] Novick couldn't understand why the Air Force did not jump at his ideas.

Like Novick, Enthoven saw the promise of a resource allocation system based on programming and systems analysis. He was enamored with the application of the scientific method, which "itself does not depend upon the personalities or vested interests."[187] Such quantitative measurements and modeling allowed for the "greatest clarity of thought" to be achieved, "even when uncertainties are present."[188] Alluding to Alchian's work on systems analysis, Enthoven remarked how

> "Many people seem to feel that quantitative analysis is not possible if there are any uncertainties. But this view is incorrect. In fact there is substantial literature on the logic of decision-making under uncertainty going back at least as far as Pascal, Bernoulli, and Bayes in the 17th and 18th centuries."[189]

To Enthoven, the triumph of the scientific method in management and economics replaced the need for so-called "direct experience" and "reading of history books."[190] He held the highest hopes that the marginal analysis he learned in sophomore class would translate into actual defense decisions.[191] He wrote that "The economic theory of price and allocation, a branch of moral philosophy in Adam Smith's day, had been reduced to mathematical terms and made into a useable instrument for quantitative analysis of problems of choice."[192]

The allocation mechanism developed by Enthoven, Novick, Hitch, and others at RAND became called the Planning-Programming-Budgeting System (PPBS). When Robert McNamara took over as Secretary of Defense in 1961, he went full bore on implementing the PPBS. McNamara hired Hitch to take over as his number two in the Comptroller spot, charging him with expediting the PPBS. Hitch recommended Enthoven to direct the Office of Systems Analysis with its critical role of coordinating the entire defense program.

Observing the exuberance over the PPBS reforms, Frederick Mosher wondered "what is really new and distinctive about it?" To Mosher, the PPBS had little to distinguish itself from the Title IV performance budget.[193] But his critiques of the budgeting system, like Alchian's critiques of systems analysis, fell on deaf ears.

4.1 PPBS in context

The program budget represents an idea that naturally arises from the requirements of central economic planning. It displaced exchange with allocation as the focal point of economic discourse. In fact, the War Industries Board (WIB) during the First World War represented the culmination of a generation's work in economic planning. The WIB's Central Bureau of Planning and Statistics was headed by Harvard graduate school dean Edwin F. Gay. He fixed prices in more than 60 strategic industries and directed railroads by determining output priorities and resource allocations. Gay said that the scientific administration used by the WIB was "the most important advance in industry since the introduction of the factory system and power machinery." WIB member and historian Grosvenor Clarkson echoed the sentiment, finding that the "whole productive and distributive machinery of America could be directed successfully from Washington." John Dewey found that the WIB represented a "revolution" in economics and finally demonstrated the efficiency of expert central planners.[194]

The program budget was part of a broader discourse on resource allocation. All central planning requires relating resources to objectives through an analytical framework. The PPBS relates dollar budgets to military force structures using systems analysis. Similarly, the socialist central planner relates physical capital to the social welfare using industrial analysis. The economic expert and socialist alike believed that central planning could far outstrip the productive capability of uncoordinated markets. John Dewey said that the WIB did more to advance central planning than a generation of socialist theorizing.[195] It was not hyperbole when historian John C. Ries described military staff planning in 1964 to be "almost socialist in its metaphysics."[196]

Centralized planning for an entire economy arose from a belief in the power of science and human rationality. It stemmed from a Newtonian view that if a scientist knew the disposition of all particles at a given instant, then the future is completely predictable based on a set of equations. With confidence that administrative experts could emulate the triumphs of the natural sciences through planning, prominent scholars such as Austrian Otto Neurath believed that the war economy should be extended. Neurath wrote that, "As a result of the war, in-kind calculus was applied more often and more systematically than before… war was fought with ammunition and with the supply of food, not with money."[197] Neurath advocated a moneyless system planned from the center that allocated resources based on labor standards.

Ludwig von Mises, also an Austrian, rebutted that economic calculation is impossible without reference to prices. Changing factors affecting resource shortages or surpluses are reflected by participants bidding the price up or down. Allocation decisions do not require any single individual to have detailed knowledge of all relevant information dispersed across the economy. The impossibility of centralizing the knowledge of ever changing production factors to solve a system of equations means that there is no rational basis for allocation decisions without reference prices.

Many socialist thinkers appreciated Mises' arguments exposing problems in central planning. Oskar Lange wrote how "a statue of Professor Mises ought to occupy an honourable place in the great hall of the Ministry of Socialisation or of the Central Planning Board."[198] Lange recognized the challenge, but believed central planning could work by employing neoclassical economics to equilibrate supply and demand. He described the problem of the central planner:

> "The economic problem is a problem of choice between different alternatives. To solve the problem three data are needed: (1) a preference scale which guides the activity of choice, (2) knowledge of the 'terms on which alternatives are offered,' and, finally, (3) knowledge of the amount of resources available. Those three data given, the problem of choice is soluble."[199]

The market economy took the first as given to consumers, the third as given to suppliers, and the second as given by prices that arise from market exchanges. Central planning, whether in the socialist form, traditional budgeting, or PPBS, assumes that the first and third are also given, and that the "terms on which alternatives are offered" is generated through analysis. In socialism, the alternatives are determined through industrial analysis; in traditional budgeting, political analysis; and in the PPBS, systems analysis.

The final solution proposed by Lange and elaborated on by Abba Lerner is that prices were required, but they need not emerge from decentralized market exchanges. Instead, industrial units would produce from a given supply of inputs and set price equal to marginal cost of production based on labor standards. Shortages and surpluses then exposed the need to adjust allocations to industrial units. Production would be coordinated not through immaculate calculations, but from a series of trial-and-error approaches that sequentially minimized the misallocation of resources.

Belief in the efficacy of central planning pervaded not only economists who leaned toward government intervention like J. M. Keynes and Irving Fisher, but also the market oriented thinkers like Frank Knight and Joseph Schumpeter. Schumpeter is often revered as a champion of market economics, associated with the creative destruction view of technological innovation. Yet Schumpeter was smitten with the Lange-Lerner model of central planning. He even believed that innovation itself could be planned. In his 1942 classic, *Capitalism, Socialism, and Democracy*, Schumpeter wrote that:

> "… innovation itself is being reduced to a routine. Technological progress is increasingly becoming the business of teams of trained specialists who turn out what is required and make it work in predictable ways. The romance of earlier commercial adventure is rapidly wearing

away, because so many more things can be strictly calculated that had of old to be visualized in a flash of genius."[200]

Schumpeter's views gravitated toward central planning because he thought innovation worked in "predictable ways." Creative destruction could then be planned for. It was not the outcome of decentralized actions associated with tinkering and exchange. The view is consistent with systems analysis because technology could be predicted during the planning stage and its parameters "reduced to a routine."

4.2 Uses of knowledge

A withering critique of central planning came in 1945 from Friedrich A. Hayek, an Austrian economist of Mises' mold.[201] He posed a simple question, "What is the problem we wish to solve when we try to construct a rational economic order?" Hayek started his answer in a similar way Alchian did when analyzing weapons choice:

> "*If* we possess all the relevant information, *if* we can start out from a given system of preferences, and *if* we command complete knowledge of available means, the problem which remains is purely one of logic. That is, the answer to the question of what is the best use of the available means is implicit in our assumptions."

If information is perfectly known to the central planner, he can determine the optimal allocation of resources across an entire economy as much as he can across weapon systems.[202] Hayek said that his contemporaries believed scientific knowledge to be the only relevant knowledge in existence. If that were the case, then a body of suitably chosen experts would be in the best position to command all the best knowledge available.

Hayek disagreed. He found a different form of knowledge to be at the center of economic progress. "Today it is almost heresy to suggest that scientific knowledge is not the sum of all knowledge. But a little reflection," he continued, "will show that there is beyond question a body of very important but unorganized knowledge which cannot possibly be called scientific in the sense of knowledge of general rules: the knowledge of the particular circumstances of time and place." He explained:

> "…the sort of knowledge with which I have been concerned is knowledge of the kind which by its nature cannot enter into statistics and therefore cannot be conveyed to any central authority in statistical form. The statistics which such a central authority would have to use would have to be arrived at precisely by abstracting from minor differences between the things,

> by lumping together, as resources of one kind, items which differ as regards location, quality, and other particulars, in a way which may be very significant for the specific decision.
>
> "It follows from this that central planning based on statistical information by its nature cannot take direct account of these circumstances of time and place and that the central planner will have to find some way or other in which the decisions depending on them can be left to the 'man on the spot.'"

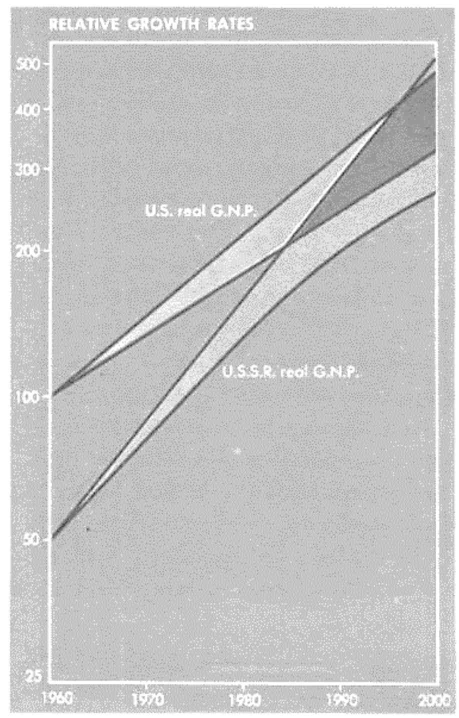
Hayek identified the problem that only dispersed actors had access to local knowledge of time and place. A rational economic order, then, required a solution that is produced by the interactions of people each of whom possesses only partial knowledge. To assume all such knowledge is available to a central planner is to "disregard everything that is important and significant in the real world."

Hayek's idea that knowledge of economic activity was inherently non-aggregable harmonized with Alchian's ideas on weapon systems analysis. They both pertained to the discovery of knowledge dispersed across time and place. For Hayek, entrepreneurs acted upon localized information and those who speculated well were rewarded with profits. For Alchian, defense decision makers must take advantage of knowledge discovery in a similar way. Knowledge of the correct technology does not exist in the planning stage. It only revealed itself in the process of its discovery across time and multiple technical approaches. Innovation in weapons and the economy more broadly are then processes which generate information which would not otherwise have existed for quantitative analysis. "Successful" solutions are then selected by the environment.

At the time very few shared the economic outlook of Hayek and Alchian, who themselves differed in several respects. The particulars of time and place were largely discounted in favor of macroeconomics, which utilized economic aggregates such as total consumption, investment, and employment to direct future policy decisions. In his path-breaking 1947 textbook *Foundations of Economic Analysis*, Paul Samuelson developed a mathematical framework that explained macroeconomic theory and swept through the economics profession. Before that time, economics still relied on the spoken language and diagrams. By providing a rigorous mathematical treatment of the social welfare function, the fiscal multiplier, the production function, and other abstract concepts, the textbook first and foremost presented policy makers with a formula to influence the economy.

Throughout Samuelson's life, however, he could not appreciate Hayek's ideas about the dispersed knowledge of time and place. His textbook took the initial conditions as given and solved for the equilibrium without any treatment of process in which the equilibrium came about. One consequence of Samuelson's macro-economic approach was that he looked at aggregate investments and not the particular qualities of individual choices. Samuelson concluded that Soviet income would grow "two to three times" faster than the U.S. due to its higher investment rate. In at least ten editions of his textbook up until the fall of the Soviet Union, Samuelson continually updated a graph showing Soviet income at half the level of the U.S. in the present, but growing and surpassing the U.S. in the future. That future in which Soviet income exceeded the U.S. never came, but it did not force the economic mainstream to reconsider their confidence in predictions based on statistical aggregates.[203]

The historical context of the economics profession in the middle part of the twentieth century is central to understanding the rise of the PPBS. It focused on mathematical models, identification of market failures, and administrative remedies. Axel Leijonhuvud recalled the economic atmosphere inherited by the 1960s. "What I learned in graduate school," he said, "was arid stuff, trivial optimization exercises combined with equilibrium conditions that had no foundation in any examination of how actual markets work. This was not the fault of my teachers—this was the state of the art in the profession in general." James Buchanan echoed the sentiment, commending Armen Alchian and Friedrich Hayek for breaking with the mainstream and introducing evolutionary thinking into economics.[204]



Graph from Paul Samuelson's Foundations of Economic Analysis *showing the real gross national product (GNP) for the U.S.S.R. (bottom) growing faster and eventually surpassing that for the U.S. (top). Despite contrary evidence, Samuelson did not update his prediction.*

Both the optimization and evolution models of economics were reflected in RAND during the 1950s. While the optimization approach led to systems analysis, the evolutionary approach led to diversified investments. The contrasting models were also entangled in the seminal 1960 book on the PPBS by Charles J. Hitch and Roland McKean.

4.3 Defense applications

In *The Economics of Defense in the Nuclear Age*, Hitch and McKean laid out the principles for PPBS. Presented in the economic jargon of the day, the authors explained that the goals was to "facilitate an economic calculus within the services." In the effort, the most important reform is to "reveal the costs of meaningful end-product missions or programs (like 'active air defense'), rather than the costs of classes of objects (like 'personnel—military')."[205] Programming provides the important link that allows for traceability between resource inputs (budgets) and military outputs (plans).

The system allowed for a holistic "economic analysis" of the defense organization by joining cost and capability analyses under program elements. Just like goods and services in the market, program elements could be subjected to optimization exercises. Much of the language used by Hitch and McKean suggested Samuelson's framework.

> "We want to choose that efficient point which maximizes the "utility" or "military worth" of the combined forces. In practice… the explicit measurement of military worth frequently presents formidable difficulties. If we abstract from these difficulties for the moment in order to clarify definitions, we can draw curves (called indifference curves) that reflect our preference for some combinations of target destruction or kill potential over others."[206]

The tangency point of the indifference curve and the production possibilities frontier, together with the budget constraint, represents the optimal allocation. Despite "formidable difficulties" presented by defense problems, the authors devoted large swaths of the book to optimization exercises in the context of defense. At the same time, however, the book contained ideas that seemed to align with Alchian; they wrote:

> "Research and development are uncertain by definition. Research is a search, and one rarely knows in advance whether the search will be successful at all, let alone how long it will take or which route will lead to the treasure. The military Services have all too frequently tried to command the research and development community to invent new weapons to specification, just as they would command a platoon of infantry to march by the right flank… One of the most important and obvious corollaries of the uncertain character or research and development is the desirability of some duplication."[207]

The inconsistency between optimization and duplication was picked up in a 1962 Congressional hearing on systems development and management. By that time, Hitch had been right-hand man of Secretary of Defense Robert McNamara for more than a year. He had been working to strengthen centralized control in the Office of the Secretary of Defense, including in the recently established Director, Defense Research and Engineering (DDR&E). *The Economics of Defense in* *the Nuclear Age*, however, criticized just this centralization of R&D. Herbert Roback, a committee staffer, asked the incisive questions:

Mr. Roback. "… One of the points you made in that book was that it was a serious mistake to try to centralize control over R. & D., because you might dry up initiative or you might do many other things… Now, how does it look to you today?"

Mr. Hitch. "I do not remember having said anything like that in that book."

Mr. Roback. "You do not? … Under the caption 'Reorganizing Research and Development,' the authors discussed these critics who had been complaining about the uncoordinated nature of R. & D., the diffusion, the duplication, and who had recommended strong central direction and coordination. 'In response to these criticisms,' say the authors at page 256, 'a new echelon of research and development planners and managers is being added to the Pentagon at the Department of Defense (DOD) level to direct all lower echelons—'"

Mr. Hitch. "Let me assume that that sentence was written by Mr. McKean. [Laughter.]"[208]

Representative Chet Holifield piled on, reading out the paragraph. The authors wrote of those who would centralize R&D: "They try to suppress competition and diversification because particular duplications are obviously wasteful from the vantage point of hindsight, apparently unaware that duplication is a rational necessity when we are confronted with uncertainty and that competition is our best protection against bureaucratic inertia." The book Hitch co-authored strongly criticized management techniques that Hitch now testified in support of.

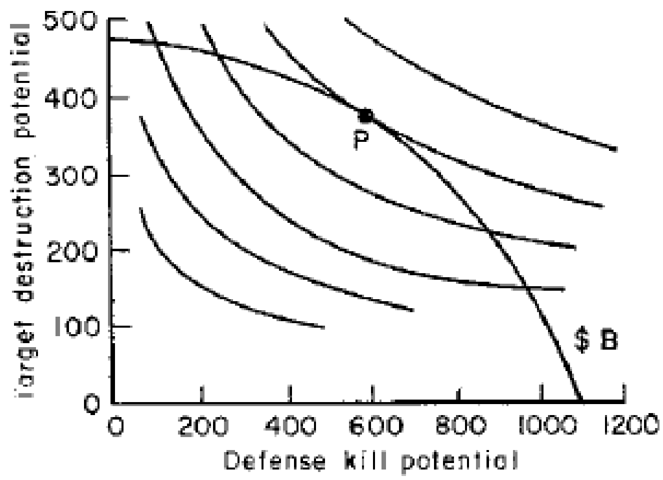
Hitch, after again deflecting the comments onto McKean, felt he had to address the point. "No, I have not changed by views, Mr. Chairman, about the fundamental nature of research and development," Hitch said bluntly, "it is important to distinguish between… research and development that is directed toward the development of new ideas and the testing of those ideas, on the one hand, and the fabrication of prototypes of operational systems, on the other." He continued, "I think that the kinds of remarks that you have just quoted are directly applicable to the first kind of research and development."

Perhaps as a concession to Alchian's views, Hitch and his team at RAND had been working on distinguishing the stages of R&D.[209] Hitch believed that basic research, or the pursuit of science, played by different rules than full-scale development, or the pursuit of engineering. The latter was better suited in Hitch's mind to optimizations, detailed long range plans, and tight central control throughout execution. The apparent contradiction between Hitch's book and his policy plans may therefore be seen as a difference of opinions between authors as to which stages of R&D required diversification. McKean believed diversification should be pursued for a wider range of R&D activities than Hitch, who believed diversified investments only make sense in the earliest stages. McKean's position sat closer to Alchian, who applied diversification to all stages of R&D, as well as test and evaluation. McKean later wrote how it is "good practice" in budgeting for R&D to leave an "empty place here and there." This allowed decision-makers to postpone commitments until more information presented itself.[210] Hitch, on the other hand, wanted program elements defined in the budget once scientific knowledge is put toward operational hardware. The intent of operational capability called for program definition and central control through the program budget.

4.4 To optimize, or not to optimize?

While Hitch's Congressional testimony may have resolved the apparent contradiction in his book with McKean—there only existed a difference in opinions as to matters of degree—there still lingers another issue. Hitch and McKean remained committed to systems analysis despite the presence of uncertainties and other fundamental issues. The authors reconciled the problem by arguing that a central planner does not need perfect information in order to employ optimizing techniques. Sub-optimizations on smaller defense problems can improve decisions actually made, moving the planner toward an optimum. The authors wrote that "while we cannot usually find optimal, or second-best, or even j^{th}-best, solutions, it frequently enables us to identify improvements over existing proposed policies."[211] Simply put, sub-optimization might not generate perfect solutions, but it should be used so long as benefits outweigh costs. Harvard researchers Martin Peck and Frederic Scherer addressed the topic. They start by quoting Hitch, who viewed optimizations with some pessimism:

"So what does the poor operations researcher do? Here he is, faced by his fundamental difficulty. The future is uncertain. Nature is unpredictable, and enemies and allies even more so. He has no good general purpose technique, neither maximizing expected somethings, nor *max-mining*, nor gaming it, to reveal the preferred strategy. How can he find the optimal course of action to recommend to the decision maker? The simple answer is that he probably cannot…"



Graph from Hitch and McKean's The Economics of Defense in the Nuclear Age, *labeled "Indifference curves and optimal point." The convex curves are indifference curves and the concave curve is the budget constraint. Any allocation that does not create a point of tangency is associated with a lower indifference curve representing less utility gained.*

Yet Hitch clearly intended for weapons choice to have a quantitative foundation. Peck and Scherer also subscribed to the power of optimizing in spite of their appreciation for uncertainty. They explained why Hitch may also have endorsed the practice despite the numerous obstacles he identified:

"Hitch recommends that instead of attempting to find optimal solutions and to implement them on a single-minded basis, development planners and decision makers seek merely to find solutions *better* than those already existing. Hitch's emphasis on the search for the better instead of the best solution follows more general concepts advanced by Professor Herbert Simon. Simon uses the term 'satisficing' to describe decision making as a process of reaching 'satisfactory' positions rather than optimal positions, where the standard of satisfactory is given by complex psychological and sociological considerations. He argues that the satisficing notion not only describes more realistically how organizations actually make decisions, but also that it is a better normative decision-making rule, given uncertainty and limits of the problem-solving capabilities of organizations.

"… we are committed to an optimizing model. Yet the conceptual differences between optimizing and satisficing are not necessarily great, since optimizing considerations may play a role in determining what positions are 'satisfactory.' As March and Simon point out: 'The standard setting process may itself meet standards of rationality; for example, an 'optimizing'

> rule would be to set the standard at the level where the marginal improvement in alternatives obtainable by increasing it would be just balanced by the marginal cost of searching for alternatives meeting the higher standard. Of course, in practice the 'marginal improvement' and the 'marginal cost' are seldom measureable in comparable units, or with much accuracy. Nevertheless, a similar result would be automatically attained if the standards were raised whenever alternatives proved easy to discover, and lowered whenever they were difficult to discover. Under these circumstances, the alternative chosen would not be far from the optima, if the cost of search were taken into consideration…'
>
> "Thus, in a dynamic context the concepts of satisficing, optimizing, and successive improvement tend to be congruent. There remain differences in emphasis, but these are not decisive for our present analysis, especially since program decision makers must take the costs of searching for additional technical alternatives into account. Furthermore, for indicating the significant relationships among variables in program decisions, the optimizing approach provides a more meaningful and powerful analysis. It is for this reason, we believe, that Hitch—no doctrinaire optimizer—retains the optimizing approach in his analysis of efficiency in military decisions."[212]

The passage touches on an important belief of the optimizer, a critical thinker who seeks to fully embrace uncertainty. Decisions must be made whether or not they face uncertainty, or even unknown uncertainty distributions. For each decision, the only relevant question is whether or not it is efficient to attempt a quantified optimization across identified alternatives to inform judgement. Herbert Simon put it well himself: "My argument is that men satisfice because they have not the wits to maximize. I think this is a verifiable empirical proposition. It can be turned around, if anyone prefers: If you have the wits to maximize, it is silly to satisfice."[213]

The problem with deciding between optimization and incrementalism is that it requires the analyst to know what it is they do not know. Simon's heuristic for deciding whether to optimize or advance incrementally is for the analyst to identify when alternatives are "easy" or "difficult" to discover. This merely pushes the problem back one step further. When are alternatives "easy" enough to discover to suggest an optimization? The problem is similar to that encountered by the economics of search. The analyst is assumed to know the marginal cost and benefit of gathering more information for the optimization exercise. Analysts know in advance what it costs to get the knowledge and what the knowledge will enable them to achieve. The knowledge already exists;

the analyst is aware of its cost and significance, and based on that, can choose between incremental and optimizing strategies.[214]

For Charles Hitch and others, the choice was clear. Alternatives were easier to find in an analysis then to test out empirically. The cost of a systems analysis is a pittance compared to the cost of large development projects. Because path dependency in large projects leads to extreme variation in outcomes, it should pay well to consider the final system and how it will be achieved. Systems analysis clarifies issues and guides decisions toward the optimum, even if the result is non-optimal in the rigid sense. Hitch testified that "I think that the expense of the systems dictates the necessity of that approach."[215]

One error in the logic is assuming the problems of systems analyses are limited to problems of optimization. It also includes problems of defining the problem and predicting future .[216] Surely systems analysis incorporates elements of uncertainty, but it remains committed to absolute certainty about its assumptions. The systems analyst assumes that when he cannot predict the precise outcome, he can still know the distribution that all outcomes will fall under. In other words, unexpected outcomes are ruled out by a systems analysis. No new information can be discovered. Novelty is impossible.

Another error in the optimizer's logic is that the choice between performing an optimization across alternatives and acting on diversification is not independent of the management regime. Hitch installed the program budget to generate the kinds of information required to get "good estimates of the cost of systems for use in RAND's systems analyses."[217] The whole purpose of the program budget was to measure programs and the performance of their administration. Budget justifications required precise definition of the system and a consistent means for evaluation throughout. Hitch wrote that "Economic efficiency demands that alternative programs… be costed *prior* to the selection of the preferred program." For programs to be institutionally viable, they first required the exact type of information produced by a systems analysis. To perform a systems analysis, there needed to be a history of program budget information, the very purpose of which was to spot and remove duplication. The entire framework of defense management prohibited the pursuit of competitive developments.

Funding a diversity of approaches with regularly placed options to change direction defeats any generalizable measure of program success, even when success and failure is clear to the subjective observer. Program budgets and systems analyses are not conducive to adaptive planning by local actors who will naturally overlap one another. Instead, they gravitate toward holistic planning of the force structure. Enthoven explained that the "system" in systems analysis "should be considered in as broad a context as necessary."[218] Hitch agreed that systems analyses should encompass all components of the operational system, and extend its predictions from R&D all the way through disposal. It should also be performed at even higher levels of complexity than Minuteman squadrons or Polaris submarines; systems analyses applied even to "the determination of forces required to perform the strategic retaliatory mission."[219]

By contrast, Alchian clearly stated that systems analyses should be confined to procurement decisions. In his view, they should have no role in determining the performance characteristics of weapons, let alone the technical decisions needed to get there.[220] For Alchian, systems analyses were confined to determining which already fully developed system should be procured, as only well-defined problems over short time horizons were amenable to measurement and optimization.

4.5 Management systems

To illuminate the connection between institutions and program decision making, it is necessary to describe the defense management systems employed by Charles Hitch with the PPBS. The management systems largely depended upon deciding in advance the particulars of what must be done, and measuring progress to the centrally approved plan. The intended result was a unified budget that outlined the cost and objectives of programs, including the implications of funding changes.

Hitch believed that the earlier attempts at the PPBS, such as the Title IV performance budget, provided "little unification in fact." The Secretary of Defense had used budget ceilings rather proactively selecting between service programs because he "lacked the management techniques to do it."[221] Hitch complained that "military planning and budgeting have traditionally been treated as independent activities… the first falling within the province of the Joint Chiefs of Staff… and the second within the province of the Comptroller." As a result, each year the Secretary of Defense "found himself in a position where he had to make major decisions on forces and programs without adequate information, and all within a matter of the few weeks allocated to his budget review."[222] Hitch tried to bind programming and budgeting in the Comptroller's office, which had purview over the Office of Systems Analysis (OSA).

The program budget process started from military requirements set by the JCS in the Joint Strategic Objectives Plan. The service staffs then interpreted those requirements into well-defined program packages in the Draft Presidential Memoranda (DPMs), submitted for review by OSA and the Secretary of Defense. The systems analysis laying out a quantified program plan became unquestionably the largest factor in Secretary McNamara's decisions.[223]

After elaborate stages of review and revision, ASD Comptroller then tied together all the information for the entire Department of Defense. The result—reminiscent of socialist industrial plans—is a Five Year Defense Program (FYDP), a register of approved program elements with budget estimates for the next five years.[224] The services could only request changes to the FYDP by submitting a Program Change Proposal (PCP) to OSA.

The centralizing process naturally created a huge flow of paper. The Bureau of the Budget reported that the amount of paperwork involved, particularly for the PCPs, was "bogging down" the system. As a result, OSA attempted to head off PCPs by providing guidance for changes likely to be approved in the Tentative Force Guidance (TFG).[225] By the spring of 1964, the Systems Analysis office of about fifty analysts became in the words of one former member, "the basic force planners in the whole system."[226]

Admiral Hyman Rickover commented how "It is important to recognize the degree of detailed technical control over military matters the systems analysts exercise through the DPMs." He noted that the DPMs and PCPs did not provide the services a "serious voice at the table."[227] Captain Stanley Barnes worried that "*programming*, as it is now conceived by civilian authority, will dominate *the total defense planning process*," eventually replacing military planning with "a body of ad hoc civilian sponsored, directed, or conducted studies and analyses."[228] In fact, that was precisely Hitch's goal. He wrote that "the job of economizing, which some would delegate to budgeteers and comptrollers, cannot be distinguished from the whole task of making military decisions."[229]

In order to monitor execution to the approved program, bookkeeping devices were required throughout the services. The PPBS program elements decomposed into well-defined systems managed by the systems program offices. However, most of the information required to make good estimates and evaluate performance was held not with the SPOs, but with the contractors performing the work. The PPBS therefore required reporting structures that extended down into the contractor's management system.

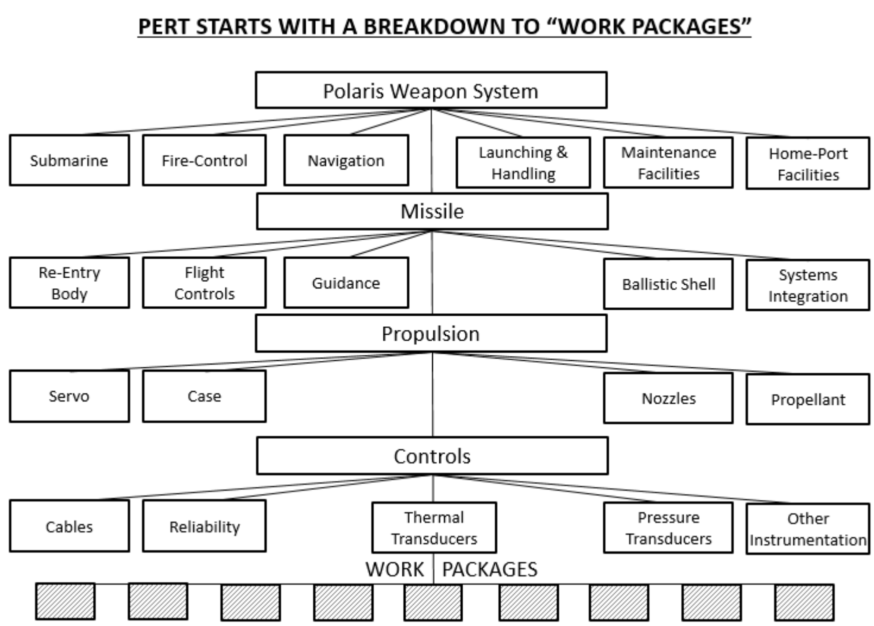
The framework for lower-level management reports came from similar systems independently developed by DuPont and the Navy. DuPont developed the Critical Path Method, and the Navy, in concert with consultants, developed the Program Evaluation and Review Technique (PERT). The latter was formulated in 1958 and applied to the Navy Polaris program in 1959.[230]

4.6 Direct controls

Thomas D. Morris, Assistant Secretary for Installations and Logistics, described the PERT system to Congress. PERT was specifically designed to pre-plan the "fantastic complexity of modern weapon systems." Polaris, for example, employed over 10,000 people itself. "What is PERT?" Morris asked rhetorically.

> "First, break down each project into those tasks which are significant for control… The second objective of PERT is to estimate the expected time and cost required to complete each task. Third, to continually review actual performance versus estimates, in order to readjust schedules and financial plans well in advance of time slippages and cost overruns."[231]

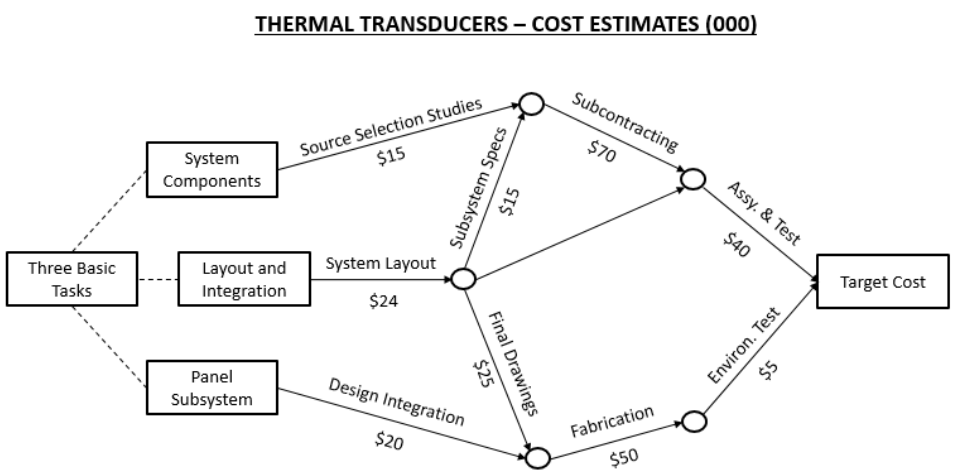
Morris then went into an in-depth discussion. PERT breaks down the system into a hierarchy of parent-child relationships between subsystems, components, and assemblies called a Work Breakdown Structure (WBS). For example, the Polaris system includes the missile, the submarine, facilities, and other subsystem elements. The missile itself has children elements for guidance, body, propulsion, etc. The missile propulsion is made up of the case, nozzles, controls, etc. The missile propulsion controls include cables, reliability, thermal transducers, etc. But the planning process did not end there.



Reproduced figure from "Systems Development and Management (Part 2)." The Work Breakdown Structure begins with the total system, and is divided into parent-child relationships with subsystems and components, and eventually scheduled work packages and activities. The product oriented structure aligns with, and may "feed," the program budget structure.

WBS elements are themselves made up of smaller work units. Thermal transducers, for example, are made up of several work packages which are further divided into a set of logically identified activities. A set of thermal transducer activities might include System Layout, Source Selection Studies, Final Drawings, Fabrication, Assembly, and Operational Test. Each activity requires estimates as to duration, sequencing, and inter-relationships.

With a network of activities connecting every step necessary to complete the project, the longest single path of activities in the schedule represents the "critical path." Any slippage to activities on the critical path will cause the entire program to slip. PERT appreciates the fact that a project progresses only as fast as its weakest link and seeks a targeted application of management. Activities not on the critical path have "slack" to slip without affecting the rest of the scheduled network of activities. Admiral William "Red" Raborn, program manager of the Polaris system, commented that the effect of changes on the critical path was calculated "through the magic of computers."

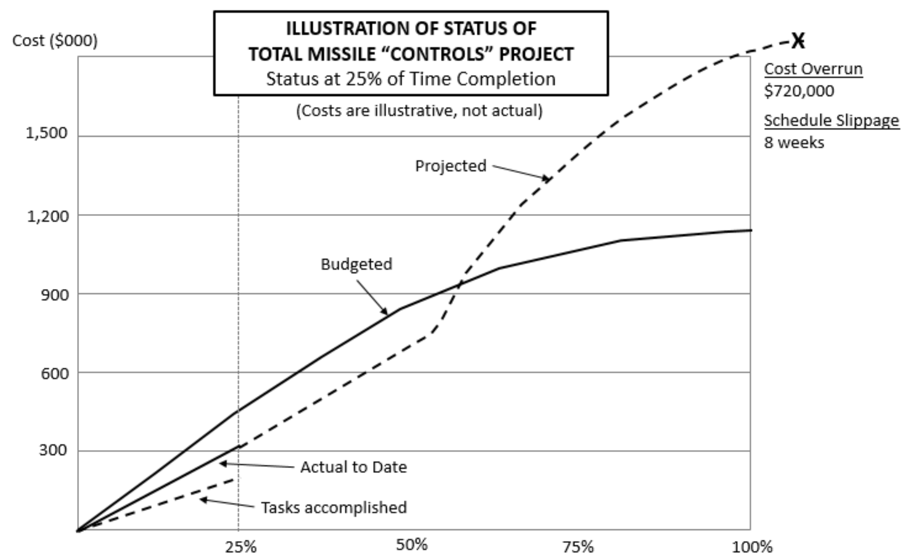


Each work package associated with the lowest level WBS elements is scheduled in a network. They are then provided a cost estimate to which actual expenditures are tracked. Reproduced figure.

Activities were also given cost estimates, which enabled a time-phased baseline upon which to measure performance. For example, suppose an activity was planned to take a month and cost $1,000. If that activity were actually accomplished in month at a cost of $1,000, then that portion of the project is on-time and on-cost. However, suppose the activity slipped. In that case, by the time the activity was baselined for completion, the project could not claim accomplishment of $1,000 worth of work and is behind schedule by that value. Suppose that the activity is actually completed two weeks late and at a much higher cost, it took $1,500 of actual expenditures to complete the activity that was planned to cost $1,000. Therefore, the activity experienced $1,000 worth of schedule variance for the two weeks it was behind and contributes to $500 worth of cumulative cost variance. In this manner, when activities are completed the project *earns value* which is compared to the baseline in terms of cost and schedule.[232] Problem areas may be exposed quickly and can receive managerial attention.

The PERT system also generated internal predictions. An independent cost estimate at completion is possible by projecting forward current cost performance. Suppose that, having aggregated all activities, the project has expended $1,000,000 to accomplish only $500,000 worth of baseline work. If current performance persists, the entire project may cost twice as much as expected. Let's further suppose that the project had only planned to accomplish $500,000 worth of work by that time. Then we can conclude that the project is maintaining schedule by burning at a higher expenditure rate.

With a fully costed network of activities, the actual amount and timing of expenditures can be compared to the budgeted plan, providing the basis for quantitative measures of progress. In the figure, the project is 25% of the way into the baseline project schedule. But only half of the tasks budgeted had actually been accomplished, the project is behind schedule. The finished activities costed more than budgeted. The project is over-running on cost.



In 1962, the joint DoD/NASA PERT Guide was released and over 200 major defense projects began employing PERT systems. David Novick at RAND called the change a "major step toward effective control of new programs." While the systems had only impacted acquisition projects, Novick held hopes that the same kind of progress reporting could be employed for military operations using workload indicators.[233]

The information generated by PERT has implications on the budget process. Centralized management through the PPBS requires a flow of detailed information, or else the process could grind to a halt. When decision-makers at the top are provided real-time data on performance, they can make tradeoffs in a timely manner. With greater responsibilities put on prime contractors, the reporting system had to extend into industry at large.

Major obstacles to the PERT method included poor government implementation and inadequate computer software to support it.[234] But even the best accounting systems were strained by the complex requirements. Contractors kept a dual set of books rather than fully switching over to management by PERT.[235] The second set of books proved inevitable because of the same organizational issues inherent with program budgeting. Even if defense organizations could be made unifunctional with respect to the program structure, individual contractors could not be forced to align organization with program. This is especially true for large and complex firms that performed a wide variety of contracts. The contractor organization, in other words, is prior to the government program. Contractors had to keep one set of books for the government programming and another based on organization and object for their internal administration. While the first set of books aligned with the product-oriented Work Breakdown Structure mandated by the government, the second set of books aligned with what became called a contractor-defined Organizational Breakdown Structure. Prime contractors, then, ran into similar problems that the arsenals and bureaus did before their replacement with project offices ushered in by the PPBS.

Contractors complained bitterly about increased direction of management systems from the government. For one, the planning, scheduling, and accounting systems required enormous investments in new computers. One contractor submitted an estimate of $7 million to perform work on a $1 million contract due to the cost of PERT.[236] Robert Anthony, Hitch's replacement as ASD Comptroller, recognized that government officials were placing excessive costs on contractors, and often usurped detailed planning. In 1967, Anthony issued guidance that prevented micro-management of contractors, and instead required them to conform to 35 industry standards.[237] Even with relaxed guidance, progress on contractor control systems proved slow.

PERT not only strained organizations and accounting, but impeded the success of R&D projects. "Huge sums of money," L. E. Loveall wrote in 1966, "have been spent on PERT programs before discovering that the PERT approach was not feasible within the context in which it was planned." He found that in the Polaris program, "Many of the activities were compressed into time periods that were not adequate for completion. Other activities were allocated too much time and effort."[238] Small errors in estimates could lead to major re-planning of scheduled activities.

The early success of the Polaris program was in fact not due to PERT. By the time PERT had been employed in 1959, Polaris had been a SPO for 4 years. Further, Polaris did not deliver the full operational capability in the performance estimates. The first missile had half the range and destruction, and it wasn't until 1964 that its requirements were met. Polaris benefitted from diversity in the early stages and rapid testing; it did not set detailed plans until many technical issues had been resolved.[239] Some of those working on Polaris from 1955-1960 argued they would have been hamstrung by the policies instituted during 1961-1965.[240] Oskar Morgenstern had "great doubts" about the success of Polaris had systems analysis been applied from the start.[241]

In 1967, Harvard researcher Harvey M. Sapolsky was invited by the Polaris Special Projects Office to write a history of the program. In *The Polaris System Development*, Sapolsky devoted a chapter to "PERT and the Myth of Managerial Effectiveness." He found that PERT was not used for major parts of the effort until years after the first Polaris launch. Not a single group within the project claimed to have benefitted from the original PERT:

> "In interviews with contractor executives reviewing their experience with the original PERT system, not one of them said that he had used the data… Instead many thought that it was the Special Projects Office technical officers and engineers that actually had used the PERT system data. The technical officers and engineers, in turn, denied ever using PERT data to manage their segments of the FBM [Polaris] Program; they thought it was the program evaluators in the Plans and Programs Division, if anyone, who made use of the PERT system. Persons who held positions in Plans and Programs, however, admitted that they themselves never used the system; rather, they thought it was either the technical branch heads or the Special Projects plant representatives who worked with the PERT reports. The plant representatives were similar in their response: 'No, it must have been someone else.'"

Though not a single group of project participants could be found that benefitted from PERT, the project as a whole did. Sapolsky was told how "It had lots of pizzazz and that's valuable in selling a program." Another participant said that "The real thing to be done was to build a fence to keep the rest of the Navy off of us. We discovered that PERT charts and the rest of the gibberish could do this. It showed them we were top managers."

Sapolsky discovered that Polaris advocates used PERT to market themselves to leadership in defense, Congress, and the public. The tactic worked. Polaris easily secured large budgets without the detailed oversight that often comes with it. With the privileged position, the SPO pursued two or three alternatives simultaneously for major components and subsystems. Sapolsky reported on an encounter that typified the SPO's unorthodox methods: "When a Navy field office accountant sought to apply the usual bureaucratic delays to FBM contractor requests, he was told that he would be immediately transferred to another, less desirable assignment if he attempted to do so again. 'Think big or get out' was the message."[242]

4.7 Error suppression

The advantages of networked schedules like PERT arguably apply best to procurement efforts, which tend to require numerous repetitive tasks that interact deterministically. They can estimate the impact of contingencies with known probabilities. Unlike procurement projects which tend to be close-ended systems, R&D projects are open-ended systems. Interactions between activities cannot be predicted, often creating unexpected outcomes. If interactions between activities cannot be defined, or are reflexive rather than causal, then a networked schedule falsely represents as crisp and precise that which is highly uncertain. "Why is there only one critical path?" Aaron Wildavsky asked. "After all, the larger the project, the more separate paths needed, the lower the absolute probability any single path will be the critical one."[243]

Uncertain environments require a learning process to overcome problems. Philosopher Karl Popper found that all problem solving, whether in nature or in the lab, required the trial-and-error method. "To be more precise," he elaborated, "it is the method of *trying out* solutions to our problem and then discarding the false ones as erroneous. This method assumes that we work with a large number of *experimental* solutions. One solution after another is put to the test and eliminated." By making the entire weapon system a single potential solution, the systems approach constrains problem solving by restricting the number of solutions tried and thus errors exposed. Popper wrote that "if there were not *very many* [solutions], they would not be worth considering as attempted solutions." Without numerous solutions tried, there can be no experiment in which errors are identified and new problems exposed. Popper realized that "We are always learning a whole host of things through falsification. We learn not only *that* a theory is wrong; we learn *why* it is wrong. Above all else, we gain a *new and more sharply focused problem.*"[244]

Because PERT fixates on completing interdependent tasks, each task becomes inseparable from the whole system. An error in one task is no longer localized. The only new solutions available are close substitutes in system integration. When scale increases in such tightly networked systems, errors become increasingly harmful and the solution space for problem solving very much narrowed. New problems and new solutions no longer have the freedom to arise; instead, more resources and management pressure is placed on the same solutions. Popper concluded that "Error correction is the most important method in technology and learning in general. In biological evolution, it appears to be the only means of progress. One rightly speaks of the trial-and-error method, but this understates the importance of mistakes or errors—of the erroneous trial."[245] Methods such as PERT and systems analysis create an institutional bias against error correction and towards error suppression.

The trial-and-error origins of industrial revolution technologies, such as textiles and the steam engine, are well established. "Engineers are notoriously more successful," RAND analysts found in 1958, "when they can tinker with pieces of machinery than when they are asked to make all their decisions at the drawing table before there are any test data on which to base them."[246] The PERT method, however, has little managerial value when activities require trial-and-error. PERT systems handle uncertainty by assuming a distribution of potential outcomes for each estimate of an activity's cost and duration. The total effect on the project's cost and schedule is calculated using a Monte Carlo simulation that randomly selects an outcome for each activity according to specified distributions.[247] Numerous runs of randomized selections allows the Monte Carlo to generate a distribution of cost and schedule outcomes for the project as a whole, including the worst, most likely, and best case scenarios. Despite the enormous effort required for such integrated cost-schedule risk analyses, and the weeks or months of computer programming it required, the Monte Carlo method only works if there is zero uncertainty as to the content or interrelationship of activities, only as to how much time or effort each one will take.

Under true uncertainty, when planners cannot know the content or interrelationships of future activities until more information is generated, PERT proves a wasted effort at best and a rigid encumbrance at worst. Suppose a planner accepts that innovation cannot be predicted and would like to schedule a trial-and-error approach. While each trial can have a notional schedule for its activities, there exists no acceptable way for defining the activities involved in the second solution due to uncertainty as to what will be learned in the first solution—assuming a second solution is needed at all. Integration plans cannot be scheduled until characteristics of the components are discovered. A similar fate befalls the costing of options. There can be no detailed plan outlining when and by how much a success should be followed up by, or when it is time to cut losses and seek alternatives.

PERT does not allow for rapid updates to expectations of the project's direction. As the Monte Carlo exercise illustrates, PERT fixes the project's technical specifications and allows cost and schedule to vary. Projects managed by PERT are then fragile with respect to uncertainty. The more uncertainty is present, the more likely it is that overruns will far outweigh underruns. Yet PERT also neglects the benefits of uncertainty, such as opportunities to generate vastly superior performance by a change of technical direction. Positive unintended consequences are thus foregone. Exposure to cost risk is maximized. Klein, Meckling and Mesthene pinpointed two key weaknesses of the PERT method in 1958:

> "Any attempt to schedule an entire R&D program at one time is likely to lead to inefficiency, either because plans for the later stages may have to be scrapped and remade on the basis of information yielded by early tests, or because, in pursuing premature plans, a development program may fail to profit from new information gained along the way. Either case will cause delays, or raise costs, or both."[248]

Perhaps all sides accepted the role of diversified investment in the earliest stages of scientific research. And perhaps all sides saw the logic of unified planning in quantity production decisions which deployed large amounts of resources. The critical questions came in development and its boundaries. Hitch felt development benefitted from detailed planning much as procurement did. Alchian—as well as Roland McKean and various others—believed that development, like research, was primarily a search of the unknown that benefitted from diversity.

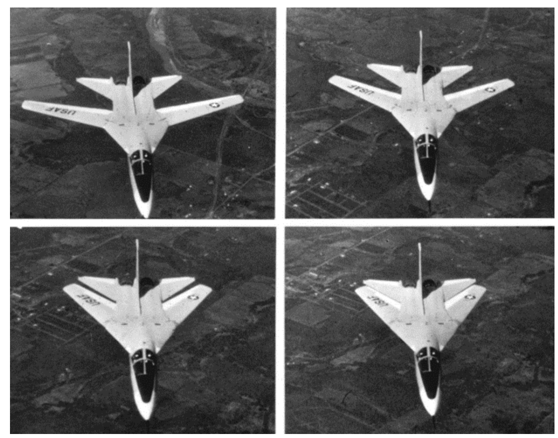
McNamara and most experts at the time subscribed to Hitch's view of management. McNamara's increased confidence in predictions created major problems for one of his first acquisition initiatives, the TFX aircraft. Not only was the TFX intended to fulfill the roles of interceptor, fighter-bomber, *and* strategic bomber for both the Navy *and* Air Force, the TFX also included pioneering technologies in airframes, engines, and radar.[249] The fiasco of the TFX program, eventually the F-111 Aardvark, is a source of disagreement. However, the facts are that the program cost quadrupled even though the Navy dropped out after only 8 aircraft and the Air Force reduced its procurement to one-third the planned level. This does not even take into account the substantial decrease in aircraft performance from estimates. Program troubles arose despite a long program definition phase devoted to planning.

The TFX's technical failures must be viewed as institutional failures in acquisition management. Cost effectiveness was the greatest factor in driving decisions. McNamara, and even top military advisors like General Schriever, believed that the roles of multiple aircraft could be achieved with only one development program, one set of tests, and one supply network.[250] The TFX would also generate enormous economies of scale in procurement and vastly simplify maintenance and logistics. Unfortunately, none of those realities, which appeared so certain as the result of systems analyses, came to pass.[251]

Congress repeatedly questioned cost realism and activity scheduling in 1963 and 1964. McNamara, however, successfully defended the program from the Congressional chopping-block. By the end of the decade, the program had become a crisis. Yet a 1970 investigation failed to attribute responsibility. It stated that not enough information existed at the time to make a final determination. It needed to know more about the reasonableness of system estimates that ultimately led to an "operationally inferior and more costly aircraft design."[252] The planning stage prematurely locked in technical decisions on the F-111, causing rounds of rework. The same planning error has since been repeated numerous times in the defense decision making.

4.8 Participatory management

Cracks quickly formed in the integrated program budget under the Office of the Comptroller. To start, many Program Change Proposals were not decided upon until after the budget had passed. This implied ad hoc planning by the services. However, what truly marked the breakdown of the integrated PPB System was the exit of Charles Hitch.



The F-111A, formerly Tactical-Fighter Experimental (TFX), showing its variable sweep wings in flight.

When Robert N. Anthony became ASD Comptroller in 1965, he believed that programming and budgeting required different types of information. He explicitly sought to "undermine the programming system" that Hitch worked so hard to build. Anthony wrote that "Strategic planning is essentially *irregular*. Problems, opportunities, and 'bright ideas' do not arise according to some set timetable."[253]

Hitch, keenly aware of Anthony's disposition, insisted that the Office of Systems Analysis move out of the Comptroller's office prior to his departure. Still sympathetic to Enthoven and systems analysis, McNamara elevated OSA to an Assistant Secretary. With financial management split in the Pentagon, some insiders began to observe a power struggle emerging between Enthoven and Anthony.

Anthony struck first. He commissioned the McKinsey Company to study the programming portion of the budget, expecting to find extensive rigidities. The report indeed concluded that program process hampered effective administration. Anthony did what he could to stymie the intent of the PPBS. One official recalled that during Hitch's time as Comptroller, "OSA was automatically fed into the budget; but once separate offices were created, OSA often was not even consulted in decisions taken during the budget phase."[254]

In the same year that Anthony took the Comptroller spot, President Lyndon B. Johnson implemented the PPBS principles across the other departments. The Bureau of the Budget instructed that each department develop a program budget along with systems analysis capabilities.[255] Without prior experience in the analytical tools necessary for the program budget, implementation proved controversial. Two years later, in 1967, the Congress started to hear testimonies on the effectiveness of the PPBS. The final report emanating from the Jackson Subcommittee clearly showed skepticism of the new techniques.

The report opened with thirty famous passages from a wide range of thinkers. From Aesop's Fable and Aristotle to David Hume and Machiavelli, it even included pieces of the Bible. The passages have a clear message. Technical specialism associated with program budgeting is not a panacea for coordinating complex human interactions. Instead, the political process was accredited for its ability to generate decisions in uncertain environments where participants have diverse and legitimate interests. Chairman Henry M. ("Scoop") Jackson provided a concise explanation. "Modern-day specialists can make important contributions in decision-making; but there is no substitute in government for the wise generalist with skill and shrewdness."[256]

The Jackson Committee report presented many sides of the argument, from Admiral Rickover on one extreme to Assistant Secretary Enthoven on the other. Professor Aaron Wildavsky gave particularly stirring arguments when he attacked the extreme centralization brought on by the PPBS.[257] Yet Jackson's own centrist viewpoint appears to have prevailed among witnesses. For example, professor Klaus Knorr wrote that systems analysis studies "must count for no more, and no less, than their due."[258] The studies provided valuable insights even if they were not perfect oracles. At least within the Department of Defense, the PPBS survived the only major challenge it would ever face.

McNamara's successor as Secretary of Defense, Melvin Laird, vowed to "purge" the DoD of Enthoven's control through systems analysis. Regardless of the rhetoric, Laird did not abolish the systems approach. He devolved many of OSA's functions to the services, and in 1972 changed its name to Program Analysis and Evaluation (PA&E). The role of PA&E was largely to assist in the review of service programs at major "milestone" decision points.

By giving the military services primary control over programming, Laird sought to generate "participatory management." Yet the form of decision making in the PPBS changed little. It still required extensive before-the-fact controls on program requirements and cost. Laird replaced the Draft Presidential Memorandum (DPM) with the Program Objective Memorandum (POM), which retained the essentials from McNamara's program package framework that fed the same Five Year Defense Program, but with greater service administration.

The services, which had grown their own systems analysis capabilities to combat OSA, now employed them to justify programs. John Dawson wrote in *Armed Forces Comptroller* in 1972 that "Today is not a replay of the 1950s" because systems analysis was "firmly established" in the DoD.[259] Craig Powell shared the sentiments, believing that "the majority of volleys that have been fired at the principles of Systems Analysis have been blanks." Historian Charles R. Schrader found it "evident that both at the DoD level and within the Service Departments, systems analysis is considered sound application of economic theory and scientific method… and is generally accepted as a good thing." He concluded that the McNamara era reforms "prevailed in the battle" because its concepts "proved superior to traditional ways of doing things. Their triumph thus represented a triumph of rational scientific methods over experience and intuition."[260]

Scientific management of weapons acquisition proved unassailable. Extensive before-the-fact control mechanisms continued to proliferate. Reflecting on its poor track record, historian Walter Poole asked "Should centralization be labeled an acquisition failure?" He answered that "'Unanticipated unknowns' continually thwarted efforts to trade off cost against performance in setting requirements."[261] If unanticipated unknowns are expected in acquisition, and certainly the pursuit of R&D is the pursuit of the unknown, then acquisition processes that are fragile with respect to uncertainty should be replaced with those that are robust to, or benefit from, uncertainty. Instead, systematic errors were viewed as challenges to develop better estimates.

5. Contracting

> It is a profoundly erroneous truism, repeated by all copy-books and by eminent people when they are making speeches, that we should cultivate the habit of thinking what we are doing. The precise opposite is the case. Civilization advances by extending the number of important operations which we can perform without thinking about them.
>
> Alfred North Whitehead
>
> *An Introduction to Mathematics*, 1911

Before program budgeting existed, bureaucratic control was placed on organization and object. The budget estimating process usually performed a straight-line extrapolation from past rates of expenditures with incremental adjustments. Accountants kept only the records needed for business administration. They did not seek to apportion each dollar expended to a pre-specified military output. Cost information existed only in bits and pieces scattered both across and within contributing organizations. Administrative superiors evaluated the military output with less regard to preconceived metrics. They had discretion to reward or punish behavior as seen fit. The traditional set of rules associated with military procurement, as with operations, focused on conduct as judged after-the-fact.

Perhaps the most significant effect of the comptroller's rise in defense is the replacement of local control with control at a distance. Whereas local control is usually intimate enough to be evaluated qualitatively, control at a distance is typified by measurement of cost, schedule, and technical performance. The PPBS not only increased the scope of control at a distance within the Department of Defense, pushing decision-making up to OSD staff. It was also biased against in-house development capabilities, favoring outsourced work on weapon systems to a single prime contractor. The increased emphasis on high-dollar contracts enlarged further the scope of control at a distance, where contract language stipulated all matters of evaluation before-the-fact.

5.1 Outsourced

Prior to World War II, the services had robust in-house technical capabilities. Army production centered around six arsenals in the Ordnance Department, the first established in Springfield, Massachusetts in 1794. The Navy had its technical bureaus and owned a large network of shipyards. Except for wartime surges when private industry supported production, the services' in-house capabilities were the centerpiece of U.S. weapons expenditures. For example, between 1866 and 1883, two-thirds of Navy ships were constructed in government yards.[262] Even though Congress pushed Navy procurement toward the private sector in 1883, and did the same for the Army in 1916, it wasn't until after WWII that lasting emphasis placed on outsourcing.

The top administrator of the entire Government R&D effort also favored outsourcing. In his famous 1945 essay "Science—The Endless Frontier," Vannevar Bush recommended contracts or grants be used to conduct all public research. "It should not operate any laboratories of its own," Bush said of the federal government.[263] His opinion turned mainstream.

The Air Force, for example, argued successfully for their independence from the Army by promising to not only adopt practices from private businesses, but to outsource most of its weapon system work to industry. Without a legacy bureau system to weigh it down, the Air Force had by 1953 already outsourced 90% of its R&D budget. Even the Navy, which had a strong research focused organization since 1923, quickly increased its share of outsourcing. After WWII, the Navy outsourced 65% of research, though the figure for development was somewhat less at 40%.[264] In 1946, the Army's Ordnance Department had already allocated two-thirds of its R&D to private sources.[265]

The postwar decline of Army and Navy in-house capabilities accelerated in the 1960s. The Army technical services lost their statutory role in 1962 and later scaled back operations, including shutting down Springfield, Watertown, and Frankford arsenals. For Navy bureaus, they had already lost control of R&D in 1958. The Navy abolished the bureau system in 1966, though their remnants continued to be a source of innovation in missiles, lasers, and other important areas.[266]

The transfer of weapon systems expenditures to organizations external to the Defense Department brought issues of contracting to the fore. When the actual operations of doing experiments or bending metal occur in-house, the executive may act very much like a military commander in the field. He can express his desires, or lay out his "demand function," and command action. Depending on how he judges the resulting action when compared with his updated expectations, the executive or commander can reward or punish his subordinates. This method of administrative control is often called *after-the-fact control*.

When defense executives seek production from the open market, whether it be firms, universities, or non-profits, they must use market exchange mechanisms characterized by contracts. A contract seeks voluntary agreement between two or more parties. The exact responsibilities of each party, as well as methods for evaluation, are detailed before action is taken. A similar method of administrative control is wielded by the controller using program budgets. Both contracts and program budgets use the method of *before-the-fact control.* Professor Fred Thompson compared the two methods with respect to internal administration:

> "[Before-the-fact] controls necessarily take the form of authoritative mandates, rules, or regulations that specify what the subject must do, may do, or must not do. The subjects of before-the-fact controls are held responsible for complying with these commands and the controller attempts to monitor and enforce compliance with them.
>
> "After-the-fact controls are executed after the subject, either an organization or an individual, decides on and carries out a course of action and, therefore, after some of the consequences of the subject's decisions are known."[267]

The congruence between contracting and program budgeting made the two natural bedfellows, the enabler being the unifunctional project office structure. The program budget demands that organizations find perfect alignment with program structure, which Mosher had showed impossible for any significant organization. These forces, coupled with an expressed desire for private production, led the Air Force to favor the systems project office and a single prime contractor.

For the pre-existing Army and Navy organizations to be viable, there needed to exist an auditable system of accounting by program. Without such an accounting system, the policy maker could not effectively monitor execution to plan; nor could the policy maker forecast future plans. Though Congress mandated such an accounting system in 1955, it was never accomplished.[268] Thus, the move toward unifunctional project offices can be seen as a means of outsourcing accounting compliance as well as production knowledge to industry. Control through the program budget would otherwise require multifunctional in-house organizations to perform such accounting themselves.

5.2 Contracting

Increased reliance on industry required different forms of contracting than those historically permitted by Congress. Contracting before WWII was almost entirely of the fixed-price sealed-bid procurement auction form. In such an auction, the government advertised its requirements publically. Interested parties responded with proposals. Advertisement and unbiased appraisal was viewed as a democratic means of source-selection. It also had the benefit of holding the supplier to reasonable speculations in the cost, schedule, and technical trade-space. The supplier bore the full risk of not meeting the contract obligations.

The uncertainty of R&D contracts made them legally ambiguous because terms could not always be met in the manner pre-specified. Instead of taking firms to court for contractual default, the bureaus more often punished firms which did not expend resources in an appropriate way when judged after-the-fact by not awarding them future work, bringing the work in-house if needed. The repeated interactions between a diverse set of government and industry participants led to significant reputational effects. Contract specification as written before-the-fact therefore mattered less than the purchaser's satisfaction when viewed after-the-fact.

The weapon system concept put emphasis on pre-specified plans such that all components could integrate with the greatest technical advancement in the shortest possible time. The systems approach then required detailed specifications of future components for ensuring integration. The increased scale and complexity of the task strained the fixed-price contracting regime mandated by legislation. In 1947, Congress added eleven broadly worded exemptions to the use of advertised fixed-price contracts in the Armed Services Procurement Regulation. For exempted contracts, it also required detailed documentation and justification for each obligation, leading to "tedious and time consuming steps."[269] But the process allowed the services to skip advertisement and directly negotiate with a single supplier.[270] Further, the legislation authorized the use of cost-reimbursable, or "cost-plus," contracts. Cost-plus contracts shielded contractors from risk by having the government reimburse the contractor for all auditable cost expenditures related to the project, as well as a fair share of overhead expenses. On the downside, cost-plus contracts discouraged cost control in favor of achieving the required performance in the shortest schedule. Companies also expensed the buildup of future capabilities to the current contract.

The expense control problems resulting from negotiated cost-plus contracts seemed to remove the competitive incentives from the defense industry. Perhaps the most pernicious problem of cost-plus contracts to the PPBS was that it encouraged overly optimistic pricing. Contractors could "buy in" on a major weapon system with low bids and get fully reimbursed for overruns. Systematic use of "foot in the door" strategies distorted the decision trade space and crowded out future investment to cover impending overruns.

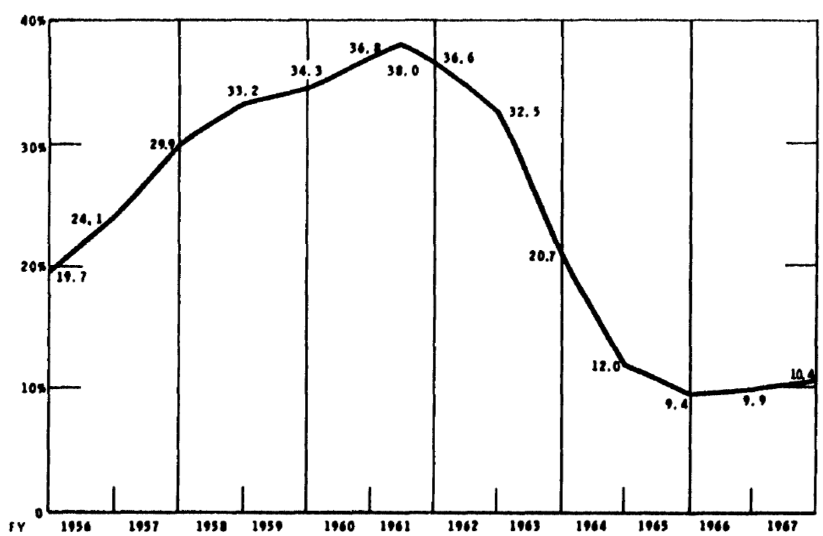
Cost-plus fixed fee (CPFF) contracts were especially pervasive in missiles due to the high risk nature of the work. The contract type accounted for over three-quarters of all missile contracts in 1960.[271] As a percentage of the total DoD contracts, CPFF had steadily risen until it peaked at 38% in 1961, the year McNamara took office. At the time, nearly 40% of the DoD budget went to cover cost overruns. McNamara sought to turn the tide on CPFF contracts. Over the course of five years he cut the total proportion of CPFF contracts by three-quarters, down to near nine percent.[272] A memo from McNamara to President Johnson in 1964 claimed that "At a minimum, our analyses indicate that 10 cents is saved for each dollar shifted from a CPFF to other forms of contracts."[273] The contracts let for weapons acquisitions did not, however, return to the old model of advertisement and firm fixed-price contracts. Sole-source awards continued, and contractors were forced to share more of the risk on fixed-price incentive basis.

5.3 Incentives

Adding incentives to contract structures seemed to offer a cure for expense control problems. Using an incentive contract, both parties agree to a share ratio whereby the supplier retains a proportion of underruns as profits and pays for a proportion of overruns as losses. A common share ratio is 80/20 where the government retains 80% of risk and reward while 20% is retained by the contractor. In other words, for every dollar the contractor went over the target cost, the contractor would pay 20 cents and the government 80 cents.

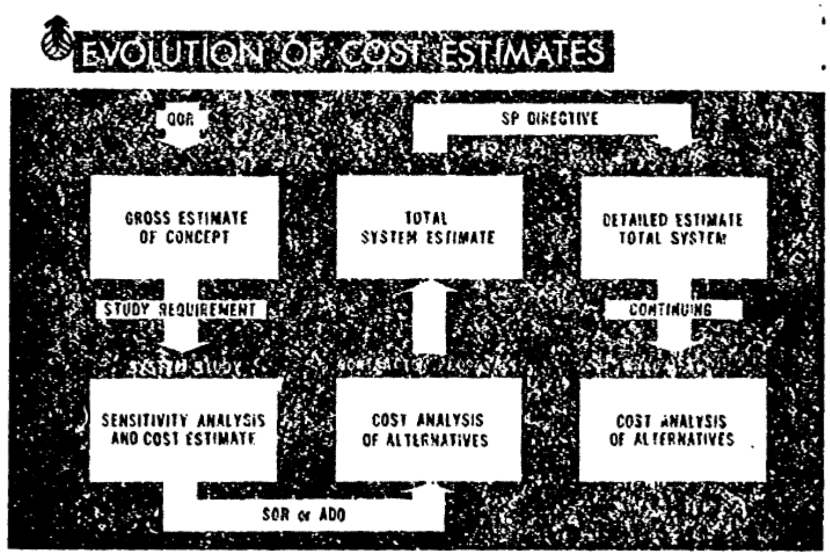
The contract share ratios could be tailored on either side of the target depending on circumstance. At one extreme, a CPFF contract has a continuous government share ratio of 100/0. At the other extreme, a firm fixed-price contract flips the ratio to 0/100 forcing the contractor to accept all of the risk as well as reward. Because of the stakes involved, the incentive approach put a premium on target cost negotiation. It also required auditable accounting for all expenditures.

In June 1962, Frederick T. Moore published a seminal paper examining the uses of contract types for aircraft and missile programs. In "Military Procurement and Contracting: An Economic Analysis," Moore examined 290 incentive contracts of all types and 2,501 CPFF contracts. He found that while less than 5% of CPFF contracts resulted in cost underruns, 74% of incentive contracts did.[274] However, Moore could not conclude that incentive contracts automatically led to better outcomes. He fully recognized that CPFF contracts systematically received lowball estimates while incentive contracts received high estimates.[275] Though Moore could not determine what each contract objectively should have cost, and thus which contract type provided relative efficiencies, he admitted that "Clearly we don't want to go to cost-type contracts." Without much substantiation, Moore wrote that for CPFF contracts, "the results would be much worse" than if incentive contracts had been used. He reached the conclusion despite the obvious fact that incentive contracts led to higher target costs, as well as "windfall" profits for the contractor.[276] Moore's primary recommendation to control high target costs was the idea of a "hard target," whereby after traditional negotiations, the government provided the contractor the option to accept a lower target cost with an increased share of profits if the lower target is achieved.



Cost-plus fixed fee (CPFF) contracts as a percent of total Department of Defense contract awards, presented to the Congress for the 1969 budget request. The proportion of CPFF contracts doubled between 1955 and 1961, and fell by nearly three-quarters between 1961 and 1965.

Despite the problems of fixed-price incentive contracts, namely contractors playing it safe by negotiating high target costs, they became fashion in 1960s weapons procurement. In a second installation of *The Weapons Acquisition Process*, Frederic Scherer, this time writing alone, provided a searching review of incentive contracting. Scherer wrote that “Virtually all the detailed cost estimation for weapons program budget decisions of the 1950s was undertaken by contractors.” Because contractor accounting systems often did not allow for estimating unit costs of items already produced, let alone future items, the ambiguity over a reasonable cost often strained contract negotiations. Scherer reported on one government negotiator’s frustration, “We have piles of cost documents, but none of them tell us what we need to know in making projections.” Scherer characterized the contractor who could respond that “the cost of collecting data detailed enough to be useful in cost projections exceeds the value of the additional precision attainable.” PERT regulations, Scherer noted elsewhere, mandated programmatic accounting that also supported estimating techniques. The resulting data not only benefitted the contractor, but the government as well. He reasoned that if better target costs were to be negotiated, “the military services and the Office of the Secretary of Defense must acquire independent competence in estimating program costs.” Scherer wrote how after observing “many large negotiations… our case study research turned up only one trifling example (involving costs of roughly $1 million) in which a really penetrating job of cost analysis was done by the buying agency.” He applauded government investment to strengthen cost analysis, writing “That such efforts will lead to improvements seems a virtual certainty.”[277]



Air Force Headquarters methodology taught to Systems Project Offices in a 5 week cost estimating course at Air Force Institute of Technology. Scherer applauded building up government capabilities in cost estimation to counter the contractor’s asymmetric information.

5.4 Total Package Procurement

A year after Scherer's book, a new form of contracting emerged. The Total Package Procurement (TPP) concept attempted to acquire the entire program in just two big fixed-price contracts, one for development and one for production. The scheme put even greater emphasis on the government's ability to validate target costs. It was the brainchild of Assistant Secretary of the Air Force for Installations and Logistics, Robert Charles.

The intent of the TPP was to alleviate the problem of unrealistically low buy-ins where the contractors expected to make up the revenue on change orders or procurement. The TPP induced realism by exposing the contractor to three risks: "1. Commitment to the price and performance of production articles before their development; 2. Total system performance responsibility; 3. Extreme length of commitment."[278]

The TPP's pilot program, the C-5A cargo aircraft, experienced the exact problems that the TPP tried to avoid. Lockheed's winning bid came in at half the cost of the next competitor, Boeing.[279] Despite the C-5A being, from an engineering standpoint, a "straight-line extrapolation" based on "proven" technologies, substantial cost growth ensued.

The TPP supposedly provided contractors freedom from government oversight to develop and produce the best system within a negotiated price. It attempted to more clearly place responsibility for performance with the contractor. Assistant Secretary Charles promised that the C-5A would "get away from the fuzzy notion that the Government and industry should be 'partners.'" For Charles, entangled responsibility led to "several adverse results."[280] Yet for the C-5A, the government did not isolate its responsibility. The Air Force levied excessively detailed requirements, suppressing the contractor's freedom to explore improved solutions. Charles later agonized about the problematic requirements:

> "We wanted a transport which has only a few basic requirements, such as cargo area, cruise speed, range, payload, takeoff and landing distances and conditions, and navigational capabilities. But it took us over 1,500 pages to say this. In reply, the five competitors sent in… 240,000 pages."[281]

Just two years after the Air Force had called the program "a miracle of procurement," one of its own officials, Earnest A. Fitzgerald, disclosed a $2 billion cost overrun on the C-5A. For his efforts, Fitzgerald was fired. He later told the Congress that "I think Lockheed was confident that they were going to be bailed out. I think they never believed from the very start that they were going to be held to their contract, because other people were not then being held to their contracts."[282] While an analyst at the Office of Systems Analysis said that the C-5A was "one of the major successes of systems analysis in the Defense Department,"[283] Senator William Proxmire criticized the C-5A program for severe cost overruns and performance defects. He charged the Air Force with acquiring it in a "scandalous way."

Despite his tough stance, Proxmire did not place blame with the TPP scheme. He said, "Would it have made any difference if the C-5A contract was written or awarded differently? I don't think so."[284] A report on military spending prepared for Congress in 1969 disagreed. "Total-package and other large contracts," it reported, "should be broken down into smaller, more manageable segments."[285] The General Accounting Office and the Fitzhugh Commission Report followed up with their own cautions about the TPP, with the latter recommending an outright prohibition.[286]

5.5 Task partitioning

Addressing the issue of contract scale before the consequences of the TPP became clear was RAND economist and future Nobel laureate Oliver E. Williamson. When considering Scherer's analysis on contract control, Williamson noticed a conspicuous omission. Scherer wrote that the government had "two main ways" of attaining successful weapon systems without the "guides and restraints provided by the market's 'invisible hand.'" The first way is using direct control, characterized by participation in the contractor's internal operations (e.g., PERT). The second way is using incentives characterized by rewarding desirable performance and penalizing unsatisfactory performance (e.g., incentives). Williamson, however, saw a third option: breaking the contract down into smaller segments. In 1965, he complained that Scherer "does not even consider task definition as a means of influencing contract behavior."[287] Two years later, Williamson concluded that:

> "…neither the manipulation of profit incentives nor the monitoring of contract progress can be expected, in any dependable sense, to yield significant improvements in contract performance as long as the specification of the task remains unchanged. From a contractual point of view at least, the 'systems approach' to weapons procurement which has prevailed since 1953 appears to be distinctly suboptimal."

Using a mathematical model, Williamson showed that adjusting the share ratio changes optimal contractor behavior with respect to negotiating target cost. Under sufficient uncertainty as to an objective target cost, contract incentives induce higher bids to mitigate the risk. Uncertainty also means that the government is not positioned to refute the substance of the proposal. “The principal difficulty,” Williamson wrote, “in evaluating the effect of incentive contracts on cost performance rests on the negotiation of target costs.” Many observers of defense contracts understood the importance of establishing an objective target cost from an analysis of historical data. But rather than discussing smaller contracts for certain components, the weapon system approach focused cost analysis on a single contract to execute the entire development program. That vastly increased the amount of uncertainty built into the contract.

Williamson suggested major system contracts be partitioned and contracted separately, thereby narrowing the scope of each contract task and narrowing the range of an objective target cost. He argued that rather than designing incentives, a “more fundamental way by which to improve defense contracting is to decompose the task into technically separable components.”[288] Task partitioning provides a practical method for arriving at a contract cost target of objective significance. Williamson summarized the “manifold” advantages task partitioning promised:

> “1. It reduces the amount of uncertainty and hence increases objectivity in contract negotiations, reduces the felt need for defensibility in administering contracts, and permits more reliable evaluations which in turn allow cost-performance reputation effects to be assigned with confidence. Each of these effects should help to prevent excessive contract costs.
>
> “2. It creates a contract environment in which the full potential of parallel R-and-D approaches… can be exploited.
>
> “3. It complements R-and-D strategies which emphasize the need for maintaining options by providing support for work on adaptable components and flexible capabilities…
>
> “4. It permits greater competition by increasing the number of eligible contractors.
>
> “5. It lends itself to sales and employment stabilization.”[289]

Williamson argued that both the military services and the contractors avoided task partitioning, and consequently increased uncertainty, “because of the beneficial consequences that each associates with it.” The benefits to both parties derive from defensibility. For the service purchasers, “Defensibility can be secured if, in the nature of the task, a wide range of outcomes are ex ante possible. And nonuniqueness will result if the task is defined in such a way as to preserve substantial uncertainty.” For the contract supplier, defensibility exists when “it is difficult to assess efficiency-reputation effects with any degree of confidence.” Large contracts satisfied both parties’ interests by making defensible almost any conceivable outcome.

Williamson identified four drawbacks to task partitioning: "(1) possible interfacial problems, (2) contract proliferation expenses, (3) sacrifice of scale economies, and (4) possible time delays." He addressed each in turn. First, he found issues of interfacing, or integrating components into a final system, "exaggerated." In the normal course of system developments when the entire work is contracted at once, the prime contractor will partition tasks across components but without the option to partition tasks across time. Second, "although contracts will increase in number they will decrease in complexity—both at the negotiation and administration stages—so that administrative cost increases for this reason may be kept within quite acceptable limits." Third, Williamson called the economies of scale issue "mainly a bogus one" with five quick jabs. In 1962, Peck and Scherer arrived at the same conclusion that economies of scale "are not so significant as to be the decisive factor in the organization of the weapons industry."[290] Fourth, Williamson gave credence to the "time-is-of-the-essence" critique and the occasional need for a crash basis through the systems approach, but he did not find moon-shots appropriate on a continuing peacetime basis.[291]

Williamson looked back on the work of RAND colleagues Klein, Meckling, and Mesthene. He agreed with their perspective. The problem is not "one of choosing among specific end-product alternatives, but rather a problem of choosing a course of action initially consistent with a wide range of such alternatives; and of narrowing the choice as development proceeds." This is exactly what Alchian meant when he said that "the essence of the decision process is to affect the scope of random factors so as to give a 'good' probability distribution of outcomes." The practical application, as Williamson noted, is overlapping research efforts with regularly placed options.

5.6 Whither uncertainty?

Williamson's analysis sought to reduce and control uncertainty as opposed to harness it as a fundamental aspect of innovation. He did not discuss "broadening the scope" of tasks and delegating authority as Klein and others had. Williamson's stated that "My proposal for *limiting discretionary opportunities* involves restructuring the problem by partitioning the task" [emphasis added]. He saw task partitioning as a way to better define contract requirements, limit contractor discretion, and arrive at an objective target cost. He rejected any "drastic changes in the institutional arrangement." Williamson continued to view specifications as fixed and focused on the cost of achievement. Perhaps unwittingly, Williamson's plan to partition tasks would move more technical planning out of the contractor's hands and back into a military acquisition system characterized by decreasing in-house capabilities and increasingly centralized decisions.

As previously discussed, uncertainty benefits projects in performance aspects due to the unbounded possibilities of innovation. Karl Popper wrote that "the scientific method is not *cumulative*… it is fundamentally *revolutionary*."[292] Achieving a "good probability distribution of outcomes" depends on expanding task discretion for those at the lowest level possible because it cannot be predicted in advance which outcomes, and whose expectations, will prove most successful. Nassim Taleb argued that payoffs from research follows a "power-law type of statistical distribution, with big, nearly unlimited upside but, because of optionality, limited downside. Consequently, payoff from research should necessarily be linear to number of trials, not total funds involved in the trials." Taleb and Benoit Mandelbrot recommend the "1/N" research policy which can simply be expressed as "if you face *n* options, invest in all of them in equal amounts."[293] For the defense system of innovation, the 1/N rule pertains to people and organizations, not ideas. It is a matter of having the right set of structural rules guiding exchange; the set of voluntary choices resulting from local states of knowledge is, in some sense, both random and efficient.[294]

The most important innovations occur from ideas that a diverse set of competent observers do not agree on. Otherwise any idea whose benefit and technical achievement are obvious should already have been pursued. Pursuit of politically agreeable specifications is then an invitation to surprise challenges. Pursuit of non-consensual concepts by independent and responsible decision makers invite surprise payoffs.[295] Peck and Scherer described the institutions of successful innovation in a similar way:

> "When technological uncertainty is substantial, it may be desirable to base weapons program decisions on something resembling interpersonal confidence rather than, or as well as, on objective analysis. The history of technology is replete with examples of innovations which were supported, not because the logic behind the idea was overwhelming, but because someone with funds believed in someone with an idea."[296]

Innovation often results from non-consensual ideas precisely because non-consensual ideas represent greater uncertainty. When institutions do not tolerate failure, political programs will accept extreme cost risk and must limit performance gains in order to avoid surprises. When quantitative evidence is limited, meaning (1) political support is unlikely, and (2) the benefits are unknown and possibly revolutionary, then a successful portfolio of projects requires a diversity of investment. This is best accomplished when each participant is also provided broad and alienable budgetary authority, as well as opportunity to build "interpersonal confidence" with other, potentially private, individuals advocating for non-consensual ideas. Such interpersonal confidence can only arise in the context of repeated exchanges where reputation effects can be established. Peck and Scherer found that interpersonal confidence allowed important innovations to overcome political barriers of adequate justification because the service manager and contractor together risked reputation and resources to achieve it. In many cases, the innovations came from the riskiest firms—new entrants to the defense industry—who eagerly sought to build a reputation.[297]

5.7 Exchange and welfare

In a 1969 compendium of economic papers assembled for the Jackson Committee hearings on the PPBS, two papers in particular provided insights into exchange. First, future Nobel laureate and long-time RAND analyst Kenneth Arrow, discussed social choice theory. Known for his logical mind and mastery of mathematical modeling, Arrow nevertheless arrived at non-quantifiable answer:

> "I want, however, to conclude by calling attention to a less visible form of social action: norms of social behavior, including ethical and moral codes. I suggest as one possible interpretation that they are reactions of society to compensate for market failures. It is useful for individuals to have some trust in each other's word. In the absence of trust, it would become very costly to arrange for alternative sanctions and guarantees, and many opportunities for mutually beneficial cooperation would have to be foregone."[298]

However, under significant information asymmetry, Arrow warned that an abuse of trust could lead to monopoly rents. Economist Harold Demsetz wrote the second paper of interest. He found that the key test for determining whether an exchange improves welfare is if it was voluntary. If both parties consented to the agreement, then they must both find some advantages to it. He wrote that "The test of voluntary consent… is the filter that separates and selects efficient resource allocations from inefficient ones." Only where the test of voluntary consent is lacking did Demsetz concede recourse to cost-benefit calculations. Yet when government is called upon to solve market failures, it encounters two problems. First, unless the state is authoritarian, it must incur costs to "secure the consent of many." Second, by treating all individuals in a cost-benefit analysis uniformly, it abstracts away from the peculiarities which matter to individual choices. In other words, government encounters a "greater likelihood of error."[299]

It is illuminating to examine why interpersonal confidence resulting from repeated exchanges plays such a large role in weapons acquisition. The criterion for success in any exchange is whether or not both parties felt better off as a result. Did the purchaser feel gratitude toward the supplier for making a good use of his resources, and if so, was the supplier rewarded? Equally important to any system of exchange, however, is assigning punishment for harm.

Contracts embody a system of negative evaluation. Either the supplier met the requirement as written before-the-fact or not. The criterion benefits the purchaser as it allows for precise and accurate measurement of outcomes that forces the suppliers to submit reasonable proposals. An equally important point is that unspecified attributes don't come for free. Ultimately, the purchaser cares about the capabilities and not physical attributes. As weapon systems become increasingly complicated, the number of attributes which must be pre-specified and evaluated increases as well. If unmeasurable or unforeseen attributes are complements of the specified attributes, then no problem exists. If they are substitutes, then the suppliers can provide a system that in no way meets its expectations while fulfilling all contractual requirements.

Consider the supplier who found one or more of the requirements were ill-conceived given new knowledge discovered in the production process. The situation often occurs because contract assumptions do not turn out to be realistic, or even desirable, from the purchaser's point of view. If the supplier delivers on all contract requirements, he clearly has not violated the agreement. A symmetrically informed observer may, however, step back and ask whether the supplier acted properly with respect to the exchange, and whether or not he deserves reward or punishment.

Because the contract comes at the expense of the taxpayers, and its deficiency could cause harm to the common security, the supplier did not act properly with regards to the deployment of its resources. Yet had it done differently, the supplier would have taken a loss for either the greater expense or breach of contract requirements. Was the supplier blameworthy for his prudence? Was the supplier blamable for an entirely legal action, even if it put the interest of shareholders above the purchaser's interest, and indeed the national interest? The matter demonstrates that the terms of the contract were loose and vague, and were made more so by treating their judgment as precise and accurate. From the supplier's perspective, he was praiseworthy for meeting contractual requirements on-time and on-cost. However, from the observer's perspective, the supplier was blameworthy for not acting upon the harmonized sympathies around the shared goals, as opposed to the contract requirements which they imperfectly represented.

Using a contract to procure innovation, then, takes a loose and vague matter that requires after-the-fact judgment using updated information, and forces it into a system of negative evaluations according to requirements written before-the-fact. The different forms of evaluation do not agree in all circumstances. After-the-fact controls are flexible with respect to time and the accumulation of knowledge. Before-the-fact controls, however, are rigid and invariant to time or context.

5.8 Boundaries of administration

When asymmetric knowledge problems can be alleviated, the worst deformities to before-the-fact controls are corrected. If the purchaser knew as well as the supplier whether a contract requirement was proving technically infeasible, or that it would create negative unintended consequences, the purchaser prefers to renegotiate the contract so that the assumptions which connect the requirements to his ends incorporate updated knowledge. At the limit, if transaction costs to knowledge transference are zero, the contract requirements can reflect a specific application of the after-the-fact evaluations at every point in time and maintain their agreement. However, if knowledge transfer is imperfect or difficult, the contract becomes a poor mechanism as it forces evaluation using controls based on potentially incorrect expectations.

Defense officials have sought to directly achieve knowledge symmetry by requiring regular cost, schedule, and technical reporting. PERT, for example, reports cost and schedule by technical component, attempting to provide near real-time information on contract progress. As new information arrives and changes the purchaser’s perspective of propriety, the purchaser may choose to exercise his decision rights to amend the contract requirements so that the eventual outcomes with respect to contractual requirements conforms to his subjective judgment after having reviewed the updated information. Cost-plus contracts, in this light, allow for continual updates to cost targets without the need for expensive contract renegotiations.

With a stream of detailed contract information available, defense analysts attempt to approximate the idealized outcome where both parties to the contract have identical knowledge. In such cases, the contract can with little trouble be modified such that the terms of the contract will approximate what an informed third-party would estimate to be proper given access to the most comprehensive and timely information. The ideal, however, can never be implemented because no report can fully capture the specific information of time and place that the supplier holds. Even if it could, it cannot be guaranteed that the information would be interpreted in the same way as the supplier.

When the government attempts to duplicate the supplier's knowledge and continually redirect the contract, it is tantamount to actually directing the firm's capital itself. As F.A. Hayek wrote about similar proposals, "All this involves planning on the part of the central authority on much the same scale as if it were actually running the enterprise… This division in the disposition over the resources would then simply have the effect that neither the entrepreneur nor the central authority would really be in a position to plan."[300] When attempting to obtain and exercise knowledge, defense officials first incur substantial investment costs to duplicate the knowledge outsourced to private firms, then they incur transaction costs to renegotiate and modify the contracts, and finally they risk having misinterpreted the information, or having received misleading information.

In order for a purchaser to ensure that he receives justice with the fulfillment of contract requirements, he will have to incur large transaction costs of knowledge generation and contract modification. Ronald Coase drew similar conclusions in his landmark 1937 essay "The Nature of the Firm." Coase wrote that when direction of resources in a contract must be decided later by the purchaser, relative efficiencies can be gained by internalizing those resources to avoid transaction costs. He found that

> "… owing to the difficulty of forecasting, the longer the period of the contract is for the supply of the commodity or service, the less possible, and indeed, the less desirable it is for the person purchasing to specify what the other contracting party is expected to do… A firm is likely therefore to emerge in those cases where a very short term contract would be unsatisfactory."[301]

Like Williamson, Alchian, and Klein, William Meckling was a RAND analyst who later made significant contributions to economic theories of the firm. Meckling used Coase's concepts of transaction costs to explore the relative efficiencies of internal administration and markets. He determined that both processes successfully co-located decision rights and knowledge:

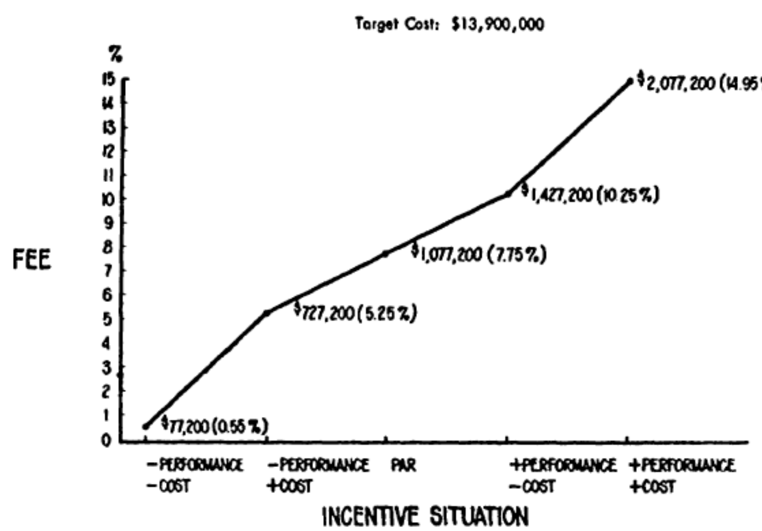
> "When knowledge is valuable in decision-making, there are benefits to collocating decision authority with the knowledge that is valuable to those decisions. There are two ways to collocate knowledge and decision rights. One is by moving the knowledge to those with the decision rights; the other is by moving the decision rights to those with the knowledge. The process for moving knowledge to those with decision rights has received much attention from researchers and designers of management information systems. But the process for moving

decision rights to those with the relevant knowledge has received relatively little attention in either economics or management."[302]

The government's attempt to use information reporting systems, such as PERT, has produced an ineffective mix where the defense officials outsource production knowledge but continue to demand the information necessary to exercise decision rights. The matter is made more difficult because defense production requires "specific" knowledge that, "almost by definition, is difficult or impossible to aggregate and summarize." In effect, Meckling argued that government procuring agencies should seek to either provide more decision rights to its contractors, or, to acquire in-house capabilities necessary to exercise those decision rights.

When a purchaser internalizes production capabilities, he evaluates resource allocations using general, as opposed to precise and accurate, rules. Within the firm's boundaries, the entrepreneur can, up to a point, direct resources at will and is no longer obliged to act according with pre-specified rules. The matter is reduced to the loose and vague judgments about whether or not the resources were justly distributed as evaluated after-the-fact. If the entrepreneur fully approves of employee behavior, then he feels gratitude and the proper objects of gratitude deserve reward. If he cannot approve of employee actions and feels resources, such as time and attention, were misallocated, he feels resentment and the proper objects of resentment deserve punishment.

Illustration of an actual incentive arrangement applied to a spacecraft program, presented to the Congress by Assistant Secretary of Defense for Installations and Logistics Thomas D. Morris on 26 July 1962. Note that within the range of contract incentives, contractor profit or fee is determined by pre-specified performance and cost targets.



Theories of the firm suggest that for uncertain ventures using highly specific knowledge or capital assets, the government should internalize resources to avoid transaction costs associated with loose and vague contracts. For relatively mature production processes, the government can use tightly coupled contracts where requirements are somewhat stable. While Demsetz and Williamson gave this view merit—and indeed it was the predominating acquisition approach from before WWII—the economists believed a better option is to lower transaction costs to contracting. Stated simply, this can be done by partitioning tasks, matching the level of discretion with the level of uncertainty, and allowing reputation through repeated exchanges to hold more sway than legal reprisals. However, government in-house capabilities remain vital to building technical knowledge that allows for reputational effects, because no impartial and symmetrically informed observer exists to reference. Both private and public managers know how difficult monitoring can be.

As economic activity moved away from reproducible goods and towards advanced technology, contracts become mired in uncertainty. The proper course of action cannot always be articulated before-the-fact but is discovered along with the growth of knowledge. The realities of the innovation process proved counter to assumptions made by defense officials, who instead put greater effort into defining requirements and setting objective target costs. As Ronald Fox later observed, "McNamara did not foresee that setting realistic target costs, vital to the success of fixed pricing, would prove to be well-nigh impossible."[303] If tightly-coupled contracts could not incentivize particular outcomes, then new strategies for acquiring innovation had to be devised.

6. Innovation

> Today the solitary inventor, tinkering in his shop, has been overshadowed by task forces of scientists in laboratories and testing fields… Partly because of the huge costs involved, a government contract becomes virtually a substitute for intellectual curiosity.
>
> Ike Eisenhower
>
> *Farewell Address*, 1961

After a burst of military innovation in World War II and the decade after, the pace of new ideas in weapons technologies seemed to slow down. By the late 1950s, some circles thought that nuclear warfare reached a point that no further advance could break the stalemate between the U.S. and the Soviet Union. They whispered of a "technological plateau." On May 12, 1960, Senator Thomas J. Dodd called attention to the "fallacy of the ultimate technological plateau." He urged continued devotion to advancing technology.[304]

While at first the technological plateau meant that it was not economically feasible to seek defense from, or something more terrible than, nuclear weapons, certain quarters misinterpreted the viewpoint. They believed that scientific understanding itself had reached a plateau. For example, Representative Melvin Price, chairman of important subcommittees on research and development, warned that the government research program was "entering a leveling-off period, a plateau, in the total dimensions."[305]

6.1 A technological plateau

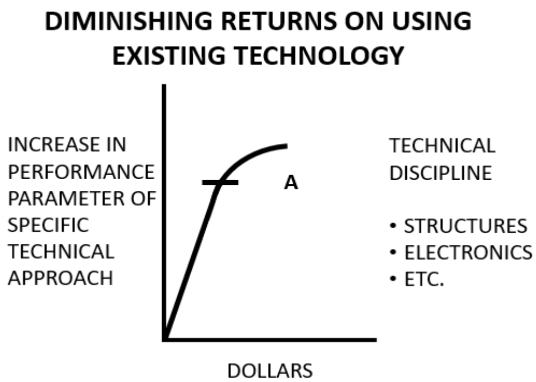
In June 1965, Senator Henry Jackson asked for comment on the "technological plateau." He defined the term to be "the sense that no major breakthrough—quantum advances—in military technology are now in sight." General Thomas D. White replied that "There is no reason to think that a curve of advancement such as we can trace today is suddenly going to level off." He pointed to space exploration. "We didn't dream anybody was going to be floating in space hitched to an umbilical cord even 5 years ago."

Nobel Prize winning physicist Walter H. Brattain seconded the opinion. He observed how "past experience shows that whenever one thinks he understands everything, then is just the time when unexpected new understanding is most likely to occur." Brattain argued that the error of a technological plateau has been repeated many times before. He quoted the famous 19th century physicist Ernest Mach who had observed the same phenomenon before him. Mach wrote how

> "The French Encyclopaedists of the eighteenth century imagined they were not far from a final explanation of the world by physical and mechanical principles. Laplace even conceived a mind competent to foretell the progress of nature for all eternity if but the masses and their velocities were given."[306]

Mach had been dealing with similar arguments toward the end of the nineteenth century. And yet, for everyone at the Congressional hearing decades later, it was obvious that revolutionary discoveries were around the corner. Claims of a complete description of nature, and perfect predictions based on them, sounded naïve at best.

Despite pronouncements that military technology was not slowing down, by the start of the 1970s it started to seem that way. For Frederic Scherer, it became an "obvious historical trend" that technological revolutions in "weapon systems concepts… were largely concentrated in the 1940s and the 1950s. There are some exceptions, to be sure; but they are not nearly so prominent in the 1960s." Scherer explained that the second-generation programs of the 1960s seemed a "disappointment." They tackled "small but stubborn technical problems that were left over."[307] Where was the new generation of technologies, many wondered, that could rival radars, missiles, jet engines, transistors, and nuclear power? Writing in *Foreign Affairs*, Hanson W. Baldwin stated that "there appears to have been in the first half of the 1960s a definition reduction, as compared to the 1950-1960 period, in the evolution and production of new weapons."[308]



Reproduced figure from the 1972 Commission on Government Procurement (COGP) Report, depicting the leveling-off of performance gains as more dollars are expended on a specific technology. The figure suggests the importance of discovering new technologies, the only source of progress in the long-run.

Believing that military technology reached a plateau, Secretary of Defense Robert McNamara pushed for a different kind of innovation strategy from the freewheeling of the 1950s.[309] It focused on risk reduction through analysis without experimental effort associated with concurrency, technological leaps, and soaring costs. It meant a higher justification barrier for a project to receive funding. It required perfection on paper before contract effort could start.

Not only did McNamara curtail new program starts, over his first few years he could be perhaps credited with cancelling more programs than he started. For example, despite a clear-cut military requirement, McNamara cancelled a nuclear-powered ramjet engine after $200 million had been spent. Dr. Edward Teller, father of the hydrogen bomb and catalyst to the Polaris program, was enflamed. "I believe this is the biggest mistake we have made," Teller said, "since the years following World War II when we failed to develop the I.C.B.M."[310]

Less than a year-and-a-half after McNamara took the helm, Congress noticed the Air Force struggling to innovate. In a 1962 review of PPBS management systems, the vigilant committee staffer Herbert Roback sought to understand what had stifled new system developments. He suspected that the PPBS led to a suppression of diversity and progress in systems development. Not only was it unusual for a staffer to directly question Congressional witnesses, Roback challenged the now famous General Bernard Schriever, credited with the stunning success of the Atlas ICBM program. He asked Schriever whether or not cost effectiveness analyses were suppressing new system ideas. Schriever said, "I wouldn't say that is suppressing new system ideas..." and proceeded to dodge the matter. Roback then sharpened his line of questioning:

> Mr. Roback. "Well, is this the case, that there are new system concepts which are being proposed but not being acted upon? Do you consider that the emergence of new systems is proceeding at a satisfactory rate?"

> General Schriever. "Well, from where I sit I think that we could move faster on certain of our programs. We have not really initiated a new system program for some time."
>
> Mr. Roback. "For some time. Can you give in a year basis, 2 years?"
>
> General Schriever. "Well, it has been over a year. We have several under consideration now in the so-called definition phase… With respect to programs which are now under consideration, it has been that we are defining programs to a higher degree than we have in the past. Essentially this has been the factor that has delayed the initiation of programs as such."

The program definition phase, Schriever admitted, delayed program starts. Program definition generally includes a systems analysis where the cost and effectiveness of alternative paper studies were compared to determine which single-best design made it to full-scale development. The process took a great deal of time and effort, resulting in decreased program starts.

Schriever countered that program definition resulted more stable specifications, more realistic cost estimates, and ultimately a better program. He happily pointed to one new aircraft program authorized into development, the TFX. Schriever said of the TFX, "I might say that I completely agree with the steps that are being taken with respect to it." While under pressure, Schriever concluded that the dearth of program starts did not harm national security. He believed that better programs would emerge from the rigorous planning process.[311]

Less than a decade later, the deficiency of new programs had reached a crisis point. It became the highlight of a string of Congressional hearings in December 1971, collectively called the "Weapon Systems Acquisition Process." Stuart Symington, the first Secretary of the Air Force and later a Senator from Missouri, made a startling complaint. "I have pictures," he said, "which prove that the Soviets have developed 13 new fighters since 1954. We have not developed one."[312] At the time of the Senator's shocking and factually incorrect statement, the TFX aircraft—which became designated the F-111—had not been deemed fully operational. Its belated introduction into operations occurred in July 1967, but a malfunctioning horizontal stabilizer postponed full-operability when it took down three F-111 aircraft over Vietnam in 1968. Not until four years of defect correction had passed was the F-111A deemed fully operational.

To its embarrassment, the Air Force adopted several Navy aircraft for its operations throughout the 1960s. The mainstay fighter in Vietnam was the Navy's F-4 Phantom II, which reached first flight in May 1958. Using dated aircraft modified from the Navy, U.S. airmen began to feel outmatched in equipment. Senator Symington reported his interactions with no fewer than a hundred pilots in Vietnam who told him that they would prefer to fly in their opponent's plane, the maneuverable Soviet MiG-21.[313]

The problem of getting new hardware to field did not limit itself to fighter aircraft. Admiral Hyman Rickover complained that “In the past 6 years the Soviets have built almost three times as many combatant ships as the United States... On a ship-to-ship basis,” he continued, “the Soviets have designed combatant ships that are faster, more modern, and more heavily armed than their U.S. counterparts.” In terms of submarine production, Rickover claimed the Soviets put out more than 580 modern submarines over a 26 year period when the U.S. had only built 113.[314]

To round out the tri-service crisis, the Army's new main battle tank, the MBT-70, proved a continuing drama of technical challenges and cost growth. The program had been in development by 1971 for close to a decade. Projections at the time had each production unit costing four times more than its M-60 predecessor, even after removing inflationary effects.[315] Congress had cancelled the MBT-70 earlier that month.

6.2 International assessments

RAND analysts may have been behind many of the management methods ushered by the PPBS, but its analysts were reporting on the advantages of foreign processes in the December 1971 Congressional hearings. Robert Perry wrote a paper in preparation for the hearings entitled “European and U.S. Aircraft Development Strategies.”[316] He found that without depending on U.S. technical efforts, European aircraft firms nevertheless developed systems without any “striking inferiorities.” The only exception appeared to be the complexity of installed electronics.

France, for example, had developed a robust aircraft industry with an R&D budget only 10% that of the United States. Robert Perry extolled the virtues of the French company Dassault, which averaged one prototype a year for nearly 20 years while keeping costs low. Lavishing praise, Perry wrote of Dassault’s seemingly “unlimited” ability to “create interesting options at low cost.” Dassault’s success in foreign sales to 13 countries, representing two-thirds of its revenues in 1971, perhaps proved the point. Perry explained how European success came from a “different mode of aircraft development”:

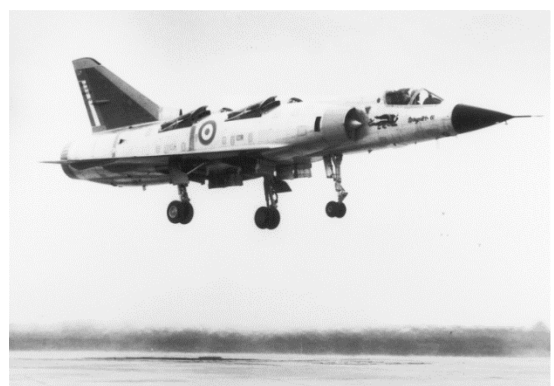
> “Dassault uses very small design and production staffs. For the Mirage IC bomber, which is a mach 2.2 supersonic bomber with a range of more than 1,000 miles, they used fewer than 85 engineers and draftsmen in the development phase. During the development of the vertical fighter they used an average of about 20 engineers and draftsman and a high of 30.”[317]

Not only were the design teams nimble; the French government project offices averaged just 10 people or less. The largest project office had 40. Compare that to a typical Air Force project office comprising between 150 and 250 people. Perry wrote:

> "Government program or project offices in supporting fighter aircraft programs in France, England, and Sweden rarely contain more than 20 to 30 specialists; the ordinary government program office in the United States for a comparable program is staffed by at least five times as many specialists.
>
> "The total of engineers, draftsmen, and experimental shop personnel engaged in such a European program rarely exceeds 700… In American experience, from two to ten times as many comparable specialists are employed."[318]

As a result, European aircraft were characterized by simpler design, fewer production changes, and lower indirect costs. Overall, Perry found program costs to be "plainly lower in France and Sweden than in the United States, and probably at least as low in Great Britain." Despite his praise, Perry cautioned over-enthusiasm for a European system that also struggled to integrate complex electronics. But his testimony to the Congress pointed at two major differences between the European and U.S. acquisition systems. First,

> "… the ordinary European aircraft developer does not invest heavily in the sorts of elaborate program analysis that we do. They run computerized program tracking, things like PERT, for example, one of our favorite systems, in France, in Sweden and in Great Britain. But they ordinarily run them at a level of just about 10 percent of ours. They simply don't invest in that sort of detailed analysis."



Dassault Mirage IIIV vertical take-off and landing aircraft. Two prototypes were developed in 1965 and 1966, but the project was abandoned shortly after one crashed. The number of engineers and draftsmen on the project peaked at 30.

While U.S. contractors were subjected to myriad management control systems, their European counterparts remained largely unrestricted. In fact much of the reduction in government staff was achieved through streamlining information reporting and approvals. Perry found, for example, that the French government requirements for the vertical-lift aircraft totaled only 15 pages. In terms of continuous reporting during project execution, the Dassault Mirage III-G variable swing-wing fighter program—

comparable to the F-111 in the U.S.—provided two reports a month totaling a mere 10 pages, in addition to a short quarterly project summary.

"Second," Perry continued, "they don't make any substantial production commitment until they are very sure that what they are going to put into production will perform." His paper elaborated how Europeans insisted on early proof testing of subsystems. They delayed production decisions until subsystems have been appropriately demonstrated. However, early austere testing and incremental changes neither led to inferior performance nor longer development times. Dassault took measured risks. For example, Dassault flew the vertical-rise fighter prototype just nine months after approval to start design, and the Mirage III-G prototype 16 months after design start.

Prototypes made it to production in relatively short order due to employee incentives. Perry explained how "rewards are not for innovation, for new ideas, but for simplicity and cost effectiveness in initial design." He said that "Dassault does not tolerate engineers who propose expensive or hard-to-produce parts, or who suggest costly 'improvements' that may also require high cost operating or maintenance procedures."

Perhaps just as important as incentives is employment stability. The French achieved high retention by funding development independently of production. Perry explained that "We pay for development as part of a system process, as the prelude to production. In France, it is paid for separately; it is separate contractually and in time. That is an important distinction." As a result, some designers at Dassault had been "doing essentially the same tasks for 20 years."[319] By contrast, employment at U.S. contractors varied greatly due to the fits of starts and stops concerning major winner-take-all programs.[320] Intermittent overfunding of major developments corresponds with a weak ability for U.S. contractors to build institutional knowledge and a culture of success.

Aircraft systems development in the Soviet Union was similarly characterized by simplicity, incrementalism, and flexibility at the bottom. Arthur J. Alexander, also from RAND, told Congress how the Soviets relied on a minimum of reports. The Soviet pre-project document which solicited designs from the bureaus, "does not appear to be a complicated document." Rather, it was primarily a list of goals and relative importance. For example, an all-weather interceptor was described in three pages.

Another difference was that the Soviets actively separated the stages of acquisition. "One of the major differences," Alexander explained of the Soviet aircraft industry, "is that the research institutes, the design bureaus, and the manufacturing plants are… autonomous and separated from each other. They are not linked together in a vertical structure." Even though all prototype designs must be approved by the Ministry, lead designers had absolute authority and responsibility.[321] The built-in flexibility at the bottom reportedly came from Stalin himself, who believed that

> "… the designer was the one individual who could be held responsible for success or failure, that the designer has the duty of protecting the integrity of his design from the demands of others… The designer must not be at everybody's beck and call. He has to protest irresponsible demands… It is hard to make a good machine and very easy to spoil it and it is a designer who is responsible."

Design chiefs were responsible for getting sound aircraft into production. To go along with their responsibility, successful designers received large rewards. On the flip side, designers that did not perform adequately were relieved. Entire bureaus could be dissolved. "Ironically," Alexander concluded,

> "Soviet aircraft production is similar to the way the American industry operated before the government began to participate heavily in project management… Soviet aircraft production is similar to what I would call profit-motivated capitalism, and that have taken over the best points of our pragmatic system of trying and experimenting before making decisions."[322]

Yet the capitalist features of Soviet aircraft production were limited in their dimensions. Alexander found that the Aircraft Ministry could not depend on delivery of critical inputs from other ministries, such as piece parts and raw materials. It was forced to create new organizations to produce the necessary inputs. Even then, shortfalls were widespread. As just one example, the Aircraft Ministry prevented the use of titanium for all engine designs in 1958.[323]

The French Dassault company, by contrast, was able to dependably rely on Western markets to fulfill most of their needs. It allowed Dassault to outsource almost the entire production process of its aircraft. The one exception that could not be outsourced was final assembly, which the firm found critical for maintaining proficiency in design.[324]

Not only did advanced foreign countries reject the intensive management processes associated with the PPBS, they successfully separated system development from production. Whereas the Soviets did so organizationally, the Western Europeans did so contractually. And while U.S. emphasis on concurrency led to faster innovation in theory, in reality the smaller French industry had kept pace in most respects.

6.3 5000-series

The elephant in the room seemed to go completely ignored during the December 1971 hearings on the Weapons System Acquisition Process. Less than five months before, Secretary of Defense Melvin Laird and his Deputy, David Packard, officially released the first of the 5000-series regulations. It sought to implement many of the processes that Perry and Alexander found so beneficial in Western Europe and the Soviet Union. For example, the 5000.1 decentralized responsibility to a single program manager and shield him from the detailed reporting demands of OSD. Further, it limited OSD's role on deciding program progress to major acquisition milestones.

Of course none of this was new. The 5000.1 released on July 13, 1971 was based on a May 28, 1970 memo from Packard, which itself built on the milestone process established on May 30, 1969. Congress, however, never had any hearings on the Laird and Packard reforms which eventually solidified into the 5000-series. Several members expressed how new the information was to them.[325]

Though the reforms largely avoided scrutiny during the Vietnam War, the acquisition system did not. The Jackson Committee hearings on the PPBS immediately preceded the President's Blue Ribbon Defense Panel, which issued the "Fitzhugh Committee Report" on July 1, 1970.[326] Additionally, the Commission on Government Procurement (COGP) formed in 1969 and continued to study the problem even after it issued a report in 1972. The recommendations of these studies were also arrived at, by-and-large, by Laird and Packard. Packard remarked that "The actions we have taken represent both a continuation of efforts we began shortly after taking office in early 1969 and an initiation of new proposals drawn from our own subsequent experience and the work of the Blue Ribbon Defense Panel."[327]

As Laird's chief management officer, Packard's first major change was to disengage OSD from most acquisition decisions. He returned the initiative to the services. They could once again formulate program concepts and determine alternatives, a critical function centralized by OSD systems analysts for the better part of the 1960s. Packard retained for OSD the power to set general policy, collect information, and evaluate major programs at three critical points in the acquisition life-cycle called program milestones. The three milestones that initiated OSD involvement went as follows:

> "First, when the sponsoring service desires to initiate contract definition—or equivalent effort; second, when it is desired to go from contract definition to full scale development; and

third, when it is desired to transition from development to production for service deployment."[328]

To make decisions on behalf of the Secretary of Defense at each milestone review for major defense programs, Packard created the Defense Systems Acquisition Review Council (DSARC). It included representatives from DDR&E, ASD Installations & Logistics, ASD Systems Analysis, and ASD Comptroller. The DSARC advised the Secretary of Defense or his Deputy on whether he should approve a program onto the next phase of the acquisition life-cycle.

The most important document in the review was the Development Concept Paper (DCP), later the Decision Coordinating Paper. It outlined the program's requirements, technical solution or approach, and cost and schedule estimates. Packard said that "The DCP is a concise statement describing the project, what is to be done, and how it is to be done. It covers the technical uncertainties, the operating requirements and the alternatives. It requires the originating Service to carefully prepare its case on a proposed new weapons program."[329] Comptroller General Elmer Staats provided an interpretation of the DCP. "It serves," he said, "to some extent, as a written agreement between the services and the Secretary of Defense. The DSARC and DCP are intended to be complementary; together, they constitute the formal DOD system for managing the acquisition of major weapon systems."[330]

David Packard: electrical engineer; co-founder of Hewlett-Packard; and Deputy Secretary of Defense (1969-1971).

While the DSARC process separated distinct phases of acquisition, the DCP reduced the amount of bureaucratic reporting. Packard issued a directive in October 1970 requesting recommendations to streamline acquisition. He testified to Congress that "of the 1,227 directives reviewed, 35% could be cancelled outright or through consolidation and 29% could be simplified through modification."[331]

Just as importantly, the services were invited back into the budget process. Under participatory management, Packard described how the services could once again "propose how their monies should be spent."[332] For the fiscal year 1972 budget, it "was the first time in over ten years that the Defense program submitted to the Congress was one developed at the initiative of the Military Departments and the JCS rather than the initiative of the Secretary of Defense."[333]

Even though the services could plan their programs, only OSD could decide. OSD retained the power to approve major program decisions which set the framework for service execution. The policy-administration concept, which up until this time had been used to further centralize powers, was for the first time used by Laird and Packard to control the decentralization of power.

During the McNamara years, OSD's policy-making apparatus encroached on defining not only what must be accomplished, but the specifications on how to accomplish it using a systems analysis. The milestone process, incorporating the DSARC and the DCP, returned program definition and execution to the services. Yet it preserved OSD's accountability to Congress; only it could approve policies with respect to program requirements, initiation, and progress. Packard kept in line with the policy-administration dichotomy. He asserted that

> "… the services have the responsibility to get the job done… It is the responsibility of OSD to approve the policies which the services are to follow, to evaluate the performance of the services in implementing the approved policies, and to make decisions on proceeding into the next phase in each major acquisition program."[334]

Dr. John Foster, Director of Defense Research and Engineering and chairman of the DSARC, provided Congress with a similar interpretation:

> "Decentralization, as we intend it, means that each DOD component, or military department, is responsible for identifying the new defense systems deemed necessary to meet potential threats to our national security and for proposing the systems to the Secretary of Defense for his approval. Upon such approval, it becomes the responsibility of the DOD component to conduct the program within pre-established and mutually agreed-upon limitations."[335]

The process depended on the Secretary of Defense's ability to establish wise policies, and have the proper tools to evaluate progress. What's more, the competence would have to span over an enormously diverse set of technologies and missions. The assumption becomes especially problematic in areas of research and development, where outside experts have a poor record of predicting the winners and losers.

Whereas McNamara's solution to program choice was a systems analysis, Packard relied on functional prototypes. Instead of interfering with service administration, prototyping improves systems acquisition by introducing early test articles that generate knowledge and reduce program risks. The focus then shifts from paper studies and mathematical analysis to bending metal and writing computer code. It brings forward functional products that improves the basis of third-party evaluation—particularly when it can be compared to a competitor. The French Dassault company, for example, insisted on continuous prototyping of individual components. Even when developing new aircraft, prototyping limited the cost and complexity of integration.[336] The process allows for a rapidly evolving family of proven designs. The concept was followed in certain U.S. firms as well, such as the family of jet engines maintained by company investment at General Electric.[337]

6.4 Prototyping

Packard told the Congressmen how systematic prototyping efforts can alleviate "two problems" that had grown under the McNamara years, leading to "excessive costs and unsatisfactory results." He explained:

> "One is the excessive reliance on paper studies and paper analysis. This difficulty has been evident in all stages of past programs, advanced development, full development, and production. The other problem is the concurrency between development and production—simply that development has not been sufficiently complete before production is started.
>
> "We believe that adopting the prototype approach on new programs will help to minimize these two difficulties…
>
> "The programs we are recommending for prototyping generally will not have the objective of producing a complete operational system. For example, the fighter aircraft prototype will primarily be used to demonstrate the capability of the airframe and engine in actual aerodynamic performance but it will not include all of the avionics, weapons, et cetera, which are necessary for a fully operational weapons system."[338]

Alluding to Robert Perry and others' work, Packard stated that "We have looked at how the French buy a new aircraft. They do not do it by getting a big new weapons system program going and using a great deal of paperwork and controls. They simply go to the contractor and say, 'If you can give us a model that will fly and do this, we will pay you so much money.'" To deal with the "stop-and-go fashion" of U.S. defense programs, Packard even went so far as to discuss fixing design team budgets and letting them operate with relative autonomy. For "about $25 million per year," Packard believed, "we would obtain from each team two prototype models about every 3-4 years."[339] The "design-to-cost" approach reached similar ends, where program unit costs instead of organizational funding were fixed. In either case, Packard encouraged creative freedom to generate new solutions instead of pursuing pre-conceived ones:

> "If these prototype programs are to be efficient, they must be managed with the minimum of constraints. They should be designed to meet performance goals, not detailed specifications.
>
> "They should not require detailed confirmation of requirements nor careful consideration of all alternatives in advance because the very purpose of building prototypes is to use operational testing of hardware to confirm requirements and evaluate alternatives."[340]

Top military brass enthusiastically supported Packard's prototyping approach on visits to Senate and House committees on September 9 and 16, 1971. "The Army is enthusiastic about the broadened use of prototyping," Chief of Army R&D General W. C. Gribble said. "The Navy would like to add its enthusiastic support to this concept," Rear Admiral T. D. Davies chimed in. Air Force General K. R. Chapman followed suit.

Packard and his military leadership went to the Congress for more than just an informational briefing. Fiscal year 1972 had already started more than two months before, on July 1, 1971. Packard, however, wanted additional funding for prototypes without forcing the DoD to pilfer funds from existing programs. "We believe," Packard told the Senate, "this should be an authorization rather than a reprograming or tradeoff action." In other words, Packard asked Congress to retroactively increase the DoD top line. After explaining how vital the new prototypes were to national security, Packard threatened that "If the prototyping can only be supported at the expense of existing programs, I think the emphasis and scope is likely to be reduced." Senator Vernon Sikes asked plainly, "You are proposing to add $67.5 million for 1972?" Packard confirmed that "We are requesting an add-on in this amount for the specific programs." Though Chairman John C. Stennis was taken aback with the size of the request after the "fiscal year had runout," he expressed pleasure with the direction of management.

The military representatives then introduced their proposed prototypes. The Army requested $23.5 million, including $8.0 million for an unmanned aerial vehicle and $3.5 million for a clean air engine. The Navy requested an additional $20 million for anti-submarine sensors, ship-based missile launchers, and vertical/short take-off and landing (V/STOL) aircraft. The Air Force requested $24 million, including $5 million for a very low radar cross section test vehicle (stealth), $5 million for a Medium STOL transport, $4 million for quiet aircraft, and $10 million for a small lightweight fighter.[341] The Weapon Systems Acquisition Process hearings that took place three months later had a pivotal role in the outcome of the request. On December 14, just six days after the hearings, Congress authorized two of the Air Force's four requests, and actually increased the small lightweight fighter's funding to $12 million for fiscal year 1972.[342]

Four months after requesting additional funds from Congress and one month after having the funds authorized, the Air Force solicited contract proposals for the Lightweight Fighter (LWF) program in January 1972. In February, five companies submitted proposals and on April 13, the Air Force selected General Dynamics and Northrop to design and build two prototypes each.[343]

For business in the Pentagon, the turn-around was lightning fast. It often took three years to coordinate a budget request through the PPBS, to Congress, and have the funds appropriated. It would often take another year or more for the government to solicit contracts, evaluate proposals, and send final documents out to the contractor. The LWF contracts accomplished a four or five year journey in just seven months.

The official first flight for General Dynamics' YF-16 took place on February 2, 1974, and for Northrop's YF-17, it was June 9, 1974. Over the next seven months, as many pilots as possible were found to test the YF-16s and YF-17s. Although the prototypes never flew against each other, they were pitted against Soviet MiG-17s and MiG-21s "acquired" by the Air Force.[344] Overall, the two YF-16 prototypes underwent 417 hours of testing during 330 flights while the YF-17s underwent 345 hours of testing during 299 flights. On January 13, 1975, the Air Force announced that the YF-16 had won the competition due to "advantages in agility, in acceleration, in turn rate and endurance. These factors applied principally in the transonic and supersonic regimes… This is indicative of the fact that the YF-16 has lower drag and was a cleaner design."[345] The YF-16 achieved high maneuverability at the expense of airframe stability, requiring a revolutionary "fly-by-wire" computer system to make instantaneous adjustments without the pilot's input.

General Dynamics' lead designer, Harry Hillaker, remarked on the contracting process that made the LWF competition successful. "The contract for the lightweight fighter prototype was for a best effort. We did not have to deliver an airplane, legally. Once we spent our $3 million, we could have piled all the parts on a flatbed trailer and said to Mr. Air Force, here's your airplane." The competition sought to achieve performance goals without pre-specifying detailed designs, leaving the contractors with near-total decision rights to build the best product. Hillaker, called the "Father of the F-16," said that "my point is that we were not working against a difficult, but arbitrary schedule… The airplane was simply a technology demonstrator."[346] DDR&E Malcolm R. Currie told Congress that such a competition in fighter aircraft had not been done for over 20 years and resulted in "virtually no increase in the overall cost of ownership."[347] Robert Perry from RAND wrote in 1975 that "in my judgement the F-16 is the first American aircraft in nearly twenty years that not only outperforms its Dassault-designed contemporary in every respect but if developed as now planned probably will cost no more."[348] Belgium, Denmark, Norway, and the Netherlands were so enthusiastic about the YF-16 at the Paris Air Show that they ordered a total of 348 aircraft on June 7, 1975, more than two months before General Dynamics started work on the first full-scale development unit.


General Dynamics' YF-16 (bottom) and Northrop's YF-17 (top).

While the YF-16 provided capabilities the Air Force needed to complement its more costly F-15 aircraft in a "high-low" mix, Northrop's YF-17 was not without attractive features. Navy airmen liked the safety of its twin-engines for operations over water. Importantly, naval aviators liked the YF-17's ability to operate at very low speeds, improving the reliability of carrier landings. While the YF-16 fell into a spin on at least three occasions during the tests, the YF-17 was virtually stall-proof. The two YF-17 prototypes could circle around each other at speeds as low as 37 miles-per-hour with their nose faced upward, a move that looked like two cobra snakes facing off. It suited the aircraft's nickname, the "Cobra."

Looking for a lightweight fighter complement to the F-14, the Navy received carrier-suitable redesigns of the YF-16 and YF-17 a month before the Air Force selected its winner. By May 1975, the Navy selected a derivative of the YF-17, but this time with Northrop as the junior partner to McDonnell Douglas. Though the aircraft looked superficially similar to the YF-17, it received a new engine and was structurally different enough to earn a new designation, the F-18. Without another prototype, the F-18 went into full-scale development and first flew on November 18, 1978. When the F-18 got into dogfights with the Air Force's top-end F-15 in the spring of 1981—an opportunity the Air Force denied the F-16—the F-18 won all four engagement due to its operability at low speeds, its ability to get behind its opponent, and most surprisingly, its endurance.[349]

The LWF prototype competition was a stunning success and seemed to prove Packard's management philosophy. It resulted in two of the finest weapon systems in the U.S. arsenal, the F-16 and the F-18, which due to their affordability became Air Force and Navy work-horses for decades to come. Other notable prototype competitions included the Advanced Attack Helicopter

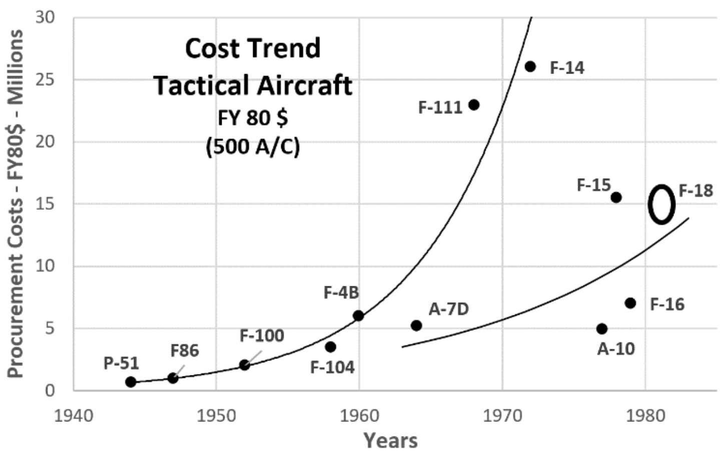
(YAH-63A versus YAH-64A), the STOL Transport program (YC-14 versus YC-15), and the A-X Close Air Support program (YA-9 versus YA-10). For the A-10, another Air Force work-horse that proved extremely robust and a tremendous value, the DSARC did not approve production until after two years of testing.[350] Robert Perry reported how test program participants expressed conviction that neither the F-16, the A-10, nor the UH-60 would have been selected had only paper designed been evaluated. Their merit became apparent only after prototype test data came in.[351]

An example of prototyping without competition came with the B-1 next generation swing-wing bomber. Packard said that "it was too expensive to develop two new bombers, and test them against each other." Instead of a competition, he explained how "The contractor will build three prototypes and we will thoroughly test those before a production decision is made."[352] Despite Packard's hope that the B-1 prototype effort would save "several hundred million dollars," the program began to falter and was cancelled for a time by President Jimmy Carter in 1977. Pierre Sprey told Congress in 1975 that "if we cannot afford to execute a program under competitive prototype conditions, then I would conclude that that is probably an indication that we are not ready for that program, that we have not developed enough of the components to be sure that the program will be a success."[353] Though several prototypes without competition were successful, they often limited new technology by making maximum use of mature components. For example, the F-117 prototype achieved a remarkable airframe design, but leveraged numerous existing components including the engine from the T-38A, flight controls from the F-16, landing gears from the A-10, and environmental systems from the C-130.[354]

In 1979, the former head of air warfare for DDR&E, Chuck Myers, provided Congressmen with a chart of tactical aircraft costs in constant (inflation-adjusted) FY 1980 dollars. It showed the production cost of a P-51 at less than $1 million in 1944, with costs of successive fighters increasing along an exponential curve. From the P-51 to the F-86 and onto the $2 million F-100 and $3.5 million F-104; then in 1960 the F-4B cost $6 million, in 1968 the F-111 cost $23 million, and in 1972 the F-14 cost $26 million. It seemed that the next aircraft might cost so much that it should jump off the chart, but it did not.

In 1977, the A-10 cost just $5 million and two years later the F-16 cost roughly $7 million. Though the prototyped aircraft created a downward shift in the cost trend, the un-prototyped F-15 and F-18 had uncomfortably high unit costs of roughly $15 million each. They seemed to renew the exponential trend upward. Myers told Congress that "YF-17 to F-18 growth came as a Navy coup. It was explosive and appeared to erase the cost difference between it and the F-14 it was meant to complement. The F-16 growth was more subtle." Myers explained how the desire for the services to pursue multi-role missions with unproven technologies would renew the exponential cost growth of aircraft unless proven and effective systems were pursued.[355]

As it turned out, the services continued their pursuit of multi-role platforms. The relative success of several aircraft from the 1970s was by no means secured with the seemingly well-designed policies of the Laird and Packard administration. The aircraft may well have never flown had the reforms not fortuitously aligned with the doggedly anti-social behavior of a few men willing to contravene Air Force doctrine, including Chuck Myers, Pierre Sprey, and perhaps most of all, John Boyd. The extreme irregularity with which the "teen" series aircraft were developed, and the personal nature of interventions required, provides a glimpse into the systemic rigidities against non-consensual innovation in the Department of Defense and suggests the limitations to reforms envisaged by Packard.



Aircraft cost trend presented by Charles ("Chuck") Myers to the Congress in 1979. The unit costs have the effects of inflation removed relative to 1980, and were further adjusted to a total procurement quantity of 500 aircraft. Note the F-18 has a larger circle to represent uncertainty in its costs, still years out from Initial Operational Capability (IOC). Reproduced figure.

6.5 Precarious prototypes

The LWF concept may have started in 1960 as Captain John Boyd packed his bags to go study industrial engineering at Georgia Tech. At thirty-three years old, Boyd was already a famous Air Force pilot. While instructing tactics at Nellis Air Base, he offered a running bet that he could beat anyone in mock air combat within forty seconds or he'd pay them forty dollars. Never having lost, he earned the nickname "40 second Boyd." He had also recently finished an instruction guide called "Aerial Attack Study," which became the definitive encyclopedia on air-to-air combat. But it was in his time at George Tech that Boyd began developing a theory that would transform the evaluation of aircraft designs. Within two years Boyd "discovered he could explain air-to-air combat in terms of energy relationships, in which the altitude is potential energy to be traded for speed—kinetic energy—and vice versa."[356]

The concept, completed with Thomas Christie at Eglin Air Force Base, became known as Energy-Maneuverability (EM) theory. It seemed to have independently discovered many principles already described by Edward S. Rutowski in 1954.[357] Boyd and Christie, however, were to first to apply the ideas to military aircraft. EM theory quickly found acceptance in the Air Force.

After receiving several awards for his contributions, Boyd was sent to the Pentagon in 1966 to help a new F-X aircraft succeed where the F-111 failed. His reaction to the F-X in its early stages was typical of Boyd. "I could fuck up and do better than this," he said.[358] The F-X initially copied many of the design features that failed in the F-111.

Boyd worked tirelessly to reduce the weight and complexity of the F-X design. He nixed the swing-wing design and improved its maneuverability in accordance with EM theory. Yet this provided little space for complex electronics. Others in the Air Force pushed back on the basis that modern combat required a powerful radar to see the enemy first and a long-range missile to destroy him before close air combat commenced. Such capabilities required a larger platform at the expense of agility. The F-X project went into full-scale development without a prototype in 1969. Though Boyd had some success defining the aircraft, eventually the F-15 Eagle, it was more than twice the weight he desired.

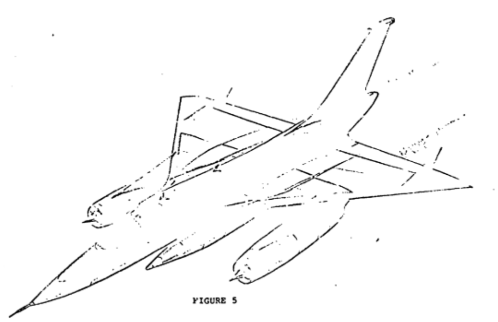
Still displeased with the design compromises made by responsible elements in the Air Force that resulted in a less agile plane, Boyd and a handful of likeminded pilots, analysts, and engineers pushed for a fighter weighing about 20,000 pounds. The core group included John Boyd, Pierre Sprey, Harry Hillaker, Everest Riccioni, Thomas Christie, and Chuck Myers. Already in 1967, Boyd and Sprey were briefing leadership on a lightweight fighter, but disengaged after getting no results from Air Force Systems Command, which had already committed substantial funding to the F-15 and F-111. Undeterred and without official authorization, Sprey sketched designs of a lightweight "F-XX" aircraft in 1968. The next year he wrote a paper on the F-XX concept which fell flat in the Air Force.

Yet the dissident group slowly grew in numbers and influence. Engineer Harry Hillaker got on board shortly after encountering Boyd in an officer's club while Boyd was loudly disparaging his company's aircraft, the F-111. Hillaker remembered that the group was once called a "mafia" by people in the Air Force because they "were viewed as an underground group that was challenging the establishment."[359] Other sources have Colonel Riccioni coming up with the group's name, playing on the post-WWII "bomber mafia." In either case, the name of Boyd's group became the "fighter mafia." And as the name suggested, the fighter mafia would have to throw out the rule book out in order to get the LWF program off the ground.

After Pierre Sprey's F-XX paper was rejected by the Air Force in 1969, he presented it to the American Institute of Aeronautics and Astronautics (AIAA) in a meeting at McDonnell Douglas' St. Louis facility.[360] It seemed to bear fruit when "125 McDonnell guys" became interested in the LWF concept. Despite their obligation to the F-15, McDonnell Douglas engineers provided assistance to their competitor, General Dynamics. Most notably, they provided critical insight into the fly-by-wire system necessary to the YF-16 design.[361]

The LWF designs were helped further by Colonel Riccioni, who obtained funding for an innocuously named study. General Dynamics and Northrop understood the real objectives of the study were to pursue a lightweight fighter. Boyd and Sprey contend that without it, the F-16 program wouldn't have existed. Riccioni was a master promoter of the LWF concept, but rubbed some officials the wrong way. In December 1970, Riccioni got himself removed from the Pentagon after a heated argument on the lightweight fighter.

While Riccioni's study kept it breathing, the lightweight fighter was given new life the very next month. Kelly Johnson from Lockheed submitted an unsolicited proposal to prototype a low cost aircraft based on the F-104. Three companies followed Lockheed with unsolicited proposals of their own, prompting John Foster to inform Packard of the situation. Packard responded with the instructions that "two, at least, aircraft should be obtained. Only the price shall be firm. All specifications shall be open. A plan for fly-off testing will be required."[362]



A faded 1968 sketch of the F-XX, presented by Pierre Sprey to Congress in December 1971. Funding for the lightweight competition was authorized by Congress within a week.

Boyd wanted to influence the prototype competition to reflect his lightweight concept. However, he soon got word of an Air Force conspiracy to waste time by moving his proposal up to the highest level before receiving ultimate rejection. In response, Boyd used a friend close to Packard to successfully go over the head of the Air Staff.[363] On August 25, 1971, Secretary of Defense Laird personally intervened by issuing a memorandum directing the Air Force to establish a LWF program.[364] A couple weeks later, Packard brought General Kenneth R. Chapman before Congress to find additional funds specifically for the LWF competition. Even with substantial help from Packard, the fighter mafia's Harry Hillaker judged that the F-16 would have never flown without buy-in from Air Force regulars, including General Chapman.[365]

Even after Packard and Laird's personal intervention generated extra funding to pursue to the LWF competition, its progress proved to be in continual jeopardy. Several congressmen railed against the LWF concept. In a statement entitled "Lightweight Fighters No Panacea," Senator Howard Cannon viewed the LWF to be a low-capability threat to aircraft already in development. Packard assuaged Congress and the Air Force by repeatedly stating that the LWF competition was a technology demonstrator. He did not commit to any production orders.[366]

Major General William "Hollywood Bill" Evans picked up on the line that the LWF program did not meet a defined requirement. As the YF-16 and YF-17 were preparing for their first flights toward the end of 1973, the Air Force attempted to squash the program by underfunding it in the next budget submission. Both LWF management and General Dynamics believed the program would be killed. Once again, fighter mafia proponents got the ear of incoming Secretary of Defense James Schlesinger. He sympathetically added $36 million to missionize the LWF program for eventual production in January 1974.[367]

The LWF program would have continued to threaten the Air Force's F-15 if not for two developments. First, the Nixon Doctrine provided a requirement for low cost aircraft to assist equipping foreign allies. In 1970, Northrop's inexpensive F-5 won the International Fighter Aircraft competition, prompting Lockheed's unsolicited proposal that got the LWF competition underway. Later, when U.S. allies went looking for more fighters in 1974, it was clear that an outdated F-5 and a pricey F-15 did not provide attractive options. Lieutenant General John J. Burns claimed that the F-16 entered the Air Force not because of its combat effectiveness. In order to keep costs down and win the international competition, the Air Force had to join the purchase it bump up quantities. "They were going to buy about 350, so we had to buy 650," Burns said.[368]

Second, Schlesinger authorized increasing the number of Air Force fighter air wings by six on July 29, 1974.[369] This came a year after cost growth had caused the Air Force to request a reduction in the number of authorized air wings by five, from 24 to 19.[370] Schlesinger wrote that the force structure increase was "approved specifically for the purpose of accepting [LWF] deliveries."[371] With additional funding carved out in the budget that supported both the F-15 and the new F-16 programs, Air Force resistance fell away. As General Robert T. Marsh reflected, "I do not believe, it is fair to say that anybody in the United States Air Force, in a senior position, planned to inventory the F-16. I think it was thrust upon us."[372]

6.6 Permission to innovate

The obstacles faced by the fighter mafia are not unique to the Air Force; the obstacles are common to the administration of large organizations. Formal processes in defense acquisition, however, exacerbated the problem. First, a lengthy requirements phase sought concept validation from the dozens of offices in the military services. Second, the DSARC created a forum for building a consensus at the OSD level. Finally, the PPBS process brings in financial management and other layers of bureaucracy for funding to be made available. Weapon systems innovators were required to justify themselves to a crowd of people, each of them with some power to veto the whole project.

The ability to innovate in the DoD requires permission from both competitor programs and from the established experts. Otherwise, as the LWF story suggests, it takes a nearly impossible appeal to political powers. Henry Hillaker recalled the fighter mafia facing institutional resistance for two similar reasons.[373]

First, the fighter mafia threatened the viability of the F-15, a competitor program. In a program budget, the total cost of acquisition programs must be estimated up-front. The authorization of F-15's development also committed the Air Force to a large procurement that would tie up much of the tactical aircraft budget. For a once in a generation plane, the fighter mafia had a fair shake in defining the F-15. They then wanted a whole new program, and if it went into production, there may not be enough funding for the F-15. The result might be reduced F-15 quantities leading to increased unit costs, possibly spiraling into cancellation. F-15 program advocates then had legitimate interests in the LWF program because they all drew from the same limited source of funding. Even when adequate funds for both programs were provided, it did not erase the memory of subversion. Just two months before the Air Force selected McDonnell Douglas for full-scale development, fighter mafioso Chuck Myers wrote a critical memo of the F-15 requirements in a last ditch effort to push the lightweight concept.[374] In a resourced constrained environment, successful developments can have long term implications on the forecasted life cycle budgets of established programs. Competitor programs whose budgets have already been justified can then use the authorization as a counter argument to any threatening new development.

Second, the fighter mafia moved against expert advice. They were "perceived as being anti-technology."[375] Post-war experts in air combat agreed, and not without good reason, that fighter aircraft needed a high top speed, advanced avionics, and long range missiles. Despite the troubles encountered by the F-111, its all-weather terrain following radar proved highly capable. The fighter mafia took a very different view, arguing that the primary mission of air-to-air combat required agility. Though the YF-16 and YF-17 were state-of-the-art in their own rights, their LWF concept did not seek to over-engineer the planes with negative consequences to agility, reliability, and cost. Skeptics interpreted the fighter mafia to be anti-technology, particularly Pierre Sprey, who was called "a true Luddite" by General John M. Loh, the LWF program manager during the critical stages.[376] Though the slogan "Make it simple" pervaded fighter mafia thinking, Hillaker recalled it being an oversimplification. "We didn't articulate ourselves well early on," Hillaker said more than twenty years later.[377] If the fighter mafia wanted to shape the F-15 program, the LWF program, or any major program, it would have to influence the entire set of experts represented in the Air Staff, or, as it turned out, go over their heads.

The pursuit of defense innovation requires the support of numerous officials from the commands, the service staff, service headquarters, OSD, and even from the President and Congress. The involvement arises because prototype efforts continued to be as much a prelude to full-scale development as full-scale development was a prelude to production. Both the competitor and the expert can, in almost all circumstances, provide a plausible case that a new project either meets no military requirement or is duplicative with the requirements sought by an existing program. In both requirements and duplication, program nay-sayers found especially easy targets in the lightweight F-16 and F-18.

More than a year after Schlesinger authorized the LWF program to be missionized, the services still had no formal requirement for the F-16 or the F-18. The GAO believed that the F-16 and F-18 programs must be curtailed until requirements were detailed and agreed upon with Congress.[378] When the Air Force got around to formalizing requirements, competitive meddling continued as F-15 advocates laid claim to the air-to-air superiority mission. They pushed the F-16 toward an air-to-ground role not envisioned by the fighter mafia, in some ways corrupting its design.[379] F-14 advocates in the Navy successfully pushed for even more substantial changes to the requirements of the F-18. For the F-18, the Navy wasn't the only hazard.

6.7 We are in trouble!

In some ways, the institutional challenges faced by the F-16 pale in comparison to those faced by the F-18. The program faced cancellation by Congress in every year of the F-18's development.[380] The Navy first caught the ire of congressmen when the Naval Air Systems Command (NAVAIR) blatantly disregarded their direction. Congress wanted the Navy to select a derivative of the Air Force's winner, still undecided at the time. In a September 18, 1974 conference report, the House Committee on Appropriations said that "Adaption of the selected Air Force Air Combat Fighter to be capable of carrier operations is the prerequisite for use of the funds provided."[381] $20 million provided to the Navy by Congress was then fenced off for the contractor who won the Air Force competition. But Navy participants did not feel that they have a voice at the source selection board which determined the joint service aircraft.

On November 1, 1974, the Deputy Secretary of Defense William Clements wrote a letter to the chairmen of both House and Senate appropriations committees. He requested them to make Navy funding available to pursue derivatives from either the YF-16 or the YF-17. Neither chairman objected, but that was before the Air Force selected its winner. Completed proposals were received by the Navy on January 13, 1975, the same day that the Air Force selected the YF-16. As the Navy evaluated the designs, General Dynamics fully expected to also win the Navy effort; they must have thought that the Navy was spending time evaluating among its three derivative proposals for the YF-16. But on March 7, 1975, Clements again wrote the Appropriations' committee chairmen requesting for $12 million to go toward derivative designs from both of the Air Force competitors and $8 million towards a "contract with the selected firm to refine its design and sustain its engineering effort… whichever firm is selected." Both chairmen again wrote back with "no objection."[382] Perhaps House Appropriations chairman George H. Mahon would have objected at the time had he known the details. On May 2, 1975, the Navy selected the derivative of the YF-17 and Mahon quickly reversed direction. He seemed genuinely bewildered by the Navy's decision:

> "This Committee has supported the Air Force Lightweight Fighter Prototype development program. The Committee's objective has always been that this program would develop a light-weight, low cost, advanced technology fighter aircraft that could meet both Navy and Air Force requirements. While the Lightweight Fighter program appears to have developed prototypes that fulfill this objective, the Navy has disregarded Congressional intent and is initiating

> development of an entirely different, larger and more expensive aircraft… Since the Navy has proceeded in an entirely different direction, the Committee recommends deletion of all the funds requested."[383]

What is more curious about Chairman Mahon's turnaround is that he previously expressed doubt over the benefits of commonality. While discussing the A-X Close Air Support aircraft in a 1971 hearing, Mahon said that "We think commonality is good, but, we do not want to undertake to achieve something that cannot be realistically achieved."[384] In 1975, however, Mahon pointed to the F-4 and A-7 as joint service planes that benefited from the large production run provided by commonality. Yet those aircraft were designed for the Navy and stripped down for the Air Force. Removing weight from naval aircraft is easier than adding weight to handle the stress of catapult launches and arrested landings, to increase wing area for carrier approaches, and to overcome various other matters besides, as discovered in the F-111B which the Navy backed out of.[385] Admiral William D. Houser said that for carrier operations, "you have to add several thousands of pounds of structural weight so it becomes heavier. You have to add a great deal to the wing area and complicated devices that fold in and out of the wings to give it its approach characteristics… And then it is too heavy for the same engine."[386] Moreover, neither of the LWF competitors had ever built a naval aircraft, requiring them to team up with an experienced partner.

Realistic speculation that Congress would only fund a derivative of the Air Force winner drove the teaming arrangements for Navy designs. Northrop first approached Ling-Temco-Vought (LTV) to help on the YF-17, but LTV turned them down because by the summer of 1974, and it looked like the YF-16 would win the Air Force competition. LTV took an inferior offer from General Dynamics, pushing Northrop into a deal that made them the junior partner to McDonnell Douglas on the navalized YF-17. The teaming arrangement mattered greatly, because both General Dynamics and LTV were based in the Dallas-Fort Worth area of Texas, the home state of Chairman Mahon. And it was clear to all involved that a joint service aircraft ensured plenty of defense dollars for local jobs.

While Mahon's congressional district was a couple counties away from Fort Worth, perhaps affecting his opinion, junior member Dale Milford served the suburban area in between Dallas and Fort Worth. Milford consequently railed loudest against the Navy's decision. "Will Congress surrender its constitutional prerogatives," he asked with a hint of excess, "by permitting an executive agency to act in clear defiance of the law?" Milford called the Navy's actions a "ripoff" due to the projected $2 billion savings provided by commonality. The projection was perhaps not made by the most independent of sources, General Dynamics and LTV.[387]

On May 9, 1975, LTV submitted a formal protest to the Navy's decision citing Congressional language. Apparently, many in the Navy were unaware of the matter until after the protest. NAVAIR General Counsel Harvey Wilco exclaimed "Holy moly! We are in trouble!"[388] Indeed they were. Within a couple weeks, Representative Milford brought the protest and a personal statement before the Senate to discuss the matter.[389] The two issues Milford later identified were first, is the F-18 cost effective? And second, did the Navy break the law?[390]

With respect to the first, the Navy built a convincing case that all proposed F-16 derivatives required substantial modification. LTV's navalized 1600 model, for example, added 38 percent to the empty weight of the YF-16 and increased the wing and horizontal tail areas by 32 and 76 percent, respectively. The 1600 model also proposed a different engine than the F-100 used in both the F-15 and F-16, reducing commonality further. By contrast, the F-18 was only 23 percent heavier than the YF-17, 14 percent larger on the wing area, and saw no change to either the horizontal and vertical tail areas.

But the required changes do not speak to the effectiveness of carrier operations. Admiral Kent Lee and the source selection committee found that, the unlike the LTV proposals, the "F-18 substantially meets or betters all… requirements."[391] The YF-17's natural operability at low speeds put the F-18 in a good position to win the Navy effort. Appreciating the deficiencies of their designs, LTV argued that they may have won had they also deviated from the Congressional requirement of commonality with the F-16.[392] The claim did not hold water, considering LTV submitted three designs of 60, 15, and 1-2 percent commonality with the F-16. Of the least common 1602 model, Admiral Kent Lee said that "It was essentially a new airplane."[393]

The Navy made a convincing case that the F-18 was more cost effective than any F-16 derivative. OSD's independent cost office verified that the F-16 program was cost effective enough to proceed without the benefits of joint production orders. Yet all sides agreed that the Navy went against the language of the conference report, and the matter ultimately came down to legality. The Congressional Research Service wrote a legal opinion on September 12, 1975, stating that "matters resolved at conference and passed by both Houses of Congress must be absolutely determinative."[394] Though the opinion went against the Navy, it was overruled by the General Accounting Office (GAO) on October 1. The GAO decided that the Navy's F-18 award was valid because conference report language is not legally binding. The GAO went further to say that the Navy award "does not represent a violation of moral or ethical standards."[395]

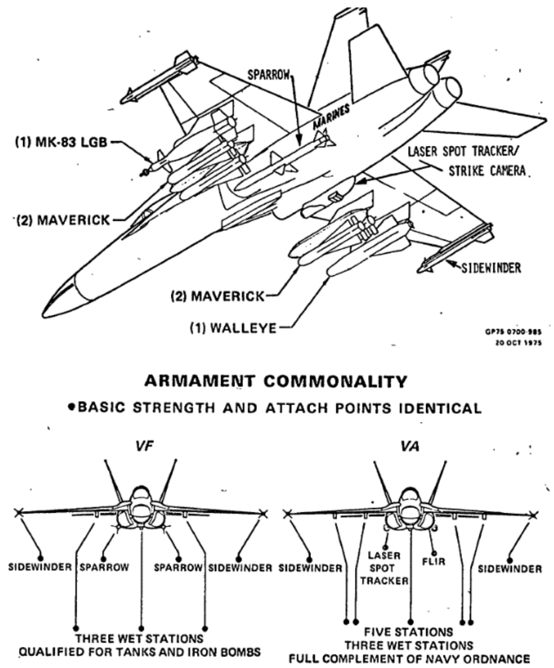


Figure presented to the Congress on 8 Oct. 1975 showing the fighter and attack variants of the F-18, which were similar enough to eventually merge into the F/A-18. Because fighter and attack definitions overlap, the aircraft may be simply referred to as the F-18.

The Navy's successful defiance was a rather unlikely outcome. It demonstrated to many the need for additional Congressional involvement in the requirements definition of weapons systems. Senator Barry Goldwater's sentiments may have been typical of Congressmen. "I want to make it clear," Goldwater said, "that I don't oppose the F-18 weapon system. I oppose the way that they have gone about obtaining it."[396] And like many Congressmen, Goldwater still held hopes that joint service programs would generate substantial savings. He admitted that "This may only be an impossible dream that some of us have, but… we cannot continue forever to pay for these separate air forces."[397] Non-consensual programs not only had to contend with institutional biases within the services. Biases were also injected from OSD, the President, Congress, and the public, who all associated cost savings with economies of scale. "But," as Edward Luttwak aptly pointed out, "conflict is not like civilian business and efficiency is the wrong goal to pursue." He continued:

> "… efficiency in making a radar or refueling a ship, of course; efficiency in making radars, or refueling ships, no, for efficient economies of scale in purchasing radars lead to a single mass-produced radar that will be more easily counter-measured, and efficient refueling

> leads to a few large fleet oilers that are more easily intercepted and destroyed by the enemy. (Each of our majestic aircraft-carrier task forces is now dangerously dependent on a single, very large, very efficient resupply ship.) Conflict *is* different."[398]

Consolidating capabilities into single platforms not only creates combat risk, but it also increases the risk of missing out on alternative technologies. Unlike a market economy, where various entrepreneurs independently pursued the option space, diverse lines of development must be consciously pursued in the military. Armen Alchian wrote, "In the private economy other competing firms can duplicate or take different points of view about the nature of desirable products. But there are not two departments of defense to provide the competitive survival and selection of preferred products." The defense acquisition process itself had to act in lieu of a market through an endless cycle of testing alternative solutions to reimagined requirements. Yet as the lightweight fighter case study has shown, intragovernmental competition was actively suppressed.

For all the debate about the benefits of prototyping and competition, policy-makers still concerned themselves with finding the single best system to fulfill the most possible missions. In the lightweight fighter case, as with others, the Navy and Air Force were expected to produce one common aircraft. The lack of diversity was noticed by the Commission of Government Procurement. They observed how the U.S. had only two fixed-wing and one helicopter "design bureaus," whereas the Soviet Union had two helicopter, eight fixed-wing, and six engine design bureaus, with an additional six research institutes.[399]

6.8 Resistance

In retrospect, the lightweight fighter concept proved a good value for first the Air Force and later the Navy. Yet as a brief impression of institutional challenges facing the LWF programs demonstrates, it was unlikely to have ever happened. It required foresight and determination, as well as the personal intervention of unusually sympathetic leadership at the Secretary of Defense level who went to bat for beleaguered outsiders. Usually, career military insiders outlast a particular administration to get their way on major programs. In the LWF case, advocates successfully appealed to Laird as well as his replacement, Schlesinger. By then it was too late to stop. Boyd's fighter mafia was uncommon in their willingness to criticize as well as their ability to appeal to the highest echelons of government. Frederic Scherer observed that "There is a common belief at the intermediate levels of the military decisionmaking hierarchy that one should not rock the boat too vigorously through criticism at the start of a program."[400] The common belief was not shared by men in the fighter mafia.

The lightweight fighter program followed a pattern of military innovation overcoming resistance. Historian James F. Nagle found that in the early twentieth century, "Developments like the airplane and submarine… had to be engrafted onto military thought. They could not evolve."[401] One seemingly mundane innovation at the time which met heavy resistance was an elevation system to keep naval guns steady while the ship rolled and pitched at sea. The technology, called continuous aim-firing, undoubtedly revolutionized naval gunnery. It increased fire effectiveness by literally a thousand fold. In 1966, historian E. E. Morison put forward a generalized process that brought the Navy continuous aim-firing at the turn of the twentieth century:

> "1. The essential idea for change occurred in part by chance but in an environment that contained all the essential elements for change and to a mind prepared to recognize the possibility of change.
>
> "2. The basic elements… were put in the environment by other men, men interested in designing machinery to serve different purposes or simply interested in the instruments themselves.
>
> "3. These elements were brought into successful combination by minds not interested in the instruments for themselves but in what they could do with them…
>
> "4. [They] were opposed on this occasion by men who were apparently moved by three considerations: honest disbelief in the dramatic but substantiated claims of the new process, protection of the existing devices and instruments with which they identified themselves, and maintenance of the existing society with which they were identified.
>
> "5. The deadlock between those who sought change and those who sought to retain things as they were was broken only by an appeal to superior force, a force removed from and unidentified with the mores, conventions, devices of the society."[402]

All five steps are as readily apparent in the lightweight fighter case as they are for continuous aim-firing; and the same is true for the atomic bomb[403] and ballistic missiles,[404] if not a host of other technologies.[405] Yet the first three steps alone relate to technological innovation while the fourth and fifth relate to the process of innovating, or changing, the social institutions that embed the new technologies. The cases presented all required a "superior force" to break the deadlock, which is by no means certain. If the acceptance of technological innovation depends on social adaptability, and, as Morison suggests, societies in the military services have trouble reforming themselves without outside direction, the extended implications present a "discouraging thought." Morison asked what if "no society can reform itself? Is the process of adaptation to change, for example, too important to be left up to human beings?" He invoked the Bessemer steel process as one instance where the broader industrial economy adapted slowly to technological change. Two readily available examples could be added, the standard shipping container and the electric motor.[406] Morison recommended, as a partial remedy, for individuals to think of their mission more broadly and not wed themselves to particular technologies or doctrines. It implies the need for individuals to learn continuously and foster what Morison called an emotionally "adaptive society."[407]

The problem of adaptation in weapons acquisition led Robert Perry to question not only the systems approach, but also the evolutionary approach to innovation pushed by Armen Alchian, Burton Klein, and others. If decision makers are wedded to particular technologies or doctrines, then the evolutionary approach can lead to dead ends while high-value opportunities go unpursued. Robert Perry pointed to the "misconstrued technological logic" associated with evolution; for example, "any sensible military engineer" expected cruise missiles to precede ballistic missiles, and similarly would expect turboprop engines to precede the supposedly "much more complex, much less efficient" turbojet engines.[408] In the case of ballistic missiles, the error arose from "a set of value judgments accepted uncritically by Air Force analysts." In the case of the jet engine, "the Americans seem to have overstated the difficulty and underestimated the worth on every possible occasion."[409]

Why were the new technologies being so badly misrepresented? Perry concluded that "the answer seems plain enough: cultural resistance."[410] Such resistance may lead to endless tinkering along safe and well-trodden lines, as seemed to happen in the Navy bureau and Army arsenal systems before WWII. "The assumption," Perry wrote, "that technology and doctrine will alike change in traditional, evolutionary ways is comfortable, but it is not necessarily true, and as some of the instances noted above suggest, it may also be an invitation to disaster."[411]

One issue with the evolutionary approach is knowing when to pursue, or by how much to follow-up on, a new branch of technical demonstration. Here, the problem of institutional bias is particularly acute. In the case of ballistic missiles, analysts misjudged the option to be unlikely and eliminated it early on. "I feel confident," Vannevar Bush testified on ballistic missiles, "it will not be done for a long period of time to come."[412] Prevailing attitudes may still reject change even when new options show promise. Swing-wing airframes and jet engines were eliminated, even after technical feasibility was demonstrated, because civil and military "institutions… could not be diverted from their preoccupation with marginal, evolutionary improvements in the sorts of mechanisms they were familiar with."[413]

In the evaluation of substantial military technologies, subjectivity cannot be avoided. When decision-makers think narrowly, the evolutionary approach may neglect new designs that branch off in unfamiliar patterns. The risk is particularly worrisome because, as Perry put it, "success is in many respects a random event that does not conform to any standard pattern of behavior."[414] Standard patterns of behavior are precisely what good administrators intend to accomplish; but as administrative theorist Lyndall F. Urwick described, the paradox of a leader is "to protect from their wrath the originals, the inventors, the crazy people to whom order is anathema… because it is from this lunatic fringe that he is most likely to derive something original."[415] Similarly, of inventors E. E. Morison wrote that:

> "A surprising number turned out to be people with little formal education, who drank a good deal, who were careless with money, and who had trouble with wives or other women. This is also, I suppose, what is now called a good stereotype of the painter or poet. And it is quite probable that the inventor who is also something of an engineer is, like all great engineers, an artist."

Theorists and practitioners, however, avoided the matter of the individualistic inventor with the argument that modern systems had become so complicated that they could only arise from teams of highly specialized personnel using rigorous management control systems. Morison addressed the matter briefly, stating that "We have pretty well left the point where the most interesting work can be done by single men working all alone… which is one way of saying that the virtuosity of the inventor has on the whole given way to systematic research and development." [416] Even theorists oriented toward decentralized processes, such as Alfred Whitehead and Joseph Schumpeter, believed that innovative processes in the twentieth century required large teams with directed objectives. They sidelined almost entirely the motives and sentiments of individuals that make the teams work.

6.9 Stage-gates

The defense innovation process did not stress the career path of employees and how they contribute to military solutions. Instead, it stressed the lifecycle of military projects and the formulation of their requirements. In 1965, RAND analyst Thomas K. Glennan bucketed the technical development process into two categories, requirements-pull and technology-push. He described them akin to top-down and bottom-up:

> "Technology-push efforts are those efforts where the research personnel determine what research efforts will contribute to needs as they, the researchers, perceive them. Requirements-pull efforts are efforts where the needs are perceived by those external to the research efforts, the research is initiated by planners and operationally oriented organizations…
>
> "If the decisions are made at the top of the organization we have clear requirements-pull efforts. If they are made at the bottom, by the individual researcher, they are technology-push."[417]

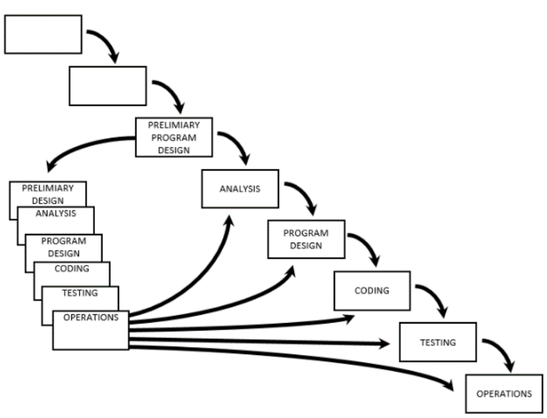
Utilizing the framework, Robert Perry rejected the predominating systems approach because it was entirely requirements-pull. He also rejected the evolutionary approach for the opposite reason, that it was entirely technology-push. "The flaw in all these viewpoints," Perry wrote in 1967, "is that they tend to ignore the reactive influence of innovative technology on requirements, and of requirements on the handling of innovations." Perry advocated what at first appears to be a different matter, a three-step decision process that resembles "the classical investment model."[418] A project may start with either a validated requirement or an invention, and at specified points, technical feasibility will be demonstrated for leadership. Feedback is then provided on requirements and cost parameters that can generate iterative loops.

Despite Robert Perry's appreciation for the interaction between requirements and technology, his preferred three-step process became associated with the "linear" model of innovation. In the linear model, a program matures in sequential steps, such as from scientific knowledge to product engineering to customer diffusion. "Non-linear" models of technology transition emphasize a back-and-forth process of communication. Engineers generate questions for scientists to answer as much of scientists generate knowledge for engineers to apply. Similarly, customers provide guidance to technologists as much as technologists provide new option-spaces for customers.[419] Performing such interactions only three times does not generate the required communication for success.

The linear approach to development may be characterized by Winston W. Royce's 1970 classic, "Managing the Development of Large Software Systems." In it, he outlined a linear path from system requirements through coding, testing, and operations. The model later became known as the "waterfall" process of software development. It shared a lot in common with the steps involved in other intensive planning methods such as PERT.

What is often forgotten, however, is that in the same paper Royce understood that successful developments had to iterate.[420] "I believe in this [linear] concept, but the implementation described above is risky and invites failure." Royce recommended "doing it twice," or changes in requirements could create "up to a 100-percent overrun in schedule and/or costs." A "pilot model" should address only the most critical requirements which may then generate important feedback and buy-in from the customer early on.[421] The delivering of incremental capabilities became the basis of iterative, spiral, and agile methods of software development.[422]

Perhaps an idea once popularized sheds the underlying complexity to its truth, only to be rediscovered by successive generations using the language and concepts of their own time. Though Robert Perry and Winston Royce could perhaps be pointed to as exemplars of the linear model, they certainly thought in terms of non-linear implementation. There are two general circumstances necessitating non-linear processes: first, when critical information is provided after product launch; and second, when a project's mission is to create new options and new requirements.[423]



Reproduced figure from Winston Royce (1970) showing non-linear implementation of the linear developmental process. Labeled "Figure 7. Step 3: Attempt to do the job twice - the first result provides an early simulation of the final product."

Non-linear approaches to technology development can be loosely described as communication between innovators and users. Early feedback and advocacy from users is central to product success. Elements of non-linearity include "flexibility, a willingness to take risks, open communication without regard to hierarchy, a sense of responsibility that replaces unquestioned authority, and a commitment to success that goes beyond functional roles."[424]

The linear three-step decision making process was adopted by David Packard in the 5000-series. It continued to guide acquisitions policy fifty years later. The top award in acquisition excellence is attached to David Packard's name. Yet his vaunted connection to acquisition reform is curious considering he largely rebranded McNamara's existing policies. DoD Instruction 3200.6, dated June 7, 1962, defined the same three key decision that later became program milestones.[425] Similarly, the Development Concept Paper (DCP) of 20 pages or less was initiated by McNamara in 1967 in order to streamline reporting. What Packard seemed to accomplish was a short-lived emphasis on system prototypes rather than paper studies. Yet the characterization is not totally accurate, as McNamara updated his guidance to a "building block" approach in advanced development, proving out components and subsystems. It was the bridge to full-scale development where McNamara suffered.[426] The only real change Packard, and his boss Laird, introduced was a return to providing budget ceilings for the services, who then formulated programs which OSD would approve. As Clarke Murdock observed in 1974:

> "At the level of general defense policy-making, changes initiated by the new administration represent a return to the practices of the 1950s. In the area of weapons innovation and acquisition, however, despite rhetoric to the contrary, Laird's innovations represented for the most part a renewed commitment to trends begun by McNamara…
>
> "Laird's 'fly before you buy' systems development approach, despite his efforts to differentiate it publicly from practices under McNamara, contained many similar features."[427]

Even Murdock's description may have been charitable. Laird did not return to general policies of the 1950s, which were dominated by organizational budgets and strong in-house technical staffs. Instead, Laird continued to operate under McNamara's overall management framework, the Planning-Programming-Budgeting System. "The realities point to more rather than less centralizing tendencies," a Congressional report surmised in 1970.[428]

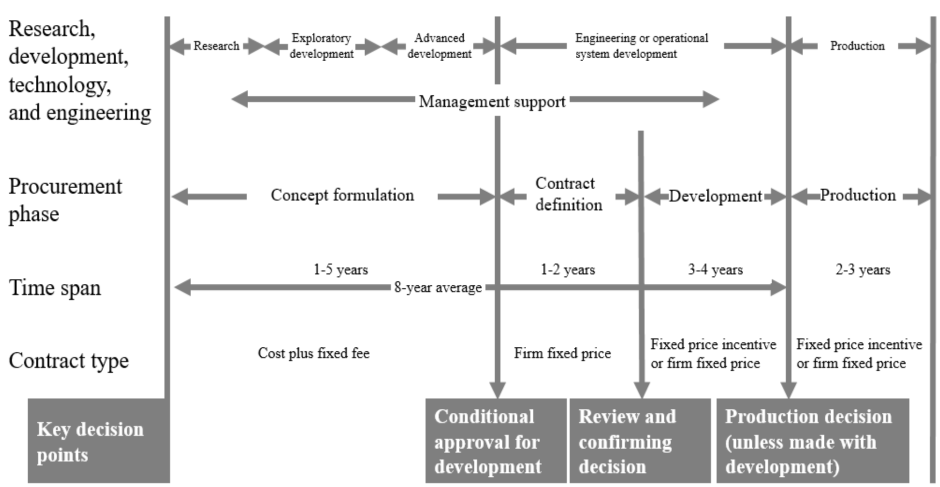


Figure depicting the DODI 3200.6 R&D cycle, dated June 7, 1962. The McNamara innovation process was largely retained by Laird and Packard. Reproduced from Martin Meyerson's 1967 article, "Price of Admission into the Defense Business."

The PPBS has been a consistent force for centralization by locking in program production plans at the start of development, and, more importantly, suppressing competitors. Consider the daunting task to starting a program, whether initiated in the services or OSD. Decisions made through the separate DSARC acquisition process do not authorize funding. To initiate a program, it is first necessary for the Secretary of Defense or his deputy to first line up funding through the PPBS—which then becomes the basis of the President's Budget to be approved by Congress.[429] Any program decision made through the DSARC had to be anticipated 29 months ahead of time in the PPBS for funding to be available when the project needs it.[430] Before all that occurs, the program concept must be vetted by numerous layers of bureaucracy in the requirements process. In all, it may take five to eight years before funding is released to an approved program.

Any degree of decentralization achieved by Laird and Packard quickly dissipated. In 1972, the Commission on Government Procurement claimed decentralized management to be a "serious flaw." A year later, Comptroller General Elmer Staats agreed that the Secretary of Defense needed to require more "comprehensive and objective analyses of missions and weapons requirements."[431] In 1976, OMB Circular A-109 established new acquisition rules for the executive branch, seeking central authorization to create concepts.[432] In January 1977, Secretary of Defense Harold Brown implemented OMB Circular A-109 by adding a Milestone Zero, which sought approval for whether or not a mission need in fact existed.[433] Any exploration of alternative technologies or requirements would first have to be tied to a mission needs statement approved through the DSARC process. Milestone Zero proved a cumbersome process, and was cancelled just five years later, but complex interactions between the acquisition and budgeting cycles continued to create forces towards a top-down, or requirements-pull, approach. Technology-push concepts—and iterative feedback from requirements—remained illegitimate in defense policy.

7. Complexity

> Of course I was attacked, from all around. "Don't you think that order can come from chaos?"
>
> "Uh, well, as a general principle, or…" I didn't understand what to do with a question like "Can order come from chaos?" Yes, no, what of it?
>
> Richard Feynman
>
> *Surely You're Joking, Mr. Feynman!* 1985

Describing the process of innovation as a nonlinear interaction between technology-push and requirements-pull is but one framing of a larger philosophical question: What are the foundations and methods of scientific inquiry? Two general processes are first, starting from a comprehensive whole and breaking it down to its particulars, and second, starting with the particulars and building towards a comprehensive whole.

On the one hand, requirements-pull proceeds from the general to the specific and is related to reason, deduction, analysis, and differentiation. For example, the requirement for air superiority is a general concept that can be expressed by many arrangements of particular technologies, the selection of which depends in part on the attitudes and culture of the decision maker. On the other hand, technology-push proceeds from the specific to the general and is related to empirics, induction, synthesis, and integration. For example, independent technologies such as the jet engine, airframe structures, electronics, and ordnance can be integrated into a system that expresses the air superiority concept. The inductive progression builds up to a concept by relating observed elements.

7.1 Concept building

Though an interplay between the deductive and inductive methods was considered perhaps as long ago as Aristotle, it continued to be debated into the 20th century.[434] Alfred North Whitehead described the differences between the two, arguing that natural sciences were not the "rigid method" of induction alone, as Francis Bacon believed.[435] Science also required the deductive reasoning from mathematics to verify the internal consistency of its conceptual system. "What Bacon omitted," Whitehead wrote,

> "… was the play of a free imagination, controlled by the requirements of coherence and logic. The true method of discovery is like the flight of an aeroplane. It starts from the ground of particular observation; it makes a flight into the thin air of imaginative generalization; and it again lands for renewed observation rendered acute by rational interpretation."[436]

Structuring ideas from observations, followed by an unstructuring, restructuring and restructuring again is the basic method of learning. By contrast, the systems analysis approach expressed in the Department of Defense is deductive in nature. Indeed, the very term "systems analysis" invokes deductive as opposed to inductive methods. "Rather than waiting upon experience in the real world," Aaron Wildavsky explained, "the [systems] analyst tries various moves in his model and runs them through to see if they work."[437]

Systems analyses sprang out of operations research in WWII, which generally had well-defined objectives amenable to mathematical tools such as linear programming and queuing theory. While the objectives were given and assumptions about the environment specified in operations research, Alain Enthoven and others explained that a major task of systems analysis was defining objectives and assumptions.[438] E.S. Quade observed that systems analysts are

> "… likely to be forced to deal with problems in which the difficulty lies in deciding *what out to be done, not simply in how to do it*… The situation is not like an *empirical science*, which starts with observed facts, but more like that of *mathematics*, where the results take any

'validity' they might have in the real world from the assumptions… it is important that the assumptions be the 'right' assumptions."[439]

Quade clearly expressed the deductive methods of systems analysis and contrasted it to empiricism. Nevertheless, Quade could not put systems analysis on the firm foundations of reason because "judgment and intuition permeate" the models, particularly when framing the goals and assumptions.[440] It is no surprise, then, that systems analysts largely defended weapon requirements rather than the feasibility of certain technologies.[441]

Though critics appreciated the logic and rigor inherent to systems analysis, they repeatedly pointed to disconnects from empiricism—from knowledge gained by trying things out. James Schlesinger explained how "our ability to formulate models depends upon our knowledge of the mechanics of the real world."[442] Admiral Rickover complained how systems analysts "have little or no scientific training or technical expertise… Their studies are, in general, abstractions. They read more like the rules of a game of classroom logic than a prognosis of real events in the real world."[443] Representative Porter Hardy Jr. provided a similar assessment during an appropriation hearing in May 1968. "My best information," he said, "is that there are no significant military inputs into these analyses."[444]

John Boyd, hero of the lightweight fighter program, also struggled with the systems analysis approach dominant in DoD decision making. Yet Boyd's experience reveals the subtleties of its implementation. When evaluating the designs of the F-X project in 1966, Boyd criticized the people and institutions who "wormed their pet technologies into the final design." Instead of valid technical features emerging from the requirements, Boyd found that the F-X requirements were altered to fit the desired technical features.[445]

Even the flailing F-111 may not have been a product of pure systems analysis. I.F. Stone reported that systems analysts at the OSD level wrote a memo critical of the F-111 early in its design phase. Enthoven, however, rejected it "on the grounds that it would call down bureaucratic wrath on the fledgling systems analysis office."[446] Systems analysis may have led to successful designs if the model remained uncorrupted by special interests. As it happened, political realities prevailed over analytical independence. Schlesinger noticed how "Studies are driven by the underlying assumptions, and these may be imposed directly or indirectly from above… The role of analysis then becomes not so much to *sharpen* the intuitions of the decisionmaker as to *confirm* them."[447]

John Boyd disapproved of the prevailing intuition of the bigger-higher-faster-farther aircraft. A speed of Mach 2.5 was only built into the F-X requirements because a new technology emerged, variable geometry inlets, despite the fact that the technology entailed design penalties to maintenance, cost, and range.[448] James Burton reported how Boyd believed that technical features are the output from a disciplined design trade-off, and not the input.[449] His design philosophy at the time appears true to the deductive method and aligned with the intent—though perhaps not the practice—of systems analysis. Yet as Boyd came to discover, his actual process of learning was more like that described by Whitehead, an interaction between inductive and deductive approaches.

Consider a sketch of Boyd's journey to the lightweight fighter. He first spent many years gaining experience as a fighter pilot. Then, he classified all of his observed air combat maneuvers in "Aerial Attack Study." Boyd's schemata were so thorough that no major additions have been identified. Having so matched his classification system with experience, he wondered what tied the maneuver-countermaneuver strategies together.[450] By studying engineering at Georgia Tech, a broadened experience led Boyd to the useful real-world concept of entropy. He then applied the concepts back to air combat scenarios with Energy-Maneuverability (EM) theory.[451]

An F-15, formerly the F-X, showing its variable geometry inlets in two positions.

The F-X design provided Boyd his first opportunity to apply EM theory to evaluate aircraft design. However, to deduce proper technical evaluations from EM theory, it first took several rounds of induction and deduction to build up to the EM theory concept. Concepts so aligned with reality do not arise from pure thinking alone or axiomatic "truths" such as "more speed is better."

The inductive-deductive cycle continued when the inadequacies of EM theory were demonstrated during the fly-off competition between the YF-16 and YF-17 in 1974. While both planes were predicted on paper to have similar maneuverability, pilots gave a distinct advantage to the YF-16. EM theory certainly improved fighter aircraft evaluation but it was not yet a map of reality. It called for the structuring of an improved concept. Boyd, however, had moved on.

Weary of the politics surrounding aircraft development, Boyd looked instead to apply his maneuverability concepts to more general topics including learning, human organization, and war. For the previous few years Boyd was keenly interested in a range of subjects, including epistemological debates on the theory of knowledge by luminaries such as Karl Popper, Michael Polanyi, and Thomas Kuhn. As debates raged in 1975 over whether the Air Force would inventory the F-16 and A-10, Boyd resigned his post.

The next year, John Boyd released a short paper entitled "Destruction and Creation" which described the concepts that became the foundation of all of his subsequent work on the military sciences. He provided a justification that an inductive and deductive cycle is not just desirable for model building, but an inevitable fact of life.[452] Over the next two decades, Boyd refined and presented his ideas on maneuver warfare and the "OODA" loop. It will be shown how Boyd anticipated the interdisciplinary studies of complexity and nonlinear systems which contribute substantially to our understanding of economic systems.

7.2 Destruction and creation

Boyd's short 1976 paper, "Destruction and Creation," will be used as an introduction to a broader shift in both the natural and social sciences towards thinking in terms of complex adaptive systems. In this chapter and the next, these ideas will be applied to defense acquisition. Boyd went after a big idea in the paper, a general theory of how we create mental concepts that allows us to adapt to a changing environment and "improve our capacity for independent action." The ability to generate mental concepts and use them to decide upon real world actions is indeed what sets humans apart.[453] For example, Schrödinger's equation is an articulation of quantum mechanical concepts which became usefully applied to our understanding of technologies such as computers, GPS, and lasers. The relevance of technology to our survival needs no elaboration.

We can say that survival depends on adaptation which, in the human world, need not take place in our genes but in our minds. Human adaptation in the world depends on decision-making about technologies in the broadest sense, an activity dependent upon underlying mental concepts. Boyd wondered, "How do we generate or create the mental concepts to support this decision-making activity?" The question also underpins systems analysis, where military survival necessitates decisions concerning the direction of technological progress. Mental concepts frame the assumptions about technologies and requirements which decide the course of resource investment.

Boyd then described the inductive and deductive approaches for building mental concepts introduced above. "Now keeping these two opposing idea chains in mind," one from the specific-to-general and the other general-to-specific, Boyd likened deduction to the "destruction" of a domain or concept into its many parts and likened induction to the "constructive" process of reconstituting the parts into new domains or concepts. So long as the reconstitution does not create the exact same relations among the parts—indicating creativity—new and different concepts have emerged.

After many iterations of destructive deduction and creative induction, Boyd imagines how we may create a powerful concept. It may match-up with reality so well that there is no further appeal to expand, complete, or modify the concept. The only way to improve the concept's explanatory power is an inward-oriented effort to make increasingly subtle observations. Boyd suspected at some point, anomalies or inconsistencies will appear from the inward-oriented application of deduction and induction. Any anticipated difference between the newer and more subtle observations with previous observations

> "… suggests we should expect a mismatch between the new observations and the anticipated concept description of these observations. To assume otherwise would be tantamount to admitting that the previous constituents and interactions would produce the same synthesis as any newer constituents and interactions."

Subtler observations provide fodder for creatively synthesizing different and potentially more powerful concepts. Boyd quickly introduced the idea of an ultimate concept requiring no further expansion or modification before he quickly cuts it down. No concept, he claimed, can so completely describe the real world that we can consistently explain all observations. Boyd stated that "we should anticipate a mismatch between phenomena observation and concept description of that observation."

As we shall see, the idea is important for human organization, whether military, economic or otherwise, because it implies the limits of planning; no centralized office can hold a complete concept which can be used to calculate optimal courses of action in all cases. Boyd supports the claim by integrating three notions: Gödel's Incompleteness Theorems; Heisenberg's Uncertainty Principle; and

Colonel John R. Boyd retired from the Air Force in 1975 to pursue a wide-range of studies.

the 2^{nd} Law of Thermodynamics (i.e., entropy). Before elucidating the three notions and interpreting their relevance, an epistemological background will be provided, one that Boyd was familiar with from his readings.

7.3 Positivism

Though most histories must start before the beginning, this brief overview will start with Isaac Newton who, in 1687, published *Principia Mathematica*. He found quantitatively precise laws of Nature in classical mechanics and the inverse-square rule for gravity. If a consistent and complete description of nature can be deduced from a finite set of quantitative laws, the logical conclusion is a scientific determinism. Pierre-Simon LaPlace conjectured that if all the positions and velocities of all the particles in the universe could be known, then the laws of Nature will allow a "vast enough" intellect to calculate all past and future states of the universe. Free will must have been an illusion.

By the end of 19^{th} century, many scientists believed they were reaching a complete description of natural laws, that they could theoretically describe and predict all aspects of our empirical world. As related in Chapter 4, the vaunted success of natural laws in prediction eventually inspired the German Historical School and the American Progressive movement. The scientific revolution was reflected in business organization and public policy under the banner of rational management.

The positivist view also provides a compelling philosophical rationale for weapon systems analysis. If a systems analyst knew all the laws of physics, he could derive all feasible engineering arrangements. The optimal course could then be chosen based on the military requirements involved. Technical solutions need not be derived from the crude and wasteful empirical method of trial-and-error. All solutions could be calculated from the natural laws underlying elementary parts. Moreover, the solutions can be validated or refuted by an independent third-party.

If our knowledge of natural laws were complete, literally every technology the future may hold can be planned today, even if it couldn't practically be accomplished. As a result, a small number of the brightest people—those with the best grasp of natural laws—could sit in the Pentagon and steer the course of defense technology. As an added benefit, holistic as opposed to parochial requirements will balance the equations. The process provides a logical basis for weapons choice. It cannot be refuted without challenging the requirements or, what might seem outrageous, the laws of physics. Systems analysis becomes a far humbler endeavor, however, if it turned out that the models of natural laws were either incomplete—they cannot determine all feasible technologies—or inconsistent—they may wrongly assess technical feasibility.

For Immanuel Kant in the 18th century, natural laws such as Newton's inverse-square rule for gravity are not a window into the real world, or "things in themselves." Instead, our understanding of natural laws structures the way things, or phenomena, appear to us. The reason mathematics is so effectively applied to our world, such as Newton's law of gravity, is because our perception of the world has been structured by that mathematics. Our minds are hardwired with geometry and arithmetic, so when we look at the world and order our surroundings, Kant argued that it is already structured spatially (geometrically) and temporally (arithmetically). We cannot experience a world that doesn't conform to our own geometry and arithmetic. Mathematics, in a sense, is the language in which we interact with the world of phenomena. Different geometries and arithmetics can correspond to different ways of structuring the world around us.

Curiously enough, Kant believed that Euclidean geometry of flat planes was the last word on geometry, yet when Carl Gauss and others dropped the parallel lines axiom, a non-Euclidean geometry of curved space was created. The concept proved crucial to Albert Einstein's formulation of relativity in which it was discovered that the structure of space and time is in fact curved. Mathematics for Kant was not the "truth" or a line of communication to Plato's world of forms; humans brought mathematics into the world and it structures our view of phenomena. For Einstein, it provided the mental lens in 1919 to see light bending due to the curvature of space-time.[454]

Kant set the agenda for later debates on epistemology. Bertrand Russell observed that "Kant's inconsistencies were such as to make it inevitable that philosophers who were influenced by him should develop rapidly either in the empirical or in the absolutist [deductive] direction."[455] In fact, Russell himself and fellow mathematician Gottlob Frege were convinced earlier in their careers that Kant was wrong; they believed that mathematical truths were not of our own making. The question they wanted to resolve was whether people discovered mathematics or invented it, with implications for whether it was objectively true or not. Frege set out to put mathematics on a logical foundation by proving that set theory really belonged to logicism.

Bertrand Russell recognized a paradox which presented a serious challenge to Frege's work. He sought to put mathematics into logical form without encountering the vagaries and paradoxes of language. Language that is rich enough to talk about itself, however, encounters inconsistencies such as the "liar paradox." For example, the statement "This statement is false" is neither true nor false. If it were true, then the statement is false, and vice versa. The “liar paradox” problem turned out not to be limited to language; Russell and others showed how the same problems fell onto mathematics as well.[456]

Starting in 1900, David Hilbert, one of the most famous mathematicians of his day, sought to put mathematics on a solid axiomatic footing from which all propositions can be proven either true or false. Of twenty-three problems identified, two are problems about what can be proved by mathematics. They can be summarized in three questions: Is mathematics consistent (only proves true statements)? Is it complete (proves all true statements)? Is it decidable (a definite procedure for every statement with results in finite time)?

Hilbert’s program was crucial not just for mathematics but for logical positivism, which viewed physics—and by extension all of the sciences—as an application of mathematics. With a definite procedure for correctly proving all true statements, mathematics and the sciences could move towards finality. But if mathematics were inconsistent, incomplete, and/or undecidable, then it cannot be a fountain of discovery for all scientific truths. Such a result would also destroy the framework used by elements in the Department of Defense, who went headlong first into unification, and then into systems analysis and program budgeting.

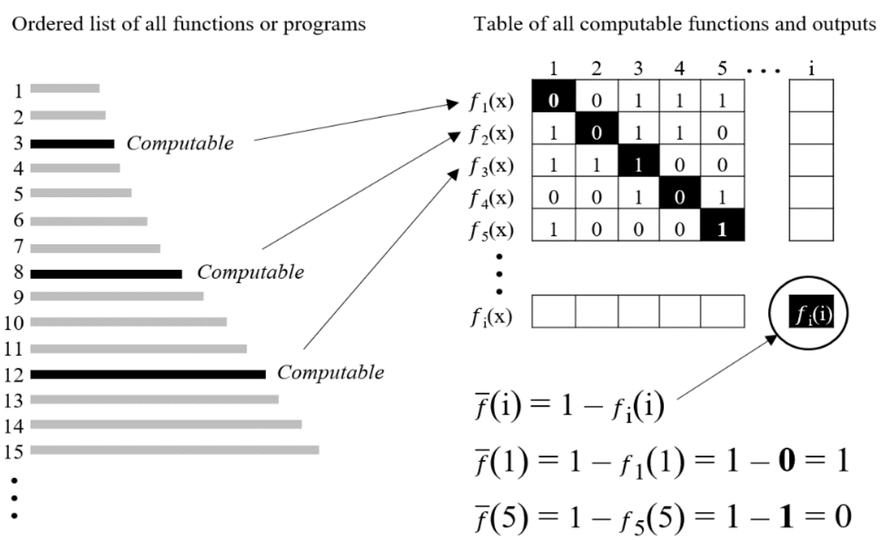
Hilbert’s program was thoroughly dashed in 1931 by a young man named Kurt Gödel. In essence, he demonstrably proved using arithmetic that arithmetic itself was either incomplete or inconsistent (later, Alan Turing proved it was undecidable). Gödel accomplished this feat—the first major result in logic since Aristotle—by generating a situation like the “liar paradox.” The analogous statement Gödel mathematically employed is: “This statement is unproveable.” If it is proved, the system is inconsistent. Otherwise, the system is incomplete. To make the self-referential statement mathematically, Gödel cleverly invented a way for mathematics to talk about itself. He imagined an enumerator that would codify every arithmetical function into a unique code number. The following will illustrate Gödel’s proof.[457]

7.4 Incompleteness

Imagine listing the code of every computer program possible in order of code length. Short programs correspond to simple tasks and are placed higher on the list. Other long programs will execute complex tasks and would be lower on the list. Many programs would amount to gibberish with no practical value, but still, they’re ordered in the list. The point is that every possible computer program, representing every mathematical function, is fully enumerated in the list and ordered by length.

Let's assume that from this list, we can collect the set of all computable programs, or functions, that takes in any positive integer "x" and outputs "$f(x)$" where the output is either a 1 or 0 (true or false). We now have a set of all computable functions (it appears complete) and for any input we can derive whether it is true or not (it appears consistent). Here is where the self-referencing comes into play.

Let's define a new function: $\overline{f}(i) = 1 - f_i(i)$, where $f_i(i)$ is simply the output from the i^{th} function in our enumerated set when we input the i^{th} positive integer. So if the first function in our ordered set were $f_1(x)$ and we input the integer x = 1, suppose the output were 0. Our new function would then equal (1 – 0) or 1. And if the fifth function in our ordered set were $f_5(x)$ and inputting x = 5 gave the output of 1, then our new function $\overline{f}(5) = 1 - f_5(5) = 1 - 1 = 0$. In other words, the new function will output the opposite value from different functions enumerated in our set, the choice of which depends on the input value.



Gödel incompleteness illustration. All computable functions are ordered in a list and we can generate a table of all possible states of all computable functions. We can recognize a particular function is a valid part of our system, but it cannot be found in our enumerated table.

Briefly, we have shown that our new function, $\overline{f}(i)$, provides a valid output of 1 or 0 (true or false), but that output cannot be found anywhere in our enumerated set of computable functions. We have created a statement which we can recognize to be valid, but it cannot be derived within the standard axioms of set theory. Not all true statements are provable in the system because we have enumerated the entire system and still cannot find the answer.

This is Gödel's First Incompleteness Theorem: Any consistent formal system *F* within which a certain amount of elementary arithmetic can be carried out is incomplete. Gödel then went further with his Second Theorem: The consistency of any consistent system *F* cannot be proved in *F* itself. Even if arithmetic were consistent, we cannot prove its consistency by the axioms that comprise it. As John Boyd explained in "Destruction and Creation":

> "Such a result does not imply that it is impossible to prove the consistency of a system. It only means that such a proof cannot be accomplished inside the system. As a matter of fact since Gödel, Gerhard Gentzen and others have shown that a consistency proof of arithmetic can be found by appealing to systems outside that arithmetic. Thus, Gödel's Proof indirectly shows that in order to determine the consistency of any new system we must construct or uncover another system beyond it. Over and over this cycle must be repeated to determine the consistency of more and more elaborate systems."

Indeed, consistency and completeness at one level of mathematics can be proved by appealing to higher levels of mathematics so long as the former is a strict subset of the latter. The reason in a nutshell is that if you have problems emanating from self-referencing statements, uncovering a more powerful system again fixes your point of reference. You cannot observe your own system from the inside. Such a problem occurs when you think about thinking. It also occurs when you take the systems analysis approach. The analyst's formal model requires talking about itself, talking about sets of technologies and missions and requirements, where each member has quantifiable attributes that can be related. In jargon, it requires second-order logic such as found in the statement "every set of requirements has an optimal technical solution" whereas first-order logic is found in the statement "every requirement has a technical solution."

It is worthy of note that Gentzen only proved the consistency and completeness of arithmetic in full for first-order logic, not second-order logic.[458] Yet systems analysts care about finding better or best decisions, not any valid decision. It requires self-referential statements as to what is best for "national security." As we observe, sometimes the answer to defense questions are found by appealing to a larger system, or national policy objectives.

Going back to Boyd, we have a concept—a formal system—that we use for decision-making. If the concept is in fact consistent and rich enough to talk about itself, then by Gödel's First Theorem it must be incomplete. If the concept is incomplete, then Boyd argues that we must expect a mismatch between concept description and real-world observations. There is no room for the unexplained fact in a domain covered by a complete theory. Boyd only applied Gödel to a person's conceptual model; it is incomplete. He was not reasoning by analogy by applying Gödel incompleteness to a person's range of action or observation.

If valid, it follows that when we interact with a larger and more powerful system, namely the universe, we will inevitably find *surprise and novelty*. This does not mean we can never completely describe all the laws of Nature; rather, we cannot predict all phenomena emanating from them in a well-defined system. In mathematics, the problem arises when statements cannot be proved from the axioms. It could be a result of Gödel incompleteness, or it could be that we have not been clever enough to derive the proof from the known axioms.

In order to test natural theories, we must understand the dynamics of elementary particles. Otherwise, our predictions would be lacking a major ingredient of causality. To test alternative conjectures and discover which ones yield accurate predictions, we must gather information on the initial conditions. This requires us to make increasingly precise observations. However, we cannot make arbitrarily precise predictions at very small scales without first refuting Heisenberg's Uncertainty Principle which, briefly, finds that information on initial conditions cannot exist regardless of the precision of our measurements. Only a statistical description of possible futures can be made. Gödel and Heisenberg imply indeterminacy is built into our mental and physical worlds.

7.5 Uncertainty

Werner Heisenberg's 1927 results have enjoyed a long history of successful replication. It has been tested across a wide range of application without contradiction. As Boyd explained, we cannot "simultaneously fix or determine precisely the velocity and position of a particle or body… Examination of Heisenberg's Principle reveals that as a mass becomes exceedingly small the uncertainty or indeterminacy, becomes exceedingly large." In other words, even if there existed an intellect "vast enough" to compute all past and future states of the universe, it could never collect the initial conditions on position and velocity for even a single particle with which to make that computation. If it wanted to know the position of a particle with arbitrary accuracy, then by Heisenberg, the intellect could no longer know the precise velocity, and vice versa. Both values are simultaneously required to make point predictions of the particle's future.

One common analogy is to consider a table of rows and columns. Finding what row a particular value is in tells us nothing about what column it is in. If we move up the table to discover the column header, we lose track of value's row. Like Heisenberg, Boyd attributed the effect to the influence of an observer. When we attempt to measure an electron by a microscope, the accuracy is limited by the wavelength of light employed. As we shorten the wavelength to more precisely determine the position of the electron, we are also increasing the energy of the light which disturbs the electron. Heisenberg described the consequences from the effect called Compton scattering:

> "At the instant of time when the position is determined, that is, at the instant when the photon is scattered by the electron, the electron undergoes a discontinuous change in momentum. This change is the greater the smaller the wavelength of the light employed, i.e., the more exact the determination of the position. At the instant at which the position of the electron is known, its momentum therefore can be known only up to magnitudes which correspond to that discontinuous change; thus, the more precisely the position is determined, the less precisely the momentum is known, and conversely."[459]

When we ask the question of position, the electron scatters and we lose the ability to simultaneously ask precise questions of velocity. Heisenberg originally suggested that the electron really has a definite position and velocity, but we run into a practical problem of measuring that fact because we disturb the system with our measurement.[460] In short, we are ignorant of reality.

Though Heisenberg later abandoned the deterministic view, it was later retained by Bohmian mechanics which found that particles have precise positions at all moments.[461] However, particle velocities (and therefore trajectories) are determined by a "pilot wave" whose value depends simultaneously on all other particles (they share a "universal wave"). Any quantum experiment in a closed system must include an observing apparatus A whose pilot wave interacts with the observed phenomena P. A bit more technically, if P were decoupled from the apparatus A, then P would be guided by a pilot wave with a definite velocity that obeys Schrödinger's linear, and therefore predictable, equation.

When we place apparatus A into P's closed system (creating the larger system A + P) particle P's pilot wave is conditional on the pilot wave of apparatus A. In other words, when we attempt to observe the particle's position, our presence influences the particle's velocity described by the pilot wave. Because our observing apparatus cannot measure itself, we cannot predict the deterministic path of the particle. In Bohmian mechanics, when we attempt to more precisely measure the position, our apparatus becomes an increasingly important part of the combined system, A + P, and affects the particle's velocity.

If we accept that Heisenberg's Principle "implicitly depends upon the indeterminate presence and influence of an observer," Boyd argued that "the magnitude of the uncertainty values represent the degree of intrusion by the observer upon the observed." We return the self-referencing problem. To measure a closed quantum system we must also measure our experimental apparatus creating a larger system, but we can never look into this larger system undisturbed from the outside.

Heisenberg himself did not subscribe to Bohmian mechanics and instead, along with Niels Bohr, founded the Copenhagen interpretation of quantum mechanics. However, in both the Copenhagen and Bohmian views invoke the observer "intruding" upon complementary aspects of the observed, thereby affecting its future.[462] Physicist Steven Weinberg commented that "As much as we would like to take a unified view of nature, we keep encountering a stubborn duality in the role of intelligent life in the universe, as both subject and student."[463]

Regardless of interpretation, uncertainty emerges and reduces any predictions one can make about future states into probabilities. The more precisely we want to measure a particle's position, the less we can know about its velocity. Without both values, we cannot precisely predict the particle's future which would otherwise be fully determined by Schrödinger's equation. One example where we only have statistical knowledge is radioactive decay. If we have 20 grams of a radioactive element and the half-life is one year, then we can predict that 10 grams will decay the first year and 5 grams will decay in the next. However, we cannot say whether an individual atom will decay or not; in the example it has a 50% likelihood in each year.[464] Indeed, the randomness is genuine for radioactive decay in the sense that information about it cannot be compressed.[465]

Uncertainty implies randomness in physics, which is axiomatic in the Copenhagen view and a result of our ignorance in the Bohmian.[466] Still, a probabilistic (as opposed to deterministic) view of quantum objects has proven highly accurate and useful for describing ensemble behavior. This break between our uncertain descriptions at the individual level and our accurate pattern predictions at the ensemble level is significant. Humans are indeed ensembles of quantum objects, where uncertainty is either minimal or averaged out. It is precisely when we are not observing and intruding at the individual level that quantum objects act predictably at the statistical level.

The act of observation creates uncertainty in our description at the individual level and prevents us from evaluating the match-up between our concept and reality. We cannot predict which atom will decay at a given rate, or which photon will reflect at a given angle, but we can predict what proportion of atoms will have decayed and what proportion of photons will have reflected. Boyd concludes his section on Heisenberg by remarking on the self-referentiality of the quantum situation:

> "When intrusion is total (that is, when the intended distinction between observer and observed essentially disappears), the uncertainty values indicate erratic behavior. When intrusion is low the uncertainty values do not hide or mask observed phenomena behavior, nor indicate significant erratic behavior. In other words, the uncertainty values not only represent the degree of intrusion by the observer upon the observed but also the degree of confusion and disorder perceived by that observer."

7.6 Entropy

Boyd related the confusion and disorder perceived by the observer when making point predictions to entropy and the Second Law of Thermodynamics. Entropy is a unique aspect of natural law because it points to an "arrow of time."[467] By contrast, all physical descriptions are time-reversible in the quantum, classical, and relativistic theories. In other words, the equations work the same way forwards into the future as they do backwards into the past. Time-reversible theories leave no room for confusion. We can calculate all past and future states of the system.

Entropy, on the other hand, is an irreversible process. Unlike quantum mechanics or relativity, entropy corresponds with many of the experiences we have in our daily lives. For example, when we add milk to coffee it evenly mixes and never spontaneously separates. In this case and many others we can see an irreversible process where the past is fundamentally different than the future; a closed system goes from a well-ordered state to a disorganized, messy state. For another example, when we boil water, we are putting energy into the system and it gains potential for doing work (like cooking pasta or generating steam for turbines). The tumultuous boiling of the water may appear disorganized, but it is really generating complex order in the form of convection. If we leave the system alone, the water disperses heat into its environment, not the other way. We never expect water at room-temperature to spontaneously draw in heat from the air and start boiling.

Closed systems evolve irreversibly from an ordered state towards disorder; from a state with capacity for doing work to one where work cannot be drawn out of it without putting energy in.[468] Closed systems always evolve towards higher entropy, like our disorienting attempt to more precisely match consistent—but necessarily incomplete—concept descriptions with real-world observations.

The confusion and disorder caused by Heisenberg's Uncertainty Principle is indeed related to entropy.[469] Both our descriptions of quantum systems and entropy are necessarily statistical. A closed system of particles moving about has many more ways to find itself disordered than ordered. From this, we may expect our world to inevitably move towards more disorder and lifelessness, but that is not what we observe. Indeed, the Earth continuously draws in energy from the Sun which animates the weather and brings organic life to ecosystems.

Boyd recognized that the only way to overcome entropy—to generate negative entropy—is to import order from another system that is larger and better organized. Boyd reasoned that "From this law it follows that entropy must increase in any closed system—or, for that matter, any system that cannot communicate in an ordered fashion with some other systems or environments external to itself." For Boyd's system of building concepts and matching them to reality, this means importing order from a stronger concept that can make sense of unexplained facts. We cannot work within one static objective view of reality. Boyd put it all together:

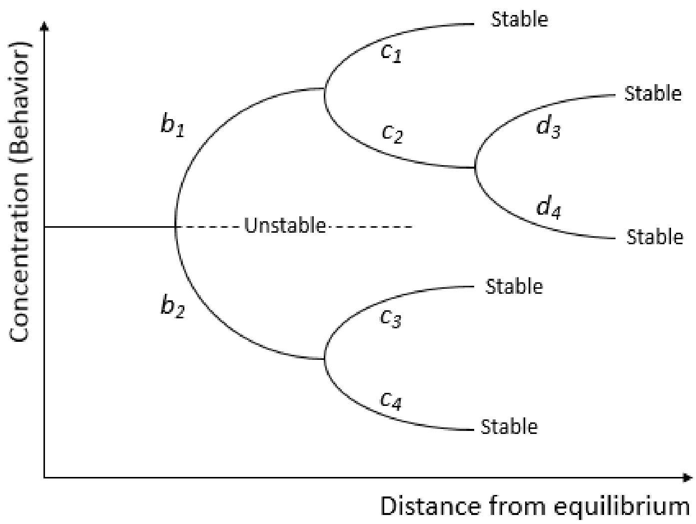
> "What an interesting result! According to Gödel we cannot—in general—determine the consistency, hence the character or nature, of an abstract system within itself. According to Heisenberg and the Second Law of Thermodynamics any attempt to do so in the real world will expose uncertainty and generate disorder. Taken together, these three notions support the idea that any inward-oriented and continued effort to improve the match-up of concept with observed reality will only increase the degree of mismatch."

Boyd viewed the increasing disorder within a closed system as a control mechanism that excites us into creatively building new and more powerful concepts. The cycle endlessly drives towards ever more complex concepts and actions. For Boyd, the human mind effectively combats an increase in entropy. Though Boyd stopped here in "Destruction and Creation," he continued to expand his ideas over the next two decades to better describe negative entropy systems. He later wrote how "Living systems are open systems; closed systems are non-living systems."[470]

As an open system, the human mind creates new concepts and negative entropy. Julian Simon later recognized how the human mind is the *ultimate resource*.[471] Yet the physical brain is itself a highly ordered system, the product of evolution. Concept building, as an output of the brain, must result from completely natural processes of negative entropy. The human mind is also part of the human body, which continually draws energy from the environment and disperses entropy back into the environment.

Erwin Schrödinger found that all life feeds on negative entropy.[472] Living systems do not violate the Second Law of Thermodynamics because even though they generate pockets of negative entropy, they export more entropy into the environment consistent with an increase in the overall entropy. Negative entropy systems openly interact with their environment but remain self-bounded and self-perpetuating.[473] The process of generating complex order in the natural world was pioneered by Ilya Prigogine who developed a theory of dissipative structures.

Entropy has generally been associated with waste in an otherwise reversible process. For example, the entropy associated with friction causes a pendulum's swinging motion to stop. Prigogine, however, showed that open systems can generate negative entropy, and indeed self-organization, when two conditions prevail.



When a nonlinear system moves far from equilibrium, resonances create bifurcations where new stable states of increasing complexity emerge. As distance from equilibrium increases, bifurcations become increasingly frequent. Reproduced figure from Prigogine, The End of Certainty.

First The ordering process of negative entropy can occur when large amounts of energy or matter flow through a system. The system gains order at the expense of its environment, in which overall entropy increases. Second Circular feedback loops, where the system's inputs reference its own outputs, sparks sudden bifurcations which keep the system coherent and stable. The bifurcations create a place for irreversibility and the arrow of time. Feedback mechanisms lead to nonlinear effects, allowing systems to self-organize when far from equilibrium.[474]

7.7 Nonlinear dynamics

We will dive just a bit deeper into the nature of bifurcations, and how they make nonlinear systems unpredictable, before reemerging to contrast the ideas of self-organization with the ideas of predictable control from the logical positivists.

Linearity allows us to predict the long-term future and past because we do not encounter bifurcations where the system chooses among valid states. Linear systems and reversible processes tend to be idealizations, such as the frictionless pendulum. By contrast, nonlinear systems have several stable states. When a nonlinear system reaches a bifurcation point, we reach an irreversible process where the choice of state can only be described statistically.

The real world regularly exhibits nonlinearity. One crucial aspect of nonlinear systems is that in most cases, they cannot be solved for.[475] This was discovered by polymaths Jules-Henri Poincaré, who found that long-term predictions cannot be made, even in fully deterministic systems, so long as nonlinearities prevail. Poincaré took Newton's famous equation for gravity and confirmed that indeed, the long-term future of a two-bodied system can be fully predicted with arbitrary accuracy using Newton's equations. However, when the influence of a third body is introduced, the system is no longer stable in most cases and long-term predictions cannot be made. The system becomes chaotic. Many futures are possible. Similarly, you cannot unwind the system back into its history, several histories could have resulted in the present state of the system.[476]

Closed form solutions require integrability for all system states. Yet resonance can lead to unbounded motion—infinities in phase space—making them non-integrable. We cannot predict

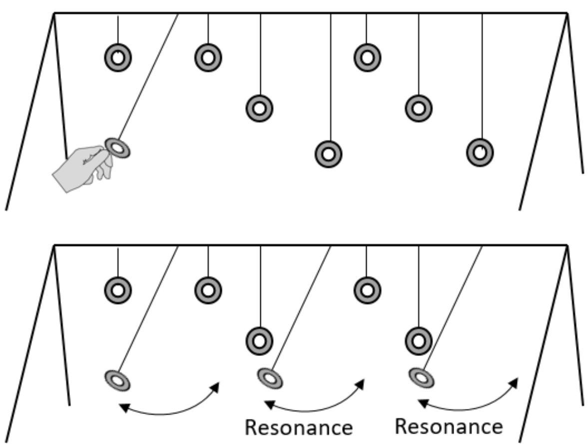


Illustration of resonance and nonlocality. Suppose we hang weights at varying lengths from a common string. If we pull one of the weights and let it act as a pendulum, the other weights of the same length (corresponding to a particular frequency) will start swinging in sympathy. Other weights whose string length is a rational multiple will also resonate, but not as strongly as the 1:1 case of same length. The system to the left has eight weights, and therefore has eight degrees of freedom, or eight directions of independent motion.

future or past states of systems when they encounter resonance. As time continues, one of our three erratic bodies will be ejected from the system due to resonance. We are left with a stable two-body system, and from this stable system we could not determine that its previous state had included three bodies. We arrive at an irreversible process. The resonant feature of dynamical systems is what makes them non-integrable and thus defines them as nonlinear. In short, resonance introduces outsized reactions and uncertainty to an otherwise deterministic system.[477]

By now we have fully dismantled the reductionist view of logical positivism. Gödel proved that any logical system consistent with the real world is incomplete. There will be phenomena we cannot explain, or predict, using a unified system. When we try to ascertain whether any particular unpredictable fact is due to our ignorance rather than Gödel incompleteness, we run into Heisenberg's Uncertainty Principle. We are limited in the precision with which we can gather the positions and velocities necessary to make predictions at the individual level. We can only make statistical predictions.

Quite separately from Heisenberg uncertainty, we have nonlinear systems in which we cannot make point predictions, *even when we know initial conditions with infinite precision*. Resonance leads to the non-integrability of most real-world systems because it destroys trajectory descriptions and by doing so, it introduces irreversible processes associated with entropy. When more energy flows through a nonlinear system, moving it further away from equilibrium, resonances cause increasingly frequent bifurcations.

Bifurcations in nature can be interpreted as a manifestation of the system's effort to maintain itself, moving it towards new behaviors to export entropy at ever faster rates. From bifurcations we get turbulence, oscillating chemical reactions, and the seeds of life. Consider one example relevant to defense decision-making. Turbulence is onset by resonance and bifurcations rather than a steady build-up of competing frequencies. Knowledge gained about turbulence is special, not universal. Information on the turbulence forming around the wing of a Boeing 707 has no relevance for an F-16 fighter.

If the three-body problem is worse than hard, then real systems on the order of 10^{23} particles are impossible. They require trial-and-error rather than prediction, regardless of computer power. Richard Feynman wondered "Why should it take an infinite amount of logic to figure out what one tiny piece of space/time is going to do?"[478] Though the future cannot be fully predicted, we know that when matter is moved far from equilibrium it takes on new statistical properties. It can move towards higher states of negative entropy. We may now speak of self-organizing behaviors that adapt to the environment.

7.8 Complex adaptive systems

While working on "Destruction and Creation" in 1976, John Boyd did not know how the revolution in complexity would unfold. Ilya Prigogine's work on dissipative structures hadn't yet earned him a Nobel Prize. The Sante Fe Institute for complexity studies had not yet been founded. Despite evidence to the contrary, most scientists still viewed biological organization as the outcome of central direction rather than the unintended result of collective phenomena. Thinking had it that "founder" cells directed other cellular functions. Similarly, the queen ant was still thought to direct the many detailed activities of the ant colony.

Across many disciplines, discoveries slowly chipped away at the core of the reductionist view represented by logical positivism. Systems cannot be fully understood through analysis. The future cannot be precisely predicted. Equilibrium conditions in linear systems are not of interest in the real world. John Boyd grasped from early on the importance of negative entropy systems, those that learn and adapt to a changing environment, and followed the scientific developments around the idea. These ideas coalesced around complex adaptive systems theory, which found forerunners in Norbert Wiener and Ludwig Bertalanffy. It has no relation whatsoever to the RAND method of systems analysis. Boyd continued to draw from a wide range of complexity studies until his death in 1996, as Frans Osinga thoroughly documented in *Science, Strategy, and War: The Strategic Theory of John Boyd*.

Though "complex adaptive systems" has become an umbrella term for a diverse range of research, we can briefly introduce it by contrasting it to so-called complicated systems. Complicated systems are generally man-made objects like tanks, airplanes, and satellites. They are made up of many parts, each of which may follow a complicated set of rules. If we study the characteristics of each part, we can fully describe the system. We can predict precisely how the complicated system will act under most circumstances.

An important aspect to complicated systems is that their functioning abruptly stops when we remove random parts. The lesson was hard learned after the failure of a single component caused the space shuttle Challenger to crash in 1986. While complicated systems are fragile and at best robust to shocks, they can still adapt. For example, the fly-by-wire system on the F-16 makes instantaneous adjustments to stabilize the aircraft. However, complicated systems are only adaptive to the extent that the range of possible environments and responses are enumerated. They cannot adapt to unforeseen circumstances.

By contrast, complex adaptive systems are generally natural objects like the brain, ant colonies, and social networks. They are made up of many relatively simple parts working in parallel whose nonlinear interactions create novel system behaviors. Studying individual parts cannot provide us an understanding of complex system behaviors.

When random parts are removed from complex systems they continue to function. Performance degrades slowly as more and more parts are removed because of redundant causal pathways, allowing for adaptation to new or unforeseen environments. Complex systems are not only robust to external shocks—or far from equilibrium conditions—but can benefit from those shocks. Internal feedback loops create novel behaviors required for complex systems to maintain themselves under unexpected conditions. Such environmental perturbations would quickly destroy a complicated system.

Matters of self-reference have been highlighted because of its asymmetric role in deductive and inductive systems. For deductive systems, self-referential feedback creates destructive limitations shown in the Russell paradox and Gödel incompleteness, elaborated on by Alan Turing with his halting problem for computing. Attempts to apply a consistent logical system to the real-world also encounter problems of prediction and measurement. Initial conditions cannot be known with infinite precision due in one way or another to the self-referential presence of an observer. We need multiple frames of references, or mental models, simultaneously.[479] To avoid increasing disorientation, the observer must remain satisfied with statistical descriptions.

For inductive systems, on the other hand, the "observer" is part of the system rather than distinct from the system. The observer cannot isolate the subject from their shared context to gain a controlled understanding of its function. All the system's parts act and react to one-another and the environment through resonant phenomena. Resonance is a form of feedback which creates nonlinearities and irreversible processes that can only be described statistically. As the system moves further from equilibrium, bifurcations are points where the system either evolves or dies. Feedback loops allow simple elements of matter to effectively coordinate by reacting to their neighbors rather than "waiting on orders from above."[480] Here, we see the creativity of bottom-up inductive processes.

Feedback loops play an important role in the self-organization of complex systems. Positive feedback, like resonance, propels the system forward. It is an essential attribute of Prigogine's concept for dissipative structures, providing context for bifurcations. Outputs are routed to inputs, creating an iterative and self-reinforcing process.

Feedback loops act along three general channels. First, as already discussed, outputs are routed to inputs in an iterative loop represented by exponential functions. Second, the macro-scale affects the micro-scale in a process called downward causation. Here, we recognize that systems are hierarchical. They have "integrative levels" such as a society being composed of people. In fact the word "society" has no meaning for a person in isolation. Integrative levels continue from people to organs, then tissues to cells, and so forth.

Reductionist accounts see only upward causality, that all system behaviors can be described by attributes of the most basic parts. A holistic view finds that higher levels of the system affect, and are affected by, lower level constituents. For example, societies constrain the actions and attitudes of the people as much as people contribute to societal behaviors. Similarly, the atomic structure downwardly affects the valence conditions of its electrons.

A third channel of feedback is backward causation, where considerations about the future affect the present. Backward causation is most apparent in markets, where future expectations become embedded in today's price. The result may be the herd behavior of market bubbles and crashes, or the regulating behavior of arbitrage and entrepreneurship. The system effect from each of the three feedback channels is nonlinear. Outputs are not proportional to inputs.

Numerous feedback loops between decentralized parts help complex adaptive systems build resilience to environmental perturbations. The importance of feedback loops was recognized by Norbert Wiener and W. Ross Ashby in the study of cybernetics. As Wiener's 1948 book explained, cybernetics is the science of control and communication in the animal and the machine.[481] Ashby argued that the internal regulation must have a requisite variety of mechanisms to deal with an environment characterized by continual flow and change.[482] As environmental challenges grow, the system needs to achieve a larger number of stable states to cope. Such variety requires a large the number of parts and numerous paths of communication.

Naturally, with resilience comes inefficiencies associated with the maintenance of spare parts and idle feedback loops. These were precisely the critiques levied by efficiency experts. Yet what they neglect is the necessity of seemingly inefficient duplication. As Nassim Taleb claimed, "Redundancy *equals* insurance… The organism with the largest number of secondary uses is the one that will gain the most from environmental randomness and epistemic opacity!"[483]

7.9 Emergence

Nearly all complex organizations in the nature have foundations in relatively simple and decentralized elements, but due to their nonlinear interactions, create stable emergent patterns. They build up from the bottom, shaped by continuous environmental feedback. The fact is equally true for economic marketplaces, which result from human action but not from human *design*.

For a system to generate complexity, the parts must coordinate in a way that is beyond the information available to any individual part. Biological cells specialize based on what their neighbors are doing, but they end up with a functioning organism. A single ant could never assess the global situation of its colony, but by following the pheromones of its neighbors the colony thrives in a coordinated way. No single model can direct a nation's resources to their most highly valued use, economic progress results from many individuals making separate plans and coordinating after-the-fact using the price mechanism.

The theme is that systems generate complexity when relatively simple parts coordinate using local information only. They do not have order imposed on them independent of emergent properties. Perhaps unintuitively, simple systems give rise to complex behavior whereas complex systems give rise to simple behavior.[484] This is because nonlinearities create emergent properties that cannot be predicted. On the other hand, predictability of response is often desirable for complicated systems like tanks, airplanes, and satellites. We might not want to negotiate and train with an airplane as it learns its environment just yet. We can identify and program most airspace conditions.

That being said, information on *future* technologies and environments cannot be held in one place, it is dispersed across all the people and institutions that engage in the larger economic process. We should almost certainly want our larger system of technology development, production, sustainment, and disposal to exhibit complex adaptive behaviors associated with bottom-up processes. The defense acquisition system is an abstract order unlike the tanks, airplanes, and satellites that emerge from its functioning. Researchers C.K. Biebracher, G. Nicolis, and P. Schuster summarized the viewpoint:

> "The maintenance of organization in nature is not—and cannot be—achieved by central management; order can only be maintained by self-organization. Self-organizing systems allow adaptation to the prevailing environment… We want to point out the superiority of self-

organizing systems over conventional human technology which carefully avoids complexity and hierarchically manages nearly all technical processes."[485]

The purpose of this chapter has been to explain how complex order in the real world emerges from simple and iterative systems of nonlinear interactions. The umbrella term of complex adaptive systems is used to describe self-organizing systems of emergent order that adapt to an uncertain environment. While these properties are not in general desirable for weapon systems that humans use in the field, they are certainly desirable properties for the defense acquisition system as much as they are for market economies.

Sustained technological progress cannot occur outside of a complex adaptive system. An analysis of quantitative natural laws cannot provide perfect foresight as to proper technological arrangements. No definite procedure can adapt to the unforeseen events bound to happen in the real world. Adaptation requires a different process of creativity and surprise resulting in new information.

The core concepts of complex adaptive systems were integrated into John Boyd's theories of human organization, leading him away from attrition warfare epitomized in World War I towards an idea of irregular maneuver warfare. Boyd found many predecessors of this form of thinking, from Sun-Tzu to Clausewitz and Liddell Hart. Strategic thinkers like Hans Delbruck and J.C. Wylie also investigated maneuver warfare. These philosophical trends toward thinking in terms of unpredictable, nonlinear systems coalesced into military doctrine in 1989 when Captain John Schmitt finished the capstone doctrinal publication for the U.S. Marines titled *Warfighting*. For example, Schmitt wrote how

"The very nature of war makes certainty impossible; all actions in war will be based on incomplete, inaccurate, or even contradictory information… While past battlefields could be described by linear formations and uninterrupted linear fronts, we cannot think of today's battlefield in linear terms… As a result, war is not governed by the actions or decisions of a single individual in any one place but emerges from the collective behavior of all the individual parts in the system interacting locally in response to local conditions and incomplete information.

"A military action is not the monolithic execution of a single decision by a single entity but necessarily involves near-countless independent but interrelated decisions and actions being taken simultaneously throughout the organization. Efforts to fully centralize military

> operations and to exert complete control by a single decisionmaker are inconsistent with the intrinsically complex and distributed nature of war."[486]

While complexity theories have penetrated the philosophy of military operations, attempts to translate the ideas into acquisition policy have been few. Like combat, the development and deployment of technologies is an inherently uncertain and nonlinear process. Central direction by one or a small set of individual minds cannot generate the enormous complexity required for constant progress. The lesson was dramatically learned with the failure of socialist economies the world over. While apologists continue to dream of computing machines that will prevail over the seemingly chaotic and redundant coordination of the market economy, the impossibility of such a dream appears to be deeply built into the structure of our universe. The only realistic way to generate a system that exhibits complex behaviors beyond the foresight of any individual is to build from the bottom-up according to simple rules. Tacit coordination based on local conditions can then give rise to emergent order, a process not appreciated by advocates of top-down planning.

Attributes of Complex Adaptive Systems

- *Self-organization*—Process where many local interactions create order without direction from above.
- *Feedback loop*—A circular process in which the system's output is returned or "fed back" to the system as input.
- *Nonlinearity*—Many possible responses are possible to a stimulus, and the cause and effect relationship is not evident.
- *Chaotic behavior*—Small changes in initial conditions can generate large changes in the outcome.
- *Stochastic*—Governed by chance. The behavior of a complex adaptive system can be inherently stochastic as elements of the system, the agents, can have randomness in their movement, and thus, in their interactions.
- *Attractors*—Catalysts that allow new behaviors to occur.
- *Inherent order*—Broad and complex outcomes resulting from local application of simple rules.
- *Emergent behavior*—New behavior represented by constant innovation and creativity
- *Context and embeddedness*—Systems reside within, and interacts with, other systems that influence it.
- *Porous boundaries*—Boundaries of the elements are blurry, allowing exchange and movement between them.
- *Co-evolution*—Progress occurs with constant tension and balance.

Adapted from Chaffee, Mary W and Margaret M McNeill. "A model of nursing as a complex adaptive system." Nursing Outlook 55 5 (2007): 232-241.

8. Competition

> When one competitor undercuts the price of a rival; when one consumer buys the last retail item in stock before another consumer gets there; when one inventor beats another to the punch on a profitable innovation—that is economic rivalry… In short, some plans are necessarily disappointed by the carrying out of rival plans by others.
>
> Don Lavoie,
>
> *Rivalry and Central Planning*, 1985

Robert McNamara’s most important management tool escaped the 1969-1971 reforms. As the conduit to Congressional appropriations, the Planning-Programming-Budgeting System continued to coordinate defense activities. Competing perspectives were suppressed in favor of a single favored position. The unified defense plan presented industry with a coordinated collection of single buyers. In other words, industry faced a monopsony across defense commodities. Representing the only game in town, firms competed less on delivering useful systems to the government and more on brochuresmanship in order to secure the flow of funds. After all was said and done, the end product had no competitor to compare it to in order to judge the efficiency of decisions actually made.

Competition not only regulates incentives by prospect of punishment and reward. Just as importantly, the competitive process solves critical problems of knowledge. In fact, competition is most important under the presence of uncertainty. Planners cannot know what is optimal outside the process in which alternative courses of action are developed, brought into competition, and evaluated. Friedrich Hayek described how "In sporting events, examinations, the awarding of government contracts, or the bestowal of prizes for poems, not to mention science, it would be patently absurd to sponsor a contest if we knew in advance who the winner would be."[487] The information on which sports team performs better, or which project plan provides the most value, is only discovered in the process of competition. Otherwise, the rivalry is wasteful if one could reliably pre-determine the winner.

Dynamic competition results in the emergence of complex patterns of economic behavior, and consequently, technological growth. It is very different from the type of competition taught in economic textbooks or practiced in defense management. In economics, we are told about "perfect" competition, a concept which relies on bizarre assumptions of complete information and product homogeneity. In defense, we are told that contracts are awarded "competitively," even when solutions are pre-specified and the contractors who buy-in get bailed-out.

While officials in the Department of Defense have often talked about the benefits of competition, the policies they've pursued continually run counter to the one real condition necessary for competitive forces to occur: free entry. Contrary to traditional wisdom, the history of defense acquisition has shown that the advertisement and open bid process does not provide assurance of free entry. When government is the only buyer, free entry requires an organization designed for pluralism.

8.1 Reappraisal

Before James Schlesinger finished the economics program at Harvard in 1956, he had already lined up a teaching job at the University of Virginia. Just as Schlesinger moved down to Charlottesville, the university began assembling a unique blend of economists including G. Warren Nutter, James Buchanan, Gordon Tullock, and Ronald Coase. While most economic departments focused on mathematical approaches to finding the equilibrium, the UVA economists applied their field to law, constitution, and public administration.

Schlesinger found himself immersed in the dynamic environment of what became called the Virginia School of political-economy. Quite separate from the other professors, however, Schlesinger's thoughts revolved around the Department of Defense. He recalled how a brief exchange at the Naval War College "crystallized" the connection in his mind between economic analysis and defense. It inspired him to write a book, *The Political Economy of National Security*. As the title suggested, it attempted to apply ideas from the Virginia School to defense problems.

Schlesinger's first book was released early in 1960. Surprisingly, there weren't many books published about the economics of defense at the time. Although his book was poised to generate attention, the timing proved unfortunate. The estimable Charles Hitch and Roland McKean had also been working on their classic, *The Economics of Defense in the Nuclear Age*. They went to publication just weeks after Schlesinger. Compared to Schlesinger, a defense outsider, Hitch and McKean occupied a formidable location at RAND from which to market their book. The advantage did not stop their collaborator from releasing negative advertisement about Schlesinger.

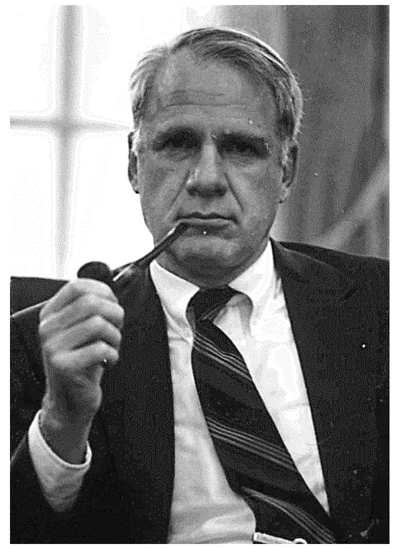
Racing to get published in what seemed like the first available place, a review of Schlesinger appeared in the April 15 issue of *Science*. It was penned by Stephen Enke. He was the third economists hired by RAND, and in 1953 he founded their Logistics Department. Though his name did not appear on the title, he contributed a full chapter to Hitch and McKean's book. Enke was also an eminent university professor, so his judgment on the 31 year old Schlesinger weighed heavily. Enke wrote of the book,

> "This one is written by a professional economist for laymen… Some of the chapters seem rather disjointed. And the treatment of the various subjects is definitely uneven in quality and originality."

His harshest criticism, however, was saved for the "question of economic efficiency." Enke summarily dismissed Schlesinger's discussion. It covered "too small a portion of the problem to be useful." He then went on to set Schlesinger straight about the nature of the problem conveyed by Hitch and McKean. The only points on which he could praise the young Schlesinger were those irrelevant to defense planning.[488]

It took Schlesinger more than a year to gather a response. By that time, the basic Planning-Programming-Budgeting System laid out by Hitch and McKean had been adopted in the Department of Defense. Hitch himself became ASD Comptroller, and his reforms were in full-swing. In the meantime, Schlesinger took Enke's criticisms to heart. He focused on the issues presented by systems analysis and program budgeting.

It a mostly laudatory review of Hitch and McKean's book, Schlesinger inserted a negative comment. He attacked the "most novel aspect" of the book: systematic quantitative analysis. He distinguished between low-level problems, such as the length of an aircraft runway, from high-level problems, such as whether to devote additional resources to missiles or anti-submarine warfare. Schlesinger found that only low-level problems are amenable to quantitative analysis. For high-level problems, they "would fail to handle the complexities of choosing a strategy. The reasons for this," he continued, "are the existence of uncertainty and the impossibility of comparing incommensurables."[489]



James Schlesinger was Secretary of Defense between 1973 and 1975. In the picture, Schlesinger is holding a tobacco pipe, as was characteristic of him.

By 1961, Schlesinger's review had a more receptive audience at RAND. After Charles Hitch left his position as chief of the economics division, Burton H. Klein took it over. Klein carried forward the ideas of evolution and competitive developments after the departure of Armen Alchian. The two remained close collaborators for many years to come with Alchian working just a few miles away at the UCLA campus. Klein's leadership of the economics department marked a new era at RAND. Even members of the old guard, such as Roland McKean, moved closer into alignment with Klein after witnessing the centralizing effects of the PPBS under McNamara.[490]

In 1963, Schlesinger moved across the country to join the economics department at RAND.[491] Schlesinger brought with him valuable concepts from the Virginia School on the role of bureaucratic incentives and political bargaining. Under Klein's approving watch, Roland McKean began cultivating Schlesinger's arguments on the PPBS. Within a year, the two married their ideas in a paper called "Defense Planning and Budgeting: The Issue of Centralized Control."[492]

8.2 Suppression of dissent

In 1963, Burton Klein became a special adviser to Secretary of Defense Robert McNamara. With Charles Hitch and others deeply immersed implementing the PPBS reforms, some complaints from the services were starting to pop up. In order to anticipate the implications of the PPBS, Klein tasked McKean and Schlesinger with a study.[493] They in turn concluded that the expected challenges wouldn't arise due to the PPB System itself, but due to the centralization of decisions that seemed to accompany it.

McKean and Schlesinger did not deny that centralization brought some improvements. It better coordinated interrelated decisions requiring large expenditures. Yet with uncertainty, the cost of communication increases. Centralized decision processes are forced to simplify a wide array of information. The bottleneck generates a smaller number of increasingly important decisions. The result is a neglect of alternative solutions and the full range of costs. As McKean and Schlesinger wrote of analyses performed under uncertainty:

> "They are perhaps especially prone to ignore certain costs… probably because these costs are so hard to measure. If such costs are neglected, people are in effect insisting that performance be improved or efficiency increased—no matter what the cost!"

Without considering the full costs and gains of a decision born by all its participants, quantitative analyses could lead to gross inefficiencies in the name of efficiency. Indeed, centralization avoids the indecision of political bargaining precisely by neglecting costs that may fall on others. The authors pointed to numerous studies that found centralization permits faster decisions "through the suppression of disagreement and of deviant expressions of opinion."[494] With their distance from critics, top management may then generate an echo chamber of bias. Heightened uniformity often leads to over-confidence, which causes leveraged decisions rather than hedging. As the quality of thinking deteriorates, those at the top become more sensitive to challenges to approved plans, leading to further suppression of dissent and greater uniformity. Deviant opinions, however, may reflect a more accurate view of reality if uncertainty is high. As Roland McKean summarized elsewhere:

> "With centralization, one set of views plays a greater role in decision-making, and dissenting views play lesser roles. In other words, there are fewer checks and balances on the view of the central group. And if central managers try to control in much detail, they find it imperative to simplify decision-making and to make changing the program rather difficult. Finally, lower level incentives to dissent and criticize and urge changes may diminish if such activities begin to be unrewarding. All these forces can, in the long run, produce disadvantages: (1) the suppression of alternatives; (2) a neglect of part of the costs and gains from alternative policies; and (3) a neglect of uncertainties.
>
> "One group's view of the future will be less diversified than the separate judgments of a multiplicity of groups. Dominance of one group will tend to discard tradeoffs and options that

> others may take seriously, to treat certain costs and gains more lightly than others would, and to regard a particular subset of contingencies and uncertainties as being the major ones."[495]

The RAND analysts emphasized how decentralization had the best effects in R&D. Almost as if they were quoting Armen Alchian, they wrote how "Diversity in weapon systems provides a hedge against uncertainty." However, McNamara's centralization of the Pentagon had concentrated decisions on fewer systems, each of which was expected to perform numerous missions. Pointing to the TFX aircraft (later the F-111), they wondered whether "uni-weaponism" had gone too far. Stated differently, was the Pentagon putting too many eggs in one basket?

What McKean and Schlesinger added to the debate was linking weapons diversity to the social process of bargaining. They feared the views of one group prevailing without adequate checks and balances. These ideas were influenced by Charles Lindblom, who in the 1950s had been advocating incremental decisions and political bargaining. In his 1955 paper "Bargaining: the Hidden Hand in Government," Lindblom likened the bargaining mechanism in the public sector to the price mechanism in the market economy. They both serve the same role of imparting a fuller range of costs and gains into decision-making. "Politics is not an art or science pursued by philosopher-kings who find the public interest in the sky," Lindblom argued, "but is a craft practiced by negotiators who know that the public interest can never be anything else but the common goals of different people."[496]

Michael Polanyi made similar arguments in the context of science. In his 1962 classic, "The Republic of Science," he argued that "the community of scientists is organized in a way which resembles certain features of a body politic and works according to economic principles… [Authority] is established *between* scientists, not above them." For Polanyi, science has no single authority. Instead, joint opinion is reached when each scientist has overlapping knowledge with other scientists, "so that the whole of science will be covered by chains and networks of overlapping neighbourhoods." From the competing judgments interwoven in the network emerges a consensus. Polanyi concluded that "any authority which would undertake to direct the work of the scientist centrally would bring the progress of science virtually to a standstill."[497]

Irving Janis later popularized the problems arising from too little dissent with the term "groupthink" in the early 1970s. He focused on foreign policy disasters such as Pearl Harbor, the Bay of Pigs, and the Vietnam War. In each case, he found that the suppression of contradictory views led disaster.[498] Janis explained how groupthink occurred when people engaged in "concurrence-seeking," which can become so dominant for a cohesive in-group that it overrides a realistic appraisal of alternative courses of action.[499] Janis summarized two symptoms of groupthink. First, an overestimation of the group leading to illusions of invulnerability and heightened sense of morality. Second, groupthink leads to closed-mindedness. It causes self-censorship, stereotyped outgroups, and stifled dissenters, all leading to the illusion of unanimity.

For weapon systems acquisition, McKean and Schlesinger pointed to the effects of what later became called groupthink. Reduced exploration of alternatives, neglected costs, and over-confidence all led to a bias for "safe" proposals. At the extreme, only well-understood ideas could be justified and explored. Yet for McKean and Schlesinger, "safe" proposals were anything but safe. They led to highly "unsafe" gambles if neglected contingencies materialized. Safe proposals looked to avoid uncertainty rather than *resolve it*.[500] As scientist Hans Selye understood:

> "… the more manifestly sensible and practical a research project, the closer it is to the commonplace we already know. Thus, paradoxically, knowledge about seemingly most far-fetched impractical phenomena may prove the likeliest to yield novel basic information, and lead us to new heights of discovery."[501]

The problem Selye alluded to is that "safe" proposals all work from the same base of articulated knowledge. It conforms to expectations of where technology should go based on where it has been. While the process provides a basis for setting cost and schedule targets, it also limits the discovery of new information. It could even push systems into inferior equilibria by neglecting conjecture based on unarticulated knowledge. The history of innovation has proven that the most important advances required leaps into the unknown, where no group of reasonable people could agree on the expected outcome. As Boeing Vice President George Schairer said:

> "Anything that the majority agrees to probably is wrong for tomorrow. It is right for today, but probably not right for tomorrow. I wonder about such wild ideas as you would ever fly an airplane with a jet engine or have an atomic bomb or radar, or many of the great things we base our defense upon. At the time they were initiated, certainly any group of 10 people you could have get together, presumably knowledgeable, would probably have voted them all down."[502]

For McKean and Schlesinger, the problems presented by centralization—the neglect of alternatives, costs, and uncertainties—were independent of the Planning-Programming-Budgeting System. RAND analyst Melvin Anshen agreed that "the program budget is a neutral tool. It has no politics."[503] Several others concurred, and some even went further. James Farmer, for example, suggested that the PPBS permitted greater decentralization.[504]

For Aaron Wildavsky, on the other hand, changes to the budget meant a change in politics. He stressed how the PPBS was inherently centralizing.[505] Similarly, Allen Schick documented how centralized control motivated the rise of the program budget in the early twentieth century. "PPB reverses the informational and decisional flow. Before the call for estimates is issued, top policy has to be made."[506]

The different views of whether the PPBS leads to centralization can be traced to the role of multi-year costing. For Allen Schick (as well as Charles Hitch), the essence of the program budgeting was to calculate the full cost of outputs in order to facilitate tradeoffs and control. "The environment of choice under traditional circumstances is *incremental*; in PPB it is *teletic*." In other words, in the PPBS, outcomes can be costed in full and implemented as planned without "zigzags or breaks."[507]

For McKean and Schlesinger, however, the PPBS could support incremental decisions at the lower levels. They criticized instead the Pentagon's Blue Book, which held approved financial plans for five years and force structure plans for eight years. It led to major arguments in 1963, for example, over the force level of the Minuteman program in 1969. "But why should such a controversy be permitted to develop in the first place?" They pointed to a culture that resisted changes to plans once specified. They complained how "Frequent changes of mind make one look like either an oaf or a troublemaker." With the Blue Book, managers presumed that the future was fixed. As a partial remedy, McKean and Schlesinger recommended providing "untrammeled funds for R&D" to the lower levels, and keeping parts of the budget "To be scheduled."[508]

8.3 Layered decisions

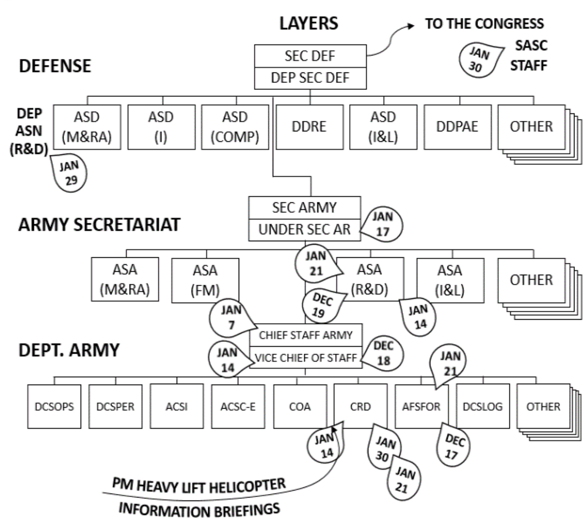
Schlesinger's foray into the world of defense management proved a boon to his career. When Congressional backlash to the PPBS started in 1967, Schlesinger was sought out by Congress to provide an assessment. In 1969, he left RAND to become assistant director of the Bureau of the Budget. Then he went onto chair the Atomic Energy Commission and after a short stint as director of the CIA, he landed a spot as Secretary of Defense on July 2, 1973.

Schlesinger had never worked in the Department of Defense before, only on the margins. Like others, he found Laird's reforms fundamentally sound. Implementation of his predecessor's policies, however, left much to be desired. He found a like-mind in the new Undersecretary of the

Army, Herman Staudt. In discussions with Staudt and Army Chief of Staff Creighton Abrams, it became apparent to Schlesinger that the Army staff was bloated due to OSD involvement in weapon systems. He gave the Army his blessing to form a committee to study problems in the defense acquisition process. The Army Materiel Acquisition Review Committee (AMARC) got started in December 1973, and on April 1 of the following year, it released a highly critical report.[509]

The reforms of Melvin Laird and David Packard had done little to turn back McNamara's centralizing policies. The AMARC report found that the Army continued to be "profoundly affected" by leadership in the Office of the Secretary of Defense. Responding to the necessity of OSD approval, the Army staff created "multiple layering" to comply with the demands. In one typical example, the program manager of the Heavy Lift Helicopter provided 14 briefings above the level of the Army Materiel Command over 31 work days. The ordeal included five trips between St. Louis and Washington flanking the Christmas holiday. Most of the manager's time was informing officials at the Army staff and headquarters level, who themselves briefed two or three more layers up into a fragmented OSD. The Army reported how

> "OSD is now hydra-headed. Questions pour out of these many heads. The questions can overlap, or deal with the same issues. They appear not to be coordinated at OSD level. The result is tri-service organizational entropy gain."[510]



The Army defined entropy to be the amount of energy in a system not available for doing work. The remarkable complaint perhaps reflected the emotional support coming from the highest levels. Schlesinger was requested another review by the Navy. The next year, the Navy Marines Acquisition Review Committee (NMARC) released its report, finding much agreement with the Army. For example, the Navy stated that "It is the clear conviction of the NMARC that sound management would call for a substantial withdrawal of OSD from specific participation in individual weapon system acquisition programs." The layering of decisions had decoupled authority, responsibility, and accountability.[511]

The problem of multiple layering was quite a bit different than McKean and Schlesinger anticipated. They believed that centralization would simply suppress alternative programs in favor of one group's views about technology or military environments. In 1964, that was a fair expectation. Nearly all program plans filtered through or originated from the Office of Systems Analysis. But power began dispersing across the Department after 1965. Centralization in defense came to involve approval-seeking from all parts of the organization in order to provide a unified front to top management.

Admiral Hyman Rickover repeatedly pointed to the problem of layered decision-making in defense. The problem with decentralized execution of central policy, as Rickover understood, was that it required detailed reporting mechanisms. When Deputy Secretary of Defense David Packard asked Rickover for comments on his draft memorandum outlining the 5000-series regulations, Rickover explained his displeasure:

> "Your proposed directive states: 'It is the responsibility of the OSD to *approve* the policies which the Services are to follow and to *evaluate* the performance of the Services in implementing the approved policies'…
>
> "So long as the bureaucracy consists of a large number of people who consider that they are properly performing their function of approval and evaluation by requiring detailed information to be submitted through the bureaucracy, program managers will never be found who can in fact effectively manage their jobs.
>
> "A program manager today would require at least 48 hours a day of his own time just to satisfy the requests for detailed information form the Service and OSD bureaucracies, the Congress, the General Accounting Office, and various other parties who have the legal right…
>
> "As long as you operate a system where the checkers… outnumber the doers… the doers can do little but spend their time responding to the checkers." [512]

Many others throughout the defense system validated Rickover's conclusions. One project official claimed to have conducted about 70 briefings associated with a DSARC milestone review.[513] A study found that a program manager's communication with personnel in the Pentagon was five times greater than communication with the contractors he managed.[514] John McLucas criticized the DSARC process in a July 1975 speech, finding a proliferation of review activities that generated excessive workloads and weakened service responsibilities. Even though he was

Secretary of the Air Force at the time of the speech, McLucas later found himself "just another voice shouting into the wind."[515]

In 1971, Rickover told Congress that it wasn't just the 5000-series acquisition process that generated excess work. His biggest problem was the constant justification of funds for the next year, a process only connected to the 5000-series at the level of Deputy Secretary of Defense. Rickover's requests encountered 20 to 30 levels of administrative review before funds could be released. A Navy study found that a typical procurement request took 60 approvals from 25 separate offices.[516] Throughout the layers, any official could veto a request. Yet only top leaders could get it approved. Rickover gave a colorful example of one person who set off for 8 months acquiring signatures from 40 officials on a single document. "Then it was lost in the labyrinths of the system." The person originating the document simply gave up because by that point, all the officials had been replaced by newcomers. Rickover described how the poor fellow couldn't face the ordeal of starting all over again.[517]

In theory, layers of review are necessary for tying together disparate pieces of information. This was precisely the point of the move toward a program budget starting in 1949. It gave leadership the ability to collect and analyze information on all the defense activities to ensure that the right programs got the right funding at the right times.

To put it another way, when the policy objective is to take advantage of specialized knowledge by decentralizing administration, the middle manager faces a problem. Because his work is closely tied to that of every other manager, the actions open to him depend on the actions taken by other managers at the same time. Consequently, the plans of all managers should be coordinated before-the-fact at the highest level to root out any misalignment of plans.

8.4 The visible hand

From the standpoint of conscious design, competition appears less than efficient. The plans of some businesses stand in competition, and therefore at odds, with other business plans. Plan mismatches are discovered only after businesses have invested, and therefore wasted, resources. Bankruptcies are a sign that too many entrepreneurs have competed for a limited amount of consumer spending. The anarchy of competing plans results in continual waste that could have been avoided if the plans were rationally coordinated according to a single plan.[518]

In contrast to the competition between firms, the environment within a firm operates according to rational coordination. The entrepreneur's plan seeks cooperation among specialized employees, guiding them toward common objectives. Competition has therefore been a dirty word in administrative theory and socialism alike. It implies dysfunction in a system designed for harmony.

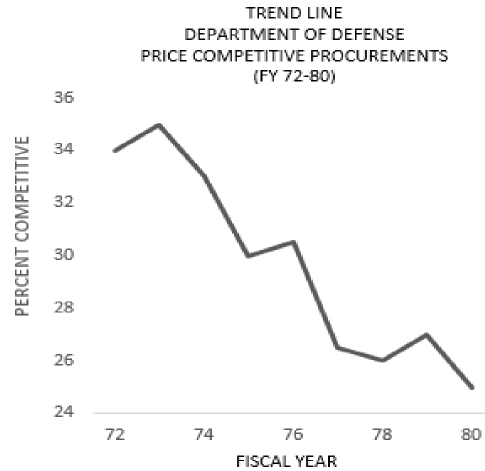
The rise of large multi-unit enterprises in the latter half of the 19th century seemed to prove, using market-tested means, that cooperative planning was more efficient than competitive prices. Inside firms, management coordinates the specialized activities rather than market prices. For all the charges against monopolists, large enterprises simply out-competed the smaller businesses at the turn of the 20th century by rapidly driving down prices.[519] Managerial historian Alfred Chandler thought it was clear by 1977 that the invisible hand had fallen to the wayside.[520] He wrote:

> "[The] modern business enterprise took the place of market mechanisms in coordinating the activities of the economy and allocating its resources. In many sectors of the economy the visible hand of management replaced what Adam Smith referred to as the invisible hand of market forces."

In *The New Industrial State*, John Kenneth Galbraith recognized that the blackboard economics of supply and demand did not reflect what was happening in the economy. Firm administration was more than mere reactions to movement in prices by the invisible hand. Firms were not "price-takers." They had significant pricing power because firms had to coordinate R&D and production in advance of consumer feedback. Long-lead times required firms to actively manage demand, such as through advertisement. "The genius the industrial system," Galbraith wrote, "lies in its organized use of capital and technology. This is made possible, as we have duly seen, by extensively replacing the market with planning."[521]

In Galbraith's formulation, industrial firms required large technostructures of bureaucratic planning. Within the technostructures, decision-making was diffused across the various specialists. This contrasted with the small entrepreneur-led firms of the past, where all coordination emanated from a single leader.[522] The technostructure provides a lens for understanding the logic to layered decision-making throughout the defense bureaucracy.

Galbraith, however, did not recognize the limit to rational planning. He simply assumed that the biggest firms would continue growing. He did not see a post-industrial world coming with its competitive startups. Galbraith assumed the opposite, industrial firms would continue maturing until their functioning merged with government. Galbraith wrote:



> "The industrial system, in fact, is inextricably associated with the state. In notable respects the mature corporation is an arm of the state. And the state, in important matters, is an instrument of the industrial system. This runs strongly counter to the accepted doctrine that assumes and affirms a clear line between government and private business enterprise."[523]

The New Industrial State was published in 1967. Two years later, Galbraith testified to Congress that the line between defense firms and government was a "fiction." He pointed to the fact that major defense firms employed hundreds of the military's retired top-brass. Defense firms, in his view, were an unaccountable part of the public bureaucracy.[524]

Soon thereafter, Galbraith wrote an op-ed in the *New York Times* arguing that defense firms were really public firms, and should be nationalized. He found competition to be excluded in defense more scrupulously than under socialist economies. Only one-tenth of defense contracts were subject to competitive bidding, meaning 90 percent of contracts were directly negotiated with an incumbent firm. The situation left no chance for new firm entry. "There was, indeed, no market between the firm and the Government," Galbraith wrote. "One public bureaucracy simply sat down and worked things out with another public bureaucracy."[525] The president of North American Rockwell's Aerospace and Systems Group confirmed Galbraith's intuitions. "A new system usually starts with a couple of military and industry people getting together to discuss common problems."[526]

8.5 Does competition exist?

Following the debates, Army analyst Wayne M. Allen alleged in June 1972 that there was "little understanding" about the nature of competition. He pointed to defense outsiders who found that a lack of competitive pressure led to profiteering, including Galbraith and Senator William Proxmire. Allen then pointed to defense insiders who found extreme competition in acquisition. David Packard, for example, discussed two areas prone to competitive pressures. First, competition within the military services to get programs approved. And second, competition among contractors to win a declining number of contracts. “There appears to be some confusion,” Allen wrote, “over whether competition exists or does not exist.”[527]

One of the most commonly cited statistics concerning competition in defense is the percentage of contracts that are formally advertised versus negotiated. As discussed above, advertisement and open bidding was the preferred method of government contracting. The process took the form of what market theorists call a procurement auction. It had an appearance of transparency, openness, and competition, all the signs of democracy and markets at their best. While advertisement was the standard approach to contracting, in 1948 Congress provided 17 broad exceptions allowing for negotiated awards.

The exceptions became the rule. Galbraith testified that competitive bidding through formal advertisement was only 11.5 percent of total contract value in fiscal year 1968. But the fact did not worry Galbraith, who believed the outcome “inevitable” because of the visible hand’s efficiency. Eventually, single-firm sectors would arise, aligning the buyer and seller’s interests. The Department of Defense was showing the way for what future high-technology sectors would look like. The “cozy” alignment of plans was thought by Galbraith to encourage innovation otherwise not well suited to markets. Nationalization would in effect solidify the relationships, streamline negotiations, and increase public accountability.[528]

COMPETITION IN MILITARY PROCUREMENT, FISCAL YEARS 1964-68

			Negotiated (percent)		
fiscal year	Total procurement (billions)	Formally advertised (percent)	Multiple sources solicited (competive procurement)	Single source solicited (non-competitve procedure)	Total
1964......................................	$28.2	14.4	30.7	54.9	85.6
1965......................................	27.4	17.5	31.1	51.3	82.4
1966......................................	37.2	14.2	35.8	50.0	85.8
1967......................................	43.4	13.4	34.1	52.5	86.6
1968......................................	42.8	11.5	30.6	57.9	88.5

Though he was asking many of the most important questions of the day, Galbraith’s view was an outside one. Most Americans were fearful of nationalization. They wanted to bring market competition to defense industry using arms-length procurement auctions, thus warding off Eisenhower’s military-industrial complex. To many analysts, the primary measure of market competition in defense is the proportion of contracts open to competitive bids. Preference for open advertisement and bid was reaffirmed in 1984 with the passage of the Competition in Contracting Act (CICA). To Army analyst Wayne Allen, the prevalence of competitive bid procedures had nothing to do with the degree of competition in defense.

Allen wrote that the proportion of contracts formally advertised and negotiated was "simply irrelevant" to the question of competition in the defense industry. First, even if contract awards were negotiated, they could arise in a highly competitive environment where the government evaluates multiple single source solicitations. Second, contract advertisement could result in little or no competition. The outcome is plain when there is only one contractor able to bid (monopolist). But it is equally true when there is only a single buyer. It doesn't matter how many suppliers are clamoring for an advertised contract. The buyer chooses the contract requirements and how it is awarded. All contractors optimize to that approach. Competitive bids can then result in contract outcomes no different than negotiated. Allen concluded that contract statistics say little about the nature of competition in of themselves. Understanding competition in defense instead requires an investigation of pre-contract decisions.[529]

8.6 Pre-contract process

In 1973, Wayne Allen joined the cost panel on the Army Materiel Acquisition Review Committee. The AMARC report highlighted the difficulty of getting funding lined up for a contract. The earliest stages of R&D, represented by budget activities 6.1 through 6.3, increasingly required project line-itemization, which in turn required the coordination of fixed requirements throughout the bureaucracy. The AMARC recommended:

> "(1) R&D effort in the 6.2, 6. 3A and 6. 3B categories should be accomplished with low-level programs, full realization of technical risks, and no management promises. (2) Developer should build it and try it and let the user I try it and see if he likes it… The preceding issue concluded that the firm requirement should not occur until entry into the Full Scale Development Phase (6.4)."

The Army discussed how the increased dependence on requirements coordination reduced diversity in weapons R&D. The science & technology panel wanted to scrap the program-orientation of the early-stage R&D budget. It wanted to provide "single element funding for each lab for its self-determinative (6.1 through 6.3) funding."[530] In effect, the AMARC recommended moving back to budget classifications based on organization, undoing nearly three decades of programming reform. The Navy report agreed in principle:

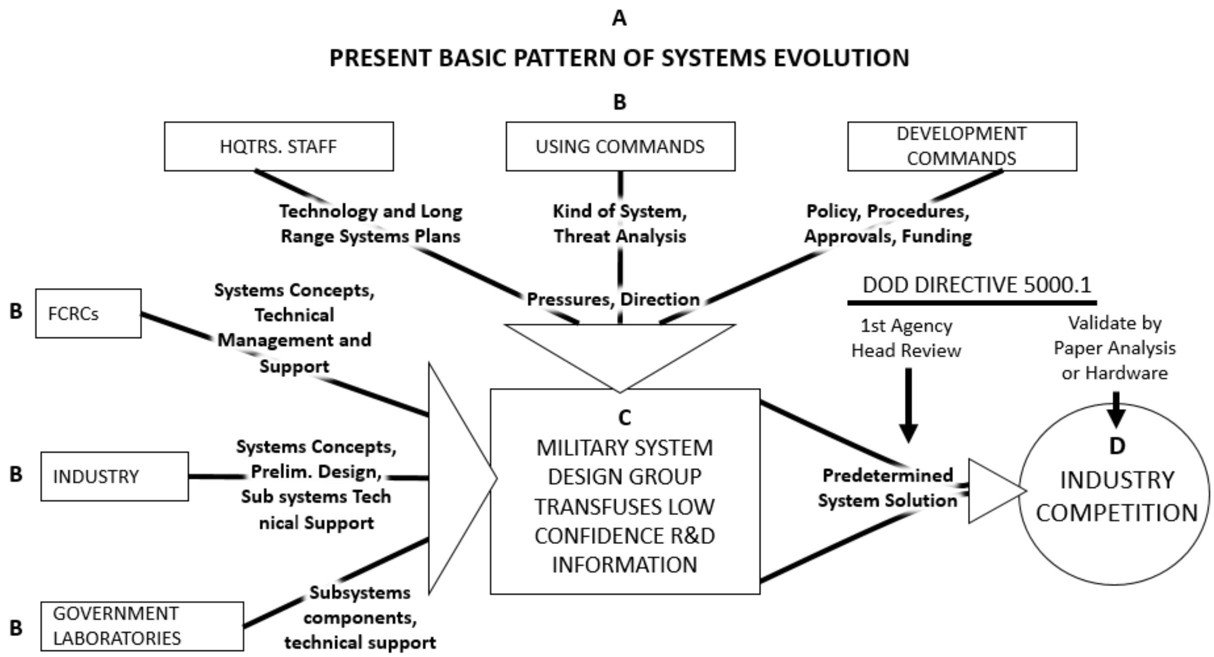
> "The fundamental feature of the Navy's method of funding its laboratories derives from its method of presenting and justifying its budget to OSD and the Congress, i.e., in terms of RDT&E work to be accomplished, not in terms of organizations to be supported. This philosophy extends to the technology base work as well as through the engineering projects. Thus, in theory, no Navy laboratory is assured any funding, and each year it must sell the services of its entire work force."[531]

On April 28, 1975, Deputy Secretary of Defense William Clements established an advisory group of OSD principals to assess the AMARC and NMARC reports. It concluded that OSD policy in the 5000-series was "sound," but "not enough authority and responsibility has been decentralized to the Military Departments." At the time, the Department of Defense was still attempting to implement the recommendations of the Committee on Government Procurement. The lack of progress on the COGP recommendations prompted Lawton Chiles, a junior senator from Florida, to make a name for himself by initiating a string of Congressional hearings starting on June 16, 1975.

First up in the hearings was the former chairman of the COGP, E. Perkin McGuire. In a fairly short time, McGuire outlined the recommendations and looked to be dismissed. "I have been told you should never stay too long in a hearing," McGuire said. His former deputy, Robert R. Judson, was less reserved. He described how military requirements initiated a long process of justification and analysis. Detail was continually added to meet the approval of each stakeholder in order to make funds available.

Prior to industry's competition for the contract, unvalidated pressures affected the design team from all sides. From above, headquarters staff provided long range objectives. The using commands decided system types and threat analyses. Development commands implemented policies and procedures, including budget justifications. From elsewhere, system concepts, design, management, and technical support came from Federal Contract Research Centers (FCRCs), industry, and government labs. There were also reviews at the OSD level in accordance with DOD Directive 5000.1. Judson found that all these factors and more influenced the design team.

The outcome of the process, Judson argued, was a predetermined solution prior to industry competition for the development contract. He explained how industry competition formally started at the engineering design phase, but the decisions made before that preset between 80 and 90 percent of the total program cost. Technical latitude became severely constrained by the time the request for proposal goes out. The contractors optimize against the predetermined solution and undercut each other on the cost estimate.[532]



(A) ***Situation at beginning***: *needs and goals independent of system solution not established/approved; pressures exist to commit prematurely to single system approach; mission responsibilities unclear.*
(B) ***Unvalidated*** *design inputs, old technology stretched, subsystems drive systems, systems seek needs.*
(C) ***Unchallenged*** *technical decisions, operational concept, technologies to be used, preliminary design, performance requirements; these preset 80-90 percent of the ultimate program cost.*
(D) ***Competes to develop a "required" system***, *limited technical latitude, promises what customer wants, buy-ins, no design continuity but accepts total system performance responsibility.*

From Robert Judson found in "Major Systems Acquisition Reform." Hearings, 94th Congress, 1st Session, Part 2, June 16, 1975, 26. Reproduced figure.

Judson discovered how well contractors understood the pre-contract process. In order to get a competitive edge, contractors marketed their technologies to the offices writing requirements. The resulting requirements, the COGP observed, "often reflect proposals and promises made by one or several contractors."[533] The "requirements-pull" model of defense innovation was, in part, founded on technology first pushed by industry. Robert B. Hall, Assistant Comptroller General, observed the same problems:

> "… an intense marketing effort would unfold as interested suppliers worked informally with the agency and its baseline system and detail specifications. Unless 'wired in' early, suppliers would otherwise have little chance at the ultimate award."

Getting wired into the process required absorbing large overhead costs for many years. Robert Hall found that the B-1 program spent six years and $140 million on paper studies before writing the development specifications. Seven companies spent $66 million preparing proposals, the cost being expensed as an overhead charge to existing contracts. Five companies spent an additional $36 million of their own funds in anticipation.[534] Albert Shapero doubted whether a U.S. company could write an aircraft proposal with less than 50 engineers and hundreds in support—roughly the same staff that European firms used to get a new aircraft into flight test.[535]

Industry executives stressed the importance of the pre-contract process. “You have to get in on the ground floor or forget it,” said one vice-president for General Dynamics. “If you wait until the RFP [request for proposal] comes out, you’re dead,” another representative said. One official at North American bluntly described how “Your ultimate goal is actually to write the RFP, and this happens more often than you think.” Industry ended up “spoon-feeding” the military—marketing program solutions that requirements would be written around—because industry ultimately had the “technical superiority” to go “on the offensive.”[536]

Most of the pre-contract process happened outside of Congressional purview. Robert Judson argued that when Congress doesn’t get involved early in the decision process, when it doesn’t engage in “preventative medicine,” it creates a crisis down the line which is then solved using “emergency room” management techniques. Such management, he estimated, increased the overhead costs of acquisition rooms between 10 and 50 times.[537]

8.7 State-planned technology

While the defense industry tried to influence program requirements, they still required approval from many corners of the bureaucracy. Each of the various layers of decision represented a set of stakeholders who had an interest in the program, no matter how remote.[538] The effect of layered decisions can be substantial. A proposed project does not simply receive a “yes” or “no” decision by a single group, resulting in the suppression of diverse opinions. Instead, the project goes through a succession of officials. The whole network of approvals encompasses varying patterns of bias. Often, approval from an official requires concessions which increases complexity, such as requiring greater survivability, lethality, or range, or imposing business regulations and reporting formats. “It is either do this,” Packard said of staff approvals, “or that is the end of the new idea”[539] As the number of layers grows, the likelihood that even small additions accumulate into disaster becomes exceedingly high. Design pressures ultimately create contract requirements written on hundreds or thousands of pages which imply severely restricted design space for competitive firms to differentiate themselves.

On June 24, 1975, the Senate committee on government operations heard a stirring testimony from industry consultant David G. Soergel. He argued that industry decisions were locked in by the government. “Mr. Chairman,” Soergel began, “I believe we are in a de facto situation of nationalized high technology industry. All that is left is to formalize the arrangement.” Alluding to Galbraith’s perspective, he said:

> “There will be some who will argue that to go ahead and nationalize selected segments of industry will produce Federal spending efficiencies, and reduce the taxpayers’ burden. I think it is pretty well agreed to, that competition between contractors does cost money to maintain long enough so that benefits can accrue to buyers, both in product values and prices. These costs of competition could be eliminated by a political decision to nationalize. Why competition is so easy to reject is because downstream buyer benefits are hard to put numbers on. So, it is more expedient to save money in the short run by eliminating competition than stand the expense of financing competition and hope for long-term imprecise benefits. I believe this trend toward formal nationalization should be reversed.”

Soergel said that many observers on industry’s side believed that since the 1960s, the U.S. had been in a situation of “state-planned technology.” Official policy had government select the conceptual design and refine it into a preliminary design, which in turn was used to prepare the contract specifications. Industry then competed on the constrained specifications, and could only differentiate themselves on price.

Responsibility for the design choices were diffused throughout the defense bureaucracy. It led to the situation where assignment of blame for poor outcomes could not be pinpointed. “Were Government’s early technical decisions at fault, or did the contractor mismanage the job?” The question couldn’t be answered in most cases. “Now, if you ask who is the ‘chief engineer’ here; who’s responsible for this split design process; who’s managing it,” Soergel said, “the answer clearly is, ‘no one.’” Soergel determined that the prevalence of cost growth and contractor bailouts was due to split decision-making in the design process between public and private design teams. He explained how “Bailouts are caused by settling on a single design too early with no remaining options and, again, no one accountable for the design.”

Soergel recommended providing private technologists more freedom to conceive new products and take responsibility for their outcomes. In other words, the “freedom to innovate.” Designs are inherently subjective, he argued. Different design groups, “having different past experiences, would most likely create an obviously different concept to solve the same problem." But the exploration of alternative concepts can only occur if design teams were given the freedom to do so. Through product development, the teams are brought into competition. Soergel clarified how "This means that one team economically survives and the other doesn't."

The prevailing process, however, did not approve contracts supporting competing designs to a given problem. Instead, it relied on what Soergel called the government's "super-wisdom" to select the correct technology from a declining number of industry suppliers. Only the biggest suppliers could compete in the long marketing and approval process which absorbed staggering amounts of overhead costs. "With 4,000 procurement related laws and 3,000 pages of regulatory procedures," Soergel noted, "we have long ago locked-out marketplace 'creative destruction.'" He concluded that a tendency toward monopoly resulted from acquisition policies that raised the entry cost for small and medium firms to challenge large firms.[540]

8.8 Monopsony

The senators agreed that Congress needed to focus on the front-end of the acquisition process. However, their minds still revolved around the Navy's defiance of Congressional intent on the lightweight fighter program. They were convinced that there needed to be more regulation in the pre-contract process to arrive at better requirements earlier.

A good place for implementing changes to the front-end of the acquisition cycle, Comptroller Elmer Staats advised the senators, was a draft "circular" emanating from the new Office of Federal Procurement Policy (OFPP). Released the next year in 1976, OMB Circular A-109 created new policies for injecting visibility at the earlier stages of concept exploration. Along the same lines, Staats recommended to Congress a Milestone Zero for major defense programs. The milestone was later implemented in 1977, bringing oversight into the question of whether or not there was a valid mission need to explore.[541] Even though both the Circular and Milestone Zero stressed broad mission needs rather than specific capabilities, more often than not the early review activities revolved around the latter. As could be expected, the policies reduced even further the number of new program approvals while increasing the level of justification required.

The military services asked for fewer controls on early R&D activities so that they could more freely explore alternative concepts. What they got instead was tighter controls. The actions represented another step in the direction of what Soergel called "state-planned technology." Soergel made many of the same arguments that Army analyst Wayne Allen did back in 1972. In fact, the two worked together on an electronics study during 1973. They correlated "one-shot" competitions on pre-specified contracts to the problem of a single buyer in military procurement.[542]

When major activities are coordinated before-the-fact, such as through a requirements process leading to milestone approvals and funding authorizations, the result is a unified plan of action for the organization. When the organization is also the only seller in a market segment, it creates the familiar problem of monopoly. Being without any effective competition, a monopolist firm is said to have the power to extract value from its buyers. For the Department of Defense, the unified acquisition plan makes it the single buyer facing the private defense industry. The DoD is a monopsonist. Certainly the public finds a monopoly in the defense industry to be an unacceptable proposition, but what about a government monopsony? Should not monopsony, Wayne Allen argued, be viewed with similar concern? He concluded that the suppression of competitive developments forced the services and contractors to fiercely compete on paper plans, which inevitably led to optimism and cost growth. "*The root cause of cost growth on major weapon systems*," the Wayne Allen emphasized, "*is monopsony. Cost Growth is the backlash of monopsonistic practices*." He continued to say that "Monopsony is a collective phenomena. It is an aggregate condition producing an aggregate result. No one is to blame; everyone is to blame."[543]

It is generally assumed that a single buyer, using its dominant position, can force lower prices. "The concept of monopsony," Herbert Spiro wrote, "assumes the inability of suppliers to one customer to find alternate buyers of their products." Indeed, defense contractors are often unable to transfer specialized technical, marketing, and management resources—all of which are regulated by the government—over to the commercial sector. "In effect," Spiro continued, a monopsonist "can command, at least in the short run, prices which are below even the marginal cost of the suppliers."[544]

However, the situation introduces serious questions with regard to the long-run strength of the industry.[545] One industry executive remarked in 1970 that "there isn't a company in this country today whose board isn't sitting up nights trying to think up ways to get out of the defense business."[546] By the 1980s, investors were rewarding companies for leaving the defense sector as the industry rapidly consolidated despite growing military budgets.[547] All this happened before the government encouraged industry consolidation in the post-Cold War 1990s, leaving only two or three prime contractors in each commodity class.

Government powers as a monopsonist in defense markets are often exerted through conditions and regulations placed on contract vehicles. For example, the government will not reimburse "unallowable" costs—such as advertising and some forms of interest—and puts caps on other costs such as pre-contract, travel, and training costs. Such costs are part of normal business operations in the commercial sector. Special reporting requirements, such as PERT and other business data, also contributed to a significant share of defense costs.

Perhaps most onerously, a long list of regulations restricted contractor decision-making. Murray Widenbaum found that the government has decision power in: (1) make-or-buy practices; (2) selection of subcontractors; (3) purchases made foreign and domestic; (4) internal financial reporting systems; (5) industrial engineering and planning systems; and (6) minimum and average wage rates. Costs are expected to increase from such interventions "Unless one is willing to adopt the view that the government buyer can manage a private organization better than can the company's own management."[548] Such a view, however, is adopted in official policies for evaluating contractor operations, which presumed that "Government analysts are better trained, more knowledgeable, more objective and/or more dedicated to achieving more for the defense dollar than are their counterparts in the defense industry."[549]

In many ways, the long list of rules and regulations mandated in defense contracts is a reaction to the government's *disadvantage* in contract negotiations. RAND analyst Frederick T. Moore found that the government could not press its monopsony position in defense markets because it "lacks the skills and resources to make the necessary technical and cost evaluations of contractors' proposals." It must rely instead on "information supplied by the firm."[550] Special disadvantages to the government in contract negotiations include asymmetry of rewards and disparity of status between bargainers. And when these matters do not take precedent, to press upon industry the government's monopsony position invites the charge of an arbitrary exercise of power.[551] The government used its monopsony power in specific and reactionary ways, not to force the lowest possible cost, but to offset the information and incentive disadvantages inherent to its position.

Firms must accept the government's conditions if they want to win work. They must also accept the government's pre-contract process, which seeks to generate a consensus on requirements. However, because of uncertainty as to technical and military feasibility, there is no single articulation of the future that all participants can agree on. The official consensus that generates a monopsony can only be reached by suppressing dissenting viewpoints. If dissention was tolerated and competing projects supported, then the central plan is no longer internally consistent. It reflects constituent parts that conflict with one another in terms of their assumptions about technology or environments. Some could only succeed if others failed. Such plurality stands in contrast to nearly a century of reforms seeking to unify decision-making.

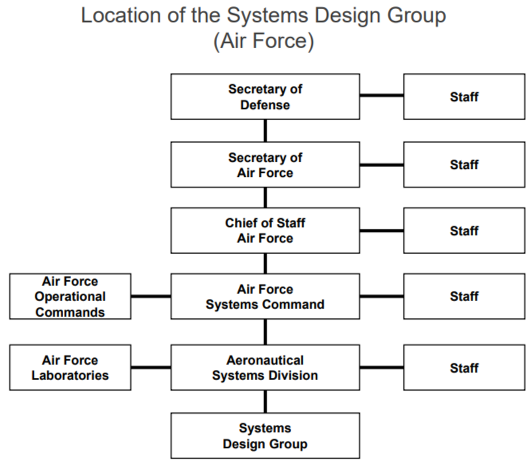
The inconsistency of plans, such as those which naturally arise in a market economy, are fundamental to systems whose functioning is more complex than any individual's comprehension. For complex processes to operate, numerous interconnected plans must be made simultaneously by constituents with unique and partial sets of knowledge. This creates a degree of contention between the plans, which are coordinated after-the-fact. The rivalry in the 1940s and 1950s that was stamped out of defense acquisition is necessary to generate information that no rival on its own could have possessed in the absence of that rivalry.[552]

In the 1960s, Robert McNamara finally reined in the rivalrous competition. The system analyses he relied on takes as "givens" basic questions of technical specification and cost. Those "givens," generated through the consensus-building bureaucracies, are transmitted to industry which "competes" for them in a narrow and orderly sense. However, the real utility of competition is in discovering the decision-maker's "givens," or what the product should look like and how it should be priced. These are decisions of the innovator, not the consumer whose feedback comes in the form of sales against real competitors. The value of any choice cannot be known until the product is realized, and even then, institutions have their biases and military environments will change. Competition depends on divergent expectations and only provides after-the-fact realization of the preferred product, never the optimal product. As Armen Alchian explained in 1967:

> "In the private economy other competing firms can duplicate or take different points of view about the nature of desirable products. But there are not two departments of defense to provide the competitive survival and selection of preferred products… Without competitors a

monopoly does not ensure that alternatives will be tested and explored with the efficiency of competing firms.

"A quiet, uncomplicated life without so much bickering and fighting about wealth values of alternative products is more viable. Centralization under government contexts implies less exposure and testing of differences of opinion, easier suppression of alternatives, less effective response to costs, and loss flexible adjustments of programs despite more exhortations to the contrary."[553]



Reproduced figure. Source: Commission on Government Procurement Studies Program. Similar illustrations could be made for the Army and Navy.

The most important aspect of the competitive view is that it establishes multiple buyers, as well as sellers, with overlapping interests to engage in exchange. If each participant has meaningful specialization, it is natural for "parochial" views to emerge. It is in special knowledge that divergent expectations arise, and under uncertainty, the only way to discover whose expectations better conforms to reality is to execute the alternatives. Decentralized organizations naturally develop those alternatives and bring them into competition. Failure to deliver a product more desirable than the competitors acts as a filter, removing inefficient performers which otherwise could not be identified. Though superficially redundant and inefficient, the competitive process ultimately saves resources because of the filtering process.

8.9 Redundancy

Scientific management demanded the elimination of redundancy. Through analysis, it claimed that the optimal plan could be selected without the need for wasteful competition. The drive for a single unified plan with a minimum of program overlap led to military unification, the rise of program budgeting, and the suppression of exploratory developments. Secretary of Defense Louis Johnson described the vision for defense planning in 1950:

"Unification has given us an integrated defense budget, in which the needs of each service are balanced against the requirements of national defense as a whole and appropriations are allotted accordingly. This has reduced needless duplication, inefficiency, and wasteful competition."[554]

His successor Charlie Wilson agreed in 1953 that "competition between military departments in buying must be prevented."[555] In 1957, assistant secretary for R&D Clifford Furnas said that "there is some very severe and wasteful, difficult, unbridled competition; and this unbridled competition is undesirable."[556] In 1961, Robert McNamara installed the ultimate expression of the active view, the Planning-Programming-Budgeting System. Whereas in the 1950s, Army General James Gavin was able to personally authorize a $12 million development "in the face" of the Secretary of Defense's disapproval, such deviant behavior was more or less stamped out by McNamara's PPBS regime.[557]

AVIATION RESEARCH AND DESIGN ORGANIZATIONS
OF THE MINISTRY OF AVIATION INDUSTRY

Research Institutes

Central Aerohydrodynamics Institute (TsAGI)
Central Institute of Aviation Motor Building (TsIAM)
All Union Institute of Aviation Materials (VIAM)
Scientific Research Institute for Aviation Technology and Organization of Production (NIAT)
Scientific Research Institute for Aviation Equipment (NISO)
Flight Research Institute (LII)

Design Bureau Heads and Chief Designers Active Since 1950

Airframe Design Bureaus	Engine Design Bureaus
O. K. Antonov	M. M. Bondaryuk
A. A. Arkhangel'skii	Glushenkov
G. M. Beriyev	A. G. Ivchenko
M. I. Gurevich	S. P. Izotov
N. K. Kamov	V. Ya. Klimov (dec. 1962)
S. A. Lavochkin (dec. 1960)	S. A. Kosberg (dec. 1965)
A. I. Mikoyan	N. D. Kuznetsov
M. L. Mil (dec. 1970)	A. M. Lyulka
V. M. Myashishchev	A. A. Mikulin
P. O. Sukhoi	A. D. Shvetsov (dec. 1953)
A. N. Tupolev	P. A. Solovyev
A. S. Yakovlev	S. K. Tumanskii
	I. M. Vedeneev

"R&D in Soviet Aviation." Arthur J. Alexander, RAND Corp., R-589-PR, Nov. 1970.

The prevailing consensus appeared to revolve around efficiency notions which regarded redundancy as wasteful. However, in 1956 John Von Neumann described the beneficial role redundant processes can play in creating highly reliable systems. He found that a system (such as a computer) could be more reliable than its constituent parts (such as vacuum tubes) through redundancy. When one part fails, back-ups are available. The paper set the foundations for high reliability engineering for the rest of the century.[558]

The idea caught on to theories of administration as part of a backlash to Weberian straight-line hierarchies of zero redundancy. UC Berkeley professor Martin Landau applied Von Neumann's concept to organizational theory. He recognized how the probability of failure in an organization, like any system, decreased exponentially as redundant factors were increased. Yet the driving orthodoxy had neglected the method for managing risks:

> "Taylorism and scientific management… demanded the wholesale removal of duplication and overlap as they pressed for 'streamlined organizations' that would operate with the absolutely minimal number of units that could possibly be employed in the performance of a task. Zero redundancy constituted the measure of optimal efficiency."

Landau realized, however, that redundancy did not only entail adding duplication. Looking to biology for inspiration, he recognized how "self-organizing systems exhibit a degree of reliability that is so far superior to anything we can build." They entailed "richly redundant networks" that not only responded to known risks, they could adapt to unknown risks. Organisms diagnose errors as they occur, readjust themselves, and correct their constituent parts. Landau pointed to Bertalanffy's idea of multiple causal pathways which provides systems with an "extraordinary adaptive power."

For human organizations, Landau recommended pursuing several strategies both simultaneously and separately. The competing plans acted as a kind of experimental control to determine which action performed best. He made the important observation that in a tightly ordered system like the programmed budget, there are no comparisons to determine whether an error had occurred. The cost of errors, without hedging, could run very high. As Landau concluded:

> "It can be seen, then, that any attempt to 'program' solutions prematurely is the height of folly. Managements may do this in the interest of economy and control, but the economy will be false and the control a ritual—for we are acting, and organizing, as if we 'know' when we do not… Whatever claims are made for programmed decision making, it is to be recognized that if its organizational structure consisted only of the 'absolutely minimal number of parts,' error could not be detected."[559]

Whereas simply adding redundant parts with some mechanism for control can ensure system reliability for quantified risks, when the decision-maker faces "unknown unknowns," the redundant features required are a rich network of causal pathways. When unanticipated risks materialize, the programs suited well to the expected contingency may be ill-suited to the new situation. Alternative programs, which might have appeared superfluous and inefficient in normal circumstances, might then demonstrate utility. However, if the option to invest in redundant features were eliminated, then when risks materialize, the system could not recognize any other way of performing a necessary function. Without establishing competitive programs, additional resources would be devoted to the ill-suited program until it cascaded into system-wide failure.

8.10 Discovery procedure

The pre-contract process of a layered bureaucracy very much narrows the range of solutions permitted. When industry is allowed to bid for a contract, many of the most important parameters of the problem are already fixed. The resulting competition then focuses on price. In other words, the contractors competed on allocating scarce resources toward ends that were "given" by the contract requirements. Rather than competing on critical questions of technical feasibility and mission needs, contractors instead performed cost minimization procedures to the stated requirements.

The acquisition process reflected the prevailing economic theories of the time. For many economists, the market functioned as a computer. It determined the solution to the set of simultaneous ("Walrasian") equations which brought supply and demand into general equilibrium. In other words, the market optimized resource allocation across "given" means and ends. Competition was useful in that it pushed firms to lower price and raise output until the point where firms would start divesting from the market. Competition ensured that firms would not earn robber baron profits to the detriment of society.

Yet Friedrich Hayek pointed out that the whole purpose of competition is to discover the parameters of the problems to be solved. "Which goods are scarce, however, or which things are goods, or how scarce or valuable they are, is precisely one of the conditions that competition should discover."[560] Competition isn't just about bring prices into equilibrium. More importantly, competition is the procedure where people discover better ways of satisfying each other's needs. Both the means and the ends are open-ended, as is the competition.

For mainstream economics, both the means and the ends of the market process are already known. A "perfectly competitive" market, for example, is comprised of many buyers and sellers who transact over a homogeneous good, all of whom have complete knowledge of resources and production methods. As Hayek observed, "Advertising, undercutting, and improving ("differentiating") the goods or services produced are all excluded by definition—"perfect" competition means indeed the absence of all competitive activities."[561] What was important about competition for Hayek was the freedom of entry and not the number of sellers; the range and value of alternative goods and not a single homogeneous good; and the discovery of new knowledge about economic activity and not a state of perfect knowledge.

Just as economics neglected competition in discovering the "parameters" of the market equations to be solved, system analysts neglected the role of competition in discovering the right parameters to include in their models. The greater the presence of uncertainty, the more important becomes the interactive process of competition. But the apparent disorder of the process has led to calls for its abolition.

Consider the organization that subsumes all planning and proceeds under a unified direction. Naturally, program policies will arise which some at the lower levels or elsewhere find disagreeable. They have a difference of opinion about the risks and opportunities involved in the economic activity. In a liberal market economy, these everyday people are allowed to become entrepreneurs. They can exploit what they perceive as mistakes in existing supply by reallocating resources to higher valued uses. They may then engage in competition with existing suppliers. Successful entrepreneurs have, in effect, fixed errors in the existing structure of economic production. Otherwise, incumbents would have been alert to the opportunities presented by the actions. They would have invested resources to capture the profit.[562]

Entrepreneurs benefit from comparing actual prices with their estimation of prices under alternative production methods. The misuse of resources results in a pattern of prices that "invites" entrepreneurs to bid away resources in order to allocate them toward a higher valued use, which is only made evident after-the-fact by economic survival and positive profits. Yet entrepreneurial activity cannot extend too far because eventually it would lose the guidance set by market prices. As Don Lavoie illuminated:

> "Centralization of any given firm cannot continue beyond the point where the knowledge generated by the rivalrous bidding of its competitors is sufficient to rationally guide its economic calculation. Were the firm to centralize any further it would increasingly find itself 'in the dark' concerning the proper productive evaluations it should attach to the factors of production under its control. Unaided by the knowledge generated by its rivals, it would begin to lose those less centralized rivals who could still benefit from such knowledge."[563]

Decentralized rivals can observe the relative prices emanating from a monopolist, allowing them to speculate about different methods, a changing array of products, and their consequent effect on prices. These entrepreneurial activities are, through a process of trial-and-error, discovering new information as to what works or does not work. Bureaucracy, on the other hand, was defined by Michel Crozier to be "an organization that cannot correct its behavior by learning from its mistakes."[564] The competitive process of discovering and correcting errors is what sets an entrepreneurial organization apart from a bureaucratic one.

9. Cost

> At one time the pagan gods ruled the world. Later the kings. Then the warriors, followed by the lawyers. Now it is cost accountants. Ultimately some measure of common sense comes into play. Events tame them and relegate them to their proper place.
>
> Admiral Hyman Rickover
>
> Congressional testimony, 1967

Economists generally find agreement on the idea that national defense is a public good. In other words, private markets will not lead to an efficient provision of defense goods and services through the "invisible hand" mechanism alone. Governments must then provide for defense needs by administering internal budgets funded by the taxpayers. Yet for many investments in weapon systems, the Department of Defense outsources production knowledge to private suppliers. These defense-unique goods and services supplied by industry are priced at the estimated cost of production plus a small profit consideration. Two prominent methods for price determination in defense acquisition are "will cost" and "should cost" analyses.

While the administrative rule of paying production costs may appear to approximate the efficient outcomes of markets, it leads to an "orderly competition" that does not reflect the real functioning of markets. Moreover, the rule ignores non-monetary aspects of cost which have come to dominate under technological progress. Profit reflects the value generated over and above the next best alternative, and rewards those who innovate or reduce costs.

At its heart, neoclassical economics only provides a framework for understanding prices under static technology. As the economy moves away from reproducible goods and towards intangible assets like software, platform design, and institutional knowledge, competitive market outcomes will move further away from neoclassical idealizations of price equaling the objective cost of production. While accounting figures may provide a great deal of insight to a manager close to the operations, who has a deep technical understanding of the choices actually made—a manager like Admiral Hyman Rickover—accounting figures in themselves provide no context for planning future actions or holding organizations accountable. As intangible aspects of investment continue to grow, accounting figures reveal less about what really matters.

9.1 Profit

At 5'2 and 125 pounds, Hyman Rickover didn't fit the mold of a Navy ship commander. Failing to have achieved his dream of a submarine command by age 37, Rickover asked to be transferred to engineering-duty only. He excelled in bringing order to various bases, and was put in charge of the electrical division at the Bureau of Engineering just before the U.S. entered WWII. Shortly after the war, Rickover visited the Oak Ridge facility and quickly realized the potential of nuclear power for the Navy. He started organizing a reactor demonstration on a submarine platform. Despite cancellation at the end of 1946, he continued to push the program until its re-authorization in 1951. Less than four years later, Rickover oversaw the launch of the first nuclear powered submarine, the Nautilus. It provided a ready answer to Soviet's display of space technology by transiting the North Pole while submerged in 1958.

Until the end of the Nautilus, Rickover had largely limited his public voice to the areas he felt competent, namely technical matters. All that changed after a 1954 commencement speech to the Naval Postgraduate School. Announcing the pivot, he recognized that "when one talks about how a job is done, he necessarily talks about people, and not about things."[565]

Rickover started to embrace the subjective nature of public politics as a means of achieving his objectives. Over the course of the 1950s, he began a courtship with Congress not only to extend his commission, but to gather support for reform. First, he attacked the bureaucratic layering of the Pentagon, complaining to Congress how staff persons with no responsibility could delay or kill program decisions.[566] Then he moved onto contractor relations. In 1963 he began pointing to excessive contractor profits and the importance of cost accounting.[567]

Rickover's interests extended into bureaucracy and accounting because they deeply affected his ability to accomplish work. In 1968, Rickover summarized for the joint economic committee how he had perennially pointed out serious problems leading to profiteering by the contractors. The deficiencies could only be resolved, he argued, with better insight into accounting figures. "But my statements are like hammers with no anvil," Rickover said, "since the Department of Defense does not respond." He decided that only Congress could correct the accounting problems leading to excessive profits.[568]

In theory, certified cost and pricing data had been required on all non-competed contracts greater than $100,000 under the Truth-in-Negotiations Act (TINA). In practice, Rickover found contractors simply ignored the law, made possible by government agencies refusing to enforce it. Even at the government's expense, contractors refused to furnish accounting data. Rickover called TINA a "dead letter." He accused the contractors of playing tricks with their accounting to maximize profits at the expense of an unwitting government.[569]

Counter to Rickover's arguments, the Department's position was that contractor profits, if anything, were *too low*. The Renegotiation Board reported that average industry profits fell from 6 percent in 1956 to 3 percent in 1962.[570] President of the Logistic Management Institute Barry Shillito said that industry profits as a percent of capital invested fell 35 percent over the past decade. The price-to-earnings ratio for defense firms were lower than for commercial firms, indicating that investors were not optimistic about future profits in defense.[571] In response to industry pressure, the DoD sought to increase profits on negotiated contracts by 25 percent.

In Rickover's judgment, profits were already too high. He said that Shillito's report used "unverified and unaudited information volunteered by defense contractors."[572] A subsequent GAO audit of 146 defense contracts painted a different picture. The GAO found profit-on-sale 57% higher than the Shillito's study, and return-on-capital well over two times higher.[573] From his vantage point at Naval Reactors, Rickover saw profit rates double on shipbuilding contracts in the two years after 1966. Suppliers of propulsion turbines regularly insisted on 20 to 25 percent profit rates compared to just 10 percent a few years before. Yet Rickover claimed that no one really knew what industry profits were. “Nobody in government knows what profits are being made by defense contractors,” he said. “I don’t know it, you don’t know it, Congress doesn’t know it, the Pentagon doesn’t—only the contractors know it.”[574]

Rickover claimed the Defense Department was trying to increase profits without appreciating the nuances of accounting. In one case, Rickover had been contracting with a firm who was in turn procuring components, repair parts, and technical data. More than 90 percent of the cost went directly to subcontracts. Because the firm invested little capital itself, it had for several years been accepting profit-on-sales of 2.29% or less. It represented a sizeable return on the capital invested in the contract. But the Armed Services Procurement Regulation (ASPR) “allowed” for a profit of 8 to 10 percent. The Chief of Naval Materiel ordered Rickover to increase the prime’s profit.

Rickover explained the situation in a series of letters, and moreover, he explained how the contractor had been seeing record sales from the government with little competition. The Navy staff, however, continued insisting on higher profit rates. Eventually, Rickover complied by increasing the profit by a nickel, from $1,147,023 to $1,147,023.05. He stood by the fact that the negotiating team arrived at the 2.29% profit rate using ASPR 3-808 which specified the weighted profit guidelines. The correspondences became known as the “nickel letters.”

Input	Recognized costs	Weight range (percent)	Assigned weights (percent)	Fee, dollars
Subcontracts	$46,654,877	1 to 5	1.75	$816,460
Labor	1,472,972	9 to 15	12.5	184,122
Overhead	1,954,545	6 to 9	7.5	146,591
Total	50,080,387			1,147,023
Composite weight			2.29	
Risk (CPFF contract)		0 to 1	0	
Performance		-2 to +2	0	
Selected factors		-2 to +2	0	
Total, weighted guidelines			2.29	$1,147,023

One questionable way contractors maximized profits was by subcontracting work to their own divisions, called intracompany transfers. In these cases, the same contractor could earned profits at the prime and the subcontract levels. The profits earned by one division at the subcontract level came in as a material cost to the prime over at its division, as though it were any other parts supplier. The contractor earned a profit on-top of profit. Rickover said how the “extra profits will not be visible” to the government, which only has insight at the prime level.

Treatment of overhead was another area ripe for abuse. Rickover claimed that contractors unfairly spread the cost of commercial work onto government contracts. For example, contractors would charge the cost of supervisors, bid and proposal, and other functions to an overhead cost pool that gets charged back to all contracts. However, for government work, most of those costs were charged directly to the contract and so did not contribute to the overhead pool. The government was then picking up the total cost of those functions for its own work, as well as a large portion of the costs for commercial work.

Another area of attention was reimbursement claims due to changes in government direction or contract loopholes. Rickover found the government inundated with claims which were detailed in legal wording but seldom supported by accounting records. Moreover, the cost to industry of preparing the claims was charged back to government contracts as an overhead expense. It provided industry a tremendous advantage in manpower to go along with its asymmetric information. In one case, Rickover said a contractor submitted a $70 million claim on a $70 million contract. Many similar claims were routinely approved.

All the tricks to maximize profitability at the government's expense were collected in a book written by one of the developers of the Armed Services Procurement Regulations, Howard Wright. In a section titled "Ten Ways to Maximize Profits," he explained a number of gaps: the use of accelerated depreciation methods; pricing capital and tooling costs directly into the contract; recovery of all "disproportionate" cost incurred; various reimbursement strategies for unallowable costs; and more. Rickover wondered whether his testimony might inadvertently increase the sales of the nefarious book.[575]

9.2 Cost accounting standards

For Rickover, industry profits couldn't be controlled by enforcing TINA requirements for certified cost and pricing data. The peculiarities of each contractor's accounting system made profit difficult to determine, even using furnished information. Normal methods gave accountants the freedom to allocate costs "in almost any manner they choose." Consequently, Rickover claimed that "actual profits can easily be hidden by the way overhead is charged, how component parts are priced, or how intracompany profits are handled. Companies are able to report as *cost* what is actually *profit*."

Rickover highlighted a Forbes article that accused accountants of "practices that are so loose they can be used to conceal rather than reveal a company's true financial picture." The generally accepted accounting principles (GAAP) became "generally accepted as damned meaningless." He was also fond quoting famed management expert Peter Drucker, who wrote how “any accountant worth his salt can convert any profit figure into a loss figure, or vice versa, if given control of the accounting definitions, all unquestionable within the limits of the proper accounting practices.”[576]

As a result of loose rules, the Renegotiation Board, which recouped excess profits from industry, could not do its job effectively. Without a standard for measuring cost and profit, the government had to send numerous auditors, contract officers, and technical people to the contractor’s facilities to reconstruct accounting records. Being severely understaffed for the task, most instances of excess profit went unnoticed. Rickover argued:

> “Neither the Truth-in-Negotiations Act nor the Renegotiation Act effectively protects the public against excessive costs and excessive profits. As you know, the real protection in this world comes not from people’s good intentions, but from laws.”

The law Rickover asked from Congress was a set of cost accounting standards such that cost and pricing data could more readily be used to determine profits. With standards that persisted from contract proposal to cost accumulation, and finally to outbound reports, government officers would have a consistent means for measuring contractor performance and profit. The information put them on an “equal footing” with industry. Government could understand the prices under negotiation in the same way as industry.[577]

Rickover claimed that the cost accounting standards could save the taxpayers $2 billion each year. He derived the figure from his past ability to negotiate prices down 5 to 10 percent when cost information was available, and if that could be applied to the government’s $40 billion procurement program, then the savings amounted to “at least” $2 billion. Opponents found the figure incredible. The Renegotiation Board estimated total industry profits for negotiable contracts in 1969 at only $2.2 billion. Rickover responded that the Board takes at face value what industry reports. Without standard accounting data, industry’s real profits may well have been $4 billion or much higher without the Board knowing it.

Despite his rhetoric, Rickover’s purpose was not to reduce profits *per se*, but to reduce overall costs by introducing standards and quality control into financial management. Over the past two decades, Rickover had impressed upon industry the need for such technical standards in engineering and production. Industry first responded that they could not work to the stringent specifications required by the nuclear navy, but Rickover was able to build a supply chain that could. Quality control and cost control tended to go hand-in-hand, as the Japanese would later learn to their competitive advantage. Rickover wanted to extend the concept of standards to cost accounting no matter industry's bellyaching. "Industry usually overdramatizes the difficulty of change," Rickover explained.

After five years of lobbying, Rickover finally had made inroads. On the first of July 1968, Congress passed Public Law 90-370 which, in part, directed the General Accounting Office to produce a report on the feasibility of uniform cost accounting standards. The report was scheduled for February 1969, but wasn't received until nearly a year later due to some hesitancy by Comptroller General Elmer Staats. However, the evidence accumulating from GAO audits turned out to be even more embarrassing than Rickover had told Congress. The GAO found instances of double-charging, where "indirect" workers charged time to the overhead pool at the same time they were directly charging a government contract. The GAO finally found that cost accounting standards were feasible, but asked for another three or more years to develop the actual list to be implemented.

Rickover grew impatient. He told Congress that "Since the time of Fabius the Cunctator, the strategy of defeat by delay has a long history of success." When the GAO delegated responsibility for developing the cost accounting standards to an independent board, Rickover cried how one of the members was an industry accountant. He said that "It will be like the Polish Parliament of 200 years ago; one adverse vote will kill any measure." Rickover charged that the board would steer the standards to the advantage of industry.[578]

Eventually, the Cost Accounting Standards Board came out with a list of 19 standards which addressed many of the loopholes Rickover pointed to, particularly on the allocation of costs to individual orders. They also required disclosure statements, which would record any accounting assumptions up-front so that government can better audit costs and methods. Shortly after the standards rolled out, Congress let the Renegotiation Board expire in 1976. Rickover was bewildered. Now that the cost accounting standards made TINA reports reveal profit more accurately, there was no process for recouping excess profits once discovered.

9.3 Managerial accounting

Many accountants initial opposition to the cost accounting standards stemmed from the vagueness of Rickover's proposal. Just a few years before, the government seemed to overreach on cost accounting by pushing particular systems under the banner of the Program Review and Evaluation Technique (PERT). The PERT requirements not only mandated standards for cost accounting, but it mandated the particular cost objectives and allocation methods to be used by the firm. For example, the government wanted material costs to be charged to particular subassemblies only after it came out of inventory for use on the line. The detailed intrusion into the business systems of the contractors led to large reimbursement claims, and eventually, reform.

By 1967, PERT was replaced with standards for cost and performance systems, called the Cost/Schedule Control System Criteria (C/SCSC). Still, the implementation proved "long and emotionally trying." One standard, collecting costs by hardware end-item in addition to functional departments, continued to create problems. Contractors traditionally controlled costs by organization and object of payment, not by end-items like actuators, switchboards, and so forth. The C/SCSC, however, required both.

Hardware-oriented cost accounting required lower level detail, resulting in an explosion in the number of accounts to be managed. In one case, the C/SCSC forced a contractor to control 3,300 cost accounts, or points where budgets are compared to the actual costs incurred. That cost information was further allocated to 21 million work packages. However, the benefit of C/SCSC was that it allowed contractors to allocate down from cost accounts to work packages. The old PERT method would have required the contractor's accounting system to collect costs by the 21 million work packages individually rather than the 3,300 cost accounts. Still, thousands of cost accounts was far more than the firm's managers would have used to control operations. Oftentimes, firms kept a double set of books; one to control the firm and the next to satisfy the government. Two books helped maintain the integrity of financial accounting information from the complications and changes involved in managerial accounting.[579]

Many industry accountants initially feared Rickover had asked for accounting rules on how to assign costs to all manner of hardware, down to cogs and widgets. Performing the task on high-dollar programs under cost-plus contracts was hard enough. Reorganizing the accounting system to perform the functions on all contracts over $100,000 was a far-fetched endeavor.[580]

Elmer Staats interpreted Rickover differently from early on. Staats pushed for standards in the attribution of costs to particular contract orders, not necessarily hardware end-items. In other words, rather than assigning costs to a standard set of components that aggregated into weapon systems, Staats focused the cost accounting standards on defining direct labor, appropriate overhead allocation methods, and assignment of these costs to an entire contract order. This would better provide insight into contractor profit, but would not necessarily illuminate the cost of systems, subsystems, and components to better estimate cost effectiveness or plan new systems. The shift was something accountants could live with more easily.

Even with that understanding, Staats still expressed two concerns before the National Associations of Accountants. First, accountants had been working on the problem of comparability of accounting results for decades. "Of course," Staats told the accountants, "to all of us here the challenge of applying uniform cost accounting standards… is as clear as a bolt of lightning." In 1932, for example, a committee of certified public accountants and representatives from stock exchanges met to consider methods for attaining comparability of financial statements. They found "overwhelming arguments" against standards that may pigeonhole a diverse set of ever-changing company processes.

A second concern was that Rickover's standards drove to a far lower level of insight than financial accounting. Staats observed how it was the first time "cost" appeared "in the proposal of legislation with accounting standards." Before that time, accounting standards had been regulated to ensure the accuracy of overall financial information such as income statements and balance sheets. Financial reports needed to be accurate to protect investors in public companies from fraud. Even at this higher level, accountants struggled to achieve consistency.[581]

Rickover's cost accounting standards entered the realm of managerial accountancy. Whereas financial accounting informed outsiders about investment decisions, managerial accounting informed insiders about decisions within the firm. It aided in product pricing, planning the manufacturing line, and measuring efficiency. So long as financial accounting standards were met, managerial accounting had always been the prerogative of the firm. Its information was strictly confidential.

Accounting scholar Howard Wright disagreed with the deepening of accounting standards from the financial down to the managerial level. He said that the consistency advocated by the Comptroller General would "embrace the entire accounting and reporting system, including that of cost accounting; would embrace all similar divisions of a company; and would extend off into infinity without change." New accounting methods could never be substituted for old ones if all contracts required consistency because there will always be overlap between contracts in execution. He called such rigidity "unrealistic."[582]

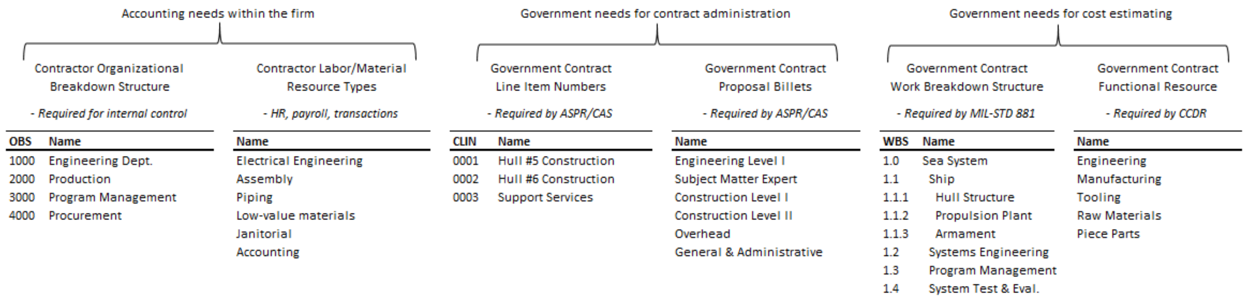
9.4 Cost estimation

While the Cost Accounting Standards sought to improve government insight into contractor profit, it did not intend to illuminate the production cost of military end-items. It therefore did not support the defense management framework envisioned by Charles Hitch, David Novick, Robert McNamara, and others who supported the Planning-Programming-Budgeting System. Cost information did not logically extend from the program orientation of the budget. Cost information at the level useful for a systems analysis was either scattered or non-existent.

Management system regulations like PERT and its successor criteria, the C/SCSC, were separate from the cost accounting standards. Their reports had to be made a contractual requirement for each effort. Though the C/SCSC required hardware-oriented cost data, it fell short of providing an adequate basis for cost estimating functions. For example, contractors could define their own hardware work breakdown structure (WBS), particularly below the major subsystem level. It was difficult for OSD to enforce the military standard on their program officers, who preferred tailoring the WBS alongside the contractor to suit their individual needs. The result made cost normalization across contracts nearly impossible. Two independent analysts could scarcely return the same results.

Another major issue was that the C/SCSC didn't apply to fixed-price contracts. Because various contract types contribute to the total system acquisition, it often missed the full scope. For example, the government may buy engines, radars, or other equipment separately and hand it over to the prime. As programs enter production, dominated by fixed-price contracts, C/SCSC information vanished. It offered no basis for estimating how price changes with the quantity produced, as reflected in learning curves. Because production is the far larger slice of the acquisition pie, small changes to the learning parameter create huge swings in program cost outcomes.[583]

More fundamentally, C/SCSC was a management and planning function rather than a cost estimating function. It did not provide three classes of accounting information necessary for cost estimators. First, a segregation of the total cost attributable to recurring expenditures of quantity production (such as touch labor) and non-recurring costs of development (such as design). Second, reporting on labor hours and component quantities, which serve as the basis for cost estimating relationships including learning curves. Third, functional break-outs of activities. Costs and hours needed to be identified by resource type, including engineering, manufacturing, subcontracts, raw materials, and so forth. They also needed identification of direct costs and indirect allocations of overhead costs to the contract. The additional breakouts, as well as required use of a standard WBS, were partially implemented in 1966 and were later revised on October 24, 1973 with the Contractor Cost Data Report (CCDR).[584]



The CCDR was essentially an itemized receipt provided at cost of production with a line-item for profit. With the information, analysts attempted to predict the cost of new program decisions using experience as the most realistic basis for future outcomes. One of the four reports required plant-wide costs to estimate future overhead rates.[585] Receiving cost information from all contractors in a standard WBS may even improve the government's position during negotiations because it could compare across contractors. Applying statistical techniques to the incoming data, government analysts could control for system characteristics and predict future costs based not on opinion or judgment, but quantitative evidence.

9.5 Will cost

The CCDR came to be applied on major acquisition contracts as a result of one particularly convincing case study. On December 2, 1971, Deputy Secretary of Defense David Packard received a briefing that compared the cost estimates for the Navy's new F-14 swing-wing fighter aircraft. It showed the cost per pound of airframe (the assumed cost-driver) as estimated by two sources. The prime contractor, Grumman, provided the first, presumably building up to the total price based on engineering plans. Government cost estimators provided the second using a parametric, or "will cost," technique based on statistical analysis of historical data. The chart showed Grumman's 1969 contract proposal cost ranging between one-quarter and one-third of the cost estimated by the government depending on the quantity of aircraft produced. Less than two years later, Grumman's estimates had grown so much as to reach the government's "will cost" estimate almost exactly.

Packard was keenly aware that the F-14 program would have looked very different had decision-makers believed the "will cost" estimate. He issued a memorandum five days later demanding an independent parametric estimate be performed for each major weapon system at program milestones. It proved one of Packard's last efforts in government. He left office on December 13, 1971.

Secretary of Defense Melvin Laird carried forward Packard's cost estimating initiative. In the next month of January 1972, he established the OSD Cost Analysis Improvement Group (CAIG). Fittingly, he placed it under the control of Program Analysis & Evaluation, the successor to ASD Systems Analysis. The CAIG performed independent cost estimates in support of the DSARC milestone review process. In order to perform its duties, Laird authorized it to collect the cost data it required.[586]

The CCDR, however, ran into accounting consistency problems that remained unresolved by the Cost Accounting Standards Board, which focused on assigning costs to contract orders. The CCDR needed stricter standardization, including cost assignment to the standard hierarchy of systems, subsystems, and components described by the MIL-STD 881 work breakdown structure. Yet this was precisely the kind of cost standards that accountants initially fought against so vehemently. When the contractor's natural structure did not align with WBS elements planned by the government in the CCDR, the contractors would allocate even direct costs to the report using assumptions which differed from person to person, and from time to time. As a result, the CCDR was difficult to interpret without normalizing for the peculiarities of the contractor's accounting system. The Cost Accounting Standards did not help in the matter.

Even if system costs could be revealed objectively, there were more problems to overcome. Historical costs, for one, may not be predictive of future system costs. Ronald Coase argued that "Business decisions depend on estimates of the future. Accounting records cannot therefore be used as a guide for future action without considering how far the conditions which have existed in the past will continue in the future."[587] The statistical problem makes historical cost data inappropriate for predicting future outcomes in an uncertain and nonlinear environment.[588]

Suppose, for example, there existed cost and effectiveness data for subsonic aircraft. One variable affecting aircraft cost is its speed. Models often assume a linear or log-linear relationship between cost and aircraft speed, holding other important variables constant. However, when predicting the cost of the first aircraft that can operate in transonic speeds, the model would neglect new difficulties presented by shock waves. After a certain point small speed increases generate outsized stresses on the airframe. The effects of these physical realities are not apparent in the historical data.

The solution arose in England in an empirical manner after diverse testing. It turned out that the elevators in the aircraft's tail had to be removed and the entire horizontal stabilizer would be movable instead. The example demonstrates that even so-called straight line extrapolations encounter unexpected nonlinearities, which in nature are the rule and not the exception. Innovation is by definition an endeavor to attain parameter values outside the range captured by the historical data. Problems take on new characteristics. Solutions tend to require new ways of doing things instead of getting more efficiency out of the old ways.

Parallel efforts, which allow for experiments in the data, are in some ways necessary to useful statistics. The larger and more flexible the systems being acquired, the fewer and less relevant are statistical data. In the 1950s, four times as many aircraft were prototyped than the next forty years combined.[589] Yet even with consciously generated experiments, statistical techniques often rely on unrealistic assumptions.

Assuming away statistical difficulties, as well as difficulties of cost accounting, "will cost" estimates may still lead to another problem. The analysis takes as sacrosanct existing cost figures and may perpetuate gross inefficiencies or neglect new opportunities. For example, the F-111 was one of the only tactical aircraft developed over the 1960s. It also provided some of the only data to analysts working on the next generation of swing-wing fighters. Yet the F-111 proved a boondoggle, and thus biased the data toward higher costs. As Ernest Fitzgerald testified to Congress:

> "… over-dependence on the probable cost estimating techniques has had a bad effect in other areas. To begin with, since the techniques used do not recognize inefficiencies in the bases used for projections, the approach tends to build excess costs into future estimates. For example, the cost estimates for the new generation of fighter aircraft, the F-14 and F-15, are heavily influenced by cost experience on the F-111, which is highly suspect to say the least."[590]

Indeed, systems experiencing the worst performance often have the best collected, organized, and analyzed data because of additional scrutiny from OSD and Congress. Future target costs based on these precedents will then have high costs baked into them. Anything other than large underruns to target costs so derived actually signal escalating prices and continued deterioration of performance. When past performance influences current standards, the system can enter a reinforcing feedback loop and drift into deteriorating performance. The process is further reinforced when decision makers tend to believe bad news more than good news, and a more realistic cost estimate is in their minds a higher one. As Burton Klein observed:

> "While lower echelon organizations sometimes underestimate the cost of program changes, my observations indicate that upper echelons almost invariable overestimate them. Often the costs of making any changes in a particular configuration are made to seem astronomical, even before a single piece of metal has been bent."[591]

One test of performance is whether the cost escalation of defense goods had been growing faster than consumer prices in the economy at-large, represented by the inflation rate. Higher rates of relative price growth in a sector tend to indicate stagnating or declining productivity. Rickover said in 1968 that the Bureau of Labor and Statistics showed wholesale prices grew about 15% over the course of a decade, while military equipment went up "30, 40, 50 percent and more" in just the past two or three years.[592]

The GAO could not find indexes tracking the prices of military goods. All they could find was research on changes in the hourly earnings of defense labor and in material prices. Yet the prices of inputs to the production process did not reveal price trends in defense outputs, such as aircraft, radars, ships, and so forth.[593] Rickover claimed that high costs in defense goods were not due to high input prices such as wage rates, but inefficiency. "The Japanese, who have to import iron ore, can build a large tanker for less than the material costs alone in America."[594] The "will cost" analysis of historical data could not solve the problem of rapidly escalating prices due to inherent inefficiencies.

9.6 Should cost

Admiral Rickover was not the only man in the Navy disputing contractor costs to get the lowest possible price. Gordon Rule, the Navy's Director of Procurement Control and Clearance, also thought that contractors were charging too much. Both Admiral Rickover and Mr. Rule firmly believed in the market system, but both held the view that price competition could not be trusted in defense to produce efficient outcomes.

Rickover charged that contract labor could easily be found standing around. When they did work, it was of poor quality. Despite all the inefficiencies, the companies earned high profits. Mr.

Rule felt similarly. He scrutinized shipbuilding claims so closely that he generated a service-wide backlog of $1 billion in 1971, a situation earning him few friends in the Navy.

While Rickover wanted to nationalize the shipyards so that he could personally oversee the contractor's operations, Mr. Rule took a different route. Instead of having contractors work in government facilities, Mr. Rule sent a team of consultants to the contractor's facilities to review operations and make cost-cutting recommendations. The very first "should cost" review in 1967 targeted Pratt & Whitney's TF30 engine for the struggling F-111 aircraft. The result was a $100 million reduction on the Navy's engine contract.[595]

Though Congress was ecstatic about the prospect of more "should cost" reviews, industry complained how the Pentagon had no business directing their management. Firing back in a letter that Robert McNamara said was the best he'd ever read, Mr. Rule wrote that the government would not spend taxpayer money for excess overhead, sub-standard labor, "abnormal spoilage and rework," poor estimating, and poor subcontracting.[596] Mr. Rule believed that by applying proper application of rational management, such as through third-party review of operations, contractors could be made effective despite the lack of competition.

Advocates of the "should cost" approach—drawing heavily from existing best practices in industry—intended to alleviate fear of a cost disease problem that may result from parametric "will cost" analyses. The "should cost" approach sought to challenge historical data for inefficiencies using a mix of methods from industrial engineering and cost auditing. The Army "'Should Cost' Guide" stated that the difference with "will cost" is "the depth of the analysis and the extent to which the Government challenges inefficiencies in the contractor's operations."[597] "Should cost" requires teams of consultants to reside in the contractor's plants for weeks or months at a time. Ten points generally addressed in a "should cost" study include: (1) plant layout; (2) labor standards; (3) material control; (4) machine loading and utilization; (5) production scheduling; (6) make-or-buy practices; (7) subcontracting procedures; (8) quality control procedures; (9) indirect cost controls and allocations; and (10) accounting and cost estimating procedures.[598]

Despite its promises, the "should cost" analysis performed by the Navy did not save its F-111B aircraft. The Navy dropped out of the program for many reasons unsolved by the "should cost" study, leaving the Air Force alone in its procurement of the F-111. The "should cost" approach, it turned out, could only solve a limited range of issues. For example, previous decisions in research and development had a major impact on the producibility of the TF30 engine, and the F-111B aircraft system more generally. The limitation of "should cost" was quickly recognized by its fathers in the Navy, which conducted only three "should cost" studies between 1973 and 1979 while the Army performed 89 such studies and the Air Force 37. Congressmen wished to understand why such a promising tool as "should cost" was being neglected by the Navy. Frank P. Sanders, Assistant Secretary of the Navy for Installations and Logistics, testified on the subject in December 1969:

> "The major 'should cost' philosophy is basically that DOD should not endorse contract inefficiency by paying excess costs. This philosophy is fully stated in the ASPR, in our pricing policy and practice. In part, at least, it is being continually implemented. The big question is how to fully implement it in a practical manner.
>
> "As Mr. Rule has discussed… and I must agree with him, that consideration should be confined to procurement areas of sole source. He and I are in agreement that it is impossible to realistically apply the technique used in Pratt & Whitney 'should cost' approach to research and development."[599]

Sanders pointed out that the "should cost" approach was only useable in high-rate manufacturing, where routine operations could be benchmarked against industry best practices. Navy leadership believed that existing regulations already required such "should cost" duties as a matter of course. However, they did not see "should cost" as practicable for evaluating research and development activities. How could a third-party be expected to evaluate the "production" process of new ideas and new technologies which are nuanced and specialized? Disagreements cannot be resolved by reference to a source of demonstrated knowledge, leading to stalemated arguments. For example, one Army "should cost" analysis reached an impasse after 44 failed negotiation sessions.[600]

Ultimately, both "should cost" and "will cost" analyses were accepted as complementary. Elmer Staats shared concerns about building in higher costs using "will cost," but believed that "should cost" is most useful "in conjunction with estimation based on historical costs."[601] Donald Rice agreed, and provided a roadmap for their use. In the early planning stages, when information on the technical details are scarce, the parametric "will cost" approach is most useful. At later acquisition stages, when contractor proposals are prepared, enough information becomes available to use the "industrial engineering cost estimating" approach. "It is important to note," Rice wrote in a widely circulated memo, "that such parametric estimates are not recommended for program control purposes, but rather as a means of providing service and OSD management with the most probable resource impact of alternative programming decisions."[602]

9.7 Marginal cost

As the single buyer of defense goods, the government was able to compel contractors to accept regulations unlike anything in the private markets. Ultimately, government officials wanted to use their market power to pay the marginal cost of production under efficient conditions, with "fair" criteria for profits. "Will cost" and "should cost" analyses sprang up in response to the needs. But even with new regulations like the Cost Accounting Standards, the Cost/Schedule Control System Criteria, and the Contractor Cost Data Report, it still proved extremely difficult to determine what the incurred costs on a military item actually were, let alone what they ought to be.

By the early 1970s, the ideal of measuring costs had been pursued for well over a century. When railroad corporations became the biggest enterprises ever created in the mid-19th century, they started to replace the market system of small entrepreneurs with an organizational hierarchy. As a result, they lost the pricing information of activities under their span of control. In markets, rivalrous bidding surfaces the prices of various inputs to the production process. There was no equivalent process within the firm. In order to measure internal "prices," firms invented new cost accounting procedures to better relate inputs to outputs. Railroad companies measured the cost-per-ton-mile, among other metrics, for various cross-sections of the firm. The information helped railroad executives control costs and evaluate the performance of a new class of middle-managers.

As managerial accounting progressed into the last decades of the 19th century, it began to support the development of scientific management. Frederick Winslow Taylor was one of the leading advocates of the movement to put management on a rational basis. He sought to improve the efficiency of labor and materials by creating standards, such as the labor hours per unit and material quantities per unit. When combined with the allocation of overhead costs, the information could be used for product pricing. This allowed managers to estimate the minimum at which new work could be taken on, depending on fluctuating demand and input prices.

Managerial accounting reached a mature state with the rise of diversified corporations. Before the DuPont Company in 1903, organizations engaged in a single type of operation. Diversified firms experienced the new problem of multiple operating groups pursuing different ends. Decision-makers needed cost information to allocate capital among competing activities. By 1925, virtually all managerial accounting practices being used in 1975 had already existed.[603]

Neoclassical economics provided a theoretical framework to guide scientific management. One of the main economic results is that the firm's profit maximizing rule is to continue expanding output until the point where the revenue from the next sale is equal to the cost of that sale. Stated differently, a firm maximizes profit on a particular good or service when marginal cost equals marginal revenue. This rule is the same for so-called "perfectly competitive" and monopolistic conditions. Yet for economic theory to become operable, firms had to be able to determine the marginal cost of output, not to mention the "elasticity" of customer demand.

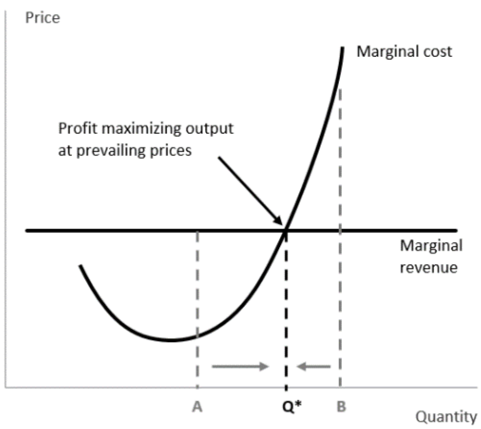


Illustration of the profit maximizing rule for the "price taking" firm. If the firm produces at quantity "A" then it can earn more profits by increasing quantity supplied. The revenue of the next unit solid is higher than its cost. However, after "Q" the firm starts to take losses where marginal costs are greater than marginal revenue. This model assumes the firm has only one output, its cost structure is fully known, and technology and consumer tastes are static.*

In theory marginal costs were measurable. In practice, however, it turned out to be very difficult. Even the best managed firms did not track direct costs to each and every class of output, let alone unit of output. More often, the firm ran a study to determine the baseline cost-per-unit, or "standard costs," then compared this baseline to aggregate flows of costs and units over an accounting period. The standard costs also formed the basis of pricing proposals, but more often reflected average rather than marginal costs. When accountants provided estimates of marginal costs as the basis for pricing, more often than not it proved "perilously" low.[604] Scientific management could not deliver on its promises; marginal cost proved a slippery concept.

When investigating the cost accounting standards in the early phases, Elmer Staats brought on Robert Anthony, an accounting scholar and former ASD Comptroller. Anthony was pleased that the standards did not address the cost of hardware end-items. To hint at the difficulties of deriving costs for even a simple product, Anthony wrote how it took seven years of industry studies to establish the standard cost of a 2" x 4" of lumber. He concluded the idea of a product's "cost" to be an abstract concept. Anthony illustrated:

> "Suppose the president of a widget company says, 'Last year our cost of manufacturing widgets was $1.80 each.' The ordinary person may think he has learned a concrete piece of information from this statement.

> "Anyone who understands the vagaries of cost accounting knows differently. He knows that 'cost' in this context has no generally accepted meaning."[605]

To Robert Anthony, the concept of cost had a large subjective component. The reality did not go completely unnoticed by economists. Even though economist James M. Buchanan received the Nobel Prize for his work on the public choice theory, he regarded his 1969 book *Cost and Choice* to be his most important contribution.[606] It explained the limits of what accounting information can convey about what is important.

Buchanan argued that neoclassical economists viewed costs as a measurable quantity of dollars, and that relative input costs of two goods determines the exchange value. Indeed, this was the underlying assumption of contract pricing in defense. However, for Buchanan, costs only existed in the mind of decision-makers at the time of choice. It is based on anticipations of the future values of alternative courses of actions. As such, costs facing one person could never be measured by another; they were tied to a subjective choice and not the resulting money outlays.[607]

9.8 Opportunity cost

The "will cost" and "should cost" analyses represent the monopsonist's tools for determining prices in lieu of those which arise from competitive exchange between buyers and sellers. Yet the analyses rely on an objective view of value. The view attaches dollar outlays to factor resources, such as labor and materials, which carry those dollars throughout the stages of production and ultimately define the end item's cost. Production cost, under the "objective view," explains the value of a good or service, and is the basis for price determination in defense acquisition.

The rivalrous competition that drives markets, however, is based on divergent expectations of the participants. The suppliers see the same factor resources—labor and materials—but disagree on what choices should be made in their combination, and therefore disagree on the true cost of the factors. If a unit of labor can produce more value in one process relative to another, then the decision-maker's view of its cost depends on the decisions he makes. Lionel Robbins wrote that "The process of valuation is essentially a process of choice, and costs are the negative aspect of this process."[608] Whether the supplier made good choices resulting from their evaluation of factor prices is determined after-the-fact by the buyers. In the "subjective view," costs are uniquely determined by each decision-maker and are only relevant at the time of the decision.[609]

Though the "objective view" dominates business practices in defense, the "subjective view" of cost has been accepted in economic theory since the marginalist revolution. The cost of producing a good is irrelevant to the buyer. Art is one obvious example. But consider the slide-rule; once the price of digital calculators came down enough the price most people would pay for a slide-rule went basically to zero even though the cost of production did not.

The price of a good or service is a cost to the buyer and the cost consists of the buyer's own valuation of foregone alternatives. Though a cost is dated at the time of commitment, its downstream benefits may change along with technology, tastes, and information. As G.F. Thirlby explained:

> "The act of discovering cost, which really means discovering which of the considered alternatives is to be rejected, inevitably involves valuation… This valuation necessarily involves estimates of happenings in the future about which the decision-maker can never be certain. The decision is based upon ex ante reckonings, or advance calculations, which involve looking into the future, and consequently must, even for this reason, be matters of opinion."[610]

In the evaluation of alternative courses of action, the next-best option represents what economists call the opportunity cost. The idea was clearly understood by Harvey Sapolsky in his classic book on the Fleet Ballistic Missile (FBM) program. "Calculating the dollar cost of the FBM system," Sapolsky wrote, "does not reveal its true price. To determine that, the opportunity costs involved in creating the system must be considered. The $10 billion allocated to the Polaris had many alternative uses, all of which had to be sacrificed with the decision to move ahead with the system." The FBM not only drew away dollars from Navy operations and maintenance as well as other missile developments, it sucked up the best talent from Navy programs and could perhaps be the cause of some failures. Yet the FBM program appeared worth the opportunity costs because the Navy and the nation placed overwhelming value on developing an invulnerable nuclear platform. Such imperatives of force structure are rarely so clear to defense decision-makers.[611]

Dollar outlays, while objectively measurable, are not necessarily indicative of opportunity costs. Two different designs costing the same money may return starkly different performance, depending on the ingenuity of the designers. Under uncertainty, input costs tell an observer nothing about the value being generated. An observer would have to know the specific details of the choices made along the way to judge whether the outlays were worth it.

On the other hand, when there is little uncertainty about the methods to be used, there is often a tight correspondence between costs and value. It is only when all relevant "factor and product values are assumed known," Jack Wiseman remarked, that "there is *no doubt* about the production decisions to be taken." The concept of cost under the assumption of perfect information is fundamentally a problem of scarcity. It contains no element of uncertainty.[612] (Wiseman, 1981).

Different cost concepts

- *Direct costs*—labor (e.g., fabrication, assembly) and material (e.g., steel, piece parts) that are traceable to a specific output.
- *Indirect costs*—costs which support more than one objective in production. Typical categories include fringe (e.g., medical, retirement), overhead costs (e.g., supervisors, facilities), general & administrative (e.g., corporate, bid & proposal, independent research & development), and facilities capital cost of money.
- *Cost accounting standards*—methods for achieving consistency in proposing, accumulating, and reporting costs. Primarily applies to expensing direct and indirect costs to individual contract orders.
- *Standard cost*—the estimated unit-cost of an activity or output which firms use as a benchmark to inform pricing and evaluate performance.
- *Marginal cost*—the additional cost incurred by producing one more unit of output.
- *Opportunity cost*—the subjective use-value of the next-best alternative foregone at the time of choice.
- *Will cost*—a statistical analysis of the most likely cost outcome given historical data; often equated with parametric analysis and cost estimating relationships.
- *Should cost*—a method of challenging historical data for inefficiencies with the use of industrial engineering and cost auditing.
- *Must cost*—an estimate of the amount of resources likely to be made available for a military program.
- *Cost growth*—the dollar increase in program or contract costs relative to the approved baseline.
- *Cost escalation*—the sustained increase in unit-costs of a particular constant-quality good or service over time; it is distinct from inflation, which represents an increase in the general price-level, usually for the economy as a whole.

9.9 Intangibles

For repetitive production associated with the industrial era, the amount of non-monetary aspects related to cost is relatively small. The output was generally of a known specification with an existing market price. It was mostly tangible, the bulk of its value coming from raw materials, machining, assembly, and distribution. If the project failed, much of the investment could be recovered in capital stock and intermediate goods. In short, there was less uncertainty.

Though tracking physical resource costs may explain long run prices under static technical conditions, the most important aspects of weapons acquisition, and the modern economy, have nothing to do with repetitive production. Costing problems are compounded when considering new ideas and non-reproducible production. For example, software represents a product whose marginal cost of reproduction is zero. Software companies do not own physical assets in the same way steel manufacturers do; they own intellectual property and a company culture that is embodied in lines of code, reputation, and the potential for great ideas. Much of their value is *intangible*.

The price of software products cannot be explained by costing activities related to tangible assets. With reproducible goods, increasing output requires adding units of labor and capital. With intangible assets, on the other hand, there is low or zero cost to producing the next unit. A combat vehicle design can be shared around the world almost for free, and software systems can be replicated onto the next machine at the push of a button. All of the value of the intangible assets is in the engineering and creativity that went into it. In other words, almost all of the money outlays are fixed and up-front while the marginal cost of reproduction is near zero. As software developer Fredrick Brooks realized in 1975, the management systems used in the Department of Defense were ill-equipped, if not dangerous, when investing in intangible assets.

The genius of industrial era manufacturing was the use of interchangeable units of labor and capital. Introducing new workers to expand output required little in terms of training and coordination. Managers could specialize employee functions to a routine, requiring little oversight and only brief—linear—communication between them.

Brooks, however, realized that adding units of labor and capital to software development did not increase output. He pointed to the presence of uncertainty and communication. First, uncertainty affects software development, like all R&D, because it explores new concepts. Development projects do not deploy labor and capital in routine ways. Second, each software task is largely inseparable from the whole project. Each worker must communicate with a far larger number of colleagues, and must be familiar with a far larger set of technologies, goals, and strategies. Brooks concluded:

> "Cost does indeed vary as the product of the number of men and the number of months. Progress does not. *Hence the man-month as a unit for measuring the size of a job is a dangerous and deceptive myth*. It implies that men and months are interchangeable."[613]

Investment in intangible assets may create economic value unrelated to money outlays and costing methodologies. Examples of intangibles assets include computerized information (software and databases), innovative property (R&D, patents, copyrights, product designs, trademarks), and economic competences (training, branding, business processes, supply chains, company culture). Intangible investments require real dollar outlays, but their precise contribution to sources of revenue is unclear.[614]

As innovation has taken preeminence over repetitive production, the importance of intangibles has only increased. Accounting scholars Baruch Lev and Feng Gu found that the value of tangible assets and earnings explained about 85 percent of companies' value when entering the stock market from 1950 to 1959. The figure fell to about 55 percent over the period 1970 to 1979. Between 2000 and 2013, the figure plummeted to under 30 percent,[615] reaching just 13 percent in 2017.[616] Costs related to tangible assets no longer adequately describe the value being generated by firms.

The value of a weapon system is not in bending metal or laying wires, even if that's where most of the money outlays go. The value is in product design. R&D decisions tightly constrain almost all subsequent decisions in production and sustainment. The design determines production methods and costs. The design determines reliability, maintainability, affordability, and other important aspects.

Managers are often told to focus attention on where the dollars go. But even though only 10 percent of money costs go to weapon system R&D, decisions made in that phase contribute to something more like 90 percent of the total opportunity costs. Weapon system value is derived from intangibles. However, in the phase where decisions matter most—research and development—the Department of Defense continues to manage itself by industrial era techniques.

Ronald Coase already understood the effects of intangibles in 1938, writing how "costs and receipts cannot be expressed unambiguously in money terms since courses of action may have advantages and disadvantages which are not monetary in character, because of the existence of uncertainty and also because of differences in the point of time at which payments are made and receipts obtained."[617] For example, when producing software, as when producing new ideas, the ultimate product and its value to potential buyers is still an imagining of the innovator. Yet he must make cost decisions before the results of those decisions can be known and cannot liquidate the investment as though it were plant or an intermediate good. Intangible investments tend to be sunk investments irredeemable in their pieces, but through synergies, spillovers, and scalability, the future value of combined investment can be quite substantial.[618]

The choice to take on a cost only makes sense in relation to the value generated down the line from that cost. When the potential value is uncertain, it cannot yet be said whether the dollar outlays were worth the cost or not. In the "objective view," the end product's value is determined by the historical cost of its factor inputs. In the "subjective view," the factor input prices are derived from evaluations placed on the future value of the final product.

9.10 Standing orders

The marginal costing rule followed by government officials' attempts to approximate the outcome of perfectly competitive markets. Such idealized markets, however, have no such rule in which firms seek to price their output at marginal cost; it is an outcome of interactions between various buyers and sellers. The final check on supplier efficiency is bankruptcy, not the marginal cost-price calculation. Yet in defense acquisition, as in market socialism, pricing outputs at marginal cost is a rule to be followed.

The rule presents a problem for determining performance. "If no rule other than the marginal cost rule is used," Jack Wiseman pointed out, "is there any check on the efficiency of the distribution of resources between uses?" He answered that there may be a check upon the reasonableness of estimates when "the alternatives considered relate to the production of known things by known methods." However, Wiseman had a different answer under uncertainty and intangible investments:

> "The imponderables, and with them the difficulty of a direct check on efficiency, become the greater the more unique or novel are the matters with which decisions are concerned. All decisions about new and major investments of resources seem likely to involve important imponderables of this kind; it appears that those decisions likely to be most important to efficiency will be those upon which no adequate check can be made with the rule as now interpreted… There seems little possibility of a direct check upon whether the marginal-cost rule has been obeyed."[619]

The only check on efficiency then becomes the comparison of budgeted outlays with realized outlays, assuming away judgments about the value of foregone alternatives. In other words, the only efficiency-check on the marginal cost rule is a check on the manager's ability to forecast. The explanation accounts for the DoD's obsession with program and contract cost growth figures. Such figures, however, can only provide a partial check not only because an initial cost estimate may be biased by institutional factors but because cost growth cannot explain whether that program plan should have been chosen at all. When the plan is that of the central authority, the problems are compounded because the ability to correct errors depends on the ability of the manager to convince the central authority that an error has indeed occurred in relation to the larger plan. Wiseman concluded that "any restriction on the field of choice of managers is… a curb on efficiency."[620]

In the Department of Defense, the centrally planned program budget restricts the decision-making of local managers. If the manager carries out the program plan decided by the consensus building bureaucracy, then he has executed *standing orders*. He has made no decision of consequence. The manager cannot be said to have incurred any costs himself, no matter how many times dollars were converted into goods by purchase or hire.[621]

A program budget provides a forum for the consensus-building bureaucracy to decide before-the-fact matters of cost, schedule, and technical or performance attributes, highly restricting the manager's ability to consider alternatives. Program funding then gets locked into a narrow range of choices, meaning the opportunity cost of alternative actions is quite low, regardless of the actual dollars paid. Managers see money as cheap. Samuel Huntington observed that the manager, "if forced to choose, normally prefers fewer resources and greater freedom to allocate them as he sees fit than more resources less subject to his control."[622] When program control is restricted, the manager is more likely to expend effort to increase his topline budget at the expense of other managers rather than seeking better contractors or projects for the money he has available.[623]

A "subjective view" finds that people's actions shape the structure of the market which in turn constrains the actions of market participants. In other words, it takes a complex adaptive system view and an exchange-oriented approach. People face genuine choices, the consequences of which cannot be fully calculated beforehand. In fact, the chooser's perception of value is "generated in the choosing process, not separately from such process… The potential participants do not know until they enter the process what their own choices will be."[624] The Department of Defense, by contrast, attempts to spread objective cost information under the expectation that managers will be able to fully consider the alternatives and develop the optimal project plan before many technical issues are resolved.

The opportunity cost of alternative actions is a valuation process that requires experience with production and people in addition to experience with money calculations. Leadership must put the development of people first, who can then build the deep experienced required to make winning value judgements in a highly competitive, and innovative, environment. The rise of intangibles has made large group coordination, which was linear and routine in the industrial era, much more difficult. As a result, a focus on training and culture becomes primary to rigid systems for justifying and approving programs. As John Boyd often said, its "People, ideas, and hardware—in that order!"[625] Decades later, after recognizing the changes brought on by intangibles, famed tech entrepreneur Ben Horowitz wrote how "We take care of the people, the products and the profits, in that order."[626]

10. Culture

> There will always be a chasm between men with specific knowledge who lack power—the men responsible for doing the work—and men with power who lack this knowledge—the men with the power to approve funds. But the present system, which requires countless reviews and briefings to bridge this chasm does not work.
>
> Admiral Hyman Rickover
>
> Congressional testimony, 1971

Major programs undertaken by the Department of Defense require the coordination of large groups. In 1958, three Air Force ballistic missile programs involved more than 70,000 employees across 200 major subcontractors, who transacted with a further 200,000 part suppliers.[627] In the same year, the DoD in-house research and development workforce numbered 11,000 officers, 43,000 civilian scientists and engineers, and 10,000 business professionals.[628] Large group sizes are important for complex economic activity because they allow for a dramatic specialization of labor, which, if harnessed, can rapidly improve productivity.

Most industrial era production requiring large groups did not at the same time require intimate coordination. Labor specialized in routine activities needed only brief communication, such as handing piece parts down an assembly line. While specialization of the manufacturing process improved productivity, knowledge was not necessarily specialized. The weight of labor did not contribute to product design, plant layout, process improvement, and other intangible assets. In other words, most labor did not incur opportunity costs; many of their activities were programmed from the top as though they were pieces of capital.

By contrast, large weapon system developments require intimate coordination of large groups. The development of the Polaris missile—a single subsystem of the Fleet Ballistic Missile nuclear submarine—involved more than 10,000 employees at major subcontractors in addition to several hundred in the government project office.[629] Most participants not only performed specialized activities, but also had local knowledge beneficial to the program. They contributed creative energy to solving myriad technical problems across a vast number of components. As a result, participants made genuine choices that weighed opportunity costs.

The kind of large group coordination needed to scale new concepts and technologies is far more difficult, and far more rewarding, than coordination of reproducible goods by known methods. It requires strong in-house technical capabilities as well as an organizational culture that engenders trust. Cultural factors remain a major pre-requisite to harnessing an innovative environment.

10.1 Assurance

As group sizes increase and economic activity becomes more complex, more of the knowledge about alternative action sets are spread across the participants. No one person can comprehend but a small part of the total knowledge related to science and technology, let alone operational environments. The more advanced economic activity becomes, the more important it is that local knowledge is effectively coordinated throughout the system. The coordination, in one way or another, introduces exchanges mediated by contracts.

Tightly specified contracts can be drawn up when knowledge is general and uncertainty is minimal. In these cases, incentives provide all the assurance the buyer needs. In the Department of Defense, contractor proposals are often based on detailed specifications which outline all major activities. The contract assures that both parties will live up to their end because all relevant incentives have been listed and deemed compatible. The principal doesn't need to trust the agent.

It is in the agent's self-interest to deliver the product at the agreed price or face consequences from breach of contract.

Contracts based on incentive compatibility can only provide assurance to both sides in a limited range of situations. Only with relatively complete and accurate knowledge of the product design, factors of production, and other aspects, can the contract outline all contingencies. If one party were to gain asymmetric knowledge, it exposes the other side to opportunism. There are two general cases where the principal is unprotected from the opportunism of the agent, cases where mutually beneficial exchange is likely foregone because of the lack of assurance provided by incentive compatibility.

First, when the principal cannot effectively monitor the effort of the agent. For example, when an employee performs routine work, the employer may do a study of how many operations can be done in a given unit of time, and tie the employee's pay to the piece rate. The principal monitors the agent's input and output directly, tying it to a benchmark measure. However, when the agent's performance requires unobservable aspects, such as specialized knowledge related to an esoteric piece of engineering, then the principal cannot monitor the agent's performance. The agent may drive up billable hours by shirking on the job, or unfairly the build-up of his own capital stock at the expense of the principal. As localized knowledge grows, more opportunities for mutually beneficial exchange may be foregone due to the monitoring problem.

Second, incentive compatibility cannot be assured when contracts are incomplete. For example, in a development contract there is often great uncertainty as to the final product design. The prevalence of engineering change-orders in defense contracts is evidence of their incomplete nature. In these cases, the principal is exposed to the opportunism of the agent. Once the principal has committed to a strategy, the agent may overprice change-orders by holding the project hostage. As exchanges become increasingly complex, not all contingencies can be foreseen and stipulated in the contract. Even though the principal wants to make best use of new information learned by the agent, there is no incentive constraining the agent to do the right thing. Instead, the agent may take advantage of the principal. As a result, instances of mutually beneficial exchange through necessarily incomplete contracts are likely foregone.

Management systems in the Department of Defense were designed to limit opportunism rather than harness local information. The policies assume that the damage done from willful abuse of government funds outweighs the dramatic increases in productivity that can be activated by local knowledge. The effect is to stimulate a bureaucratic culture mired in checking and re-checking decisions. This leads to substantial transaction costs. In 1969, Comptroller General Elmer Staats said that "Estimates as to documentation costs range from 20 to over 50 percent of development costs, but reliable information is not available."[630] Professor Robert Judson reported in 1975:

> "If you want to calculate the costs of the way we do business, and this is a conservative estimate, we spend an amount equal to 50 percent of the total dollars involved. So, if the total dollars involved are a trillion dollars, we are spending $500 billion on trying to achieve various forms of accountability, and we do not get very much for that expenditure."[631]

While technological advances correspond with a deepening of the specialization of labor, benefits can only accrue to society when the local knowledge can be coordinated through exchanges. However, local knowledge also provides agents with "golden opportunities" to exploit the principal because the incentives written into the contract cannot restrain the unobserved opportunism of the agent. If the principal cannot trust the agent to restrain himself from acting on opportunism, then a wide range of welfare enhancing exchanges will incur high transaction costs or will never get realized at all. This is true of industrial contracts as well as employment contracts. The inability to coordinate localized knowledge can cause organizations to miss out on dramatic productivity improvements.[632]

10.2 Relational contracts

When advanced economic behavior requires local knowledge, providing discretion to the individuals with the most knowledge is paramount. As Frederic Scherer testified, "given the kinds of technical problems characterizing modern-day weapons developments, inflexibility of contractual instruments is incompatible with economy."[633] Unlike contracts which limit discretion by fully defining the incentives, relational contracts are loose and vague. Relational contracts provide flexibility to adapt to unpredictable situations through a lack of specificity. Not only is the principal provided discretion to redirect the agent when he learns something new, the agent is provided discretion to redirect the principal's resources based on his own, perhaps unarticulated, knowledge. If the principal can trust the agent not to exploit the opportunism recognized to pervade the contract, then a much wider range of exchanges are allowed to take place. The benefit is a substantial increase in productivity because more complex projects can be undertaken.

Before scientific management was thoroughly applied to defense acquisition, research and development was carried out on a more relational basis. For example, in 1955 the entire specification for the F-4 development contract fit within two pages. Certainly the Navy did not enter into the contract with McDonnell Aircraft thinking it complete by any means. By contrast, in 1980 the C-17 specification consisted of 13,516 pages and 35,077 pieces of art.[634]

There was a similar decline in relational contracting within the ranks of the Department of Defense. Discretion had been liberally extended throughout the in-house labs, bureaus, and technical services, until their lead role in weapons acquisition was replaced with dedicated program offices. The DoDD 5000.1 outlined official policy related to the program offices, and in 1971 it was a scant seven pages with 14 external references. Less than a decade later, there were 60 pages and 136 reference documents, totaling thousands of pages of policy.[635] In both external contracts with industry and internal policy with the program offices, defense acquisition shifted from relational contracts to more detailed rules based on incentives.

Admiral Hyman Rickover understood the power of relational contracts to accomplish ambitious programs. Within the government, Rickover corralled a great deal of authority to direct the naval nuclear reactors program as he saw fit. He extended that authority to his trusted subordinates. Rickover's technical director, Theodore Rockwell, recounted a scene which exemplifies the relational nature of his management. "The only thing I've done," Rickover told his team, "is to surround myself with people who are smarter than I am. I'm counting on you guys to keep me out of trouble." Rockwell remembered how "With a few exceptions, we all knew we were not as smart as he was, but we did know more than he did about certain things—each of us in his own area—and he was not threatened by that situation. In fact, as he said, he was counting on it, and that was empowering."

Rickover also extended relational contracting to industry participants. A quick phone call could initiate major undefinitized efforts. Contractors would get started on significant work at their own risk trusting Rickover to come through with the funding. For example, Rickover asked Newport News shipyard to develop the very first nuclear submarine. The "reluctant dragon" refused, and so in the middle of the meeting, Rickover called the manager of Electric Boat and asked if he would do it. The immediate response of "yes" steered to the company toward leading an important new area of technology in which it had no experience.

In return for what could be considered back-room dealings, Rickover expected a high degree of transparency from the contractors, just like he did of his subordinates. He wanted to stay informed of every meticulous detail, decide on major actions, and even make firm-specific decisions. For example, Rickover expected to review and approve shipyard managers on his program. In one case, Rickover refused a name and Newport News elected to go forward anyway. Rickover said he would deal with them "officially" from then forward. In other words, he rescinded the relational contract. When Newport News decided to comply, Rickover rewarded them. He arranged for a team of their engineers to learn from Electric Boat, which had gained a technical advantage. As Rockwell recalled, "Electric Boat would certainly not have volunteered to jump-start a new competitor in this way if EB had not had the same kind of full cooperation agreement with Rickover to which Newport News had objected."[636]

Rickover's nuclear program was built with a strong element of relational contracting. However productive the relationships are at harnessing local knowledge, they inevitably create opportunities for agents to exploit principals. Relational contracts can only persist so long as there is trust between the parties. Over the decades, Rickover began losing trust in his contractors, fighting them interminably on pricing decisions. In his finals years, he accused Electric Boat of outright fraud in their cost overrun claims on the *Los Angeles*-class submarine. The relational nature of advanced technology contracts opened the government up to opportunism by the contractor, even if it only existed in Rickover's mind.

10.3 Professionalism

Without the assurance provided by incentives, relational contracts only last so long as the parties trust each other. A major element in the extension of trust is demonstrated technical knowledge by the agent. If the principal knew the opportunity costs of all choices just as well as the agent, then principal would not accrue any benefits to extending discretion. There would be no problem of local knowledge. However, major projects require so many interconnected processes that no one person or list of requirements can possibly specify all decisions.

For example, Admiral Rickover integrated all the knowledge he possibly could into his own mind, requiring direct reports from over a hundred managers. He did not blindly trust his subordinates to manage the development of nuclear reactors. Despite his vast capacity to synthesize information, Rickover also understood that he could not personally solve every problem. To accomplish his goals, Rickover's top emphasis was not project work itself, but laying the foundations for trust. He personally interviewed every recruit—amounting to tens of thousands of interviews—and ensured their technical excellence with rigorous in-house training. Authority was delegated to those deemed to have the most merit. Rickover did not follow the general practice of putting military officers ahead of civilians, or seniority ahead of technical skill, as he explained:

> "Who worked for whom depended entirely on his competence. I have had civilians working for officers, officers working for civilians, higher ranking officers working for officers junior to them. I assign people to jobs on the basis of competence, not rank. The nuclear power plant doesn't know whether the man who designed it is a civilian or an officer."[637]

An organizational reliance on technical acumen did not figure highly for routine industrial operations. Though Fredrick Winslow Taylor was himself an engineer who contributed to innovations, his recommended techniques such as time-motion studies raised the status of financial and statistical acumen. With mass production, future decisions look very much like past decisions. Routinized activities lend themselves to data collection and optimization.

When working on novel processes at the frontier, technical acumen re-takes precedence. Rickover's organization, for example, sought to build the first nuclear reactor to produce useful energy and integrate it onto a submarine. There could be no reference to benchmarks. The information required to build to nuclear navy existed nowhere. It had to be worked out in real time, thoroughly documented, and only then routinized according to the strictest standards. As Rickover explained about managing the naval reactor program, "I daily face difficult scientific and engineering problems, the resolutions of which requires melding together experience, intuition, judgment, and experimental testing."[638] Gaining such skills took many years of on-the-job training. Yet the military services expected their officers to come from an operational user perspective to lead technical developments. Rickover complained:

> "How can a man possibly take charge of complex technical matters, say a man who has been captain of a ship and has not had the requisite scientific and engineering training and experience? Why, it is an absurdity on the face of it, and this is where much of our difficulty starts."[639]

Without the necessary experience, government program managers often relied on technical direction from the contractor, which was then reviewed by staff officers with no responsibility to get the job done. After two or three years when the manager finally begins to learn something, he moves on to another assignment. For Rickover, such managers could not be considered professionals. "As long as a man will accept dictation in a technical matter," Rickover said, "he is not a professional person." He charged that on engineering matters, the "Navy is not really a profession."[640] David Packard agreed with the thrust of Rickover's arguments:

> "To be brutally frank about this situation, the services need to be organized so that the development and production of new weapons systems is managed by people who are experts in that business. This is not the practice in the services. Instead, the weapons management job is performed under a system in which too much responsibility is given to officers whose special expertise is not development and procurement."[641]

10.4 Tenure

Department of Defense officials had long emphasized the central role of the program manager (PM). In 1956, the Robertson Committee recommended that the authority and organizational standing of PMs be increased, along with their tours of duty. It asked for tours to lengthen from a little over two years to an average of five years.[642] Similar recommendations came from the "New London" conference of 1963, and in 1965, DoD Directive 5010.14 required PMs to be available for at least three year tours.[643] The pronouncements created little change.

Nearly twenty years later, Congress legislated tours of four years for defense PMs.[644] An investigational subcommittee later found that average tenure did not reach four years, or even move in that direction. *It declined*. Only 5 percent of PMs had four years' experience; the number for the Air Force was zero. The longest tour of duty was just over five years and the average less than two. The subcommittee concluded that "the services have simply flouted the law."[645]

TABLE 1—COMPLIANCE WITH FOUR-YEAR TENURE PROVISION

Rationale	Number	Percent
Completion of 48 or more months	5	5
Achievement of major program milestone	1	1
Waiver by service secretary	4	4
Non-compliance with statute	84	89
Total	94	100

Extended tenure is a precondition to vesting authority with the PM. Even if a PM has received a formal technical education, that knowledge does not immediately translate to specialized military acquisition. Without staying on long enough to understand the particulars, a PM could not effectively wield strong authority. In such cases, the PM loses control of the acquisition cycle; its role devolves into advocacy and controlling the rate of spending.[646] David Packard saw cases where "the project manager is often little more than an errand boy for all the service officers, both above him and around him in the organization." The relevance of the PM degraded so much in the case of the F-111 that the PM wasn't even invited to important meetings on his own program.[647] Without extensive technical experience and a tenure long enough to apply it, vesting authority with the PM would be misplaced.

Extended tenure also addresses the problem of responsibility. The success or failure of a project cannot be attributed unless the PM stays on board long enough to see the results. Often, defense programs are planned by personnel from the service staffs and the contractors. The PM inherits the program and expects to depart for another assignment before outcomes are realized. Each successive PM feels no responsibility for the decisions made prior to him, and moreover, feels that he will not be held accountable for his current decisions. As Rickover explained:

> "Before the results of the decisions are in, the manager will have moved and a new manager, equally unqualified technically, will take his place. Naturally the new manager will feel no responsibility for prior decisions and actions; his primary ambition will be to keep the project moving in the hope that it will not fail during his own tour. Thus, responsibility cannot be fixed and there is bound to be little continuity in technical direction for most of the defense developments underway today…
>
> "To remain inexpert by frequent emigration from one's job, to leave one's mistakes and one's past to start out for a new life—this is what the short tour of duty does; one can be carefree forever. True responsibility for one's actions is not ever comprehended. Life becomes a series of disconnected events."[648]

Excessive rotation did not just affect the PM position within the government. Rickover found that in industry, managers rarely stayed around for long. Every shipyard had seen at least one of its top three people rotate every six months over an 18 year period.[649] During that time, the average shipyard saw 10 different commanders, 15 different planning officers, and 12 different production officers.[650] Turnover within industry's ranks was equally poor. The Navy reported how one major shipbuilder had personnel turnover near 60 percent a year. Another hired 12,000 people to increase year-end employment by just 650. A third shipbuilder hired 8,000 people in a year and suffered a net loss in employment.[651]

By contrast, there was no doubt to anyone involved who was responsible for the Navy's nuclear reactor program. Senator "Scoop" Jackson praised Rickover personally for winning the race to nuclear-powered submarines and civilian power stations. "He assumed complete responsibility and did the job."[652] That kind of responsibility, Rickover claimed, required 10 to 15 years of experience before rising to PM.[653] He expected the same dedication from subordinates. By his retirement, Rickover built an organization with tremendous in-house technical knowledge based on long tours of duty:

> "An important factor in the technical accomplishments of the Naval Nuclear Propulsion Program has been the emphasis on continuity, experience and technical expertise in personnel... The most senior 100 people have an average of about 15 years of experience and the 20 division heads have an average of about 20 years of experience, having served in many technical areas including field positions."[654]

Rickover's emphasis on technical expertise and long tours of duty corresponded well with French military acquisition. Armaments engineers in France received seven years of education in science and technology before a five year "hands-in-the-grease" assignment in a production facility. Additional tours with higher levels of responsibility and operational experience were then required. After 10 to 15 years of experience, a person could become PM for a small project. 25 years was common for complicated projects. The continuity of high quality personnel built an "institutional memory" into the French acquisition system.[655]

10.5 Trust

Professional experience and lengthy tenures provide valuable signals to the principal that the agent can be trusted. Over the course of time, the agent demonstrates local knowledge and builds a reputation for excellence. "As long as a man is getting results," Rickover said, "he should be given full authority to decide what work should or should not be done and where and by whom it should be done."[656] Results, however, do not completely verify that the agent has not taken advantage of "golden opportunities."

At the technological frontier, signals of excellence and loyalty may not be apparent from outcomes due to the presence of uncertainty. The results may not be indicative of whether the agent acted in his estimation of the principal's best interests. A failed experiment is not, for example, evidence of the agent's opportunism. In order for relational contracts to reach their greatest benefit, the principal must believe that the agent would never consider acting on a "golden opportunity." It suggests that the agent has signaled a particular set of moral beliefs to the principal.[657]

In addition to experience and tenure, an important aspect to the extension of relational contracts is a general adherence to the rules of conduct. The significance of personal moral codes has a long tradition in military units. Army War College historian Andrew Hill wrote how "Militaries are societies unto themselves, with their own sociology, history, values and beliefs. Military culture is built on these principles of shared history and values."[658] The Marines' motto *semper fi*, for example, means "always faithful." People readily accept cultural norms not because of prudence, but because they desire to be worthy of the genuine esteem of their peers.

Rickover explained the kind of moral beliefs that a contractual agent must have to engender trust. "I should like to commend to you," Rickover said, "a liberal adaptation of the injunction contained in the Oath of Hippocrates that the professional man do nothing that will harm his client."[659] Rickover's own actions as an agent to the interests of Congress and the public exemplified his point. Not only did he show tremendous technical progress at every stage, Rickover acted in good faith whenever possible. In one example, Rickover carried out his program for a million dollars less than budgeted. "The only honorable thing to do with that money," Rickover told Congress, "is turn it over to the Treasury, and that I have done." The committee chairman was taken aback. "That is unprecedented. I literally have never heard of such a thing in all my years in government."[660] Repeated exchanges like this engendered trust between Rickover and many Congressmen, which stemmed more from their estimation of Rickover's moral values rather than the assurance provided by regulations and oversight.

It is also important for the agent to be able to trust the principal. For example, a civil servant may expect that dedication and excellence will earn him rewards such as a chance at the executive level. However, more often than not, these positions are filled by outsiders. "Consider the effect on the morale of a career civil servant or military employee," Rickover said, "who watches men from industry come into policymaking positions for short periods of time, and go back to industry after 2 to 3 years, sometimes less."[661]

Equally important to the agent is the belief that his own welfare will not be unfairly sacrificed by the principal, who may rationalize such betrayal to be in the interest of the greater good.[662] For example, an official approached Rickover to sequester scarce materials he had procured in order to develop the first nuclear submarine. It was touted to benefit the Air Force and the entire war effort in Korea during the early 1950s, though it came at the expense of the Navy nuclear program. Rickover fought back:

> "… you want me to take the statesmanlike position, to rise above my parochial viewpoint, to consider the good of the national as a whole, and perhaps the good of all humanity, is that it? Well, I'm not going to do it. You're not in a position to judge just how urgent or important their need really is. Neither am I. What I *do* know is that I have been ordered by the president of the United States to have a ship ready to go to sea by January 1955, and I intend to do my damnedest to make that happen."[663]

Even though Rickover had identified many sound principles for building an organizational culture, and railed against both contractors and bureaucrats on their moral standing, even he violated the trust of his superiors and the public. In his final years, General Dynamics came out with evidence that Rickover had illegally accepted gifts. While most of the cases were trivial, the fact of the matter was that such violations justly tarnished his reputation. He falsely reasoned the gifts as acceptable because of his sterling reputation, as well as all the good he had accomplished for the nation. We are humiliated when we have been deceived, Adam Smith reasoned back in 1759, and the pain of this deception far outweighs the promise of benefitting from a continued relationship. For Smith, the most important rules of conduct are the respect for life, property, and promises. They are like the "rules of grammar," and must never be violated even if it appears to achieve a greater good.

10.6 Government in-house

After World War II, the United States had its most robust in-house technical staff—although it remained in under-emphasized compared to its European counterparts. Still, the Army Ballistic Missile Agency developed almost all of Redstone and Jupiter's major subsystems and components in-house during the 1950s. Even for the Nike Ajax surface-to-air missile, which was outsourced due to a lack of in-house competence, the Army arsenals acted essentially as subcontractors to Bell Labs of Western Electric.[664] Similarly, the Navy's China Lake facility, despite being rolled back, continued to be the Navy's primary source of missile and rocket technology well into the 1970s. In both the Army and Navy, the primary function of the in-house capabilities was to furnish engineering products to weapon systems.[665] In-house effort consumed about one-third of Army and Navy R&D funding.[666]

The Air Force, however, promised a different role for their in-house staff. The Air Force Research and Development Center (ARDC) only maintained enough technical competency to tackle specialized requirements. As ARDC commanding General Donald Putt said in 1953, "ARDC's job is not to actually do the research and development job… For that we rely primarily on industry, universities, and civilian research organizations. Our job is to tell these groups the problems the Air Force wants to solve and to program, finance, monitor and evaluate the work necessary to solve them."[667] For example, at the laboratory in Rome, New York, only 10 percent of the funding remained in-house. Of Rome's in-house effort, only 2 percent went to "actual research and development," with 50 percent monitoring outside activities and the remainder supporting procurement programs.[668] Over the 1950s, 85 percent of all Air Force R&D funding went to universities or industry.[669] The balance funded about 40,000 Air Force personnel, less than 20 percent of which had any science or engineering experience. Trevor Gardner, head of R&D at Air Force headquarters, told Congress how "The portion which we spend in our own laboratory is rather small."[670]

Over the course of the 1950s, the Army and Navy were pressed to outsource more R&D. In 1955, the Chief of Naval Operations directed the "Libby Board" in its investigation of bureau system adequacy. While it found deficiencies, it supported the continued role of strong bureaus and relegated special projects offices to exceptional circumstances.[671] Yet the pressure to emulate the Air Force did not abate. Increased use of contractors became essentially an unwritten law, causing the arsenal and bureau systems to shrink significantly.[672]

General John F. Uncles, chief of Army R&D, told Congress how the services had long been under pressure to whittle in-house organizations down to a "certain minimum point." "We don't know exactly what that point is," General Uncles said in 1954, "but 25 percent or 35 percent of our program we feel should be done within our own laboratories to enable us to have people who understand what the rest of the world is doing."[673] In 1962, Bureau of the Budget Director David E. Bell issued a report finding that "there has been a serious trend toward eroding the competence of the Government's research and development establishments." It concluded that government employees need to be assigned stimulating work, given authority to do the job, and have their salaries raised.[674] The fear was that without in-house R&D, engineers became "desk engineers" who merely reviewed contracts and accepted contractor technical direction. Engineers either lost touch with technology or lost interest and left the government.[675]

Many others believed that government could evaluate contracts without performing any core work itself. For them, the Manhattan project demonstrated that the minimum point of government effort is 5 percent or lower. Industry consultant Helge Holst explained how the government should be skillful users, "not necessarily skillful designers, developers, or producers." He elaborated the position for Congress in 1962. "Let me see if I can make this almost ridiculously simple," Holst said:

> "Certainly when our wives use our automobiles and start them up and drive very successfully to school and to the grocery and all their other activities, they are performing a useful function. They are having their needs met without being able to design and build an automobile, and without indeed being able to maintain the automobile."[676]

Holst believed that increasing specialization of economic activity made it infeasible for the user to have a technical understanding of what they buy. They just needed to know if it worked. Yet for weapon systems, the government cannot rely on the collective wisdom of other purchasers. It is the single buyer. Moreover, government finances the contractor and is responsible for critical decisions before contracted work begins. The evaluation process in research and development is not limited to evaluation of fully developed test articles. Chet Holifield, chairman of the committee on government operations, fired back at Holst:

> "Now, how are we going to have that in-house capability not to create but to make wise judgments as a sophisticated consumer, particularly when we are dealing in the futures, when we are peering into a glass ball and trying to select systems for which we want to embark upon further research and development and production and use. Now, how can we do that?"[677]

Holst reiterated his position, and how it aligned with the Bell report, that the government should rely heavily on contracting and only perform work that contributes to competence in evaluation. David Bell, however, made clear that in-house R&D *should* be an objective in itself. Government employees should be given "significant and challenging" work, implying proper evaluation required a more hands-on role. In this view, the context necessary for evaluating the contribution of others is only available to those contributing to research and development themselves.

10.7 Workforce

While there were disagreements about the extent of government involvement in R&D, almost all agreed that contractors bid away skilled government staff with higher salaries. A common complaint was that government couldn't compensate high-skilled individuals nearly as much as they were worth to industry. However, those just coming out of college into the lower grades got better pay and opportunity in the government's service.[678]

By 1962, even the lower grades were being paid higher in industry than government. They could then face the prospect of increasing wage disparity with the progress of their career.[679] For example, an entry-level employee with a bachelor's degree could make about $5,954 in the government or $6,881 in industry, a healthy 15 percent premium. By the time you get to the top levels, the "supergrades," industry paid more than double the government salary.[680] The disparity was particularly large for employees negotiating contracts. Government negotiators were paid just one-third the amount—and had only one-third the experience—of their counterparts in industry.[681]

The disparity in pay allowed industry to "raid" talent from the government. Scientists and engineers were, after all, scarce resources, perhaps representing one-quarter to one-half of a percent of the population.[682] In 1957, the separation rate of Navy scientists and engineers reached 29 percent. Nearly the whole organization could turn over in just a few years' time. An Air Force study found that 70 percent of their separations cited compensation as the primary factor.[683] Armen Alchian and Kenneth Arrow agreed that inflexibility in government salaries caused an artificial shortage of scientists and engineers. "The government should not hesitate," they concluded, "to bid high for research personnel."[684]

With the passing of the Federal Salary Reform Act of 1962, Congress agreed to have government salaries catch up to industry over a three year period.[685] President Kennedy called it the "most important Federal employee pay legislation in 40 years," with the first declaration that federal salaries must be comparable to those in private enterprise.[686] Despite the increases in compensation, defense in-house facilities continued to decline.[687]

As the Bell report pointed out, compensation is not the only factor influencing an organization's ability to attract and retain talent. Professional recognition also weighs highly for many scientists and engineers. The Navy, for example, took special care to provide their employees the opportunity to openly publish the results of their work and participate in professional meetings. The trend followed Admiral Rickover's declassification of about a dozen handbooks on nuclear reactor technology which gained widespread notoriety.[688] Admiral Fredrick Furth remarked how "to be recognized as an outstanding individual in his discreet area of science—this is more important to a scientist than the compensation in dollars. And this is why the military service—and I am speaking about the Navy—has been able to retain the services of a number of our outstanding people."[689]

Achieving recognition while in the government's service, however, required performing more challenging work than the task of contract evaluation alone. DDR&E Harold Brown explained in 1965 how McNamara's efforts to improve in-house laboratories were limited to recommendations and studies rather than experimentation and development.[690] The difference was reflected in how much funding was made available to in-house R&D efforts. In fiscal year 1966, the Air Force, allocated $13 million to its laboratories and $30 million for the in-house portion of Defense Research Sciences. Another $331 million went to development and test facilities which outsourced a significant amount of its funds. Even including that amount, the total in-house effort represented just over 10 percent of the Air Force's $3.2 billion appropriation.[691] By contrast, Navy installations received 43 percent of R&D funding in fiscal year 1966, and real spending remained about constant over the next five years. Of $784 million kept in-house in fiscal year 1970, the Navy only contracted out $165 million "in support of onstation work."[692]

R.D.T. & E.N. TOTAL VERSUS IN-HOUSE EFFORT
(In thousands)

	Fiscal year— 1966 actual	1967 actual	1968 actual	1969 estimate	1970 estimate
Total R.D.T. & E.N. program....................	$1,582,457	$1,947,422	$1,886,250	$2,161,074	$2,221,500
Total R.D.T. & E.N. program performed by Navy Installations..........................	682,096	725,673	731,933	784,397	784,194
AVERAGE NUMBER OF PERSONNEL					
Total civilian personnel at R.D.T. & E.N. installations paid from R.D.T. & E.N....	30,850	29,775	31,849	31,415	30,113
Military personnel in R.D.T. & E.N. work.	7,345	8,375	7,477	7,215	7,401

[“DEPARTMENT OF DEFENSE APPROPRIATIONS FOR 1970.” (1969). HEARINGS BEFORE A SUBCOMMITTEE OF THE COMMITTEE ON APPROPRIATIONS HOUSE OF REPRESENTATIVES NINETY-FIRST CONGRESS FIRST SESSION, PART 4 RESEARCH, DEVELOPMENT, TEST, AND EVALUATION, 73.]

While the Navy made a significant portion of funding available for in-house effort, government staff did not have significant authority to accomplish the work they found important. The proportion of “level of effort” programs that worked toward broad or unspecified projects—that could be decided upon at the operational level—declined over the 1960s. Assistant Secretary of the Navy for R&D, Dr. Robert Frosch, defended a small $10 million request for independent exploratory development:

> “The purpose of the laboratory independent exploratory development program is to provide funds to the laboratory technical directors to capitalize rapidly on ideas generated by their staffs. The existence of this program thus allows them to exploit in-house capabilities and to explore the feasibility of ideas without the necessity of competing for funds with weapon systems under development. In addition the program makes more attractive to the creative scientist or engineer the atmosphere of the in-house laboratory since he can initiate work on new ideas without the time-consuming effort required by the normal budget process. To continue to be supported by the technical director, however, he must compete with other in-house generated proposals.”[693]

Similarly, Army staff often disagreed with OSD priorities, and instead wanted to expand funding to the level of effort programs.[694] The 1974 AMARC and 1975 NMARC reports from the Army and Navy both recognized the importance of funding organizations and staff.[695] The budget process, however, was transformed by the Planning-Programming-Budgeting System, which required justification by program starting three years in advance of the appropriation. Any in-house organization performing R&D then has to enter a long process of review before funding can be made available. The in-house staff can only stay around as long as they can sell their services to the higher levels. The program budget is therefore the most important motivating force behind government managers. Programs determine what work can be performed, when it will be performed, and how it will be evaluated. These parameters are decided upon by outsiders to the organization whose expertise is usually not in the particular area of R&D or procurement.

"That is why so many talented people at the operational level are leaving the Defense Department," Admiral Rickover explained, "they have experienced too often the inward fury of sincere and capable men thwarted by powerful little bureaucrats."[696] Another observer wrote how "Young people see that project and procurement officers live in a fishbowl environment, are subject to outside intervention, and become targets for criticism."[697] While the fishbowl effect deterred many talented individuals, it was precisely the intent of the program budget written into Title IV of the National Security Act amendment of 1949. It sought to rein the uncoordinated programs of the in-house facilities, whose chiefs could decide on program objectives and methods of evaluation. The Navy viewed such changes in the budget structure as threats to diminish the autonomy of its bureaus.[698] While the Navy successfully resisted the program budget in the 1950s, it became overwhelmed in the 1960s after the implementation of the PPB System.

Perhaps the most pernicious effect of the program budget is the effect on organizational culture. Aaron Wildavsky described the program budget as a contract between policy maker and line manager. Rather than a relational contract which assigns significant discretion to the one performing the work, the program budget process locks in a list of directives of what can and cannot be done. It presumes that program choice can be considered apart from the structure of organizations and incentives in which it is done. The rigidity of program objectives controlled by outsiders disempowers even the most highly skilled and trustworthy individuals, whether they work in the government or for it. "I found many, many people," Pierre Sprey testified to Congress in 1971,

> "… who are affected by the knowledge that weapons they were working on were unreliable, were unlikely to prove very effective in combat or at least dangerous, and by the general impression that these people had that they were not able to do the best possible job in their particular defense mission."[699]

The recognition of errors, however, might harm ones career because it indicates a sort of failure. The organization's funding is completely tied to the specified program. Its survival depends on suppressing information about errors rather than making them visible and correctible. "Budgeting by programs, precisely because money flows to objectives, makes it difficult to abandon objectives without abandoning simultaneously the organization that gets its money for them."[700] In this way, the people performing the work regularly see missed opportunities for improving the common security, for demonstrating their technical skills, and for earning the esteem of their peers. Leadership instead demands quick fixes and low-balled figures. The lasting impact, as the Volcker Commission Report later found in 2003, is that the best leave too early and the worst stay too long.

Conclusion

> … the procurement process itself is a weapon of war no less significant than the guns, the airplanes, and the rockets turned out by the arsenals of democracy.
>
> Irving B. Holley, Jr.
>
> Buying Aircraft, 1964

In February 2015, Leonard Wong and Stephen Gerras at the Army War College published their findings on the proliferation of requirements placed on Army combat officers. The problem had grown so great that by 2002 there were more days of mandatory training than total days available in a year. One Army officer told the authors that "We can probably do two or three things in a day, but if you give us 20, we're gonna half-ass 15 and hope you ignore the other five." Given the "impossibility" of total compliance, Army officers began individually determining the relative importance of requirements. The resulting data collected for analysis from above were inaccurate as different officers falsified different sets of reports.[701] Army leadership quickly understood that the problem lay not with its officers but with the ethical quandary placed on them in a zero defect environment.[702]

The proliferation of before-the-fact controls in Army operations has been more than matched by the defense acquisition system. For example, a program manager must execute a tightly defined program within a particular cost and schedule target, cannot make major decisions without support from over fifty separate offices, must abide by a deluge of regulations, and has no formal control over contracting officers or plant representatives. An overflow of rules and regulations quickly erodes the professional ethics that provide a basis for interpersonal trust. If resource allocations and innovation can be strictly calculated from the data, then before-the-fact controls make sense because the optimal course of action is already known. But when no individual can have but a small piece of the total knowledge, progress requires after-the-fact controls that emphasize norms and duty as they emerge from the complex operations in which they are performed.

[Remainder of the conclusion is a work in progress…]

Bibliography

End Notes

Introduction

[1] By contrast, nominal computing prices have fallen by 37 percent a year over the same time, leading to an increase in computations per dollar by over a *quadrillion*, or a factor increase of 10^{12}. See Nicholas Bloom et al. (2019, Feb. 15). "Are Ideas Getting Harder to Find?" Retrieved from https://web.stanford.edu/~chadj/IdeaPF.pdf.

[2] "Hearings on Military Posture and H.R. 1872 [H.R 4040] and H.R. 2575 [S. 429], and H.R. 3406, Part 2." 856-860. Unit costs provided by Myers were in Base Year 1980 dollars. These costs were normalized to Then Year dollars using the GDP Chain-type Price Index. U.S. Bureau of Economic Analysis, Gross Domestic Product: Chain-type Price Index [GDPCTPI], retrieved from FRED, Federal Reserve Bank of St. Louis; https://fred.stlouisfed.org/series/GDPCTPI, May 8, 2019. The reference year was the year of the aircraft's introduction into operations.

As for the F-35A unit cost, it was calculated using the December 2016 Selected Acquisition Report. The average total flyaway procurement costs for the first 500 F-35A models was extracted in Base Year 2012 dollars and normalized into Then Year 2016 dollars using the same GDP Chain-type Price Index. Note that 273 of the first 500 F-35A aircraft (fiscal years 2018-2023) were still planned figures for future year budgets. Many more aircraft on order from existing appropriations had yet to be delivered. The figures also do not include block upgrades required to make the F-35A combat ready.

Also note that the inflation adjustments should have used a weighted, rather than a raw, index to return the appropriate Then Year figures. The author did not have access to the Air Force aircraft procurement outlay profiles extending back to World War II. This deficiency does not significantly impact the results. For more on adjustments to cost estimates for inflation and escalation, see "Inflation and Escalation Best Practices for Cost Analysis: Analyst Handbook." (2017, Jan.). Office of the Secretary of Defense, Cost Assessment and Program Evaluation.

The author also took part in a study of proprietary data from defense contractors at the Pentagon using Contractor Cost Data Report (CCDR) 1921-3 forms. It found that at three contractor plants from 1970s until 2017, the direct labor rate had only grown about a percentage point above inflation, similar to the Employment Cost Index for the nation as a whole. However, fringe benefit costs grew between 5 and 9 percent *over and above inflation*. So did the overhead rates and the general and administrative (G&A) rates. Vast cost increases per hour of labor can be attributed not to take-home pay of contractor labor, but of their indirect rates. The fact is often hidden by two accounting changes. First, moving fringe costs for direct labor from the overhead pool to the direct cost base. Second, increasing the proportion of employees directly charging contracts. Some defense plants have seen shifts where direct labor used to account for 60 percent of total employment in the 1970s, while in the 2010s the proportion increased to where 90 or 95 percent of all labor charges directly to contracts. These accounting changes have the perceived effect of keeping indirect rates low when in fact they have grown substantially.

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[4] U.S. Bureau of Economic Analysis, Gross Domestic Product: Chain-type Price Index [GDPCTPI], retrieved from FRED, Federal Reserve Bank of St. Louis; https://fred.stlouisfed.org/series/GDPCTPI, May 8, 2019.
[5] Baumol's cost disease! See Why are prices so damned high! Wrestle. "The Baumol effect, however, does not explain every incidence of rising prices. For example, it is unlikely to explain the high cost of infrastructure construction in large cities such as New York and Los Angeles. In these cities, it costs 2 to 10 times as much to build a subway line as in cities of other developed countries."
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Chapter 1: Unification

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[25] Hewes, Jr., James E. 1975, "From Root to McNamara: Army Organization and Administration." Center of Military History, United States Army, Washington D.C., 67-68.
[26] Chief of Staff, Memorandum (relating to a single department of war in the postwar period), presented for consideration of the Joint Chiefs of Staff, JCS 560, November 2, 1943.
[27] Burrell, Robert S. (2011). *The Ghosts of Iwo Jima*. Texas A&M University Press, 158-59.
[28] "Hearings Before the Select Committee on Post-War Military Policy." House of Representatives Seventy Eighth Congress, second session, pursuant to H. Res. 465: A Resolution to Establish a Select Committee of Post-War Military Policy. Part 1 of 1, 31. Hereafter, Woodrum Committee.
[29] Ibid., 122-23. In the original, Rep. Woodrum mistakenly attributed the observation to Under Secretary of War Judge Robert P. Patterson rather than Robert Lovett.
[30] Ibid., 50-51.
[31] Ibid., 16.
[32] Ibid., 34-38.
[33] Ries, John. C. (1964). *The Management of Defense: Organization and Control of the U.S. Armed Services*. The Johns Hopkins Press, Baltimore, MD, 26-29. See also Ray S. Cline, *The Washington Command Post: The Operations Division.*
[34] Woodrum Committee, 40.
[35] Roherty, James. (1970). "Decisions of Robert S. McNamara: A Study of the Role of the Secretary of Defense." Coral Gables, FL, University of Miami Press, 27.
[36] Mills, Walter (ed.). (1951). *The Forrestal Diaries.* NY, Viking Press, 152. James Forrestal entry 17 April 1946.
[37] O'Donnell, James P. (Maj., USMC). (1985). "The Struggle for Survival." Citing Thomas B. Buell. (1980). *Master of Seapower* (Boston: Little, Brown and Co.), 340. Marshall's dislike for the Marines went back to his World War I experience. He believed the Marines took the Army's glory.
[38] Mills, *Forrestal Diaries*, 164.
[39] Ibid., xxii.
[40] Woodrum Committee, 122-23
[41] Heilbrunn, Jacob. (1992, Oct. 5). "The Man Without Qualities" Review of *Driven Patriot: The Life and Times of James Forrestal* by Townsend Hoopes and Douglas Brinkley, in *The New Republic*, 39. Recent studies have verified Forrestal's experience that private sector mergers and acquisitions often fail to produce anticipated efficiencies. See the classic study, "The Post-Merger Performance of Acquiring Firms: A Re-examination of an Anomaly," by Anup Agrawal, Jeffrey Jaffe, and Gershon Mandelker, *The Journal of Finance,* Vol. XLVII, No. 4, Sep. 1992.
[42] Woodrum Committee, 126.
[43] Ibid., 261.
[44] Ibid., 130
[45] Ibid., 16.
[46] Ibid., 296
[47] Mosher, Frederick C., "Program Budgeting in Foreign Affairs: Some Reflections" as part of Planning-Programming-Budgeting compendium, 142. UPDATE REFERENCE AND TO BIBLIOGRAPHY
[48] Woodrum Committee, 298-99.
[49] Memo, Lt. Gen. LeRoy Lutes, Director of the Staff, for Directors and Division Chiefs, 31 August 1948, sub: Criticisms Made Before Eberstadt Committee, folder Hoover Commission (Eberstadt Committee), box 88, entry 221, RG 330. Found in Converse III, Elliot. 2012. *Acquisition History Volume I: Rearming for the Cold War, 1945-1960*, Washington D.C., Historical Office, Office of the Secretary of Defense, Washington, 56.
[50] "First Report of the House Select Committee on Post-War Military Policy." (1944). House of Representatives Seventy Eighth Congress, second session, pursuant to H. Res. 465: A Resolution to Establish a Select Committee of Post-War Military Policy. Part 1 of 1, pp. 3.
[51] General Staff Act of 1903, Section 4. Found in Simonie, Frank L. (1975, Feb.) "Structure and Policy: The Evolution of the Military Staff." Dissertation for New York University, Graduate School of Arts and Science.
[52] Woodrum Committee, 36.
[53] Ries, *The Management*, 31.
[54] Keiser, Gordon W. (1982). *The US Marine Corps and Defense Unification 1944-47: The Politics of Survival.* National Defense University Press, Fort Lesley J. McNair, Washington D.C., 25. Note that the assistant secretaries are called "functional," which implies a non-human within systems, whereas humans are said to have "purpose."

"Purposeful" assistant secretaries is more accurate from a systems point of view. See Donella Meadows, *Thinking in Systems*, 15.
[55] Keiser, *The US Marine Corps*, 114.
[56] In 240 pages of text, the Eberstadt Report mentioned variations of the word "competition" 34 times, of which 25 were negative. Compare that to the liberal employment of variations of "coordination" at 357.
[57] (1944, Oct. 22) "Report to Hon. James Forrestal on Unification of the War and Navy Departments and Postwar Organization for National Security." United States Government Printing Office, 35 and 80.
[58] "Hearings Before the Committee on Expenditures in the Executive Departments." (1947, April 26). House of Representatives, First Session, on H.R. 2319, the National Security Act. Forrestal testified to Congress in 1947, "Well, there again, it is the battle between the specialist and what the social scientists call the generalist. I myself am for the generalist. I have the greatest respect for lawyers, accountants, military officers, and statesmen. But I think we are all very prone to look at things from the particular training that we have, and the particular job that we pursue, and I do not think that human events – I do not think anyone is wise enough to approach life from a particular point of view or a particular slant.
"Take the scientists, now. I think there is some danger of the scientists assuming that they have the universal wisdom of the universal statesmen. I think that in any field of knowledge in which a man becomes very competent, he is apt to try to impose that upon a much broader horizon… I have seen very few escape that tendency."
[59] Forrestal, James V. Letter to President Harry Truman by James V. Forrestal and Robert P. Patterson. (1946, May 31). Source: U.S. Congress. *Congressional Record,* Volume 92, Part 6. Government Printing Office, Washington, 1946, 7424-26.
[60] Cole, Alice C.; Goldberg, Alfred; Tucker, Samuel A.; Winnacker, Rudolph A. (1978). "The Department of Defense: Documents on Establishment and Organization 1944-1978." Eds. Office of the Secretary of Defense Historical Office, Washington, D.C., 54-59.
[61] The Service Secretaries seemed to have been intended to sit on the President's cabinet with their boss, the Secretary of Defense. As it turned out, the Service Secretaries did not sit on the President's cabinet despite being the heads of their executive departments. The Service Secretaries would, however, sit on the National Security Council. This point confused several Congressmen at the time.
[62] Heilbrunn, Jacob. (1992, Oct. 5). "The Man Without Qualities" Review of *Driven Patriot: The Life and Times of James Forrestal* by Townsend Hoopes and Douglas Brinkley, in The New Republic, 40. However, Douglas Kinnard reports that Patterson as refusing the post because he wanted to leave the federal service for financial reasons (he provided no citation). Patterson ended up in private law practice, having also denied a judgeship. See Kinnard, *The Secretary of Defense,* 18.
[63] Marx Leva memorandum for Forrestal. (1948, June 22). RG 330, CD 9-2-41. Found in Hogan, Michael J. (1998). *A Cross of Iron: Harry S. Truman and the Origins of the National Security State, 1945-1954.* Cambridge University Press, Cambridge, UK, pp. 167.
[64] (1948, Oct. 1). McNarney memorandum for Forrestal. Symington Papers, box 8, folder: Correspondence File, 1946-50, Memoranda, General. Found in Hogan, *A Cross of* Iron, 168.
[65] Huntington, Samuel P. (1959). T*he Solider and the State. The Theory and Politics of Civil-Military Relations*. Cambridge, MA, Belknap press of Harvard University Press, 437.
[66] "Report to the Commission on Organization of the Executive Branch of the Government by the Committee on the National Security Organization, Volume II." (1948, Nov. 15). U.S. Government Printing Office, 142-145.
[67] Memo, Gen. Joseph T. McNarney for the Secretary of Defense, 29 October 1948, sub: Research and Development Board, folder Research and Development Board, Organization and Functions, box 829 (Research and Development Board, 1947–1952), Subject Files, OSD/HO. Found in Converse III, *Acquisition History*, 31.
[68] Office of the Secretary of Defense. (1948). *First Report of the Secretary of Defense.* Washington D.C., Government Printing Office, 15.
[69] Converse III, *Acquisition History*, 34.
[70] Lutes, "Criticism."
[71] Converse III, *Acquisition History*, 54
[72] Mills, *The Forrestal Diaries*, 152 and 245.
[73] Roherty, *Decisions*, 26.
[74] Hearings, (1947, April 26), 96-97.
[75] Letter from Richard Bellman, Rand Corporation, Santa Monica, California (received March 20, 1958) in response to "On "Heuristic Problem Solving," by Simon and Newell. In "The Journal of the Operations Research Society of America," Volume 6, 448.

[76] Hitch, Charles J. (1965). *Decision-Making for Defense.* Berkeley and Los Angeles, CA, University of California Press, 15.
[77] Office of the Secretary of Defense, *First* Report, 131.
[78] Heilbrunn, "The Man Without Qualities," 42.
[79] Borklund, C.W. (1966). *Men of the Pentagon: From Forrestal to McNamara*. New York, NY, F.A. Praeger, 61-62.
[80] "Senate Committee on Armed services hearings on S. 1269 and S. 1843." (1949). 81st Cong., 1st sess., National Security Act Amendments of 1949, 9. The language Forrestal uses sounds strangely similar to Eberstadt.
[81] Borklund, C.W. (1966). *Men of the Pentagon: From Forrestal to McNamara*. New York, NY, F.A. Praeger, 63.

Chapter 2: The Program Budget

[82] Christman, Calvin Lee. (1971). "Ferdinand Eberstadt and Economic Mobilization for War, 1941-1943." Ph.D dissertation thesis for The Ohio State University. The three foregoing paragraphs drew from Chistman's work. Though the PRP generated a copper estimate that totaled three times the world supply, the Nazi estimates for copper requirements were far worse—they came to ten times the world supply. See Klein, Burton. (1959). *Germany's Economic Preparations for War.* Cambridge, MA, Harvard University Press.
[83] Dorwart, Jerrfery M. (1991). *Eberstadt and Forrestal: A National Security Partnership, 1909-1949.* College Station, TX, Texas A&M University Press.
[84] Wilson, Woodrow. (1887, June). "The Study of Administration," *Political Science Quarterly,* Vol. 2, 197-222. Public Administration scholars generally followed the administration-policy distinction at the time. For example, see J. A. Vieg (1946), E. G. Nigro (1951), Ordway Tead (1951), H. A. Simon (1955), L. D. White (1955), and J. M. Pfiffner (1960). Some scholars at the time preferred the fact-value distinction, such as Luther H. Gulick. See Fry, Brian R. (1989). *Mastering Public Administration; from Max Weber to Dwight Waldo*. Chatham, New Jersey: Chatham House Publishers, Inc., 80.
[85] The perception that War Production Board planning efforts, such the CMP, drove America's productive success during World War II is largely false. By the time the CMP got underway, the U.S was already producing more war materiel than Germany, Italy, and Japan combined. WPB Director Donald Nelson later wrote "As I understood my job, it wasn't up to me to *tell* industry how to do its job; it was our function to *show* industry what had to be done and then to do everything in our power to enable industry to do it." Before rising to director, Nelson worked for William Knudsen, an automotive executive and production genius who established a cooperative contracting system with industry. Historian Arthur Herman wrote that Nelson and Knudsen sought to keep "the drive for war production as *voluntary* as possible, so that the right incentives—which included the profit motive—found the right people to do the job. That also meant keeping the *civilian economy* as strong as possible." Herman, Bruce. (2013). *Freedom's Forge*. Random House. Herman provides insight into how wartime production actually worked, where new-comers like Henry Kaiser could provide a tremendous value if given the chance.
[86] Milward, Alan S. (1977). *War, Economy and Society: 1939-1945*. Berkeley and L.A., University of California Press, 99-100. Economist Milton Friedman has often made a similar observation, for example, in an interview with Russ Roberts published September 2006.
[87] Novick, David. (1988, March). "Beginning of Military Cost Analysis 1950-1961. RAND Corp., 8-9.
[88] "Report to the Commission on Organization of the Executive Branch of the Government by the Committee on the National Security Organization, Volume II." (1948, Nov. 15). U.S. Government Printing Office, 122 and 149.
[89] "Report to the Commission," (1948, Nov. 15), 148-49.
[90] "The Commission on Organization of the Executive Branch of the Government." (1949). The Committee on the National Security Organization. *Task Force Report on National Security Organization* (Appendix G), Washington: Government Printing Office, 11-22. Found in Cole et al., "The Department of Defense," 66-67.
[91] Ibid., 75.
[92] "Implementation of Title IV, National Security Act of 1947, As Amended,"Hearings before the Preparedness Subcommittee No. 3 of the Committee on Armed Services United States Senate Eighty-Third Congress First Session (Nov. 2-4, 1953). United States Government Printing Office, Washington: 1954, pp. 12-13.
[93] Stephenson Jr., Max O. and Plant, Jeremy F. (1991, Mar.-Apr.). "The Legacy of Frederick C. Mosher." *Public Administration Review,* Vol. 51, No. 2, 97-98. Fredrick was also son to the dean of the Maxwell School of Citizenship and Public Affairs, pp. 97. Mosher went on to professorships at UC Berkeley and the University of Virginia. He also advised numerous public offices, most notably the State Department.
[94] Mosher, *Program Budgeting,* 81-82.
[95] Ibid., 196, 198.

[96] Anderson, David R. (1949). "Controllership's Contribution to Executive Management," in Bradsaw, Thronton F. (Ed.). *Comptrollership in Modern Management*, Chicago: R.D. Irwin, 48.
[97] Mosher, *Program Budgeting*, 195, 204. Eberstadt used the word "Controller" in his 1948 report. He replaced that with the less provocative term "Comptroller" less than a year later the Title IV draft.
[98] Novick, David (Ed.) (1969). *Program Budgeting, Second Edition*. RAND Corp., xxvi-xxvii.
[99] Poole, Walter. (2013). *History of Acquisition in the Department of Defense Volume II: Adapting to Flexible Response, 1960-1968.* Historical Office, Office of the Secretary of Defense, Washington, 23-24.
[100] Mosher, *Program Budgeting*, 217-18.
[101] Ibid., 200.
[102] Ibid., 228-29.
[103] Ibid., 125.
[104] Ibid., 226.
[105] Burrows, Don S. "A Program Approach to Federal Budgeting." *Harvard Business Review*, 1 May 1949, pp. 272-85.
[106] Mosher, *Program Budgeting*, 46.
[107] "Implementation of Title IV, National Security Act of 1947, As Amended." (1953, Nov. 2-4). Hearings before the Preparedness Subcommittee No. 3 of the Committee on Armed Services United States Senate Eighty-Third Congress First Session. United States Government Printing Office, Washington, 17.
[108] Huntington, *The Soldier and the State.* "A hierarchial superior controls his subordinate by determining the goals which the subordinate is to pursue, controlling the resources available to the subordinate, or doing both. Vertical bargaining in the military establishment tends to divide these functions between superior and subordinate. The superior finds the limitation of resources easier than the definition of goals… The subordinate, if forced to choose, normally prefers fewer resources and greater freedom to allocate them as he sees fit than more resources less subject to his control. The result is a balance in which the subordinate acquiesces in the authority of the superior to limit resources while the superior leaves to the subordinate a relatively free hand in how he uses them."
[109] Meyerson, Martin. (1967, Jul.-Aug.). "Price of Admission into the Defense Business." *Harvard Business Review.* 112. "Generally, the Air Force received about 50%, the Navy (including the Marines) about 30%, and the Army about 20% of that kitty."
[110] Roherty, *Decisions*, 49.
[111] Ries, *The Management of* Defense, 181-85.
[112] "National Security Act Amendments of 1949," (1949, Mar. 24 – May 6), 235.
[113] Ibid., 129. Note that the language is correct. A set of allotments is an appropriation, but Bethesda Hospital isn't appropriated to because it is lower on the organizational hierarchy, it is allotted to. The number of allotments that Bethesda Hospital received was far higher than the 12 appropriations from which they came.
[114] "Oral History Interview with Wilfred J. McNeil by Jerry H. Hess." (1972, Sep. 19). https://www.trumanlibrary.org/oralhist/mcneilwj.htm, 19th and 93rd minutes. Oral History hereafter. McNeil, it appears, did not intend for all supply organizations to act as working capital funds which persisted through revenues from military operations, just the more commodity-based ones. Note that McNeil said that the Navy working capital fund started in 1893, but other sources have it starting as much as twenty years earlier.
[115] "To Improve Budgeting, Accounting, and Auditing Methods of the Federal Government." (1950, Feb. 2 –Mar. 7). Hearing before the Committee on Expenditures in the Executive Departments, United States Senate, Eighty-First Congress Second Session, on S.2054 (and Amendments). United States Government Printing Office, Washington: 1950, 81-82.
[116] Office of the Secretary of Defense. (1949, Jul. 1 – Dec. 31). *Semiannual Report of the Secretary of Defense*. Washington D.C., Government Printing Office, 184.
[117] Mosher, *Program Budgeting*, 114-123 and 279-80.
[118] Ibid., 94-100.
[119] Ibid., 95-99.
[120] Lassman, Thomas C. (2008). *Sources of Weapon Systems Innovation in the Department of Defense: The Role of In-House Research and Development, 1945-200.* Center for Military History, U.S. Army, 43-44.
[121] Burrows, "A Program Approach," 283.
[122] "Implementation of Title IV," (Nov. 2-4, 1953), 34.
[123] Herbert Simon commented that "flat" organizations became all the rage in the 1950s.
[124] Ibid., 87-88.
[125] Ibid., 45-46, 174-75, and 14-15.
[126] Ibid., 50.

[127] Ibid., 243.
[128] Hewes Jr., *From Root to McNamara*, 279-80.
[129] Mosher, *Program Budgeting*, 76.
[130] Ibid., 50.
[131] Stephenson Jr., "The Legacy," 101.
[132] Mosher, Frederick C. (1969, Mar.-Apr.). "Limitations and Problems of PPBS in the States," *Public Administration Review*, Vol. 24, No. 2, 160.
[133] Mosher, Frederick C. (1967, Mar.). "Letter to Editor-in-Chief. PPBS: Two Questions." *Public Administration Review*, Vol. XXVII, No. 1. Also see Mosher, Frederick C. (1968). *Democracy and the Public Service*. Oxford, UK. Oxford University Press. Mosher, however, feared whether program experts will be "on top or on tap" in a PPBS framework.
[134] Mosher, "Limitations and Problems," 160-61.
[135] Mosher, *Program Budgeting*, 239.
[136] Mosher, "Limitations and Problems," 160.
[137] Mosher, Frederick C. (1968). "Program Budgeting in Foreign Affairs: Some Reflections." Prepared by the Subcommittee on National Security and International Operations (Pursuant to S. Res. 212, 90th Cong.) of the Committee on Government Operations. United States Senate. Washington D.C. U.S. Government Printing Office, 141.
[138] Mosher, *Program Budgeting*, 228-29.

Chapter 3: Systems Analysis

[139] Hounshell, David. A. "The Medium is the Message, or How Context Matters: The RAND Corporation Builds an Economics of Innovation, 1946-1962." Book chapter in Hughes, Agatha C. and Thomas P. Hughes (Eds.). (2000). *Systems, Experts, and Computers: The Systems Approach in Management and Engineering, World War II and After*. Cambridge, MA, The MIT Press, 257-58.
[140] Converse III, *Acquisition History*, 214.
[141] Alchian, Armen A and Kessel, Reuben A. (1954). "A Proper Role of Systems Analysis," RAND Corp.
[142] Bailey, Robert A. (1953, Aug.). "Application of Operations-Research Techniques to Airborne Weapon System Planning," *Journal of Operations Research Society of America*.
[143] Alchian, "A Proper Role."
[144] Hounshell, "The Medium," 264.
[145] Converse III, *Acquisition History*, 210.
[146] Federation of American Scientists. (1997, May 27). "Early ICBMs." https://fas.org/nuke/guide/usa/icbm/early.htm.
[147] Neufeld, Jack. (2005). *Bernard A. Schriever: Challenging the Unknown*. Washington D.C., Office of Air Force History, 7-10.
[148] Converse III, *Acquisition History*, 494-95.
[149] Neufeld, *Bernard A. Schriever*, 12-14. Robert Perry reported that the firms which lost the contract for Atlas program components were the ones selected for the Titan program. See Perry, Robert. (1967, Oct.). "The Ballistic Missile Decisions." RAND Corp., P-3686.
[150] Hounshell, "The Medium," 264-65.
[151] Alchian, Armen. (1996, July). "Principles of Professional Advancement." *Economic Inquiry*, 34, 520-26.
[152] Alchian, Armen A. (1950, June). "Uncertainty, Evolution and Economic Theory." *Journal of Political Economy*, 58, 211-21.
[153] Quade, E. S. (1971, Apr.). "A History of Cost Effectiveness" Santa Monica, CA,The RAND Corp., 11.
[154] Alchian, "A Proper Role," 6.
[155] Ibid., 6.
[156] Novick, "Beginning of Military," 2.
[157] Alchian, Armen A. (1952, Mar. 24). "The Chef, Gourmet, and Gourmand." Santa Monica, CA, The RAND Corp., 7.
[158] Ibid., 8.
[159] Ibid., 8.
[160] Ibid., 11-12.
[161] Lenfle, Sylvain and Loch, Christoph. (2010, Fall). "Lost Roots: How Project Management Came to Emphasize Control Over Flexibility and Novelty." *California Management Review*, vol. 53, no. 1, 32-55.
[162] Poole, *History of Acquisition*, 101.

[163] Peck, Martin and Scherer, Frederic. (1962). *The Weapons Acquisition Process: An Economic Analysis.* Harvard University Press, 40.
[164] Ibid., 40.
[165] A reflexivity that also applies to the staff and line officers, the policy-maker and the administrator, the planner and the doer.
[166] The services sometimes competed out the production of hardware designed by one firm to other firms, particularly during war. This led to the risk of what seems like a paradox: good innovations creating losses.
[167] Atwood, L. J. (1953, Oct.). "Airframes." *Air Force*, 58. Found in Alchian, "A Proper Role," 12.
[168] Alchian, "A Proper Role," 9-10.
[169] One critique may be that a diversity of procurements would lead to far higher operating costs. However, the strength of commercial businesses is in extended lines of logistics for the variety of goods demanded by consumers. Further, if more developments are pursued which primarily seek to integrate existing technologies for ruggedness and simplicity, commonality can emerge rather than being enforced in large scale multi-mission programs. The most important and obvious reason for lower operating costs is that diversity will lead to much increased reliability. Systems which favor flexibility over simplicity are naturally more complicated, and are exponentially more likely to run into reliability problems (see O-Ring theory in economics).
[170] Alchian, "A Proper Role," 16-17.
[171] Klein, B. H., Meckling, W. H., Mesthene, E. G. (1958, Dec. 4). "Military Research and Development Policies." Santa Monica, CA, The RAND Corp., 1-2.
[172] Peck, *The Weapons Acquisition*, 300.
[173] Klein et al., "Military Research," 13-19.
[174] Converse III, *Acquisition* History, 155.
[175] Ibid., 158. "Report on Organization and Administration of the Army Research and Development Program."
[176] Johnson, Stephen B. ""From Concurrency to Phased Planning: An Episode in the History of Systems Management." Book chapter in Hughes, Agatha C. and Thomas P. Hughes (Eds.). (2000). *Systems, Experts, and Computers: The Systems Approach in Management and Engineering, World War II and After*. Cambridge, MA, The MIT Press, 97.
[177] Colonel Maxwell, Jewell C., Chief of Staff, Headquarters, Air For Systems Command. "Systems Development and Management (Part 3)," 840. GET REAL CITE, add to Bibli
[178] Ibid., 854
[179] Collbohm, Frank R. (1957, Jan. 31). "Scientific Aids to Decisionmaking – A Perspective." Santa Monica, CA, The RAND Corp., 7-9.
[180] "Systems Development and Management (Part 3)." (1962). Hearings before a Subcommittee of the Committee on Government operations House of Representatives Eighty-Seventh Congress, Second Session. Washington DC, U.S. Government Printing Office, 925.
[181] Hitch, Charles J. and Roland N. McKean. (1960). *The Economics of Defense in the Nuclear Age*. Antheneum, 106.

Chapter 4: Planning-Programming-Budgeting

[182] F. A. Hayek traced the ideas inherent in the German school, particularly logical positivism, back to the French Revolutionaries and the Ecole Polytechnique – but he attributed its spread to the U.K. and U.S. through Germany. This form of rationalism also finds precedent thinkers such as Francis Bacon, who opposed Copernican Astronomy, and Lord Kelvin, who denied evolution because he calculated the Earth too young for its emergence. Ultimately analytical holism goes back to Plato, who believed in a "Guardian" class to guide policy and abhorred asymmetries so much that he thought humans should use both hands with equal dexterity.
[183] Leonard, Thomas C. (2016). *Illiberal reformers*, Princeton University Press, 22 and 33
[184] "Planning Programming Budgeting" (1970). Inquiry of the Subcommittee on National Security and International Operations." U.S. Senate, Washington D.C., U.S. Government Printing Office, 127. Hereafter the Jackson Committee.
[185] Novick, "Beginning of Military," 3.
[186] Even the names of Novick's paper and Title IV were almost the same. The former's title was "Efficiency and Economy in Government through New Budgeting and Accounting Procedures," the latter's title was "Promotion of Economy and Efficiency Through Establishment of Uniform Budgetary and Fiscal Procedures and Organizations." Novick does admit some precedence in the WIB in Novick, *Program* Budgeting, xxi.
[187] "Planning Programming Budgeting," 1970, 3.
[188] Poole, *History of Acquisition*, 24.
[189] Jackson Committee, 4.

[190] Roherty, *Decisions of Robert S. McNamara*, 69.
[191] Enthoven, Alain. (1963, May). "Defense and Disarmament: Economic Analysis in the Department of Defense." *American Economic Review*, 53, 287-301.
[192] Tucker, Samuel A. (1966). *A Modern Design for Defense Decision: A McNamara-Hitch-Enthoven Anthology.* Washington D.C., Industrial College of the Armed Forces, 5.
[193] Mosher, Frederick C. "Letter to editor." In Allen Schick's classic review "The Road to PPB," he said that "Some old-timers interpret the PPB as a revival of the performance budgeting venture of the early 1950s." Found in Lyden, Fremonth J. and Miller, Ernest G. (Eds.). (1968). *Planning Programming Budgeting: A Systems Approach to Management*. Chicago, IL, Markham Publishing Co, 26.
[194] Leonard, *Illiberal reformers*, 47-48.
[195] Ibid., 47-48.
[196] Ries, *The Management*, 39.
[197] Cockshott, Cottrell, and Dieterich, *Transition to the 21st Century: Socialism in the European Union*. Lulu.com, 33. Calculation-in-kind was called "Naturalwirtschaft" in German. See Memeth, Schmitz, and Uebel (Eds.). (2007). *Otto Neurath's Economics in Context*. Springer.
[198] Lange, Oskar. (1936, Oct.). "On the Economic Theory of Socialism: Part One." *The Review of Economic Studies*, Vol. 4, No. 1, 53.
[199] Ibid., 54-55.
[200] Schumpeter, Joseph. (1942). *Capitalism, Socialism, and Democracy*. Harper & Brothers, 132. This extreme view of Schumpeter, largely held by Hayek, could be claimed unfair. Schumpeter quoted A. F. Burns, Production Trends in the United States Since 1870, p. 262, "Strict logic is a stern master, and if one respected it, one would never construct or use any production index," Schumpter added that "… for not only the material and the technique of constructing such an index, but the very concept of a total output of different commodities produced in ever-changing proportions, is a highly doubtful manner." See page 63. He also appreciates the "antagonisms" of capitalist society, but may not have seen antagonisms as resulting from local uses of knowledge of time and place that differ qualitatively from one another.
[201] Hayek, Friedrich A. (1954, Sep.). "The Use of Knowledge in Society." *American Economic Review*. XXXV, No. 4, 519-30.
[202] Note that the views of Hayek and Alchian maintained theoretical predictability in a deterministic system if all relevant information is known. However, Soviet mathematician Yakov Sinai proved in 1963 using "dynamical billiards" that some deterministic systems are nevertheless unpredictable. Soviet economic planners did not apply what Soviet mathematicians were saying about simple systems, namely, that predictions will not be accurate. Decades before Sinai, the great mathematician Henri Poincare pointed out that while gravitational interaction between two objects was completely described by Newton, add one more object and long-term predictions can no longer be made in most cases.
[203] Levy, David M. and Peart, Sandra J. (2009, Dec. 3). "Soviet Growth & American Textbooks." https://ssrn.com/abstract=1517983.
[204] "In Celebration of Armen Alchian's 80th Birthday: Living and Breathing Economics." (1996, Jul.). *Economic Inquiry*, Vol XXXIV, 412-426.
[205] Hitch, *The Economics of Defense*, 233.
[206] Ibid., 111.
[207] Ibid., 248-49. Lenfle and Loch also noticed that the book is contradictory, see Lenfle, "Lost Roots."
[208] "Systems Development and Management (Part 2)." (1962). Hearings before a Subcommittee of the Committee on Government operations House of Representatives Eighty-Seventh Congress, Second Session, July 23-27, 1962. Washington D.C., U.S. Government Printing Office, 541.
[209] For example, see Novick, David. (1959, Aug. 25). "What Do We Mean By 'Research and Development'?" The RAND Corp., P-1779. Novick broke down Research into basic, experimental, advanced, and applied. Development included basic, product, and application. R&D was expanded to RDT&E, with Test and Evaulation with their own sub-phases.
[210] McKean, Roland and Anshen, Melvin. "Limitations, Risks, and Problems." Book chapter in Novick, *Program Budgeting*, 285-307
[211] Hitch, *The Economics of Defense*, 114.
[212] Peck, *The Weapons Acquisition*, 304. The authors don't explain the successive improvement model and its origins thoroughly. Note that successive improvement, which is in some ways analogous to Alchian's evolution model, is explained by Lindblom, Charles E. (1959, Spring). "The Science of "Muddling Through." *Public Administration Review*, Vol. 19, No. 2, 79-88.

[213] Simon, Herbert A. (1958, Winter). "'The Decision-Making Schema': A Reply." Reprinted from *Public Administration Review*, Vol. XVIII, No. I, quarterly journal of the American Society for Public Administration 6042 Kimbark Avenue, Chicago 37, Illinois.
[214] Kirzner, Israel M. (2016.) "The History and Importance of the Austrian Theory of the Market Process." F.A. Hayek Program Podcast.
[215] "Systems Development and Management (Part 2)," 541.
[216] "Planning, Programming, Budgeting: Inquiry of the Subcommittee on National Security and International Operations." (1970). Washington D.C., U.S. Government Printing Office. Hereafter, Jackson Committee Hearings.
[217] Young, Stephanie C. (2009, Fall). "Power and the Purse: Defense Budgeting and American Politics, 1947-1972." Dissertation. Doctor of Philosophy in History in the Graduate Division of the University of California, Berkeley, 55.
[218] Young, "Power and the Purse," 50-51.
[219] "Systems Development and Management (Part 2)," 516.
[220] Alchian, "A Proper Role," 15.
[221] Hitch, *Decision-Making*, 17.
[222] Hitch, Charles J. (1963, Jan.-Feb.). "Plans, Programs, and Budgets in the Department of Defense," in *Operations Research*, Vol II, 5.
[223] Roherty, *Decisions of Robert S. McNamara*, 79-80.
[224] Called at the time the Five Year Force Structure and Financial Plan. Today it is called the "Future Years' Defense Program."
[225] Young, "Power and the Purse," 125 and 160-161.
[226] Murdock, Clark A. (1974). *Defense Policy Formation: A Comparative Analysis of the McNamara Era.* Albany, State University of New York Press, 81-84. Note that OSA was supposed to assign "primary responsibility to either the Systems Analysis Office, Director of Defense Research and Engineering (DDRE), Manpower, or Installations and Logistics." However, "All Program Change Proposals involving changes in force structure went to OSA."
[227] Hyman G. Rickover, Senate Armed Services Committee, 90th Cong., 2nd sess., March 13, 15, 19, 27, 1968, Enthoven Papers, LB J Library, Box 8, Folder "DPM Process, 'Article on the DPM Process (Rickover testimony re. DPM and OS A). Found in Young, "Power and the Purse," 177.
[228] Roherty, *Decisions of Robert S. McNamara*, 81.
[229] Hitch, *Decision-Making*, 71.
[230] Stretton, Alan. (2007, Oct.). "A Short History of Modern Project Management." *PM World Today*, Vol. IX, Issue X. The consultants included Lockheed and Booze, Allen, and Hamilton.
[231] Ibid., 555-56.
[232] Technical notes: there are various methods of accounting for earned value. The above assumes the 0/100 method where all budgeted value is earned when the activity is complete. Other methods include percent complete and 50/50, the latter earning 50% of the value when the task starts and 50% when it finishes. Progress on the work packages, where accounting is usually performed, is informed by various methods using the scheduled activities in which resource loading is a best practice. When future activities are not fully planned, they are held in what is called a planning package.
[233] Novick, David. (1962, Nov.). "Program Budgeting: Long-Range Planning in the Department of Defense." RAND Corp. RM-3359-ASDC., 11.
[234] Lee, Tae H. (1996). "Procuring contracting officer's guide to Cost/Schedule Control Systems Criteria (C/SCSC)." Monterey, California. Naval Postgraduate School, 13.
[235] Hough, Paul G. (1989, Aug.). "Birth of a Profession: Four Decades of Military Cost Analysis." RAND Corp., 9.
[236] Sapolsky, *The Polaris System*.
[237] Lee, "Procuring contracting," 14. C/SCSC eventually became the name of PERT systems, overtaken in the 1990s by Earned Value Management Systems (EVMS). This paper will continue to refer to the controls as "PERT" to avoid confusion. Also note that Work Breakdown Structures for major acquisition commodity groups were standardized in 1966 by DDR&E. See Durbrow, B.R. (1974, Apr.). "C/SCSC Implementation Guide Reflects Evolution of the Program," *Defense Management Journal*.
[238] Loveall, Lynn E. (1966). "PERT: Military Contributions to Management Science." 5-6 and 27.
[239] Lenfle, "Lost Roots," 32-55 and 8.
[240] Poole, *History of Acquisition*, 67.
[241] Murdock, *Defense Policy Formation*, 150.
[242] Sapolsky, *The Polaris System*, 123-24 and 45.
[243] Wildavsky, Aaron. (1978). "Policy Analysis is What Information Systems Are Not." *Accounting, Organizations, and Society*, Vol. 3, No. 1, 82.

[244] Popper, Karl. (1972). "The Logic and Evolution of Scientific Theory," in Popper, Karl. (1999). *All Life is Problem Solving*, Routledge, NY, 3-13.
[245] Popper, Karl. 1991. "All Life is Problem Solving," in in Popper, Karl. (1999). *All Life is Problem Solving*, Routledge, NY, 100.
[246] Klein et al., "Military Research and Development Policies." RAND Corp., 4 December 1958, pp. 11.
[247] Normally such risk analyses use a triangular distribution that only requires a min, max, and most likely estimate.
[248] Klein et al., "Military Research," 3.
[249] Reece, Brian L. (1997). "Development of the TFX F-111 in the Department of Defense's Search for Multi-Mission, Joint-Service Aerial Platforms." Thesis for Air Force Academy, Colorado Springs, CO.
[250] General Bernard Schriever, of Atlas fame, agreed with the TFX acquisition strategy. "One system that we have under consideration now is the tactical fighter-bomber. I might say that I completely agree with the steps that are being taken with respect to it." See "Systems Development and Management (Part 3)," (1962), 819.
[251] While Enthoven and the Office of Systems Analysis did not produce the study that resulted in the TFX, it did follow the prescriptions laid down by RAND. I. F. Stone reports that a systems analyst submitted a critical memo on the TFX early in the debates, and that Enthoven rejected the memo "on the grounds that it would call down bureaucratic wrath on the fledgling systems analysis office." See Murdock, *Defense Policy*, 165.
[252] "TFX Contract Investigation: (Second Series)." (1970, Mar. 24). Hearings before the Permanent Subcommittee on Investigations of the Committee on Government Operations, United States Senate, Ninety-First Congress, Second Session, S.Res 308. U.S. Government Printing Office, 3-6. Also see "TFX Contract Investigations" Parts 1-9, 1963-64. One Senator opined that Secretary McNamara should have "listened to the recommendations made by the men who knew what they were talking about" and admitted that "he was wrong and the aeronautical engineers were right."
[253] Anthony, Robert N. (1965). *Planning and Control Systems: A Framework for Analysis.* Harvard University Press, Boston, 38-39.
[254] Murdock, *Defense Policy* Formation, 99-100. In the original, "SA" was used instead of "OSA."
[255] Ibid., 53.
[256] "Planning, Programming, Budgeting," (1970), 29.
[257] Wildavsky, Aaron. (1996, Dec.). "The Political Economy of Efficiency: Cost-Benefit Analysis, Systems Analysis, and Program Budgeting." *Public Administration Review,* Vol XXVI, No. 4. Found in "Planning, Programming, Budgeting," (1970).
[258] Knorr, Klaus. "On the Cost effectiveness Approach to Military Research and Development." Found in "Planning, Programming, Budgeting," (1970). Note that the Jackson Committee hearings can be thought of as a prelude to the backlash to error-prone macroeconomic models that occurred in the 1970-1980s called the "credibility revolution." In effect, statistical modeling often involved a specification search such that historical data "fit" the model well, but because the model was in some sense arbitrary it had little use in "prediction." The credibility revolution added treatments, or so-called natural experiments, into macroeconomic regressions to better tease out relationships and causality.
[259] Young, "Power and the Purse," 282-88 and 309.
[260] Schrader, Charles R. (2008). *History of Operations Research in the United States Army, Volume II: 1961-1973.* Office of the Deputy Under Secretary of the Army for Operations Research, United States Army, Washington, 60-65.
[261] Poole, Walter. "Acquisition in the Department of Defense, 1959-1968." In Brown, Shannon A. (Ed.). (2005). *Providing the Means of War: Perspectives on Defense Acquisition, 1945-2000.* United States Army Center of Military History and Industrial College of the armed forces Washington, D.C., 93.

Chapter 5: Contracting

[262] Brunton, Bruce. (1989). "The Origins and Early Development of the American Military-Industrial Complex." Dissertation for The University of Utah.
[263] Bush, Vannevar. (1945). "Science – The Endless Frontier." http://www.nsf.gov/about/history/vbush1945.htm.
[264] Mayer, Kenneth R. (1991). *Political Economy of Defense Contracting.* Yale University Press, 44.
[265] Lassman, *Sources of Weapon*, 17.
[266] Ibid., 17, 81, 8, 50-52.
[267] Thompson, Fred. "Public Economics and Public Administration."
http://www.willamette.edu/~fthompso/ECON&PA.html.
[268] Lander, Ezra. (1961). "Performance Budgeting and Accounting Policy in the Department of the Army." The American University, Ph.D., 242. Accrual accounting was first emphasized to the Congress in the Second Hoover

Commission of 1955, but its need was understood much earlier. Amazingly, and despite repeated mandates, an auditable accrual accounting system remains years away in the Department of Defense.
[269] Converse III, *Acquisition History*, 428.
[270] The 1926 Air Corps Act was an earlier exemption to advertised sealed-bid auctions.
[271] Moore, Frederick T. (1962, June). "Military Procurement and Contracting: An Economic Analysis." The RAND Corp., RM-2948-PR, 15.
[272] Statement of Secretary of Defense Robert S. McNamara Before the House Armed Services Committee on the Fiscal Year 1969-73 Defense Program and 1969 Defense Budget. Prepared Jan 22 1968. See chart on pp. 228. These numbers pertain to cost-plus fixed fee only, and does not account for incentive fee or other cost-plus structures.
[273] "Department of Defense Cost Reduction Program – Second Annual Progress Report." (1964, Jul. 7). Memorandum from the Secretary of Defense to the President, 8.
[274] Moore, "Military Procurement," 42 and 48.
[275] Moore, "Military Procurement," 50.
[276] Moore, "Military Procurement," 75-76.
[277] Scherer, *The Weapons*, 64-67 and 206-09.
[278] Charles, Robert H. "Memorandum for Secretary Brown, Subject: C-5." Found in "Hearings on Military Posture and Legislation to Authorize Appropriations During the Fiscal Year 1970," Part 2, H.A.S.C. No. 91-14, pp. 2961.
[279] Thompson, "Public Economics."
[280] "Hearings on Military Posture," (1970), 3075.
[281] Poole, *History of Acquisition*, 71-73.
[282] "Major Systems Acquisition Reform: Part 2." (1975, Jun. 16 – Jul. 24). Hearings before the Subcommittee on Federal Spending Practices, Efficiency, and Open Government of the Committee on Government Operations, U.S. Senate, Ninety-Fourth Congress, First Session, Part 2. Government Printing Office, Washington, 119, 129, and 137. Fitzgerald, who claimed to be skeptical of TPP from the beginning, supported the TPP as a concept in certain programmatic circumstances. His claim of $2 billion overrun at the time was closer to $1.3 billion in the opinion of the General Accounting Office (GAO).
[283] Murdock, *Defense Policy*, 87. David D. Acker argues that the Maverick Air-to-Surface missile was the only success for the TPP, while the C-5A, SRAM, AH-56A, and DD-963 destroyer were largely failures. The TFX largely followed a TPP-like strategy. See Acker, David D. (1993). *Acquiring Defense Systems: A Quest for the Best*. Defense Systems Management College Press, Fort Belvoir, VA.
[284] [284] "Major Systems Acquisition Reform: Part 2." (1975, Jun. 16 – Jul. 24), 4-5.
[285] "Report on Military Spending" (1969, Jul. 2). "Hearings on Military Posture and Legislation to Authorize Appropriations During the Fiscal Year 1970." Part 2, H.A.S.C. No. 91-14, 4083. Also see Fitzgerald, Ernest A. (1970, Nov.). "Gilbert Fitzhugh's Golden Fleece." *The Washington Monthly*. Note that the 1969 President's Economic Report singled out the TPP as an improvement to defense contracting, after problems with the technique were clear.
[286] See "Report to the President and the Secretary of Defense on the Department of Defense by the Blue Ribbon Defense Panel." (1970, Jul. 1), and "Report on Military Spending" (1969, Jul. 2). "Hearings on Military Posture and Legislation to Authorize Appropriations During the Fiscal Year 1970." Part 2, H.A.S.C. No. 91-14, pp. 3056.
[287] Williamson, Oliver E. (1965, June). "Defense Contracts: An Analysis of Adaptive Response." The RAND Corp., 1.
[288] Williamson, Oliver E. (1967). "The Economics of Defense Contracting: Incentives and Performance." In McKean, Roland N. (Ed.). (1967). *Issues in Defense Economics*. Columbia University Press, 229 and 218.
[289] Williamson, "The Economics of Defense," 252. Frederick Moore suggested something similar in 1962 (p. 62): "… we may note that CPFF contracts might be used more effectively than they have been in R&D work. Rather than concentrating on the final result to be achieved, the contract might be let for a period of, say, a year with the explicit understanding that at the end of that time the contractor's performance would be evaluated, and that, if he gave evidence of substantial progress and hope of ultimate success, the contract would be extended. Otherwise it would be canceled. This puts pressure on the contractor to perform substantively in a short period of time. Of course this same procedure might be used with an incentive type contract as well."
[290] Peck, *The Weapons Acquisition*, 188.
[291] Williamson, "The Economics of Defense," 246-52. Williamson's five jabs at the scale economies issue are: (1) contracts will remain sizeable in absolute value; (2) if scale economies exist then larger firms would submit lower bids; (3) Edwin Mansfield (1964) finds R&D productivity higher in small firms; (4) smaller and more numerous contracts stabilize sales and thus diseconomies resulting from demand variation; and (5) expense control problems in defense contracts are not primarily concerned with scale.

To each of the four critiques, an additional response may be given. First, government performs well stimulating component development and contractors perform well in putting together existing products in novel ways with ruggedness and simplicity. Second, administrative costs are less because subjective reputational evaluations are increased. Third, Peck and Scherer cite a backwards-bending output curve, where adding more resources to a project actually creates negative productivity (too many cooks in the kitchen effect). Additionally, research finds small firms better able to handle "soft" information associated with incomplete contracts, see A. N. Berger et al., 2005. And fourth, Alchian found no need for crash-programs if technological states are arrived at earlier using the diversity approach.

[292] Popper, Karl. (1972). "The Logic and Evolution of Scientific Theory." Found in Popper, Karl. (1999). *All Life is Problem Solving*, Routledge, NY, 11.

[293] Taleb, Nassim N. (2012). *Antifragile: Things That Gain From Disorder.* Random House, NY, 230. That is Benoit Mandlebrot of the Mandelbrot Set and fractal geometry fame. Mandlebrot has made major contributions to many academic fields, particularly mathematics, finance, and biology. Perhaps of most relevance to defense acquisition is the idea that infinite complexity can arise from simple rules or processes.

[294] During Armen Alchian's 80th birthday celebration, John Lott said that Alchian "defined the term efficiency as 'Whatever is, is efficient.' If it wasn't efficient it would have been something different. Of course, if you try to change anything that is there, that is efficient too." Benoit Mandelbrot's views on efficiency are also as humorous as they are insightful: "Efficient is a cheerful word put to many uses. A good pump is efficient if it moves the most water for the least energy. A portfolio is efficient if it produces the most profit with the least risk."

[295] Clearly, politics is important in determining that a public good, such as defense, be addressed and can weigh judgment on broad allocations of budgets. However, because of the highly uncertain nature of defense, as well as the localized and often secret nature of its information, neither public preferences nor statistical aggregates can be used as a reasonable guide for specific action.

"Non-consensual" ideas as the basis of success makes reference to Marc Andreessen, tech entrepreneur and venture capital manager. Pursuit of non-consensual projects is often done using sky-blue research, where the individual or organization is funded and not any specific idea. It is interesting to observe that the education and skill of the acquisition workforce has often been blamed for reform failures. However, program budgets—and the resulting program office structure—is precisely what puts people and organizations in the back seat. The program is preconceived; the people and organizations that make it work are a forced fit.

[296] Peck, *The Weapons Acquisition*, 246.

[297] Peck, *The Weapons Acquisition*, 529 and 199-204. The authors write that "… an innovator in a large organization was like a fat man in quicksand." They found a history of "old money, new brains." The same behavior is observed in modern industry where large firms or venture capital buy-out small entrepreneurs with good ideas instead of generating those ideas with large internal R&D centers as Bell Labs had done in the past. More often it depends on the market. While many firms seek to buy competitive ideas, particularly in technology and pharmaceuticals, 3M has a unique internal innovation system across thousands of products.

[298] Arrow, Kenneth J. "The Organization of Economic Activity: Issues Pertinent to the Choice of Market Versus Nonmarket Allocation." Found in "The Analysis and Evaluation of Public Expenditures: The PPB System." (1969). A Compendium of Papers Submitted to the Subcommittee on Economy in the Government of the Joint Economic Committee." Congress of the United States. Volume 1. Washington: U.S. Government Printing Office, 62.

[299] Demsetz, Harold. "Contracting Cost and Public Policy." Found in "The Analysis and Evaluation of Public Expenditures: The PPB System." (1969). A Compendium of Papers Submitted to the Subcommittee on Economy in the Government of the Joint Economic Committee." Congress of the United States. Volume 1. Washington: U.S. Government Printing Office, 167-74.

[300] Hayek, F. A. (1948). *Individualism & Economic Order.* Chicago: The University of Chicago Press, 237.

[301] Coase, Ronald. (1937). "The Nature of the Firm." Economica, Vol. 4, No. 16, 391.

[302] Jensen, M., Meckling W. (1992). "Specific and General Knowledge and Organizational Structure." *Contract Economics*, Vol. 8, no. 2, 251-74 and 253-54.

[303] Fox, *Defense Acquisition Reform*, pp. 86.

Chapter 6: Innovation

[304] Dodd, Thomas J. (1960, May 12). "The Summit and the Test Ban Fallacy." Found in Congressional Record, Senator Volume 106, Part 8, Collation 10104-10166, 10137-38.

[305] Baldwin, Hanson W. (1965 Jan.). "Slow-Down in the Pentagon," *Foreign Affairs*, 263-64.

[306] "Conduct of National Security Policy." (1965, June 10 and 17). Hearings before the Subcommittee on National Security and International Operations of the Committee on Government Operations, United States Senate, Eighty-Ninth Congress, First Session, Part 2, 87 and 106.
[307] "Weapon Systems Acquisition Process." (1971, Dec. 3-9). Hearings Before the Committee on Armed Services United States Senate, Ninety-Second Congress, First Session, 132-33.
[308] Baldwin, Hanson W. "Slow-Down in the Pentagon," by, *Foreign Affairs* January 1965, pp. 262.
[309] Murdock, *Defense Policy*, 109-112.
[310] Baldwin, "Slow-Down," 263-65. Other major programs canceled include the Dynasoar and Skybolt. Major programs of the 1960s which were already underway in the 1950s include Polaris, Minuteman, B-70, T.F.X., and AR-15 rifle.
[311] "Systems Development and Management (Part 3)," (1962, June), 814-819.
[312] "Weapon Systems Acquisition Process," (1971, Dec. 3-9), 49. Although the Soviets may have put out 13 fighter aircraft between 1954 and 1971, it is not true that the U.S. failed to fully develop a single fighter over that timeframe. Senator Symington must have meant that the U.S. hasn't developed a new fighter since 1958; even then, the F-5 Freedom Fighter reached first flight in July 1959 and flew more than 2,600 combat sorties over Vietnam. It was also attractive to foreign allies. Other fighter programs were prototyped and cancelled, like the YF-12, where Lockheed's Kelly Johnson sought to convert the A-12 into a fighter.

Senator Jackson's misleading points went unchallenged by an embarrassed Air Force which had adapted the Navy's A-1 Sky Raider, A-7 Corsair II, F-4 Phantom II, and the Marines OV-10 Bronco for use in Vietnam. The Air Force also relied on Navy air-to-air missiles including the AIM-7 Sparrow and the AIM-9 Sidewinder.

It was related to the Congress elsewhere that U.S. military and space RDT&E expenditures for 1971 were estimated to be nearly 30% lower than the Soviets. In constant 1968 dollars, U.S. expenditures were estimated at roughly $8 billion whereas the figure for the Soviets was $11 billion. Drawing correct conclusions from those estimates is impossible, however. See "Department of Defense Appropriations for 1972." (1971, Mar. 18). Hearings before the House of Representatives, Ninety-Second Congress, First Session, Part 2, 113.
[313] The MiG-21 (then designated Ye-2) actually reached first flight in February 1956, more than two years before the Navy's F-4 Phantom II. Despite Senator Symington's intimation that the enemy fighters fared well in Vietnam because of newer and more advanced aircraft, the primary Soviet fighter was even older than the primary U.S. fighter. However, the Soviets made numerous incremental improvements over that time. The MiG-21 had a production run of 11,496 units over 27 years. See Gordon, Yefim. (2008). *MiG-21.* (Russian Fighters). Earl Shilton, Leicester, UK: Midland Publishing Ltd.
[314] "Weapon Systems Acquisition Process," (1971, Dec. 3-9), 344.
[315] "Weapon Systems Acquisition Process," (1971, Dec. 3-9), 154 and 262.
[316] Perry, Robert. (1971, Dec.). "European and U.S. Aircraft Development Strategies." RAND Corp., P-4748, 10.
[317] "Weapon Systems Acquisition Process," (1971, Dec. 3-9), 170-71.
[318] Perry, "European and U.S. Aircraft," 7. Perry later wrote that "… it would be preposterous to attempt to impose on Dassault the sorts of data and reporting requirements common to U.S. aircraft development. Dassault entirely lacks the staff to cope with such demands, and even if it could satisfy them neither the Air Force nor the Ministry could find the people to review the product. No one at Dassault bemoans that shortage." See Perry, Robert. (1973). "The Dassault Dossier: Aircraft Acquisition in France." Santa Monica, CA, RAND Corp.
[319] "Weapon Systems Acquisition Process," (1971, Dec. 3-9), 171.
[320] Williamson, "The Economics of Defense," 221.
[321] Alexander, Arthur J. (1970, Nov.). "R&D in Soviet Aviation." Santa Monica, CA, RAND Corp., R-589-PR, 18.
[322] "Weapon Systems Acquisition Process," (1971, Dec. 3-9), 190-200.
[323] Alexander, "R&D in Soviet Aviation," 12. Later in 1982, Alexander had noticed the Soviets putting more emphasis on production and internal fears that "an excessive orientation to production and involvement in the innovation process could impair the country's fundamental research potential." See Alexander, Arthur J. (1982). "Soviet Science and Weapons Acquisition." Santa Monica, CA, RAND Corp., 22-23.
[324] "Weapon Systems Acquisition Process," (1971, Dec. 3-9), 170-71. The total staff of around 12,500 developed and produced an impressive array of aircraft due to the emphasis on subcontracting. Over a 15 year period in fighter aircraft alone they produced over 1,500 units of various models. See also Perry, "A Dassault Dossier."
[325] The reforms were briefly mentioned in two hearings to the Joint Economic Committee in 1969 and 1970, as well as various times to the Appropriations Committee, such as by Laird on Feb. 20, 1970. The most thorough treatment was by Packard on Mar. 18, 1971. Almost two years after the reforms had started, Congressmen expressed how new the information was to them. It appears that the House and Senate Armed Services Committees were never formally informed about what would become the 5000-series.

[326] "Report to The President and the Secretary of Defense on the Department of Defense by the Blue Ribbon Defense Panel," (1970, July 1). Note that E Fitzgerald thinks Fitzhugh Commission lackeys for contractors on pp 124 of 1971 hearings, and is reflected again on pp. 12 and pp 157.
[327] "Department of Defense Appropriations for 1972," (1971, Mar. 18), 27.
[328] Memorandum from Deputy Secretary of Defense David Packard. (1969, May 30). "Subject: Establishment of a defense systems acquisition review council."
[329] "Department of Defense Appropriations for 1972," (1971, Mar. 18), 16.
[330] "Staats, Elmer D. (1978, Jan. 30). "A Critique of the Performance of the Defense Systems Acquisition Review Council: Billions of Public Funds Involved." Report to the Congress. PSAD-78-14; B-163058., 3. Staats had a long tenure as Comptroller General from 1966 to 1981.
[331] "Department of Defense Appropriations for 1972," (1971, Mar. 18), 30. Interestingly enough, one of ASD Comptroller Charles Hitch's first tasks was to review and reduce existing directives on reporting, numbering more than a thousand, and achieved considerable success. One interpretation is that the cycle of slow regulatory growth and an occasional purge an institutionally viable method for adaptive governance. Some reports, and their concomitant processes, persist. For example, PERT—becoming configuration management in 1967—and the Cost and Economic Information System (CEIS)—becoming the CCDR in 1973—were two of various winners from Hitch's consolidation of reports.
[332] Moyer, Jr., Burton B. (1973, Spring). "Evolution of PPB in DOD," *Armed Forces Comptroller*, 22.
[333] "Department of Defense Appropriations for 1972," (1971, Mar. 18), 29. The policy-administration dichotomy was also used in the Soviet Union. "We have no intention of dictating to you the details of research topics," L. Brezhev said to the Academy of Sciences in 1974, "that is a matter for the scientists themselves. But the basic directions of the development of science, the main tasks that life poses, will be determined jointly." It was in administration as well as science that "looking to the West… was the norm as well as the goal." See Alexander, "Soviet Science," 24-29.
[334] Acker, *Acquiring Defense Systems*, 147.
[335] "Weapon Systems Acquisition Process," (1971, Dec. 3-9), 60.
[336] Perry, "A Dassault Dossier," 24-28.
[337] Kelly Orr, cite, and check on it for accuracy relative to incremental prototyping.
[338] "Advanced Prototype." (1971, Sep. 9). Hearings Before the Committee on Armed Services, United States Senate, Ninety-Second Congress, First Session, 3-4.
[339] "Department of Defense Appropriations for 1972," (1971, Mar. 18), 55-56.
[340] "Advanced Prototype." (1971, Sep. 9), 3-4.
[341] "Advanced Prototype." (1971, Sep. 9), 523-539. All of the Air Force prototype programs, aside from the transport, were for "stealth" aircraft in the original sense.
[342] Stevenson, James P. (1993). *The Pentagon Paradox: The Development of the F-18 Hornet*. Naval Institute Press, Annapolis, MD, 133-34.
[343] Sanibel, Michael. (2011, Jan.). "Quest to Build a Better Fighter." *Aviation History*.
[344] "YF-16: Birth of a Fighter." http://www.f-16.net/f-16_versions_article25.html.
[345] Stevenson, *The Pentagon Paradox*, 199.
[346] "Harry Hillaker—Father of the F-16." (1991, April and July). Interview by Eric Hehs. *Code One Magazine.*
[347] "Major Systems Acquisition Reform: Part 1, Air Combat Fighter Programs." (1975, May 20). Hearings Before the Subcommittee on Federal Spending Practices, Efficiency, and Open Government of the Committee on Government Operations, United States Senate, Ninety-Fourth Congress, First Session, 62.
[348] "Major Systems Acquisition Reform: Part 2." (1975, Jun. 16 – Jul. 24), 599.
[349] Orr, Kelly. (1990). *Hornet: The Insight Story of the F/A-18*. Presidio Press, Novato, CA. Though Kelly Orr says on page 48 that the nickname "Cobra" came from a test pilot, James P. Stevenson reports in *The Pentagon Paradox* (pp. 77-78) that the YF-17 was derived from Northrop's P-530 Cobra, suggesting the nickname was already floating around before the YF-17 ever flew.

After the F-18's dogfights with the F-15 in 1981 (pp. 172-173), Admiral Gillcrist said that "I was totally astonished… Here I was flying in an airplane that had been highly criticized for its lack of internal fuel capacity, and I just ran the highly touted long-range Eagle out of fuel. Amazing!"
[350] McLucas, John L. (2006, Aug.). *Reflections of a Technocrat: Managing Defense, Air, and Space Programs during the Cost War.* Air University Press, Maxwell Air Force Base, AL, 99 and 123. Also, the A-10 was the result of the first U.S. prototype competition ever performed, according to Pierre Sprey.
[351] Perry, Robert. (1979, June). "American Styles of Military R&D." Santa Monica, CA, RAND Corp., P-6326, 25.
[352] "Department of Defense Appropriations for 1972," (1971, Mar. 18), 17.
[353] "Major Systems Acquisition Reform: Part 2." (1975, Jun. 16 – Jul. 24), 248.

[354] "The Lockheed F-117A Stealth Fighter." Found in Goodall, James C. (1992). *America's Stealth Fighters and Bombers: B-2, F-117, YF-22, and YF-23*. Motorbooks: St. Paul, MN.
[355] "Hearings on Military Posture and H.R. 1872 [H.R 4040] and H.R. 2575 [S. 429], and H.R. 3406, Part 2." 856-860. Note that the unit costs are both inflation adjusted, meaning it controls for the purchasing power of the dollar, and they are adjusted for quantities. Myers explained, "In this case, all of the planes have been reduced to common production quantities, say, 500 airplanes. In other words, if you were buying 500 of each of them in fiscal year 1980 dollars, that is the relative cost."
Sandy McDonnell was an early advocate for multi-mission aircraft. In 1954, the Navy wanted a new interceptor but McDonnell convinced them to develop a multi-mission aircraft. "If substantial quantities of aircraft are procured," McDonnell said, "the effect of the 'learning curve' is so powerful that it will more than compensate for the muiltimission aircraft size and weight, which is greater than some of the single mission aircraft such as the day interceptor." The Navy agreed and the result was the F-4 Phantom II, which significantly underperformed in Vietnam relative to the F-86 Sabre's experience in Korea. Some of the performance differences may be explained by an engineering appraisal using John Boyd's EM-Theory. See Bugos, Glenn E. (1996). *Engineering the F-4 Phantom II*. Naval Institute Press, 24; and Osinga, Frans P. B. (2007). *Science, Strategy, and War: The Strategic Theory of John Boyd*. Routledge: London and NY.
[356] Osinga, *Science, Strategy, and War*, 20-25. The LWF concept could also start with Chuck Myers, who early on criticized government requirements that forced the TFX to weigh 80,000 pounds. He explained to a sympathetic Alain Enthoven the merits of a gun-fighting aircraft, and later in 1963 wrote a paper on the requirements for a "close-combat cannon equipped fighter." As Myers recalled, "It wasn't that the whiz kids were screwed up. We aviators were doing a poor job of explaining the problem of air-to-air combat." See *The Pentagon Paradox* by J. P. Stevenson, pp. 21-29. Apparently it was Myers who, using a friend in DDR&E, got John Boyd his Pentagon assignment by lobbying the Air Force Chief of Staff to rescind Boyd's order to Okinawa. Myers may also be credited with coining the term "stealth" aircraft, though in his initial concept, he wanted to "reduce all the signatures, the visual, acoustical, radar, and infrared." Funding for lightweight and quiet aircraft were then part of the stealth movement. The A-10 has elements of reduced infrared signatures. Today, stealth refers almost solely to aircraft with a very low Radar Cross Section (RCS), like the F-117.
[357] Rutowski, Edward S. (1954). "Energy Approach to the General Aircraft Performance Problem." *Journal of the Aeronautical Sciences*, Vol. 21, 187-95. See also, Hankins, Michael. (2018, Aug. 22). "A Discourse on John Boyd: A Brief Summary of the US Air Force's Most Controversial Pilot and Thinker." BalloonsToDrones.com. Hankins says that Boyd admitted to copying Rutowski's idea, at least in the use of visualizations if not the equations themselves. See USAF Historical Research Agency. (1977, Jan. 22). "John Boyd, Corona Ace Oral History Interview." K239.0512-1066.
[358] Burton, James G. (1993). *The Pentagon Wars: Reformers Challenge the Old Guard.* Naval Institute Press, Annapolis, MD, 14. Also see Stevenson, *The Pentagon Paradox*,75-76. Boyd reportedly got the weight of the F-X down from 60,000 to 40,000 pounds and removed the possibility of a swing-wing design like the F-111. Later models of the F-15 saw their weight increase to 70,000 pounds.
[359] "Harry Hillaker—Father of the F-16." For Riccioni and the Bomber Mafia, see Hammond, Grant. (2001). *The Mind of War: John Boyd and American Security*. Smithsonian Press, Washington, D.C., 85.
[360] Stevenson, *The Pentagon Paradox*, 184.
[361] "Harry Hillaker—Father of the F-16."
[362] Stevenson, *The Pentagon Paradox*, 97-103.
[363] Burton, *The Pentagon Wars*, 19.
[364] Gable, Deborah. *Acquisition of the F-16 Fighting Falcon 1972-1980.* Report No. 87-0900, United States Air Force Air Command and Staff College, Air University: Maxwell Air Base, March 1987, pp. 8-9.
[365] Stevenson, James P. *The Pentagon Paradox: The Development of the F-18 Hornet*. Naval Institute Press, Annapolis, MD, 1993, pp. 134-35.
[366] "Weapon Systems Acquisition Process," (1971, Dec. 3-9), 281 and 69.
[367] Stevenson, *The Pentagon Paradox*, 153-61.
[368] Mets, David R. (2004, Fall). "Boydmania."*Air & Spacepower Journal.* Vol. XVIII, no. 3, 98-107.
[369] "Pierre Sprey and the Birth of the A-10." (2017). Interview on Pentagon Labyrinth, Project on Government Oversight (POGO).
[370] "Memorandum for Dr. Kissinger. Subject: FY 75 Defense Program and Budget." (1973, Aug. 10). Written by Phillip Odeen. The Air Force was authorized to have 24 fighter air wings, they could only fill 22. Note that Foster states the air wing increase to be five, not six given by Sprey or four as given by Odeen. See Foster, Peter R. (1991). *F-16: Fighting Falcon*. Ian Allan Ltd. London, 3.

[371] Stevenson, *The Pentagon Paradox*, 176. The LWF concept in the Air Force was named the Air Combat Fighter (ACF).
[372] Marsh, George T. "Interview." United States Air Force Oral History Program, 251.
[373] "Harry Hillaker—Father of the F-16." Interview by Eric Hehs. *Code One Magazine.* April and July, 1991.
[374] Stevenson, James P. *The Pentagon Paradox: The Development of the F-18 Hornet*. Naval Institute Press, Annapolis, MD, 1993
[375] "Harry Hillaker—Father of the F-16."
[376] Bjorkman, Eileen. (2014, Mar.). "The Outrageous Adolescence of the F-16." *Air & Space Magazine*.
[377] "Harry Hillaker—Father of the F-16."
[378] "Major Systems Acquisition Reform: Part 2." (1975, Jun. 16 – Jul. 24), 217.
[379] Stevenson, *The Pentagon Paradox*, 74 and 178.
[380] Orr, *Hornet*, 126.
[381] "House of Representatives Report No. 93-1363." (1974, Sep. 18). 93rd Congress, 2nd Session.
[382] "F-18 Navy Air Combat Fighter." (1975, Oct.). Hearings Before a Subcommittee of the Committee on Appropriations, U. S. Senate, First Session, on H.R. 9861 hearings, 73-74. After reading Deputy Secretary of Defense Clements' letter, one can easily come away with the wrong impression about the Navy's intent, and perhaps the chairmen (and their staff) did not fully understand what was being asked of them.
[383] "F-18 Navy Air Combat Fighter." (1975, Oct.), 181.
[384] "Department of Defense Appropriations for 1972," (1971, Mar. 18), 36.
[385] Some claim that the F-14 was only a slightly redesigned F-111B, and that the Navy could simply not accept a joint aircraft for the sake of the matter.
[386] No clue where this is from. Pp 17.
[387] "Major Systems Acquisition Reform: Part 2." (1975, Jun. 16 – Jul. 24), 6 and 44. A savings of $1 billion was estimated on page 2. On May 12, 1975, just 10 days after the Navy decision on the F-18, Rep. Milford asked Chairman Stennis of the Senate Armed Services Committee to be invited to any hearings on the F-18 program.
[388] Orr, *Hornet*, 55-56.
[389] "Major Systems Acquisition Reform: Part 1 Air Combat Fighter Programs." (1975, May 20). Hearings before the Subcommittee on Federal Spending Practices, Efficiency, and Open Government of the Committee on Government Operations, U.S. Senate, Ninety-Fourth Congress, 86.
[390] "Major Systems Acquisition Reform: Part 2." (1975, Jun. 16 – Jul. 24), 6 and 44. A savings of $1 billion was estimated on page 2. On May 12, 1975, just 10 days after the Navy decision on the F-18, House representative Dale Milford asked Chairman Stennis of the Senate Armed Services Committee to be invited to any hearings on the F-18 programs.
[391] "F-18 Program." (1975, Sep. - Oct.). Hearings Before a Subcommittee of the Committee on Appropriations, U. S. Senate, First Session, on H.R. 9861 hearings, 29-33. The one exception was approach speed, which was still too high for the F-18 design, but still much better than the three YF-16 derivatives.
[392] "Major Systems Acquisition Reform: Part 1 Air Combat Fighter Programs." (1975, May 20).
[393] "F-18 Navy Air Combat Fighter." (1975, Oct.), 77.
[394] Robert Thornton, Legislative Attorney. "Effects of Language in a Conference Report on an Appropriations Measure on the Use of Monies Appropriated Therein."
[395] "Decision, Matter Of: LTV Aerospace Corporation." (1975, Oct.1). Comptroller General of the United States, File B-183851, 1.
[396] "F-18 Navy Air Combat Fighter." (1975, Oct.), 6.
[397] Unknown.
[398] Luttwak, Edward. (1985). *The Pentagon and the Art of War: The Question of Military Reform.* Simon & Schuster, 136-38.
[399] "Report of the Commission on Government Procurement," 68-71. This count neglects U.S. contractors as a center for design, but, in the defense innovation process, only a small part of contractor expenditures go toward independent R&D, or R&D performed outside the requirements and control of the Government.
[400] "The Military Budget and National Economic Priorities." (1969, Jun.). Hearings Before the Subcommittee on Economy in Government of the Joint Economic Committee, Ninety-First Congress, Part 1, 403.
[401] Nagle, James F. (1999.) *A History of Government Contracting: Second Edition*. The George Washington University, Washington D.C., 223.
[402] Morison, Elting E. (1966). *Men, Machines, and Modern Times*. The M.I.T. Press, 37-38.
[403] "Can Weapon Leadtimes Be Shortened By Atom Lessons?" (1966, Nov.). *Armed Forces Management*, 79-83.
[404] Perry, "The Ballistic Missile," 25-26.

[405] "Significant examples can be cited where the establishment actively resisted the introduction of a materiel system (Jeep, Christie Tank, P-51 Fighter Aircraft, SIDEWINDER and… US Army rifles)." See Sel, Wendell B. (1974, April 1). AMARC report, I-7.
[406] Harford, Tim. (1997). *Fifty Things That Made the Modern Economy*. Little, Browen Books.
[407] Morison, *Men, Machines*, 37-44.
[408] Perry, "The Ballistic Missile," 2. Perry wrote that "Too few appreciated that a highly accurate 5000-mile ramjet-powered cruise missile… was perhaps a more ambitious undertaking than the atomic bomb, much less the B-29." See "The Interaction of Technology and Doctrine in the USAF," Jan. 1979, pp. 9-11.
[409] Perry, Robert. (1967, Aug.). "Innovation and Military Requirements: A Comparative Study." Santa Monica, CA, RAND, RM-5182-PR, 28.
[410] Perry, Robert. (1969, Aug.). "The Air Force and Operations Research: A Commentary of I. B. Holley's Paper." Santa Monica, CA, RAND, P-4114, 15-16.
[411] Perry, Robert. (1979, Jan.). "The Interaction of Technology and Doctrine in the USAF." Santa Monica, CA, RAND Corp., P-6281, 20.
[412] Perry, "The Ballistic Missile," 7.
[413] Perry, "Innovation and Military," 76. John Boyd's EM-Theory provided a foundation for trading off fixed-wing vs. variable sweep design aircraft, first incorporated in the F-15.
[414] Perry, "Innovation and Military," 1-2.
[415] Urwick, Lyndall F. *Leadership in the 20th Century*. Found in Borklund, C. W. (1967, Aug.). "Cost effectiveness' vs. Creativity: Part 1, Is Indecision Stifling Innovation?" *Armed Forces Management*, 51-53.
[416] Morison, *Men, Machines*, 9-12.
[417] Glennan, Thomas K. (1965, Nov.). "Policies for Military Research and Development." Santa Monica, CA, RAND Corp., P-3253, 27-29. "In passing," Glennan elaborated, "it should be noted that this [the requirements-pull approach] is the 'comfortable' way for the entire organization to proceed. It appears that it knows where it is going and is able to direct its R&D resources toward efficiently fulfilling these needs." In contrast, Glennan found that "One of the problems with technology-push types of projects is that they require faith on the part of the people outside the project. The payoffs are not obvious."
[418] Perry, "Innovation and Military," 1. To the systems and evolutionary approaches Perry adds the "incremental" approach which "calls for using only thoroughly proven technology." Both the incremental and evolutionary approaches appear to be in the same camp, as they are primarily based on "technology push" concepts. Perry also links incrementalism to countries with smaller technology bases, such as France, and evolution as applicable to countries that can afford a large and diverse technology base, such as the U.S. See Perry, Robert. (1975, July). "Reforms in System Acquisition." Santa Monica, CA, RAND.
[419] Committee on Accelerating Technology Transition. (2004). "Accelerating Technology Transition: Bridging the Valley of Death for Materials and Processes in Defense Systems." National Research Council.
[420] Palmquist, Steven M. et al. (2013). "Parallel Worlds: agile and Waterfall Differences and Similarities." Software Engineering Institute.
[421] Royce, Winston W. (1970). "Managing the Development of Large Software Systems." *Proceedings, IEEE WESCON*, 1-9. Retrieved from http://www-scf.usc.edu/~csci201/lectures/Lecture11/royce1970.pdf.
[422] For example, see: Boehm, Barry. (1986, Aug.). "A Spiral Model of Software Development and Enhancement." ACM SIGSOFT Software Engineering Notes, ACM, vol. 11, no. 4, 14-24; and Beck, Kent et al. (2001). "Manifesto for Agile Software Development." Agile Alliance.
[423] Remi Maniak, Christophe Midler, Sylvain Lenfle, and Marie Le Pellec-Dairon. (2014). "Value management for exploration projects." *Project Management Journal*.
[424] Committee on Accelerating Technology Transition, "Accelerating Technology."
[425] Meyerson, "Price of Admission," 113-114.
[426] "Evolution and Compatibility: 1965's Key Words in Tactical C&C." (1963, Jul. 9). *Armed Forced Management*, 52-55.
[427] Murdock, *Defense Policy Formation*, 167 and 175.
[428] "Policy Changes in Weapon System Procurement." (1970, Dec. 10). Forty-Second Report by the Committee on Government Operations.
[429] Levine, Peter K. (2018, May). "Lessons from the Never-Ending Search for Acquisition Reform." Institute for Defense Analyses, r NS P-8951, 29
[430] Office of the Secretary of the Navy. (1975, January). "Report of the Navy Marine Corps Acquisition Review Committee. Volume I." VII-90. Hereafter, NMARC report. The matter is most problematic for getting new efforts

approved. Programs which already have a wedge in the budget can first survive on existing funds, and second, they can seek changes later in the PPB process than a new programming effort.
[431] "Recommendations made by the Comptroller General to the House Armed Services Committee, March 29, 1973."
[432] "OMB Circular No. A-109, Subject: Major System Acquisition." (1976, Apr. 5), 12.
[433] Staats, "A Critique of the Performance."

Chapter 7: Complexity

[434] Ailman, Christy. (2013). "Philosophy of Math: The Beginnings of Mathematical Deduction by Induction." Azusa Pacific University. Retrieved from https://philarchive.org/archive/AILMDB-2.
[435] The inductive approach to science may be represented by Francis Bacon, who rejected Copernican astronomy when empirical evidence seemed to fit Ptolemaic epicycles just fine (see Hayek, Friedrich A. (1955). *The Counter-Revolution of Science*. New York, NY: First Free Press]. The deductive approach may be represented by René Descartes, who rejected empiricism due to a "deception of the senses"[435] but failed to explain how distinct truths, like mathematical axioms (e.g., if A = B, then B = A), became self-evident points from which to reason in the first place [see Descartes, Rene. (1950). *Discourse on Method*, Trans. L. J. Lafleur. Bobbs-Merrill, 5-7)] While Bacon relied on empirical evidence found through experimentation, Descartes relied on pure reason independent of experience found in mathematics and logic.
[436] Whitehead, Alfred North. (19XX). Process and Reality.
[437] Wildavsky, Aaron. (1966, December). "The Political Economy of Efficiency: Cost-Benefit Analysis, Systems Analysis, and Program Budgeting." *Public Administration Review*, Vol XXVI, No. 4.
[438] Murdock, *Defense Policy Formation*, 46.
[439] Roherty, *Decisions of Robert S. McNamara*, 85-86.
[440] Quade, E.S. (1966, March). "Systems Analysis Techniques for Planning-Programming-Budgeting." Stanta Monica, CA, RAND Corp., P-3322.
[441] Borklund, C. W. (1967, Sep.). "Cost effectiveness' vs. Creativity: Part 2, A "Wait-and-See" Philosophy Can Squelch Initiative." *Armed Forces Management*, 57 – 59.
[442] Schlesinger, James R. (1970). "Uses and Abuses of Analysis." Published in Jackson Committee Hearings, "Planning, Programming, Budgeting: Inquiry of the Subcommittee on National Security and International Operations." U.S. Government Printing Office, Washington.
[443] Alain C. Enthoven and K. Wayne Smith. (1971). *How Much Is Enough? Shaping the Defense Program, 1961-1969*. New York, NY: Harper & Row, Publishers, pp. 78.
[444] Poole, Walter. . History of Acquisition in the Department of Defense Volume II: *Adapting to Flexible Response, 1960-1968.* Historical Office, Office of the Secretary of Defense, Washington: 2013, pp. 31.
[445] Burton, James G. (1993). *The Pentagon Wars: Reformers Challenge the Old Guard.* Annapolis, MD: Naval Institute Press, pp. 14.
[446] Murdock, Clark A. (1974). *Defense Policy Formation: A Comparative Analysis of the McNamara Era*. Albany, State University of New York Press, pp. 165.
[447] Schlesinger, James R. (1970). "Uses and Abuses of Analysis." Published in Jackson Committee Hearings, "Planning, Programming, Budgeting: Inquiry of the Subcommittee on National Security and International Operations." U.S. Government Printing Office, Washington.
[448] "Impact of the Person Gulf War and the Decline of the Soviet Union on How the United States Does Its Defense Business." (1991, April 30). Committee on Armed Services, House of Representatives, No. 102-17, 688.
[449] Burton, *The Pentagon Wars*, 14. Similarly, Pierre Sprey derived the requirements for the A-10 by a detailed study of close air support missions performed by German aviators in WWII and U.S. aviators in Korea.
[450] Croam, Robert. (2002). *Boyd: The Fighter Pilot Who Changed the Art of War.* Robert Croam: USA, 116.
[451] Rutowski, "Energy Approach," 187-95. See also Hankins, "A Discourse on John Boyd."
[452] Spinney, Franklin "Chuck." (2014, December). "Evolutionary Epistemology. Version 2.4." Retrieved from https://fasttransients.files.wordpress.com/2010/03/spinneyevolutionaryepistemology2-4.pdf.
[453] Michael Polanyi made a distinction between tacit and articulated knowledge. Science and engineering are examples of articulated knowledge that can be explicitly communicated. But Polanyi argued that science nevertheless depends on tacit knowledge, such as when forming hypotheses and interpreting the results, which can only be gained through experience. Tacit knowledge underlies all articulated knowledge and can be a powerful organizing force on its own. For example, individual ants exhibit simple behaviors and cannot articulate knowledge at all. Yet colonies of ants exhibit wonderfully complex behaviors as a result of tacit knowledge, allowing ant colonies to thrive all over the world under changing environments. What makes humans stand out from ants and all other animals is our ability to articulate

knowledge. Science can be said to be the accumulation of articulated knowledge and is embodied in technology. [Move to competition section???]

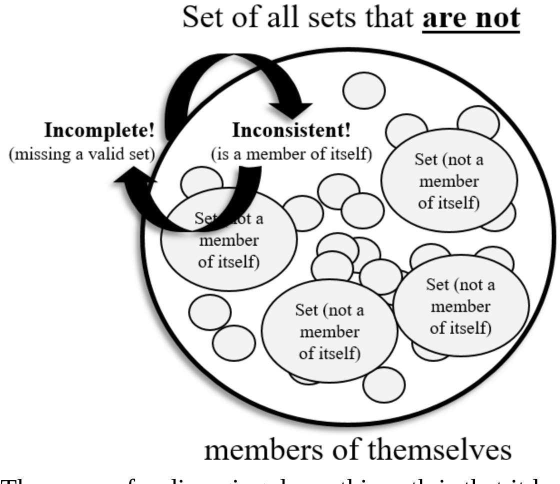
454 Monk, Ray. (1996). *Bertrand Russell: The Spirit of Solitude 1987-1921*. London: Vintage.

455 Russell, Bertrand. (1946). *History of Western Philosophy*. Simon and Schuster, 650.

456 Frege set out to put mathematics on a logical foundation by proving that set theory really belonged to logicism. To do so, numbers first had to be defined as sets where membership depends on meeting certain conditions. The number two, for example, was defined the set of all objects that had two members. A tank is the set of armored tracked vehicles with a gun turret; it includes the M4 Sherman, the T-34, the Panzer IV, and all other vehicles which fit the set described by "tank." These sets are like Boyd's domains or concepts which constitute various parts. And like Boyd who conjectured a complete concept that no new observation would contradict, Bertrand Russell conjectured the set of all sets. The paradox that Russell found led to him down a path that ended in his rejecting the reality of numbers and logical form, reducing mathematics to a useful but tautological exercise as opposed to a window into the nature of reality.

In Gottlob Frege's set theory, there are two broad types of sets: those which are members of themselves and those which are not. The set "tank" is not itself a tank, it is a concept that includes all the sets of objects fitting its conditions (M4 Sherman, T-34, Panzer IV, and so forth). The concept of a tank itself does not bring armored firepower to the real world. Similarly, the number "2" does not itself have two members, and so is not member of its own set. Most sets are not members of themselves. However, "English" is a word within the set of English language words, and so is a member of itself. "Spanish" is not a member of itself, it is an English word and so wouldn't be in the set of Spanish words. The example shows how sets which are members of themselves are self-referential and hierarchical; English is an English word that describes itself.

One way of deriving a set that is a member of itself is to find the set of objects not described by another set. For example, the set of all sets that are not tanks includes ships, roses, chairs, and so forth. When we create the set of all things that are not tanks, we have created a new set and may ask, "Is this set of all non-tank sets itself, not a tank?" The answer, of course, is "yes," the set is not a tank, and therefore it is a member of itself. Otherwise, we would observe a valid set that meets the "not a tank" condition without finding it in our set. Our set would be incomplete. To avoid this discomforting fact, the set must be a member of itself. Similarly, when we form a set of all things that do not have two members, the resulting set also does not have two members, and so it must be a member of itself. Notice we are grouping into one set various other sets at different levels of a conceptual hierarchy. Self-membership within a set results from a self-reference of that hierarchy, such as asking whether the set of all sets meeting certain conditions itself meets those same conditions.



The set of all sets which are not members of themselves is represented by the outer circle. If it is a member of itself, it is inconsistent. If not, it is incomplete.

The reason for diverging down this path is that it leads to a paradox at the heart of mathematics as applied to logical form. Bertrand Russell wrote to Frege in 1903 asking about the complete concept: the set of all sets that are not members of themselves (including tanks and the number two but leaving out sets that are not tanks and are not two). Would this set be a member of itself or not? Well, if it really is the set of all sets that are not members of themselves, the set cannot include itself. But if it doesn't include itself, then it is missing the inclusion of a valid set that isn't a member of itself. It is incomplete. If we make the set a member of itself, then the set no longer meets the conditions for inclusion in the set of all sets that *are not* members of themselves. It is inconsistent. We arrive at a paradox. The set of all sets is either a member of itself or not, but that question cannot be decided. If it were decided, it would be as if, in a sense, the set is both "itself" and "not itself" at the same time. When we look into the set of all sets that are not members of themselves, it would be inconsistent if it included itself and incomplete if it were excluded. If the matter cannot be resolved, how can we trust any result from the mathematical system?

[457] UC Davis Academics. (2015, March 10). "Gödel for Goldilocks: Gödel's First Incompleteness Theorem." https://www.youtube.com/watch?v=9JeIG_CsgvI.

[458] Alonzo Church and Alan Turing proved that first-order logic was, nevertheless, undecidable.

[459] Heisenberg, Werner. (1927, March 23). "Uber den Anschaulichen Inhalt der Quantentheoretischen Kinematik und Mechanik." *Zeitschrift f¨ur Physik* 43, 172–198. English translation in Wheeler, J.A. and H. Zurek (eds.). (1983). *Quantum Theory and Measurement*, Princeton Univ. Press, Princeton, 62–84.

[460] Heisenberg, Werner. (1930). *The Physical Principles of Quantum Theory*. Chicago, IL: University of Chicago Press.

[461] For more on De-Broglie-Bohm (Bohmian) mechanics, see: (a) Wigner, Eugene P., 1976, "Interpretation of Quantum Mechanics", lecture notes; revised and printed in Wheeler and Zurek 1983: 260–314. (b) Dürr, Detlef, Sheldon Goldstein, and Nino Zanghì, 2009, "On the Weak Measurement of Velocity in Bohmian Mechanics", *Journal of Statistical Physics*, 134(5): 1023–1032. (c) Dürr, Detlef, Sheldon Goldstein, and Nino Zanghì, 1997, "Bohmian Mechanics and the Meaning of the Wave Function", in R.S. Cohen, M. Horne, and J. Stachel (eds), *Experimental Metaphysics—Quantum Mechanical Studies for Abner Shimony, Volume One*, (Boston Studies in the Philosophy of Science 193), Boston: Kluwer Academic Publishers. (d) Bell, John S., 1964, "On the Einstein-Podolsky-Rosen Paradox", *Physics*, 1(3): 195–200. Reprinted in Bell 1987c: 14–21 and in Wheeler and Zurek 1983: 403–408. (e) Bohm, David and Basil J. Hiley, 1993, *The Undivided Universe: An Ontological Interpretation of Quantum Theory*, London: Routledge & Kegan Paul. (f) Aspect, Alan. (2015, December 16). Viewpoint: Closing the Door on Einstein and Bohr's Quantum Debate. *Physics* 8, 123.

[462] The purpose here is not to debate quantum theories. Our purpose is twofold. First, it will be argued that Boyd's use of Heisenberg's Uncertainty Principle is valid regardless of whether we subscribe to the Bohmian interpretation or the Copenhagen. [James Hasik attributed Boyd's views of Heisenberg's Uncertainty Principle to the Copenhagen interpretation and suggested problems, but as always, Boyd seems to have written generally enough that we cannot pin him to one interpretation. For example, Boyd cited *Thirty Years That Shook Physics* by George Gamow which introduced both the Copenhagen view and a view of De Broglie-Bohm mechanics from before John Bell. Frans Osinga also responded to Hasik on whether Boyd reasoned by analogy. See Hasik, James. (2012, May). "Beyond Hagiography: Theoretical and Practical Problems in the Works and Legacy of John Boyd. 2.4." Retrieved from http://www.james hasik.com/files/ 20120515_problems_of_boyd.pdf. Also see Osinga's chapter in Oslen J.A. (Ed.) (2015). *Airpower Reborn: The Strategic Concepts of John Warden and John Boyd*. Naval Institute Press.] (Because both theories make the same probabilistic predictions, many physicists choose not to interpret quantum phenomena and instead prefer to "shut up and calculate," as Richard Feynman quipped.) Second, the discussion clarifies the self-referential role of the observer.

Heisenberg's Copenhagen interpretation suggests that quantum objects like electrons do not have perfectly precise positions and velocities. An electron propagates as a wave—it is in many places at once, and in technical terms, it is in a "superposition" of all probable states—until we measure the electron's position which "collapses the wave-function" and reveals its particle-like properties [Baggot, Jim. (2011). *The Quantum Story: A History in*. Oxford University Press]. In other words, when we zoom into a specific point to see whether the electron is there or not, we not only lose focus of the electron's wave-like properties, we cause the electron to (randomly) choose a particular state from the probabilities represented by the wave. The electron was spread out in a wave but upon measurement it takes on particle-like properties and answers questions of position.

The Copenhagen interpretation finds that when an observer measures the system, quantum objects localize from a wave (with no precisely defined position) to a particle (with no precisely defined velocity).

[463] Weinberg, Steven. *Scientific American*. 271, no. 4, 44.

[464] "A Million Random Digits with 100,000 Normal Deviates." (1955). Santa Monica, CA: RAND Corporation.

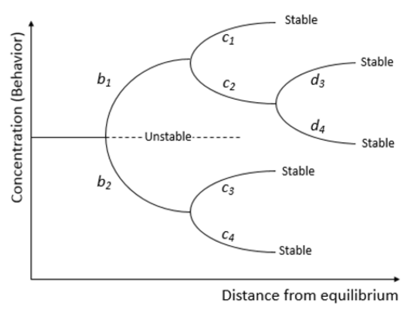
[465] Chaitin, G.J. (1990). *Information, Randomness and Incompleteness, Papers on Algorithmic Information Theory*, World Scientific, Singapore. See also Calude, Cristian S., ed. (2007). *Randomness and Complexity. From Leibniz to Chaitin*, World Scientific.

[466] Calude, Cristian S. (2005). "Algorithmic Randomness, Quantum Physics, and Incompleteness." In: Margenstern M. (eds.). (2004). "Machines, Computations, and Universality." MCU. Lecture Notes in Computer Science, Vol. 3354. Springer, Berlin. Heidelberg. See also Calude, C. and J. Michael. (2005). "Is Quantum Randomness Algorithmic Random? A Preliminary Attack." Dinneen Department of Computer Science University of Auckland, New Zealand. The authors argue that Heisenberg's uncertainty implies algorithmic randomness (as described by Gregory Chaitlin, i.e., it cannot be decided using a universal self-delimiting Turing machine whether an apparently random string of numbers is indeed random) which, in turn, implies incompleteness (in the Gödelian sense).

[467] Layzer, David. (1975, December). "The Arrow of Time." *Scientific American*.
[468] Differentials in energy have potential for doing work and as entropy spreads the energy that potential is lost.
[469] The reconciliation is particularly salient for the Copenhagen because "every act of observation is by its very nature an irreversible process." Heisenberg, Werner. (1958). *Physics and Philosophy*. New York: Harper and Row. In the Bohmian view, entropy results from deterministic equations because of our ignorance rather than, as Ilya Prigogine argues, resonance that breaks time symmetry. The author is very much biased towards Prigogine's interpretation, which builds on the Bohmian embrace realism and *nonlocality*, but removes ignorance as the cause of irreversibility.
[470] Boyd, John. (1987). "The Strategic Game of ? and ?" Unpublished document.
[471] Simon, Julian. (1983). *The Ultimate Resource.* Princeton, NJ: Princeton University Press.
[472] Schrodinger, Erwin. *What is Life?*
[473] Varela, Francisco J.; Maturana, Humberto R.; & Uribe, R. (1974). "Autopoiesis: the organization of living systems, its characterization and a model." *Biosystems* Vol. 5, 187–196
[474] Prigogoine, Ilya. (1996). *The End of Certainty.* New York, NY: The Free Press, pp. 66-69. A little more on the two conditions for dissipative structures. First, the open system must be far from equilibrium. Energy or matter from the environment must flow through the system causing an excited and unstable state. Processes near equilibrium tend to be stable and revert to equilibrium. When more energy flows through the system, pushing it further away from thermodynamic equilibrium, the system tries to recover itself. It must dissipate entropy faster, creating new structures to reach an equilibrium. The system acts deterministically as it moves away from equilibrium until it reaches a critical point where the previous pattern becomes unstable. At the critical point, the system suddenly "chooses" among the stable patterns, giving the system new properties. The new stable state can again be treated deterministically until it moves even further away from equilibrium when it reaches another critical point, and so forth. These points of probabilistic choice between stable states are called bifurcations; they come with increasing rapidity as more energy or matter flow through the system. As it bifurcates down one path of another, the system takes on more active and complex properties.

The second condition for dissipative structures relates back to our idea of self-reference, or internal circularity, which in this case keeps the dissipative system coherent (or correlated) as it moves increasingly far from equilibrium. The system requires inputs, an intermediate state, and a final set of outputs. Further, along the path to the final outputs the intermediate state must generate additional inputs as a by-product which feeds back into the system. In other words, we need self-amplifying feedback effects.

In chemistry and physics these chain reactive processes are pervasive. For example, chemical reactions can produce heat which in turn increases the rate of reactions. Prigogine explained that we need "catalytic steps," where intermediate compounds produce additional input compounds. "It is interesting to note that these conditions are satisfied in all living systems: Nucleotides code for proteins, which in turn code for nucleotides." At far from equilibrium conditions, the feedback effects react to increasing instability which sparks bifurcation towards either new stable patterns or disintegration. Physical processes may then take on complex new behaviors and exhibit self-organization. As the environment becomes more complex, the system must have increasingly elaborate mechanisms to maintain itself. As Prigogine explained, "Bifurcations are the manifestation of an intrinsic differentiation between parts of the system itself and the system and its environment."



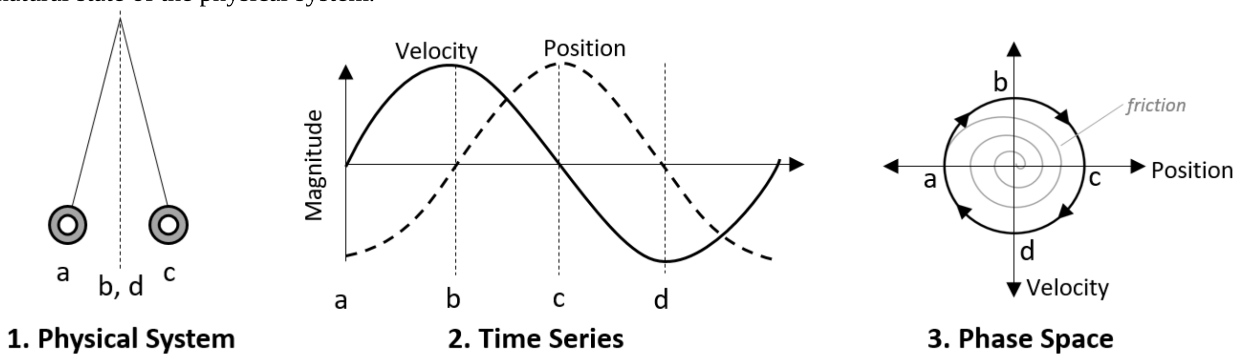
When a nonlinear system moves far from equilibrium, resonances create bifurcations where new stable states of increasing complexity emerge. As distance from equilibrium increases, bifurcations become increasingly frequent. Reproduced figure from Prigogine, The End of Certainty.

[475] Non-linear systems are *non-integrable*.
[476] It is illuminating to see how bifurcations, a term coined by Poincaré, are related to nonlinear systems. Each mode of motion, such as a celestial orbit, corresponds to a frequency in phase space. Except for special cases, the frequencies that represent each body are not a sine wave of constant and periodic amplitude such as in the case of the idealized pendulum. Frequencies are affected by the changing influences of the other two bodies. Everything is still deterministic and time-reversible at this point. However, over long enough timeframes, nonlinear systems will generate a wide range of frequencies. Inevitably, two or more of the bodies will share the same frequency,

corresponding to the same orbital period. At this point, we have resonance between frequencies. Resonance is the basic idea that when two objects share the same frequency, or share frequencies that are rational multiples of one another, they will drive each other to greater amplitudes.

In our three-body problem, this manifests as large changes in position and velocity when orbits cross each other. Their gravitational forces lead to a pocket of phase space between them where force vectors are diverging everywhere (i.e., the bodies repel one another as though there were a source between them). Once we encounter resonance, we get sudden qualitative changes in behavior leading to what Poincaré called bifurcations.

To first understand how Poincaré proved that the three-body problem was non-integrable, meaning there is no closed form solution from initial conditions, we must recognize that position and velocity are mathematically equivalent to frequency and time. That is, we can plot trajectories by wrapping frequencies around a coordinate system called phase space. For example, if we have a frictionless pendulum, we can plot the magnitude of the velocity as one frequency and position as another. When the pendulum swings through the center (from left to right) velocity hits a maximum and when its swing reaches its peak (maximal distance from the center), the velocity comes to zero. We can chart the possible states of the pendulum by plotting position on the x-axis and velocity on the y-axis of a coordinate system. Each moment in time will be represented by a point, and continuous time will be represented by a line. One full oscillation of the frequency corresponds to one rotation around the phase space graph of our example. In the case of the frictionless pendulum, we have a circle in phase space around a fixed point. And if we introduce friction, then the phase space portrait will cycle in toward a fixed point at the center because the pendulum loses velocity and the position stops at the center. In either case we have a fixed point—an "attractor"—in phase space that defines the natural state of the physical system.



(1) Each physical system, such as a pendulum, has a mode of motion. (2) The magnitude of the velocity and position can be plotted over time as separate frequencies. (3) For any given moment, the magnitude of the velocity and position can be plotted as coordinates in phase space. For the idealized pendulum, we have periodic motion around a fixed point, while the pendulum encountering friction spirals into a stationary state at the fixed point. This fixed point is called an attractor.

In the case of a pendulum, we are dealing with movement along a one-dimensional line with the need for only one position coordinate. To represent three-dimensional space, such as in the three-body problem of celestial orbits, we will need three position coordinates. Still, a three-dimensional body can be reduced to a single line in multi-dimensional phase space. We can then imagine plotting the evolution of three bodies, their position and velocity, on a single map of the combined system in phase space. Each of our three bodies is also affected by the others' gravity without physical interaction. This makes for a complicated set of 18 simultaneous equations. By calculating the net forces between the objects, we can again reduce the three-body system into a single point in phase space. Now, what makes the system non-integrable, and thus, unpredictable?

Remember, each mode of motion, such as a celestial orbit, corresponds to a frequency. Except for special cases, the frequencies that represent each body are not a sine wave of constant and periodic amplitude such as in the case of the idealized pendulum. Frequencies are affected by the changing influences of the other two bodies. The frequencies representing velocity and position morph as they move through phase space. Everything is still deterministic and time-reversible at this point. Over long enough timeframes, the nonlinear systems will generate a wide range of frequencies. Inevitably, two or more of the bodies will share the same frequency, corresponding to the same orbital period. At this point, we have resonance between frequencies.

For more on the three-body problem, see Poincaré, Henri. (1885, September). "*L'Équilibre d'une masse fluide animée d'un mouvement de rotation*." *Acta Mathematica*, vol.7, 259-380. Musiela, Z.E. and B. Quarles. (2014). "The Three-Body Problem." *Reports on Progress in Physics*, Vol. 77, No. 6; and Szebehely, V. (1990). "Chaos, Stability, and

Predictability in Newtonian Dynamics." Published in Row, A.E. (Eds.) *Predictability, Stability, and Chaos in N-Body Dynamical Systems.* New York, NY: Plenum Press, 1990.

[477] In special cases, long term solutions to the three-body problem can be found using linearization and inductive improvements. But for most cases, the methods only give us approximate solutions which become increasingly unsatisfactory as the forecast period progresses [Wayne, Eugene C. (2008, January 22). "An Introduction to KAM Theory." http://math.bu.edu/people/cew/ preprints/introkam.pdf. The Fourier transformation also gives us another view of the Bohmian interpretation of the Heisenberg Uncertainty Principle. See videos by 3Blue1Brown accessed on youtube.com, "But what is the Fourier Transform" and the follow-up video "The more general uncertainty principle, beyond quantum."]. The problem with linearization is that its approximations only hold under non-resonant conditions. When we initiate the system at time-zero, we can approximate what will happen after the first discrete moment, and feed that back into our linear approximation to get the second moment, and so forth. But when resonance is introduced, our linear calculations confront "dangerous" denominators that converges on zero, causing our answer to approach infinity [Ilya Prigogine illuminates the dangerous denominators. Consider a system characterized by two frequencies. By definition, we have resonance whenever the sum $n_1\omega_1 + n_2\omega_2 = 0$, where n_1 and n_2 are nonvanishing integers and ω_1 and ω_2 are the frequencies. This means the ratio of the frequencies is a rational number, and in dynamic equations, we will have denominators with the term $(n_1\omega_1 + n_2\omega_2)$. Resonance causes the terms to diverge.]. At this point, approximations no longer hold and the system becomes unpredictable. The Lyapunov exponent determines when vectors exponentially diverge in area around our object, in this case due to resonance. Until they diverge, we can make reasonable predictions about the nonlinear system. Individual trajectories, described by linear models, cannot be used because resonance brings nonlocal effects to the system.

[478] Gleick, James. (1987). *Chaos*. Auckland, NZ: Viking, 121-156.

[479] The scientist requires experimentation on an isolated system, but such isolation is only a theoretical construct. In nonlinear systems, seemingly negligible interactions, such as the flap of a butterfly's wings or the existence of the observer, may have significant effects.

[480] Johnson, Steven. (2001). *Emergence*. New York, NY: Scribner, 74.

[481] Wiener, Norbert. (1948). *Cybernetics: Or Control and Communication in the Animal and the Machine.* Cambridge, MA: MIT Press.

[482] Ashby, W.R. (1962). "Principles of the Self-Organizing System". Published in H. Foerster and G.W. Zopf, Jr. (Eds.), *Principles of Self-Organization*. US Office of Naval Research.

[483] Taleb, Nassim. (2008). *The Black Swan*. Penguin. 312-18.

[484] Gleick, *Chaos*.

[485] C.K. Biebracher, G. Nicolis, and P. Schuster. (1995). "Self-Organization in the Physico-Chemical and Life Sciences." European Commission Report EUR 16456.

[486] U.S. Marine Corps. (1997, June 20). *MCDP-1: Warfighting.*

[487] Hayek, 1968, Competition as a Discovery Procedure!

[488] Enke, Stephen. (1960, Apr. 15). Review: "The Political Economy of National Security." *Science*, vol. 131, no. 3407, 1093.

[489] Schlesinger, James R. (1961, June). Review: "The Economics of Defense in the Nuclear Age." *American Political Science Review*, vol. 55, no. 2, 379-380.

[490] Merewitz, Leonard and Sosnick, Stephen H. (1971). *The Budget's New Clothes: A Critique of Planning-Programming-Budgeting and Benefit-Cost Analysis*. Chicago, IL, Rand McNally College Publishing Co., 5.

[491] Klein and Alchian were also friends with James M. Buchanan, who had spent a short summer at RAND before joining the University of Virginia. The connection perhaps facilitated Schlesinger's move to RAND in 1963. When the Virginia School economists were expelled from UVA in 1968 due to the disapproval of other departments, Armen Alchian helped James M. Buchanan secure a spot at UCLA. Ironically, Roland McKean moved from UCLA to UVA in the same year Buchanan left. McKean became the Paul Goodloe McIntire professor of economics, taking over for G. Warren Nutter who also left the Virginia School. Nutter became assistant secretary of defense for international security affairs from 1969-1973. Allen, William R. (2010, Sep.). "A Life among the Econ, Particularly at UCLA" https://econjwatch.org/articles/a-life-among-the-econ-particularly-at-ucla.

[492] Schlesinger, James. (1968). "Defense Planning and Budgeting: The Issue of Centralized Control." Santa Monica, CA, RAND Corp., P-3813. Found in Schlesinger, James R. (1974, Sep.). "Selected Papers on National Security 1964-1968." RAND Corp., P-5284. Notice the difference in emphasis on political-economy between McKean's earlier work at RAND [e.g., "Systems Analysis and Education," (1959) and "Criteria of Efficiency in Government Expenditures" (1957)] and his work after Schlesinger joined in 1963 [e.g., Economics of Defense" (1964), and "Problems, Limitations, and Risks of the Program Budget" (1965)]. See also the effect on Burton Klein in "Public Administration

and the Contemporary Economic Revolution," (1967) and compare that to "Communications Satellites and Public Policy: An Introductory Report," (1961).
[493] Schlesinger, "Defense Planning," 117. The published report "Defense Planning and Budgeting" was published in four years later, in May 1968, under James Schlesinger's name only. By that time, Roland McKean had exited RAND to pursue university economics full time. But in McKean's 1964 article for the International Encyclopedia of the Social Sciences, "The Economics of Defense," McKean cites the "forthcoming" paper under "McKean, Roland N.; and Schlesinger, James R. 1964. Defense planning and budgeting. (Forthcoming)." See McKean, Roland N. (1964, July). "Economics of Defense." Santa Monica, CA, RAND Corp., P-2926.
[494] Schlesinger, "Defense Planning."
[495] McKean, "Economics of Defense," 20-21.
[496] Lindblom, Charles E. (1955). "Bargaining: The Hidden Hand in Government." Santa Monica, CA, RAND Corp., RM-1434-RC.
[497] Polanyi, Michael. (1962, Autumn). "The Republic of Science: Its Political and Economic Theory." *Minerva*, vol. I, no. 1, 54-73.
[498] Janis, Irving L. (1972). *Victims of Groupthink: A Psychological Study of Foreign-Policy Decisions and Fiascos.* Houghton Mifflin Co.
[499] Janis, Irving L. (1971, Nov.). "Groupthink." *Psychology Today*, vol. 5, no. 6.
[500] Schlesinger, "Defense Planning."
[501] Selye, Hans (1959, Jan 24). "What Makes Basic Research Basic?" *The Saturday Evening Post*. Found in Killian Jr., James R. (1959, Feb. 23). "The "Growing Edge" of Innovation: Some Observations on the Economic and Social Role of Research." Delivered before the Economic Club of Detroit, Detroit Michigan.
[502] "Major Systems Acquisition Reform: Part 2." (1975, Jun.-Jul.), 100-137.
[503] Anshen, Melvin. (1965). "The Program Budget in Operation." Found in Novick, David (Ed.). (1965). *Program Budgeting*. RAND Corp.
[504] Raider, Melvyn C. (1973). "Organization Theory and Program Budgeting." Dissertation for Wayne State University, 95.
[505] Schick, Allen. (1972). "Systems Politics and Systems Budgeting." Found in Lyden, Fremonth J. and Miller, Ernest G. (Eds.). (1972). *Planning Programming Budgeting: A Systems Approach to Management* (Second Edition). Chicago, IL, Markham Publishing Co., 78.
[506] Schick, Allen. (1966). "The Road to PPB: The Stages of Budget Reform." Reprinted in Lyden, Fremonth J. and Miller, Ernest G. (Eds.). (1968). *Planning Programming Budgeting: A Systems Approach to Management*. Chicago, IL, Markham Publishing Co.
[507] Mitchell, David and Thurmaier, Kurt. (2012). "Foundations of Public Administration: Budgeting Theory." *American Society for Public Administration.*
[508] Schlesinger, "Defense Planning." There appeared to be a tension in McKean and Schlesinger's work. Top administrators simply cannot manage a large number of ever-changing programs in the budget. Yet that is what would be asked of them if they operated under diversity and incrementalism. The old method of appropriating to organizations and objects of expenditure did not burden administrators so much because the resources changed more slowly than program plans. The new method of program control required deviations to be appraised by the top administrator.
"If OSD is to exercise any kind of control, deviations from the program have to be difficult to effect and must be appraised by OSD. How does the system facilitate OSD appraisal and control? By reducing the number of alternatives that have to be considered. If each Service submitted an entirely new program and budget each year, it would be virtually impossible for a small staff to appraise and control it. OSD would then have to confine its attention to major decisions and to aggregative budgetary limitations. By confining the new proposals to formal PCPs—that is, by reducing the number and complexity of the alternatives—appraisal and control by top management becomes feasible."
[509] "Major Systems Acquisition Reform: Part 2." (1975, Jun. 16 – Jul. 24), 724. While still Secretary of Defense, Schlesinger admitted that "I have become less sanguine regarding the efficacy of inter-Service rivalry."

[510] Office of the Secretary of the Army. (1974, April 1). "Report of the Army Materiel Acquisition Review Committee (AMARC): Volume II Committee Reports." VII-25. Hereafter referred to as the AMARC report.
[511] NMARC report, II-12.
[512] "Weapon Systems Acquisition Process," (1971, Dec. 3-9), 297-350. Even after Rickover achieved the rank of full admiral, there still were 21 officials that sat between him and the Secretary of Defense. See Rockwell, Theodore. (2002). *The Rickover Effect*.
[513] Staats, "A Critique of the Performance," 13.

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[514] NMARC report, V-30.
[515] McLucas, *Reflections of a* Technocrat, 105-106.
[516] NMARC report, VI-12.
[517] "“Weapon Systems Acquisition Process," (1971, Dec. 3-9), 297-350. In an earlier episode, Rickover told Congress, "… it took the initials of 15 or 20 officials in the Pentagon and a month's delay before the letter got out of the Pentagon. So it took 6 months just because one staff person with no responsibility but with authority had on his own decided that the policy was wrong." See "Inquiry into Satellite and Missile Programs." (1958). Committee on Armed Services, the Preparedness Investigating Subcommittee, 85th Cong., 2nd Session, 1435.
[518] Lavoie, Don. (1985). *Rivalry and Central Economic Planning*. Arlington, VA: Mercatus Center.
[519] For example, see Blicksilver, Jack. (1955, Jan.). "A Study of Some Defenders and Certain Aspects of the Defenes of Big Business in the United States, 1880-1900." Dissertation. Northwestern University.
[520] Chandler, Alfred D. (1977). *The Visible Hand: The Managerial Revolution in American Business*. The Belknap Press.
[521] Galbraith, *The New Industrial State*, 354.
[522] Technostructures correspond to ideas from the French Revolution, from thinkers like Henri de Saint-Simon, which later influenced socialist planning. See Bell, Daniel. (1976). *The Coming of Post-Industrial Society*. Basic Books; Reissue edition.
[523] Galbraith, *The New Industrial State*, 296-97.
[524] "The Military Budget and National Economic Priorities." (1969, Jun.).
[525] Galbraith, J. K. (1969, Nov. 19). "The Big Defense Firms are Really Public Firms and Should be Nationalized," *The New York Times Magazine*.
[526] Sims, David E. (1969). "Spoon-Feeding the Military—How New Weapons Come to be." Found in Rodberg, Leonard S. and Shearer, Derek (Eds.). (1970). *The Pentagon Watchers: Students Report on the National Security State.* Garden City, NY, Doubleday & Company.
[527] Allen, Wayne. (1972, June). "Should Cost/Will Cost/Must Cost – A Theory on the Cause of Cost Growth." Army SAFEGUARD System Office, AD-758 820, National Technical Information Service, 10-14.
[528] (1969, June 3). "The Military Budget and National Economic Priorities." Hearings before Joint Economic Committee, 91st Congress, First Session, Washington, DC: US Government Printing Office, pp. 5.
[529] Allen, "Should Cost/Will Cost/Must Cost," 16-17.
[530] AMARC report.
[531] NMARC report.
[532] "Major Systems Acquisition Reform: Part 2," (1975, Jun. 16 – Jul. 24), 24-44. While the vast majority of program attributes and costs were fixed prior to the engineering design phase, only then did executive and Congressional controls start. The controls implemented at the start of engineering design included a dedicated program office; application of the DoD 5000-series; approvals from agency heads (e.g., DSARCs); budget reviews; industry competition; contractual regulations; and cost/schedule/ performance monitoring.
[533] The Committee on Government Procurement Report. Found in "Hearings on Office of Management and Budget Circular A-109: Major System Acquisition Policy." (1977-1978). Hearings before the Research and Development Subcommittee of the Committee on Armed Services, House of Representatives, Ninety-Fifth Congress, First Session (Nov 1 and Dec 1, 7, 1977) and Second Session (Apr 6, 10, 14 and Sep 18, 1978), 148.
[534] Hall, Robert B. (1975, Spring). "Reinstating Competition in Systems Acquisition: A Four-Dimensional Framework." *National Contract Management Journal.*
[535] Shapero, Albert. (1969, March). "Life Styles of Engineering. *Space Aeronautics Magazine*.
[536] Sims, "Spoon-Feeding the Military."
[537] "Major Systems Acquisition Reform: Part 2," (1975, Jun. 16 – Jul. 24), 24-44.
[538] Lutton, J.M. (Maj.). (1975, Oct.). "Why Document Material Requirements?" by Maj. J. M. Lutton. *Marine Corps Gazette (pre-1994);* Vol. 59, 10.
[539] "Advanced Prototype," (1971, Sep. 9), 41.
[540] "Major Systems Acquisition Reform: Part 2," (1975, Jun. 16 – Jul. 24), 330-42.
[541] "Major Systems Acquisition Reform: Part 2," (1975, Jun. 16 – Jul. 24), 163-68 and 217-19.
[542] Howard P. Gates, Jr., et al. (1974, Jan.). "Electronics-X: A Study of Military Electronics with Particular Reference to Cost and Reliability. Volume 2: Complete Report." Institute for Defense Analyses. Prepared for Defense Advanced Research Projects Agency.
[543] Allen, "Should Cost/Will Cost/Must Cost," 59. "But what is our procedure," the Wayne Allen asked, if we have an "institution where large numbers of individuals conduct themselves in an individually commendable manner but whose collective actions create problems?" Indeed, rivalry may lead to an unbalanced military force, which the U.S.

was heading toward by the end of the 1950s prompting McNamara's call for a "flexible response." Central planning of military requirements and force structure appears the safe way to operate; planners feel like they know where they are going. Though the Army study clearly pointed to monopsony as a scourge, it did not resolve the problems that may arise from decentralization. However, another interpretation of the 1940s and 1950s era is that defense acquisition followed technology "fads" using tacit coordination. Parallel developments applying different technical or doctrinal concepts migrated from one technology area to another based on the opportunities presented to researchers and managers close to operations. A naturally evolving serial approach to parallel development—from one area of opportunity to the next—avoids busting budget caps, which would be the case if parallel projects were pursued in all military technologies at the same time.

[544] Spiro, Herbert T. (1972). *Optional Organization of the Military Hardware Industry*. Los Angles: CA: University of California, Los Angeles, 16.

[545] Orkand Corp. (1973, May). "Monopsony: A Fundamental Problem in Government Procurement." Orkand Corp., Silver Spring, MD. Published by Aerospace Research Center, Aerospace Industries Association of America, Inc., 15.

[546] "The Pentagon and Industry: Antagonism Replacing Trust." (1970, January). *Armed Forces Management*. [Microfiche]. Washington: Pentagon Library.

[547] Watts, Barry D. (2008). "The US Defense Industrial Base: Past, Present and Future." Center for Strategic and Budgetary Assessment. Retrieved from https://csbaonline.org/research/ publications/the-us-defense-industrial-base-past-present-and-future, 25-26.

[548] Orkand Corp. "Monopsony," 25-30.

[549] Allen, "Should Cost/Will Cost/Must Cost."

[550] Moore, "Military Procurement," 54.

[551] Williamson, "The Economics of Defense," 231.

[552] Lavoie, *Rivalry and Central Economic Planning*.

[553] Alchian, Armen A. (1967). "Cost effectiveness of Cost effectiveness." Found in Enke, S. (Ed.). (1967). *Defense Management*. Englewood Cliffs, N.J.': Prentice Hall, Inc., 74-86

[554] Office of the Secretary of Defense. (1950). *Semiannual Report of the Secretary of Defense*. Washington D.C., Government Printing Office.

[555] Office of the Secretary of Defense. (1953). *Semiannual Report of the Secretary of Defense*. Washington D.C., Government Printing Office, 45.

[556] Converse III, *Acquisition History*, 395.

[557] Murdock, *Defense Policy Formation*, 17.

[558] Von Neumann, John. (1956). XXXXXXXXXXXX

[559] Landau, Martin. (1968). "Redundancy, Rationality, and the Problem of Duplication and Overlap." Found in J. M. Shafritz, A. C. Hyde, and S. J. Parkes (Eds.). (2004). *Classics of Public Administration*, Fifth Edition. Thomson Wadsworth, 302-313.

[560] Hayek, F.A. (1968). "Competition as a Discovery Procedure." Translated by Marcellus S. Snow. (2002, Summer). *The Quarterly Journal of Austrian Economics.* Vol. 5, no. 3.

[561] Hayek, F.A. (1946). "The Meaning of Competition." Excerpted from Hayek, F.A. (1948). *Individualism and Economic Order*. Chicago, IL: University of Chicago Press.

[562] Kirzner, "The History and Importance."

[563] Lavoie, *Rivalry and Economic Planning*.

[564] Crozier, M. (1964). *The Bureaucratic Phenomenon*. Chicago: University of Chicago Press.

[565] Rickover, Hyman G. (1954, Mar. 16). "Administering a Large Military Development Project." U.S. Naval Postgraduate School, Monterey, CA.

[566] "Inquiry into Satellite and Missile Programs," (1958), 1435.

[567] Rickover, Hyman G. (1970, June 18). "Accounting Practices – Do They Protect the Public?" Federal Government Accountants Association, 19th Annual National Symposium, Miami, FL.

START HERE. [568] 1968 Senate hearings on Economy in Military Procurement, Part 2.

[569] After enforcement of TINA got more strict, Rickover recounted in 1971 one case where a shipyard broke $3.4 million of steel contracts into 1,200 separate orders to stay exempt from TINA's $100,000 threshold. See "Weapon Systems Acquisition Process" Hearings Before the Committee on Armed Services United States Senate, Ninety-Second Congress, First Session, December 3-9, 1971, pp. 417.

[570] Rickover claimed that would-be profits got re-invested into company overhead to avoid taxes. "A company's profits are taxed about 50 cents on the dollar. But an overhead dollar is not taxed, and is therefore worth twice as much as a profit dollar when it is used to improve a company's business. By charging these improvements to overhead the company reduces the amount of income tax it must pay. The American public is the loser." See "To Renew the Defense

Production Act of 1950, as Amended." (1968, Apr. 10-11). Hearings before the Committee on Banking and Currency, House of Representatives, Ninetieth Congress, Second Session, H.R. 15683, 77.
[571] Poole, pp. 68.
[572] 1968 Senate hearings on Economy in Military Procurement, Part 2.
[573] (1971, Apr. 28-29). "The Acquisition of Weapon Systems." Hearings before the Subcommittee on Priorities and Economy in Government of the Joint Economic Committee, Ninety-Second Congress, First Session, Part 3, 573.
[574] United Press International. (1970, Apr. 3). "Rickover Assails Buying Methods At Pentagon, Sees $2 Billion Loss. *The Washington Post, Times Herald (1959-1973),* A12.
[575] 1968 Senate hearings on Economy in Military Procurement, Part 2.
[576] Rickover, H.G. (1970, June 18). "Accounting Practices—Do They Protect the Public?" Speech before the Federal Government Accountants Association, Miami Beach, FL.
[577] 1968 Senate hearings on Economy in Military Procurement, Part 2.
[578] CASB 1970
[579] "The Effect of the Cost/Schedule Control Systems Criteria (C/SCSC) on Contractor Planning and Control" by Leonard S. Marrella, Dissertation for the George Washington University, Feb. 1973, Business Administration.
[580] Rickover seems not to have advocated for product-oriented work breakdown structures as part of the cost accounting standards. Later in December 1971, Rickover agreed with a Defense Contract Audit Office report finding a particular instance where a shipyard needed to implement a hardware WBS and more detailed work packages. "Weapon Systems Acquisition Process," (1971, Dec. 3-9), 419.
[581] Staats Elmer B. (1968, Oct. 29). "Address by the Comptroller General of the United States." Speech before the National Association of Accountants, Miami Beach, FL.
[582] 1970 CASB.
[583] In Armen Alchian's early work on World War II airframe production learning curves, or "progress" curves, he found that even using historical data to predict itself, learning curve estimates still had an average of 25% error on the total production cost. See Alchian, Armen A. (1950, Feb. 3). "Reliability of Progress Curves in Airframe Production." Santa Monica, CA, RAND Corp., RM-260-1.
[584] The CCDR was established in 1973 and replaced two earlier reports, the Cost Information Report and the Procurement Information Report. See "Inaccuracy of Department of Defense Weapons Acquisition Cost Estimates." (1979, Jun 25-26). Subcommittee on Legislation and National Security, Committee on Government Operations. House; Committee on Government Operations, 109. Also see Balut, S. J. and Cloos, J. J. (1994, Sep.). "Assessment of the Contractor Cost Data Reporting (CCDR) System." IDA Paper P-2964. Note that the earliest CCDR-like report found by the author was submitted by McDonnell Douglas in 1958 for the FY 1956 Lot 1 buy of the F-4A aircraft. The predecessor to the CIR is the Cost and Economic Information System (CEIS) which also included a contract cost report and a plant-wide report.

Contractors claimed that PERT and the CEIS required them to maintain two different books in addition a third for their internal operations. In 1964, ASD(Comptroller) Charles Hitch wanted to coordinate PERT and CEIS, intending them to use the same Work Breakdown Structure for each contract they were required on. This effort led to the standard WBSs outlined in MIL-STD 881. However, when Robert Anthony came took over as Comptroller in 1965, control over the PERT (later C/SCSC and then EVMS) policy moved to DDR&E and control over cost went to ASD Systems Analysis, later PA&E and finally in 2009 it became Cost Assessment and Program Evaluation (CAPE). With the dispersal of authority, the C/SCSC tended to allow contractors to "tailor" their WBSs in their program management systems. From this native data, contractors would usually allocate costs to the CIR, later, the CCDR, which meant that their costs were usually unauditable. The WBS question remains a contentious one well into the 21st century.
[585] While three of the CCDR's reports were oriented around contract costs, the fourth report—the plant-wide report—focused on the contractor's total business position. The plant-wide report collected costs for entire factories segregated by direct and indirect costs. Direct costs were segregated by defense programs, other government work, and commercial work, further segregated by the major functional categories engineering, manufacturing, materials, and so forth. Indirect costs were segregated by the same functional categories, but had cost line items such as employee benefits, building/land facilities, administration, and so forth. The report asked for these cost breakouts, which also included employee headcounts, for the prior year, the current year, and three years into the future. The 1973 memorandum implementing the CCDR stated a preference for cost estimators to independently assess the contractor's overhead cost status "in the context of the overall incurrence posture rather than just expressed as a non-specific rate of some base." ["Memorandum on Contractor Cost Data Reporting (CCDR)." (1973, Oct. 24). Found in "Acquisition Management Contractor Cost Data Reporting (CCDR) System" (1973, Nov. 5).]

Though the plant-wide report could be used to estimate future overhead rates, more often than not it was the on-site plant representatives who performed overhead analysis and provided the answer in the form of a "non-specific rate of some base." The contract community's own processes provided the basis for negotiating forward pricing rates with contractors for use in estimating direct and indirect costs for proposals. Because rate agreements had built into them forecasts of the business base, cost estimators could focus on estimating from direct costs or hours and apply approved rates and factors to build up to a fully burdened cost. One CAIG cost estimator remembered that "In the '70s, we spent most of our research money on understanding direct costs and we ignored overhead costing issues." [Manetti, Howard J. Found in Balut, S. J. (2004, Sep.). "IDA 2004 Cost Research Symposium: Investments in, Use of, and Management of Cost Research." Institute for Defense Analysis, IDA D-3018, 36.] A later study found that DoD cost analysts clearly preferred using contract approved overhead rates, and that "Nearly all offices reported not using the 1921-3 [plant-wide report] at all." [Balut, "Assessment of the Contractor," IV-7.].

The separation of direct and indirect costing allowed analysts to ignore a problematic feedback loop. The cost estimate of a future contract depends on other contract awards at the plants employed, and the contract awards themselves depended on the initial cost estimate. In other words, the cost estimator cannot estimate the total contract cost without knowing the contractor's future indirect rates, and the contractor cannot know its future indirect rates without knowing what its business base will be, itself determined by a set of on-going negotiations. It is not surprising, then, that more contract awards funnel to fewer contractors on the expectation that a large and stable business base will bring indirect rates down. Slowly and imperceptibly, the defense official's interests are subordinated to the contractors' interests, the former finding himself captured by the data and the narrative supplied by the latter.

586 Srull, Donald (Ed.). (1998). *The Cost Analysis Improvement Group: A History*. Logistics Management Institute, VA. Note that Laird placed the CAIG underneath the successor to Enthoven's Office of Systems Analysis, OSD Program Analysis and Evaluation (PA&E).

587 Coase, Ronald. (1938). Business Organization and the Accountant. Published in Buchanan J. and Thirlby G. (1981). *L.S.E Essays on Cost.* New York: NY.

588 The number of ways weapon systems differ exceeds the number of systems cost data can be collected on. In statistical terms, there are not enough degrees of freedom to make proper inferences. Not only does an analyst require enough data to obtain a probability distribution to make predictions, the analyst also requires enough data to generate a probability distribution as to whether the data are sufficient to make predictions. Without sufficient data that are independently and identically distributed, statistical models face a self-referencing problem that makes its predictive power is unknown.

589 Drezner, Jeffrey A., Giles K. Smith, Lucille E. Hogan, Curt Rogers, and Rachel Schmidt. (1992). *Maintaining Future Military Aircraft Design Capability*. Santa Monica, CA: RAND Corp., 28.

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591 Klein, Burton H. (1968). "Policy Issues Involved in the Conduct of Military Development Programs." Mansfield, Edwin (Ed.). (1968). *Defense, Science, and Public Policy*. New York, NY, W.W. Norton & Company.

592 Rickover 1968 Senate hearings on Economy in Military Procurement, Part 2.

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595 "The Acquisition of Weapon Systems." Hearings before the Subcommittee on Economy in Government of the Joint Economic Committee, Ninety-First Congress, Second Session, pp. 164.

596 Hume, Brit. (1973, March 25). "Admiral Kidd vs. Mr. Rule." *The New York Times Magazine*.

597 U.S. Army. (1985, January 21). "Should Cost" Analysis. Standard Operating Procedure #340, 21.

598 Stolarow, J. H. (1971, Fall). "The Should Cost Method of Pricing Government Contracts." *National Contract Management Journal*.

599 "The Acquisition of Weapon Systems." (1969). Hearings before the Subcommittee on Economy in Government of the Joint Economic Committee, Ninety-First Congress, Second Session, Part. Washington D.C.: U.S. Government Printing Office. Apparently, the consulting firm (Performance Technology Corporation) which performed the first "should cost" review of Pratt & Whitney was "blackballed" by the Pentagon.

See also, Staats, Elmer B. (1971, April 29). Statement of Elmer B. Staats, Comptroller General of the United States Before the Subcommittee on Priorities and Economy in Government. Washington DC. See also, General Accounting Office. (1971, February 26). Applications of "Should Cost" Concepts in Reviews of Contractor' Operations. Report to the Congress by the Comptroller General, B-159896.

600 General Accounting Office. (1972, October 30). Assessment of Army Should-Cost Studies." U.S. GAO, B-159896, 13.

601 As Comptroller General Staats concluded… pp. 717 – 1969 Military Budget and Econ, Pt 2

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