SSPARC

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"SSPARC BOOK" MATERIAL for Lecture 12

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DEDICATION AND NOTE ON SOURCES

This document is an excerpt of a future book or hyper-book on the MATE-CON method. It is provided for class use as a draft. Suggestions for improvement are welcome, as are warnings of errors or omissions. The notes below apply to the entire work in progress; the work or excepts of it should not be reproduced in any form without these notes.

This document is dedicated to the memory of Joyce Warmkessel, a colleague, mentor, and friend to many in the SSPARC and LAI communities. Many of the core ideas behind this work were originally expressed and developed by her, and she was a key mentor and facilitator to the development of all of this work.

The content of this document was developed by the SSPARC consortium. The primary compilers and codifiers of the MATE-CON method were Lt. Nathan Dillard and Adam Ross, in Master's thesis entitled, respectively, "Utilizing Multiple Attribute Tradespace Exploration with Concurrent Design for Creating Aerospace Systems Requirement," [1] and "Multi-Attribute Tradespace Exploration with Concurrent Design as a Value-Centric Framework for Space System Architecture and Design."[2] Major contributors of the original concepts within the method, and/or complimentary methods and tools, include our SSPARC faculty and staff colleagues Elisabeth Paté-Cornell of Stanford University, Joel Sercel and Fred Cullick of Cal Tech, and Amar Gupta of MIT, post-doctoral researcher Bill Kaliardos, and graduate students Jimmy Benjamin, Jason Derleth, Bobak Ferdowsi, Dave Ferris, Russ Garber, Andre Girerd, Seth Guikema, Cyrus Jilla, Chris Roberts, Satwik Seshasai, Nirav Shah, Todd Shuman, Tim Spaulding, Dave Stagney, Dan Thunnissen, Myles Walton, Annalisa Wiegel, and Brandon Wood, along with their advisors and committees. Many other students, staff, and undergraduate researchers also contributed. Bill Borer, Kevin Ray, and John Ballenthin of the Air Force Research Laboratory, Steve Wall of NASA JPL, and Pete Hendrickson of the Department of Defense aided with the development of the method and the development of the case studies. SSPARC research work has been supported by an active group of industry practitioners, through both an Industrial Advisory Board (IAB) and on-site implementation activities.

The text of this manual is built on SSPARC research and member documents. Much of its contents are excerpts, modifications, or paraphrases of published or unpublished work done under SSPARC sponsorship. Every effort has been made to correctly attribute all contributions. Word-for-word excerpts are identified with quotes or indented, with citations. Many other excerpts have been edited to varying degrees and are integrated into the text for clarity. Their sources are cited in the text or in endnotes. Any omissions or errors of attribution should be brought to the authors' immediate attention for correction.

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1. POLICY & OTHER ISSUES[3]

While uncertainty and flexibility are key issues that determine choices for space system architectures, there are many other issues that help to make choices among different space system architectures. These include policy issues, product development issues and enterprise level issues. All of these affect the design of complex space system architectures.

Policy issues are particularly interesting since the system architecture community and the policy community have largely operated asynchronously. This has led to many changes in the technical architecture of space systems as policy changes have been made. First however, we must define what is meant by policy and particularly space policy.

1.1. Policy Definitions

It is important to distinguish between policy and strategy and between policy and law. The following definitions attempt that distinction.

Policy: " A definite course or method of action selected from among alternatives and in light of given conditions to guide and determine present and future directions."

Strategy: "The science and art of employing the political, economic, psychological and military forces of a nation or group of nations to afford the maximum support to adopted policies in peace and war."

Thus policy → strategy

Law: "A binding custom or practice of a community: a rule of conduct or action prescribed or formally recognized as binding or enforced by a controlling authority."

Thus policy ≠ law

Based on the above, policy statements can be parsed in the following way. Policy statements have several features associated with them:

- definite course(s)
- selected from alternatives
- true in light of specific conditions→ a model of the world
- to move one in specific (desired) directions→ a model of the world

<u>An example space policy statement</u>

This example of a (space) policy statement is taken from the current definition of the US National space policy

> "In the conduct of its research and development programs, NASA will use competition and peer review to select scientific investigations."

This policy statement:
- contains a definite course (use of competition…)
- selected from among alternatives (patronage, congressional action…)
- future direction (scientifically rigorous work)

It also has an implicit world view – the best science comes from open competition among equals and the best people to do it are peers.

Boundaries

Note that space policy has to exist within boundaries. For example, space policy statements cannot cross technical boundaries, e.g. "NASA will develop perpetual motion machines" or "NASA will develop faster than light space travel by 2001." This adds an obvious seeming but important characteristic to valid policy statements:

- statements of technical nonsense are not valid statements of policy.

Space policy statements also cannot cross the boundaries of law (national, international, natural) e.g. "In the conduct of its research and development program, NASA will indiscriminately kill as many civilians as possible."

- Statements of policy must not violate national law and natural law

US National Space Policy

The US National Space Policy can be found at the following website:
http://www.ostp.gov/NSTC/html/fs/fs-5.html
A more recent statement of US National Space Policy with respect to remote sensing can be found at http://www.state.gov/g/oes/rls/fs/2003/20935.htm

The US National Space Policy can be decomposed in the following way
- Leadership in the world is good
- Space contributes to national security, relationships with other countries, etc.
- We must have access to the critical medium
- Partnerships and cooperation is good

As applied to space:
- US explicitly in the business of scientific exploration
- (part of the history/culture of the US).
- Our national security is enhanced through space
- Space use will contribute to economic competitiveness which is good
- Parties other than the Federal government must be involved. This is good.
- International cooperation is good when it furthers our interest.
- Want peaceful use of space but will protect ourselves in a muscular way and will never put ourselves in a position where our sovereign interests are threatened.

Another view of space policy comes from the world of political science

> "A space policy is a statement of the ways in which to carry out a space project to achieve a desired goal."

From a political economy analysis of the US national policy, the following goals are derived:
- National Security
- give national leaders strategic and intelligence information & communications
- give tactical forces war fighting advantage
- National Image/Foreign Policy
- Scientific Progress
- Tangible benefits to Society e.g. weather warming satellites and the hurricane of 1938
- Stimulating Commercial Payoff
- Stimulating Technological Progress
- Space a tool for Economic and Social Development
- Exploration, Expansion and Eventual Settlement beyond Earth Orbit

A simple model

Figure 1 shows a conceptual model of the operation of a space policy. Given the constraints of technology, law, and specific conditions, a good policy will guide the enterprise from its current state to a desirable future state. The "desirability" of the final state is dependent on the world-view of the policy maker.

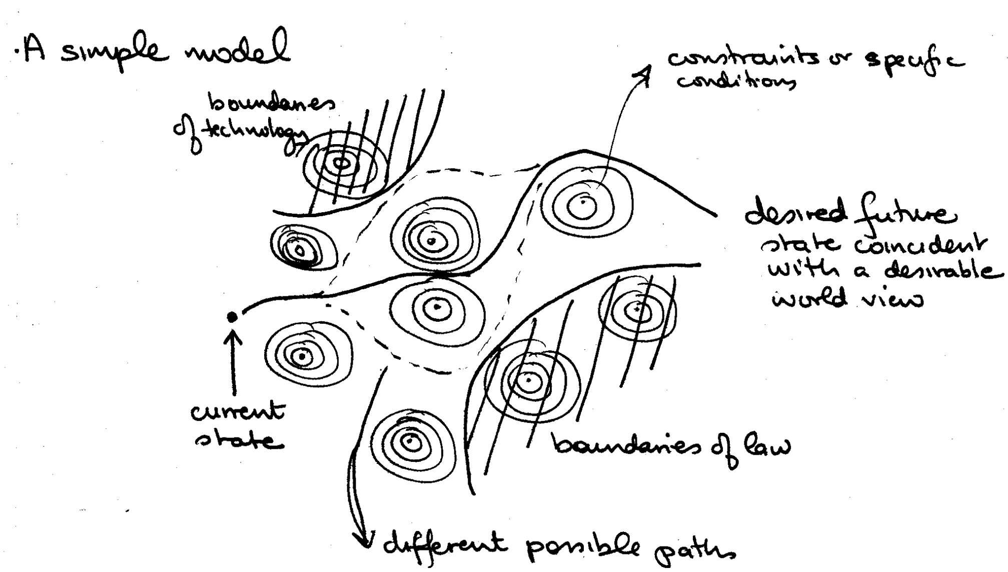

Figure 1 A simple model of the goals of policy

1.2. Policy and Space System Design

Space policy issues have traditionally been treated as exongenous issues in the technical design of space architectures. Of course, real practitioners know that this is not true. Space policies have both direct and indirect effects on the design of architectures. A good example is furnished by Iridium and Globalstar. Even though these are both LEO based PCS systems, the specific architectural choices they made were heavily influenced by their different responses to frequency allocation and local PSTN policies.

Iridium made the architectural choice to design a system that would allow a cell phone call from one user to another without ever interacting with a local PSTN. This was in keeping with the philosophy of a global communications solution. This also helped drive the cost of the system since each satellite needs to do switching in orbit and then needs and has crosslinks to other satellites. Of course, the local PSTNs did not like this. Since each country reserves the right to award "landing" rights to receive wireless signals, the local PSTNs (usually owned by the government) in several countries would not allow Iridium phones to receive signals in the country. Thus Australia for a while would not allow people to bring Iridium phones into the country and would not allow them to be sold there until an agreement was worked out with the local PSTN. By contrast, Globalstar chose from the beginning to create a simpler architecture that relied on the PSTNs thus co-opting them and allowing a cheaper alternative. The Globalstar architecture is that a cell phone call is picked up by the nearest satellite downlinked to the closest ground station, pushed into the local PSTN at the ground station through fiber to the closest ground station to uplink the phone call to the receiving cell phone. Thus, the PSTNs on each end are involved and get paid. This allows the satellite architecture to be much simpler being simply a bent pipe satellite with no cross links. The small difficulty with this architecture is that it cannot process phone calls where there are no ground stations in sight of the satellites, for example in the middle of the ocean or at the south pole. On the other hand, there is not much market in these locations.

A good review of the space policies which are codified treaties can be found in the analysis by Roberts.[4] In this paper, he analyzes many of the space related treaties in the context of National Missile Defense. He gives a quick synopsis of the relevant treaties. For a view of space policy from another country, the draft EU space policy[5] makes interesting reading. It clearly shows that policy statements come in three categories, The first are general statements of principle. For example, the policy statement that leadership in space is important to the US is a statement of principle. In the same manner, the statement in the EU space policy that they must have some independence from the US is also a statement of principle. The first type of policy statement only has general architectural implications. For example, it may mean that US designers are forced to consider using only parts procured from US providers. The second type of policy statement is one that can be expressed in heuristics. The following discussion of heuristics is taken from the PhD thesis by Weigel.

1.3. Policy Heurisics[6]

The word "heuristic" derives from Greek and Old Irish words meaning "to discover" or "to find." The adjective form of heuristic is given two definitions in the dictionary:

> "Heuristic (hyu-'ris-tik) [*adj*]: 1. involving or serving as an aid to learning, discovery, or problem-solving by experimental and especially trial-and-error methods; 2. of or relating to exploratory problem-solving techniques that utilize self-educating techniques (as the evaluation of feedback) to improve performance"[7]

This is not inconsistent with the description given to heuristics (in the noun form) by Maier and Rechtin in their book *The Art of System Architecting*. They describe a heuristic as a guideline for architecting, engineering, or designing a system. To put it another way, they describe it as a natural language expression of a lesson learned through experience that is expressed as a guideline. Heuristics typically come in one of two varieties, descriptive or prescriptive. Descriptive heuristics describe a situation, while prescriptive heuristics indicate a course of action.

"At their strongest, they [heuristics] are seen as self-evident truths requiring no proof." But what constitutes a good heuristic? A good heuristic must pass the following tests:[8]

1) The heuristic must make sense in the original domain in which it was conceived.
2) There must be readily apparent correlation between the heuristic and the successes or failures of programs and/or systems.
3) The general sense of heuristic should apply beyond original context in which it was conceived.
4) The heuristic must be easily rationalized in a few minutes or on less than a page.
5) The opposite statement of a heuristic should be foolish.
6) The basic lesson of the heuristic should have stood the test of time and earned a broad consensus.

Heuristics in application

Maier and Rechtin describe three common ways in which heuristics are applied in architecting and design. First, people use heuristics as an evocative guide. When faced with a difficult problem, a personal toolkit of heuristics can be scanned for inspiration on the context of the problem, the root of the problem, or its solution. Second, people use heuristics as a pedagogical tool. They codify their experiences in a set of heuristics, and pass the heuristic, as well as the story behind it, along to others. Third, people use heuristics by integrating them into the system development process. These heuristics would typically be prescriptive heuristics, guiding the development process. The first and second types of applications would seem to be the most appropriate for the policy impact heuristics presented in this research.

Other suggestions from Maier and Rechtin on applying heuristics are:
1) If the heuristic works, then it is useful
2) Knowing when and how to use a heuristics is as important as knowing the what and why.
3) Practice, practice, practice.
4) Heuristics aren't reality, they are just guidelines.

Before leaving this brief discussion of applying heuristics, it should be mentioned that while heuristics can be shortcuts to a problem's solution, there is no guarantee that they will solve all problems encountered.

Some old heuristics

Brenda Forman (in Maier and Rechtin) was the first to have published heuristics about the political process and aerospace system architecting and design. The heuristics she suggests are very poignant, needing relatively little explanation, and are well worth reviewing here. Her heuristics give impetus to research on the impacts of policy on systems.

Forman's Heuristic #1: *If the politics don't fly, the system never will.*

This heuristic fundamentally reflects the will of the customer in the process of procuring politico-technical systems as discussed in Chapter 2 of the Weigel PhD "Understanding the environment: How policy and engineering interact." "If the politics don't fly" is simply another way of saying "If the customer doesn't like it." Politics is simply the legally constituted way taxpayers (the customers of politico-technical systems) express their desires.

Forman's Heuristic #2: *Politics, not technology, sets the limits of what technology is allowed to achieve.*

The political domain and its resulting policies determine program budgets, and it is these budgets that limit resources to solve technical problems. Hence, policy is the limiting factor to technical performance, and the impact of policy on technical systems is important to understand.

Forman's Heuristic #3: *A strong, coherent constituency is essential.*

The political domain doles out budgets based on the strength and staying power of a program's constituency. And without budget, programs do not happen.

Forman's Heuristic #4: *Technical problems become political problems; there is no such thing as a purely technical problem.*

Technical problems frequently result in either direct budget changes on a program, or schedule changes that result in budget changes. And budget is unarguably the purview of the political domain.

Forman's Heuristic #5: *With few exceptions, schedule delays are accepted grudgingly; cost overruns are not.*

When cost overruns occur, Congress has to go back and take money away from some other program to pay for the overrun. This of course doesn't make Congress happy, for among other things, Congresspersons now have to explain why that money was taken away from the poor blameless loser.

1.4. Policy Statements and Systems Architecture

As can be see from the heuristics above, a space system architecture may be affected at level of design by the need to satisfy one of these guidelines. For example, some observers of space history contend that the choice of segmented solid rocket boosters for the STS (Space Shuttle) was driven by the need to get congressional support for the space program in another state (Utah). This motivated the choice of Morton Thiokol who then needed to design a segmented booster so that they could manufacture the pieces in Utah and transport them over restrictive rail lines to the Gulf coast. As another example, critics of the B-1 bomber have suggested that it is a plane with parts built in every state precisely so that it will have broad based congressional support.

Another type of space policy statement is one that results in specific architectural designs. Of course even these come in several flavors. There are specific statements that drive design ahead of the beginning of a design. An excellent example is the current statement of US launch policy. This states that all US Government payloads must be launched on US manufactured launch vehicles. This means that the space architect of a new NASA mission need not bother designing it to be launched on Ariane or Long March. A final flavor of policy statements which end up affecting space system architectures are often budget policy statements. Of course their effect is indirect through the budget constraints which are imposed. A good example of this was that the Clinton Administration mandated that the budget for the International Space Station by $2B a year regardless. This had the effect of delaying key pieces and also leading to the cancellation of the Crew Return Vehicle in some budget exercise. This third kind of policy can be studied for its specific architectural implications. This first requires the development o of a model for how the policy domain interactions with the architectural domain.

1.5. Analyzing Policy Impacts

Weigel is the one of the first to develop a model for how space architectures are affected by policy issues.[9] She shows that the policy domain, technical and user domain are intimately connected with the architectural domain and end up driving each other. While she did not elucidate all the feedback loops, she showed the importance of each community understanding the others. Of course not all policies are reducible to quantification as discussed earlier. In any case the Weigel analysis shows how to construct the influence diagrams that flow from policy objectives to specific architectural choices. She argues in another paper that policymakers and architects need to develop real options in order to have flexibility.[10] In two follow on papers she shows how a policy of annual budget adjustments (unhappily all too common) leads to the development of a set of options to mitigate the bad effects of this policy.[11] In another analysis she shows how the US space launch policy can be reduced to specific quantification.[12] This is the first analysis that shows the specific monetary impact of the US launch policy that underwrite national launch providers. We should note that the development of options for investment given (expected) budget fluctuations stands in stark contrast to the actual practice of space system architecting in the 90s as documented in the DSB/AFSAB space report.

In another example of how policy and architectural choices interact, another paper by Hastings et al argues that only the development of policy enablers will allow the true development of on-orbit servicing.[13] This is because the cost of setting up the infrastructure is so large (even though the benefits may be large) that only by concerted international action could this occur. The national precedent is the development of the national highway system which is underwritten by the US Federal government. This allows individual users to benefit in each state but spreads the cost over the whole US taxpayer base. The international precedent is the development of Intelsat in the mid sixties which provided cheap international satellite based communications to the free world.

To summarize, we argue that in some cases statements of space policy can and show be reduced to quantification with respect to specific architectural choices. When this can be done early in the conceptual design process, it should be for it allows design makers at the policy level (who speak a different language) to understand the impact of the policy choices and changes that they may request. Happily the same language of tradespaces and tradespace exploration may make this real time policy interaction possible. DeWeck illustrates this well in a recent paper on how LEO PCS systems could have been analyzed (including the policy and economic dimensions) using tradespace analysis.[14]

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