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Systems Concepts for Executives

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Conclusions

Transforming Defense: National Security in the 21st Century, the December 1997 final report of the National Defense Panel, discusses a "strategy of transformation" and emphasizes systemic change in procurement plans. It refers to "lock-ins" for equipment purchases, "short technological life cycles," and "changing the defense structure." Several conclusions may be drawn from the report.

- The Information Age changes the dynamics of systems. Networks, flexible manufacturing just-in-time inventories, and "increasing returns" all influence the way systems will respond.
- Systems concepts that are relevant to defense policy and planning include: accelerators, laggec feedback, transient states, stocks and flows, and discontinuous change.
- The dynamics between reducing inventories and the resulting effects on production are no proportional—reductions are more severe in the production sector than in inventory.
- Education in the dynamics of systems is needed within the Department of Defense t accommodate strategic planning for procurement.

Information Age Aspects

Rapid communications and networking characterize the Information Age. Combined, they allow flexibility—in manufacturing, logistics, and information processing itself. Resources are diverted to computers and car phones and video systems. Consumption interests have shifted somewhat, from travel and movies to computer games and net surfing. National security leans less on material and manpower delivery and more on information control and precision targeting.

Flexibility in logistics and production affects the dynamics of defense systems. To understand how, we need to explore the dynamics of systems in change.

Production Swings More than Force Levels

Consider the dynamics that occur when a defense system changes—when it is in a transient state. If each aircraft in a fleet of 100 has an average life expectancy of 10 years, then 10 aircraft—one tenth of the fleet—must be replaced each year to maintain a steady state fleet of 100 aircraft.

To reduce the fleet by 20 percent in 5 years means buying 20 fewer aircraft during that time, or 4 fewer each year. Instead of buying 10 per year, we buy 6 during the transition period. When the fleet reaches 80 aircraft after 5 years, we increase the annual buy to 8 to remain at the new steady state of 80.

Aircraft stock assets dropped by 4 percent per year for 5 years, leading to a 20 percent reduction over the 5-year transition period, while the procurement of new aircraft abruptly fell 40 percent, from 10 to 6. Then, 5 years later, procurement suddenly increased by 33 percent, from 6 to 8. Although this captures the primary "first order" effects, the actual dynamics will not be quite so crisp because attrition, delivery adjustments, and renovations will smooth the transition somewhat.

The flow of procurement—which essentially means production jobs—experiences severe dynamics compared to changes in the *stock* of assets. A "systems" distinction between stocks and flows emerges. Stocks are accumulations. Flows change the stocks. To alter a stock, the flow must change rather dramatically. Stocks and flows are essential to understanding the dynamics of system change. As a real world example, while military aircraft stock levels fell by 26 percent from 1991 to 1995, orders for aircraft engines fell by 48 percent—almost twice as much.

This demonstrates the *accelerator,* a crucial system principle. Changes to stocks lead to accelerated changes in flows. Assets change gradually while production swings widely. When force levels are reduced, production jobs fall severely, and then rebound somewhat once a new steady state is reached. Executives testifying to Congress will want to communicate that job sensitivity when discussing defense changes.

The Longer the Asset Life, the More Severe the Dynamics

Suppose the 100-aircraft fleet had been made up of units lasting 20 years each instead of 10. Then the steady state 100 aircraft fleet would require buying 5 aircraft per year instead of 10. Reducing the fleet to 80 in 5 years would mean buying 20 fewer aircraft, or no aircraft at all for 5 years, and upon reaching 80, increasing production to 4 per year. When aircraft last 20 years instead of 10, reducing the fleet by 20 percent in 5 years indicates a 100-percent reduction in production, followed by reopened production after 5 years of inactivity. The longer systems last, the more severe the accelerators are. Ships last 30 years or more, and shipbuilding has historically seen large swings in production.

Production skills lost during a period of reduced production will be hard to recapture, and suppliers may have gone out of business. In any case, long-range planning should include understanding that life span affects transformation dynamics.

Dynamics and Costs

Systems made up of units with short life spans experience less dynamic change than those made up of units with long life spans. On the other hand they cost relatively more to keep at a set steady state. A 10-year aircraft needs replacement every 10 years. A 20-year aircraft needs replacement only every 20 years. If the two aircraft have the same unit costs, then keeping the long-lived system at 100 units costs half as much.

Information Age systems tend to be short lived. By the accelerator principle they should experience less severe production dynamics, but more frequent replacement. Production changes decrease proportionately but the annual procurement costs increase.

Upstream Production Experiences More Severe Dynamics

Recall our first aircraft example. Asset stocks were lowered 20 percent while production fell 40 percent, from 10 per year to 6. Now consider what happens to the procurement of machine tools used by the aircraft factory—the lathes, metal benders, drilling machines, hydraulic presses, etc. That is, instead of focusing on aircraft production, consider the "upstream" machine tools sector. Instead of owning machinery to build 10 aircraft per year, the aircraft factory needs machines to produce only 6 aircraft per year. Orders for machine tools will therefore drop. The new machine tool ordering levels will depend on how farsighted the factory planner is and on how certain the final asset reduction will indeed be 20 percent (and not 30 or 40). The forces affecting these traditional machine tools can also be applied to the "machine tools" of the future—integrated circuits, microchips, memory chips, and software that writes, debugs, and tests software.

Suppose machine tools last 10 years. In the worst case, the stock of machine tools needed falls by 40 percent, consistent with the fall in aircraft production. This reduction in stock leads to an *accelerated reduction in the flow of orders for new machine tools.* It can be shown that the production of machine tools to accomplish that fall in 5 years will be a sudden drop of 80 percent. The reasoning is parallel to the earlier logic. If 100 machines are needed to build 10 aircraft per year, and machines last 10 years, then 10 machines need to be produced each year. To build 6 aircraft per year requires 60 machines. To get from 100 to 60 machines means ordering 40 fewer machines in 5 years, or 8 fewer each year, an 80 percent reduction. Summarizing our findings, aircraft assets fell 20 percent, aircraft production fell 40 percent, and the production of machines to build aircraft fell 80 percent. This demonstrates the principle that upstream production experiences more severe dynamics than downstream production.

Accelerators in a Surge Instead of a Reduction

In a surge, the accelerators work to cause delays in system delivery. To build an aircraft fleet from 80 to 100 in 5 years, aircraft production must increase from 8 to 12 during the transition. To build up to the higher production rate, the upstream machine tool manufacturers need to accelerate even more. The buildup may require diverting machine tools into production of machine tools themselves to accommodate the surge, which means further delaying production of weapon assets while the production sector bootstraps itself up first. The dynamics become too complex for easy calculation, and computer simulations are needed to gain perspective.

Several system insights emerge. During force reductions there will tend to be unemployment and excess plant and equipment as production drops rapidly. During buildup periods, not only will there be inadequate machinery to surge as fast as desired, but capital equipment producers may be forced to delay delivery of needed machine tools while machine tools themselves are used to make more machine tools first.

Efficiency and Effectiveness

In his November 1997 *Defense Reform Initiative Report,* the Secretary called for reducing overhead and support structures by adopting best business practices into defense management. Part of the policy called for using a "just-in-time" mindset for logistics where appropriate. The guidance does not, however, call for indiscriminate use of the just-in-time policy. The above discussion implies the logical conclusion that during times of surge it would be beneficial to retain excess inventories and production capacity so that the surge demands can be better absorbed. Exactly how much excess there should be depends on the magnitude and timing of the surge. There is no one answer, but the question deserves consideration by policy makers.

It may be effective—though seemingly inefficient from a steady-state cost viewpoint—to have some "slop" in a system. Best business practices need to consider the system dynamics that occur when no excess inventory or capacity exists. This is especially true when there are few providers of products, as is often the case in defense.

Cycle Differences and Interconnections

A reduction in assets forces an accelerated reduction in the flow of production followed by a rebound once the new steady state is achieved. A buildup has the opposite effect—an accelerated rise in production followed by a fall. The upstream effects are even more accelerated

The real world does not demonstrate an isolated fall or rise in assets. Desired stock levels change regularly from plans over time. Consequently, the flows that support the stocks of assets also continually react to these changes. Different asset changes lead to different production cycles. The cycles vary in length and magnitude depending on the timing and size of the change in assets, the life span of units, the reaction of producers to the changes, the amount of excess capacity in the system, and the availability of upstream production facilities.

Cycles are also interconnected. As aircraft production rises so does the demand for production equipment. If the demand for combat vehicles also rises, the demand for production equipment in that sector will detract from production equipment needed for aircraft. As production rises in both sectors—or in many sectors—transportation demands rise and delivery delays occur, causing cycles to be extended. The cycles become intertwined, complicating the overall production system.

Flexible Manufacturing

"Putty-clay" is an economic acquisitions-related term. Before something is acquired its characteristics are like putty—they can be molded and changed. After procurement, however, the investment becomes like baked clay—hardened and unchangeable. The National Defense Panel concern with acquisition "lock ins" becomes apparent. If systems last a long time, then acquiring them locks one in to those systems.

Information Age production generally yields systems with short life cycles. Even if future systems downplay ships and aircraft (the bulk of past defense procurements), some of these long-lasting platforms will be unavoidable and will be in procurement plans. But more to the present point, consider satellites. They are expensive and last quite a long time. Their launching systems are also long lived. "Transforming Defense" calls for flexible investments. To comply, satellites and their launching systems would need to be flexible—to be more "putty-putty" than putty-clay. The satellites might need to be reprogrammable, the launching systems to be flexible in what they can do.

The production systems that produce satellites and launching systems would also need to be flexible so they can be reprogrammed to produce perhaps quite different satellites and launchers, without themselves being significantly altered. Production software and integral circuit production might be designed to provide such flexibility.

Software programs that write, edit and debug other "downstream" software programs are already available and need continued development. This would allow the flexible manufacturing facilities to retain their flexibility without the need for "retooling" from scratch. We might also argue, on the basis of earlier logic, that such production facilities, and the related software development facilities, programs, and skills be kept in excess so that unusual surge can be met.

Widespread flexibility leads to rapid turnover of goods and production methods. Planning effectively can lead to system acquisition that is flexible in its own right. Outsourcing, flexible design and production, and lowered investment in plant and equipment lead not just to flexible production equipment but also to flexible workforces. The likely rapid turnover in personnel can lead to loss of loyalty—employees are never secure in what they will do or where they will work. Policy makers need to consider human policies to go along with the mechanics of Information Age production change.

Discontinuous Change in Information Age Systems

Production systems that create products feeding back to impact the production process itself represent "nonlinear feedback systems." Consider a software development system that produces software that in turn causes the production software to be altered. Such systems can experience *discontinuous change*. Discontinuous change indicates that complete testing of such software may not be feasible. Successfully testing an input parameter at 3 and 4 and 5 may allow the software to show a discontinuity—blow up essentially—when the parameter is 3.2346. A car successfully tested at acceleration of 3 then 4 then 5 will certainly not blow up if accelerated at 3.2346, but nonlinear feedback systems have no such assurance.

Information systems tend to have benefits that grow more rapidly than do costs (the concept of *increasing returns*). Instead of a crossover point that is reached, say, when an aircraft manufacturer reaches production levels too large for his plant, Information Age systems may have increasing benefits that outrun the costs of production. An example is Microsoft Windows, which becomes more useful to each user as more people use it. Meanwhile, overall production shows diminishing marginal costs. Monopoly becomes efficient. This may be so for various electronic and software systems. Increasing returns are part of the Information Age.

Summary

The system dynamics of force level changes is dependent on system life, the magnitude and timing of change, the phase of production (upstream or down), the interconnectivity of systems, and the simultaneity of changes. Production cycles—essentially jobs—will mimic the dynamics. The Information Age will alter the timing and magnitudes of the dynamics, but the underlying principles will change only slightly. An education in strategic affairs as well as strategic long-range planning—as recommended by the National Defense Panel—should incorporate such system dynamic concepts. We need to make systems thinking commonplace. Today it still seems too complex.

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