The Cost of Jointness and How to Manage It

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Although joint programs are typically formed to reduce costs, recent studies have suggested that joint programs experience larger cost growth than non-joint programs. To explain this phenomenon, we present a model that attributes joint program cost growth to agencies' actions to maintain or regain their autonomy. We use this model to motivate principles for architecting joint programs and outline a process that can be used to identify opportunities for reforming current joint programs or for establishing new ones. Finally, we apply our approach to analyze joint program options for NOAA's low-earth orbiting weather satellite program and in doing so, identify several risks facing NOAA's current program and strategies for mitigating them.

THE *Department of Defense Dictionary of Military and Associated Terms* defines the concept of *jointness* as "activities, operations, organizations, etc. in which elements of two or more Military Departments participate."[1] In practice, jointness is often defined more broadly and includes activities, operations, and organizations that involve more than one service department *or* more than one government agency. Joint programs are particularly common in the government space sector because only a few agencies have the expertise or budget to develop space systems independently. Example joint space programs include Milstar, a military communication satellite developed by the Air Force to meet joint Service requirements and the Joint Polar Satellite System (JPSS), an environmental monitoring satellite built by the National Aeronautics and Space Administration (NASA) for the National Oceanic and Atmospheric Administration (NOAA).

Jointness has numerous benefits: it enables government agencies to design for interoperability, to leverage a particular agency's unique technical expertise, and to benefit from mission and technical synergies. In addition to these benefits, one of the most common motivations for joint system acquisition is cost savings: theoretically, when agencies acquire systems jointly, both the cost-per-agency and the overall cost to the government are reduced, since agencies can share development, production, and operations costs. However, despite their cost savings potential, recent studies suggest that joint programs experience greater cost growth than non-joint programs[2-5] and that in some cases it may be more cost-effective for agencies to acquire systems independently rather than jointly.[2]

These recent studies motivate two questions:

- Why do joint programs cost so much?
- And how should the government structure joint programs to manage their costs more effectively in the future?

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This paper reviews results from research on joint programs that addressed these questions. In Section I, we review the basic concepts and predictions of the Agency Action Model, which explains how and why costs have grown on past joint programs. Our model was developed by analyzing data from case studies of the National Polar-Orbiting Environmental Operational Satellite System (NPOESS), the Defense Weather Satellite System (DWSS), and JPSS. In support of this analysis, approximately 70 people were interviewed, 100 hours of data was collected, and 230 program documents were reviewed. Data was analyzed using a mix of qualitative[6] and quantitative[7] methods and our model was generated after analyzing data both within and across the case studies.[8,9] Ref. 10 provides additional details on the data, methods, and analysis that was conducted in support of the model's construction.

Next, in Section II, we review the model's implications and use them to define principals for architecting future joint programs. In Section III, we outline a process that government decision makers can use to apply our principles and to analyze future opportunities for jointness. To demonstrate this process, we use NOAA's low Earth orbiting weather satellite system as a case study. In support of this case study, we utilize a trade space analysis tool that allows us to evaluate numerous system concepts with respect to metrics for cost and benefit. The trade space analysis tool was developed to study the cost and benefit trade-offs of aggregated versus disaggregated system architectures for NOAA and the DoD's low Earth orbiting weather satellite systems. Ref. 10 and 11 provide additional description of the tool's modelling methodology and input assumptions. In Section IV, we use this tool to simulate the range of system options that are available to NOAA and to illustrate how agency leaders can use the Agency Action Model, our principles, and our recommended process to select a system concept, to evaluate potential partnerships, and to identify risks.

I. The Agency Action Model

The Agency Action Model explains cost growth on joint programs in terms of their collaborating agencies' institutional interests and the actions that they motivate; specifically, the model suggests that ***collaborating agencies' institutional interest in <u>maintaining</u> or <u>regaining</u> their autonomy induces cost growth on joint programs.*** For clarity, we define *autonomy* to be the freedom to make decisions independently. The concept of autonomy is closely related to *authority*, or the power to make decisions; thus, if an agency lacks autonomy, it does not have the *authority* to make decisions independently.

The Agency Action Model identifies two mechanisms for joint program cost growth. The first occurs when the joint program is organized in one of the basic forms shown in Fig. 1. In these forms, the agencies' actions to maintain or regain their autonomy increases the program's costs. The second occurs when joint programs evolve away from the Fig. 1's basic forms and the resulting organization becomes unstable, inefficient, and costly. In this section, we explain both mechanisms and their implications in terms of the agents (i.e. the collaborating agencies) that take actions and the interests that motivate those actions. Finally, we review the actions that occur within the basic joint program forms and that those that occur across them, when programs evolve from one form to another.

A. The Agents

Agency authority is closely related to three other characteristics that define government agencies: mission responsibility, budget, and expertise. Taken together, we define these characteristics as:

- Authority: When an agency has authority, it has the power to make and sustain decisions related to its mission.
- Responsibility: When an agency has responsibility, it is accountable for delivering a technical system that executes its mission.
- Budget: When an agency provides budget, it is responsible for funding the decisions that it makes and the technical system for which it is responsible.
- Expertise: When an agency has expertise, it has the knowledge and experience necessary to make decisions effectively.

Given these definitions, we can observe the importance of aligning responsibility, budget, and expertise with authority. Authority and responsibility should be aligned so that agencies have the power to make decisions regarding the systems that execute their missions. Authority and budget should be aligned so that agencies can consider cost when making decisions. Finally, expertise and authority should be aligned to insure that agencies make informed and effective decisions.

The government's interest in aligning authority, budget, responsibility, and expertise *across* agencies often motivates government leaders to form joint programs. For example, when two agencies lack the budget to execute their missions independently, they can share a budget and execute their missions jointly. When one agency lacks the technical expertise to develop a system to execute its mission, it may partner with another agency that houses the necessary expertise. Finally, when two agencies execute similar missions, they can reduce costs by sharing authority over a single system that executes both missions. Despite the government's interest in aligning authority, responsibility, budget and expertise, the Agency Action Model suggests that joint program costs grow because oftentimes, these critical interdependencies are misaligned within joint program offices.

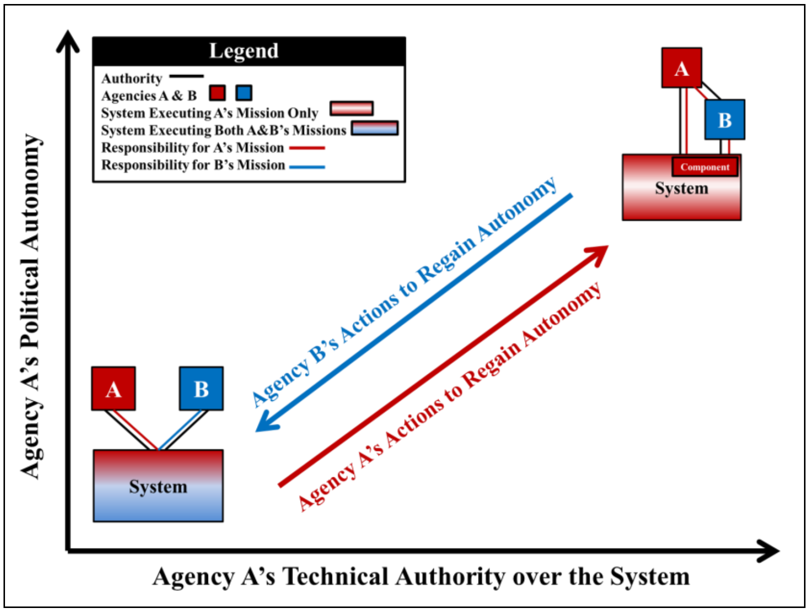

Figure 1. Agency Actions to Regain Autonomy

B. The Interests

Rational choice theory, which suggests that government agencies' actions are based on institutional interest,[12-13] provides the theoretical backbone for the Agency Action Model. Within this theoretical framework, the law of inter-organizational conflict states that every government agency is in partial conflict with one another over its authority, mission, budget, and relative expertise.[14] According to administrative theorist Anthony Downs, agencies perceive other organizations that have similar missions or overlapping jurisdictions (i.e. overlapping decision authority) to be their rivals.[14] By taking actions to gain autonomy from these organizations, agencies attempt to establish a permanent claim over their mission and jurisdiction by eliminating the external threat that is posed by rival agencies.[14-15]

Within joint programs, the collaborating agencies are rivals that threaten each other's ability to execute their individual missions. Therefore, the Agency Action Model states that the collaborating agencies are primarily interested in maintaining or regaining autonomy, or (1) their ability to execute their unique missions and (2) their ability to do so without the interference by other agencies.

C. Actions Within the Basic Forms

Agencies can execute their unique missions and do so without interference by *sharing authority* in a joint program. By sharing authority, the agencies *maintain* their autonomy: neither agency can make mission execution decisions that affect the other without consulting them first. Furthermore, when making decisions, both agencies must agree on the selected option; if an agency disagrees, it has the authority to veto the other agency's selection. Using this veto power, agencies can insure that their unique missions are executed by the joint system and that their collaborators cannot interfere with that mission's execution.

Sharing authority affects joint program costs during the requirements development process because each agency levies *all* of its requirements, regardless of whether they are shared by its partner or whether they drive the performance and configuration of the system. Neither agency vetoes its partner's requirements because each agency acts in the same way; as a result, the joint requirements set is a concatenation of each agency's unique and driving requirements. To meet these requirements, joint space programs typically develop large "Battle-star Gallacia"-like[16] satellites that aggregate numerous capabilities onto single complex platforms. Thus, by sharing authority, agencies increase joint program costs by increasing the complexity of the joint system.

If agencies do not share authority on a joint program, then at least one agency is designated as the lead and another as its subordinate; in this situation, the lead agency delegates some of its authority to the subordinate who executes the lead's mission on its behalf. According to the Agency Action Model, in this situation, the subordinate agency takes actions to erode the lead's authority and to execute its mission without interference.

The subordinate agency maximizes its ability to make decisions independently by developing a program plan that explicitly follows all of its official processes and procedures and that employs a conservative budget with more than sufficient margin. In this way, the subordinate agency reduces the frequency with which it requires decision approval from the lead or that it needs to request more funding in the case of unexpected cost growth. Therefore, with this form of jointness, it is not the concatenation of multiple agencies' requirements, but rather, the conservatism of subordinate agency's development processes, which increases the joint system's cost. If a single agency held full authority over its system, it could reduce costs by deviating from official processes and procedures when doing so was in the best interests of the program; however, because the subordinate agency seeks decision-making autonomy, such decisions—which require the approval of the lead agency—are rarely made.

D. Actions Across the Basic Forms

The basic actions described above occur in joint programs like those shown in Fig 1. In the bottom left corner, Agency A and B share authority over a system that executes both of their missions. In this case, Agency A's authority and autonomy are minimized because it shares them with Agency B. An example program of this form is the cancelled Space-Based Radar program where the Air Force and the National Reconnaissance Office were equal partners.

In contrast, in the upper right corner, Agency A's autonomy and authority are maximized. Here, Agency A develops a system that executes its unique mission and delegates authority for one component of its system to Agency B, which serves as its acquisition agent. In this case, Agency B regains autonomy from A by eroding its authority and by executing A's mission without interference. An example program of this form is the Geostationary Operational Environmental Satellite (GOES) program, where NASA acquires a spacecraft on behalf of NOAA, which independently acquires and manages the ground system and its interface to the space segment.

An important characteristic of Fig. 1 is that each agency's interest in executing its unique missions without interference drives its actions in opposing directions. Thus, as agencies take actions to regain their autonomy, Fig. 1's basic joint program forms can evolve to more complex configurations. However, regardless of where a program falls on Fig. 1's spectrum of jointness, the agencies' interest in executing their missions without interference remains the same. Faced with interference, an agency will erode the authority of its partner so that can regain autonomy to execute its mission. Absent interference, an agency will prioritize its own mission over its partner's.

An agency can erode its partner's authority directly, by second-guessing its decisions or by elevating them for further arbitration. An agency can also erode its partner's authority indirectly, by attempting to sway its decisions in favor of its own interests. In both cases, actions are enabled by an agency's expertise and budget. If an agency has greater technical capability than its partner, it can use that expertise to influence the partner's decisions and to justify its own actions. If an agency is not responsible for funding a system, it can more easily prioritize its own mission, since it pays no cost for doing so.

When agencies take action and their joint program evolves away from the basic forms shown in Fig. 1, the joint organization becomes unstable and inefficient because the agencies are in conflict with one another. Because organizational instability and inefficiency ultimately increase cost, joint programs should be architected to provide checks and balances that reduce agencies' ability to take actions. By architecting joint programs in this way, future government leaders can more reliably estimate their costs according to those predicted for the basic forms shown in Fig. 1.

II. Principles for Architecting Joint Programs

The principles for architecting joint programs focus on the ***alignment of responsibility, authority, budget, and expertise*** between the collaborating agencies and the system under development. The most important alignment is between responsibility and authority. According to the Agency Action Model, when agencies lack autonomy, they will take actions to erode their partner's authority in order to regain the autonomy to make decisions. If, for example, Agency A is assigned the independent authority to make decisions that affect Agency B's mission, then B's authority and responsibility are misaligned and it has lost some autonomy over its mission. By taking action to regain its autonomy, B generates conflict in the joint organization that slows decision-making, hinders the system development process, and ultimately induces cost growth.

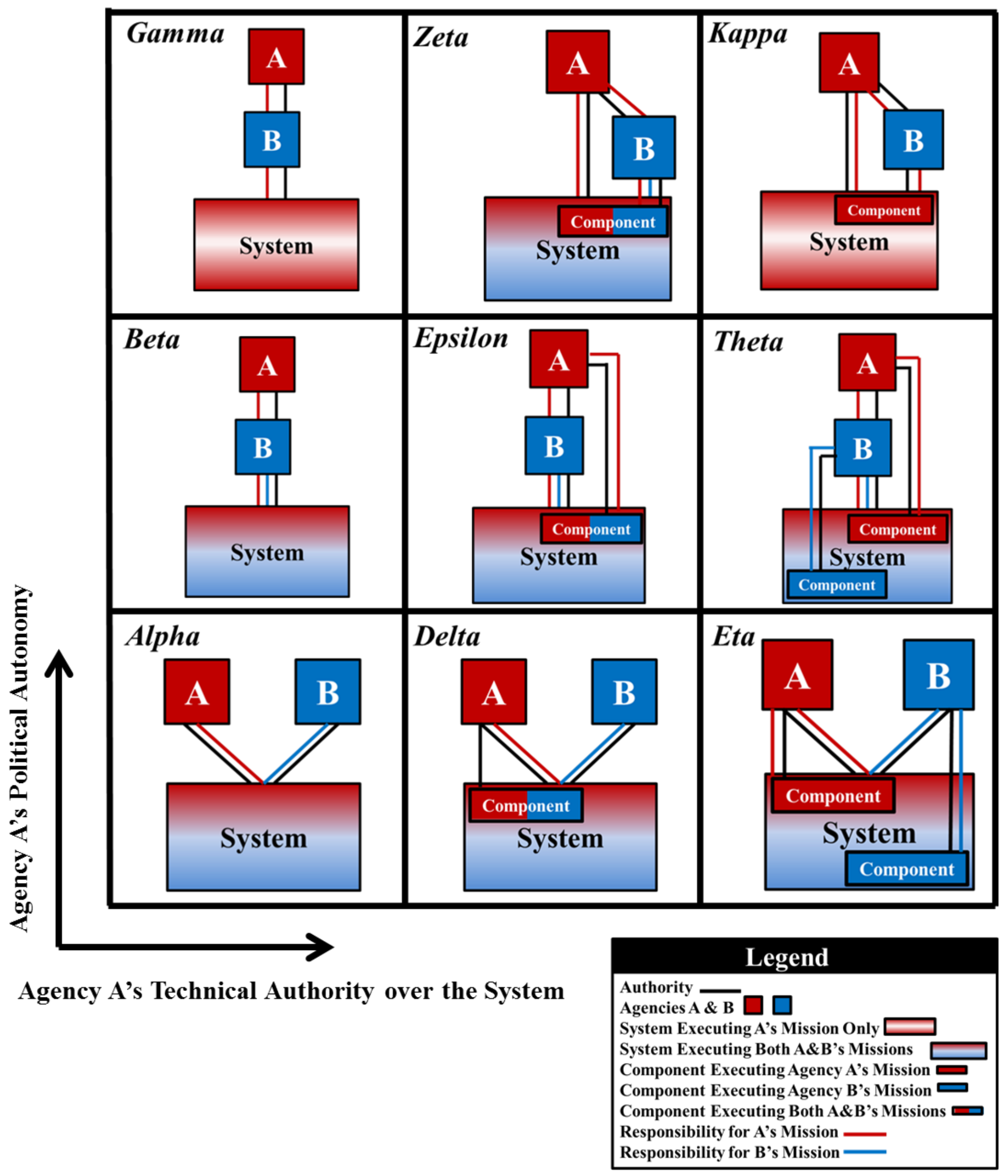

Figure 2. Forms of Jointness

Next, budget and responsibility must be aligned to insure that the agency with authority makes decisions that appropriately weigh benefit vice cost. For example, if Agency B is responsible for making decisions that affect its mission but is not responsible for funding the outcome of those decisions, B's actions will inappropriately favor its mission, rather than A's ability to fund it. In this scenario, program costs will grow because B has no incentive to consider costs when making decisions or managing A's system. Finally, expertise and authority must be aligned so that each agency can provide a check and balance on the other's interest in prioritizing its unique mission over the shared mission of the joint program.

Using these simple principles, there are numerous ways that the government can structure future joint programs. Fig. 2 illustrates some additional joint program forms; however, others can be constructed using any combination of these forms. For simplicity, Fig. 2 only shows authority and responsibility although we assume that, as recommended, authority is aligned with expertise and responsibility is aligned with budget. Using the two examples that were discussed in Section I (shown as Alpha and Kappa in Fig. 2), this means that in form Alpha, Agency A and B share the budget for the program and have equal technical expertise. In form Kappa, Agency A has the expertise to develop all of its system except for the component, which is developed by B. Although B has greater component expertise than A, Agency A still has enough expertise to effectively oversee B's work. Finally, the budget for the system is provided entirely by Agency A, since the system executes only A's mission.

An important characteristic of Fig. 2 is that only the four corner forms (Alpha, Gamma, Kappa, and Eta) completely align responsibility and authority. Form Gamma is similar to Kappa except that B develops A's entire system rather than a single component. Finally, Form Eta is similar to Alpha except that the system is modularized and A and B are each assigned authority over the components execute their unique missions.

The forms that transition from Alpha to Eta and Gamma to Kappa are unstable because authority and responsibility are misaligned. In Delta, A has been delegated the authority to manage a component which executes a mission for both A and B. Because the component executes B's mission but B has lost its autonomy to manage that component, B will take actions to erode A's authority. Agency B can do this by monitoring the component's development and by raising any issues that it has with A's decisions to the program's joint management (i.e. the leaders of Agencies A and B). It is even easier for B to take these actions if expertise or budget are misaligned in the joint organization. For example, if B has greater expertise than A, it can second-guess all of A's technical decisions. If B does not provide budget for the component, it can pressure A to make decisions that minimize risk and that maximize the performance of B's mission, but that ultimately increase the component's cost. Once B has sufficiently eroded A's authority, the program structure transitions back to form Alpha, where both agencies share authority. Until that point, the program's decision-making process will be slow, acrimonious, and unnecessarily costly.

In form Zeta, Agency B develops a component that executes both A and B's missions and hosts that component on a system that is developed by A. In this case, Agency B may erode A's decision authority by seeking greater involvement in the system development process, since the system executes its mission as well. However, Agency B will not exhibit this behavior if it lacks the expertise to manage A's system; this explains why hosted payload arrangements can remain stable (i.e. not transition to an alternate form) if Agency B's expertise is limited to the payload and does not extend to the entire system.

This brings us to the middle row of joint programs, which the Agency Action Model predicts will have the largest risk for cost growth. In these programs, Agency A delegates its mission execution authority to Agency B, which acts as an acquisition agent for the system. However, unlike the pure acquisition agent role shown in forms Alpha and Kappa, in Beta, Epsilon, and Theta, Agency A's system also execute B's mission. In these forms, Agency A is at risk that B will use its implementation authority to prioritize its own mission over Agency A's. Agency A is particularly at risk if B has greater expertise than A or B does not contribute some of the program's budget (i.e. expertise and authority and budget and responsibility are misaligned). Forms Epsilon and Theta also present these risks to A and form Epsilon poses the additional risk of inter-agency conflict like that discussed on form Delta.

III. Applying the Principles

With this understanding of the model and principles, how should government decision-makers form future joint programs? We suggest following a three-step process for assessing the costs and risks of establishing a joint program and for selecting a program form that minimizes both. The process begins with an assessment of inter-agency requirements synergies and continues with an assessment of the cost of maintaining autonomy or delegating authority. At each step of the process, key risks should be identified and mitigation plans developed.

A. Step 1: Assess Requirements Synergies

The first step of the process is to assess the requirements synergies between potential partners. Two partnership types are possible:

- A ***synergistic partnership*** is one where the agencies' requirements are well-aligned; in such cases, as a system's benefit to one organization increases, so does its benefit to the other.
- Alternatively, a ***non-synergistic partnership*** is one where the agencies' requirements are poorly aligned; in such cases, as a system's benefit to one organization increases, its benefit does not necessarily increase for the other.

To evaluate requirements synergies, we recommend that agencies *independently* determine their requirements. Once these requirements have been established, each agency should develop and evaluate multiple conceptual designs. Finally, the agencies should evaluate each other's designs with respect to their own requirements.

Fig. 3 illustrates a notional trade space of conceptual designs and how designs for agencies with synergistic or non-synergistic requirements compare. As shown, if the designs are evaluated with respect to both agencies' requirements and plotted against the benefit that they deliver to each agency, synergistic partnerships will fall towards the central region of the trade space. Alternatively, non-synergistic partnerships will result in systems that perform very well with respect to one set of requirements but very poorly with respect to another's. As will be discussed below, understanding whether agencies' requirements are synergistic or not is critical for selecting a joint program form and for actively mitigating its risks.

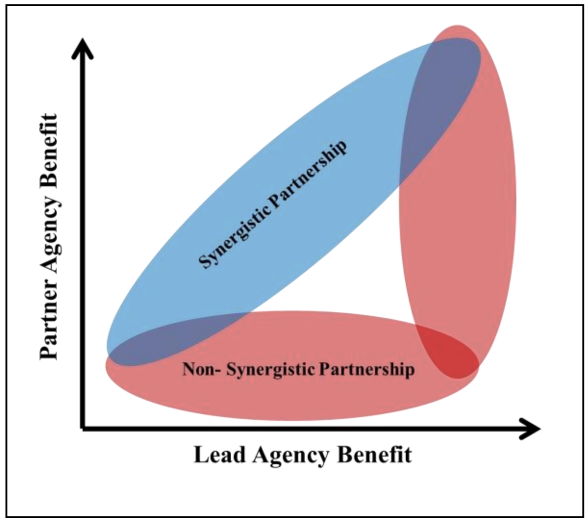

Figure 3. Partnership Types

B. Step 2: Assess the Cost of Sharing Authority

Regardless of whether their requirements are synergistic or not, agencies can maintain autonomy in a joint program by sharing authority over a system. According to the principles, an agency's authority must be aligned with its mission responsibility; therefore, if agencies share authority over a system, the system should equally execute both agencies' missions. Fig. 4 illustrates this principle on a notional trade space and shows that when agencies share authority, they must select a system that delivers approximately equal mission benefit to both partners. If the agencies select a system outside of this zone, one agency's authority will be misaligned with its mission responsibility. According to the Agency Action Model, cost growth will result when that agency attempts re-prioritize its mission's execution by the joint system. Therefore, to assess the cost of sharing authority, the agencies should generate multiple conceptual designs that equally meet both of their requirements. These designs should be compared to designs that the agencies generated independently, a cost differential determined, and additional risks identified.

Generally, sharing authority carries two key risks. First, in order to meet the joint requirements set, new technology will need to be developed since it is unlikely that either agency's heritage technology will be capable of meeting joint requirements. Developing technology is a slow and uncertain process[17] that can induce unexpected cost growth, particularly if a program undertakes multiple concurrent technology development projects. Second, once joint requirements are established, it is unlikely that the agencies will be willing to trade those requirements against cost later, since doing so poses a threat to their autonomy. Therefore, once a program establishes joint requirements, it is locked into those requirements and the complex system that meets them. To mitigate these risks, joint programs should budget for technology development and should include a large margin in their budgets since they will be unable to reduce their system's capabilities to cut costs later.

If authority is shared, the joint program can take form Alpha, Delta, or Eta from Fig. 2. If agencies have synergistic requirements, we recommend that they use form Alpha, since decoupling their individual requirements into components may be impossible and using form Delta would result in unnecessary conflict. If the agencies have non-synergistic requirements, form Eta can be used, if the system can be modularized such that the agencies' missions can be decoupled. If form Eta is used, agencies should be sure to develop components to the same sets of engineering and mission assurance standards; however, if this is impossible, the joint program should allocate some budget so that engineers can reconcile the different requirements standards that were levied on each component. Finally, in all cases, the partnering agencies should have equal expertise, so that one agency cannot use an expertise differential to erode the authority of the other.

C. Step 3: Assess the Costs of Delegating Authority

After assessing the costs of sharing authority in a joint program, agencies should consider the costs and risks of delegating it. If agencies have non-synergistic requirements, then one agency can serve as an acquisition agent for the other (i.e. forms Gamma and Kappa), as long as the system that is developed delivers benefit to one agency only. Of course, acquisition agent arrangements only make sense when one agency lacks the expertise to develop a system or its components independently. As discussed in Section I, the lead agency should contribute the full budget for the program and should account for the fact that its acquisition agent will execute the system development process conservatively and in strict accordance with its policies and procedures, even if those processes unnecessarily increase the cost of the system.

If the agencies have synergistic requirements or if they chose to develop a system that executes both agencies' non-synergistic requirements, a pure acquisition agent model is impossible, since both agencies' missions are satisfied by the system. In this case, there is a risk that the acquisition agent will prioritize its own mission over the mission of the lead agency. To mitigate this risk, the lead agency can attempt to select a design that minimizes benefit to its acquisition agent. The lead agency also needs to have sufficient technical expertise to monitor the agent's actions and should require the agent to contribute some portion of the program's budget. Again, form Epsilon is not recommended and unless the agencies' missions can be completely decoupled (a challenge when their requirements are synergistic), neither is form Theta.

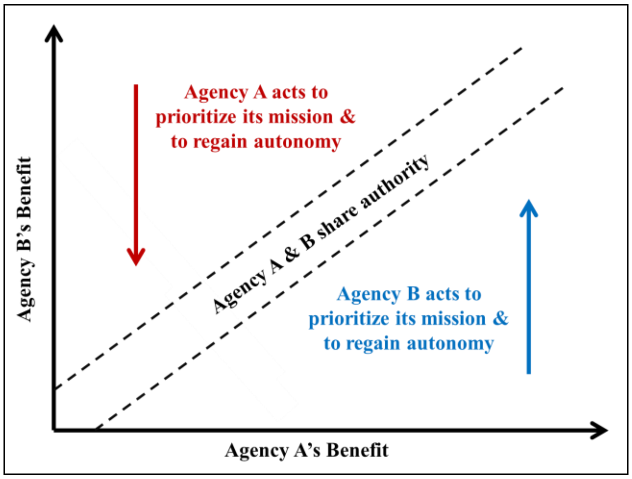

Figure 4. Cost of Sharing Authority

IV. Case Study: Applying the Principles

To illustrate how to apply the principles and to clarify some of the more abstract concepts discussed above, we use a case study of NOAA's weather satellites in low-Earth orbit. NOAA requires environmental data from low-earth orbit primarily to support weather prediction and secondarily, to support climate prediction and climate monitoring. Although NOAA has used this type of data since the 1960s, the agency lacks the in-house technical expertise that is necessary to develop satellites independently. As a result, NOAA has historically formed joint programs with either NASA or the DoD, since both agencies have resident technical expertise and collect similar data from low-earth orbit. In its current program, JPSS, NOAA is using NASA as an acquisition agent and is providing 100% of the funding for the system; for additional background on NOAA's past partnerships, please refer to Refs. (10, 18-19).

In this section, we will use the process outlined above to identify joint program forms that satisfy our principles and to identify each partnership's inherent risks. To create the conceptual system designs that are required by the process, we use a trade space analysis tool that generates numerous system concepts and evaluates them according to lifecycle cost and benefit metrics. In the analysis that follows, we use concept designs that fell on the "fuzzy" Pareto front of cost and benefit, or were three layers of Pareto dominance deep.

Our trade space analysis tool focuses only on the systems' space segment and explores different architectures by varying the number of orbits in the constellation, the number of satellites per orbital plane, the number and type of instruments flown, and the instruments' assignment into spacecraft. In modeling each system, the tool assumes that each satellite has a five-year lifetime and that each agency is developing a system to execute a ten-year mission. Our cost metric includes non-recurring, recurring, and launch costs for the space segment and our benefit metric assesses each system's capabilities according to the requirements levied during the NPOESS program and the capabilities that each agency's heritage systems fielded. To allow our analysis to focus on relative comparison between system concepts rather than on an absolute assessment of system cost and benefit, we normalize each metric by the cost and benefit of a reference system, which in this case is NPOESS.

A companion paper at this conference, listed in Ref. 11, provides a more detailed description of our trade space analysis tool. Here, we simply use results generated by the tool to illustrate how government decision-makers should reason through the process of finding an agency partner for NOAA, of selecting a joint program form that is appropriate for the partnership, and of mitigating that form's risks.

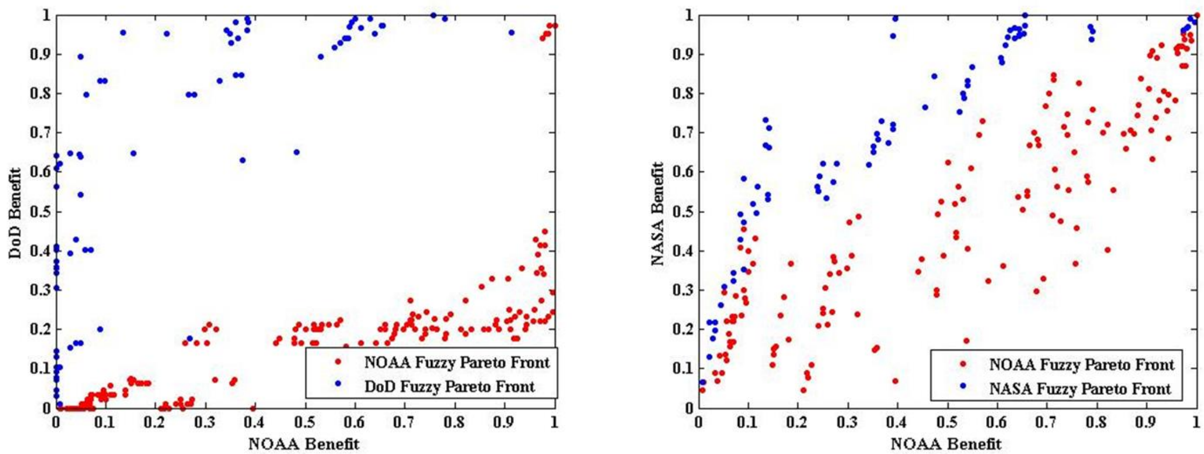

Figure 5. NOAA, NASA, and DoD Requirements Synergies

A. Step 1: Assess Requirements Synergies

NOAA, NASA, and the DoD each require similar environmental data to be collected from low-Earth orbit; however, despite the similarity of their data requirements, the agencies' requirements for *implementation* differ. As shown in Fig. 5, these differences are readily visible when the Pareto optimal systems for each agency are evaluated with respect to the other agencies' requirements. Fig. 5 clearly shows that NOAA and the DoD are non-synergistic partners. The primary reasons for their lack of requirements synergy include:

- The DoD requires data to be collected from an early-morning orbit (i.e. 5:30 right-ascension of ascending node (RAAN)) whereas NOAA requires data to be collected in an afternoon orbit (13:30 RAAN).
- The DoD prioritizes data generated by a visible-infrared (VIS-NIR) imager-radiometer and a conical microwave imager-sounder whereas NOAA's highest priority data is generated by cross-track infrared and microwave sounders. However, like the DoD, NOAA also places high priority on data collected from a VIS-NIR sensor.
- The DoD has only one mission—weather prediction. NOAA's primary mission is also weather prediction but it has an additional climate mission which the DoD does not share.

Anyone familiar with either NOAA or the DoD's heritage satellite programs could have generated the above list; however, by following our process of generating concept systems for each agency and of evaluating them against other agencies' requirements, government decision makers can observe how significantly the agencies' requirements differ and how those differences manifest themselves in the systems that each agency prefers. In this case, NOAA and the DoD's requirements are so divergent that the only systems that generate benefit to both agencies are those that also maximize it.

In contrast, NOAA and NASA's requirements are synergistic: as one agency's benefit increases, so does the other's. Again, the reasons for this synergism are well-known within the environmental monitoring community:

- Both agencies require data that is collected from afternoon orbits.
- The instruments that execute NOAA's primary weather mission are derived from instruments that were developed previously by NASA to execute its climate science mission. Therefore, NOAA's weather instruments serve dual-purposes of contributing to weather forecasting and to climate observation.
- NOAA's secondary climate mission is NASA's primary mission; importantly though, NASA does not share NOAA's weather mission.

As will be discussed below, understanding that NOAA and the DoD are non-synergistic partners and that NOAA and NASA are synergistic partners is critical for identifying which joint program forms the partners should use.

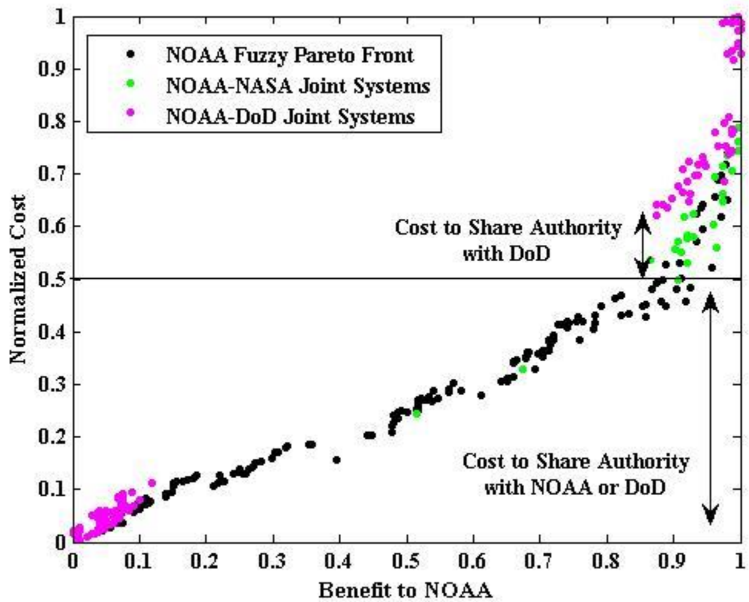

Figure 6. Cost of Sharing Authority with NASA or the DoD

B. Step 2: Assess the Cost of Sharing Authority

Regardless of their requirements synergies, NOAA could form a joint program by sharing authority with either the DoD or NASA. Fig. 6 illustrates the cost impact of sharing authority by identifying systems that equally meet both agencies' requirements and by plotting those systems against NOAA's Pareto front. Fig. 6 shows that the relationship between cost and benefit on NOAA's Pareto front is linear and constant until a knee in the curve, after which, the slope increases. Importantly, nearly all of the candidate joint systems lie *above* this point, where cost increases faster than benefit. Exceptions to this general statement included the set of systems that perform poorly with respect to both agencies' requirements and two candidate systems that meet approximately 50% and 70% of both NOAA and NASA's requirements.

Important characteristics of these systems include:

- Both systems contain a train of satellites in a single orbital plane with a 13:30 RAAN.
- Both systems contain a VIS-NIR sensor, cross-track infrared and microwave sounders, and an Earth radiation budget sensor.
- The higher performing system also includes an ozone monitor, a total solar irradiance monitor, and a conical microwave imager-sounder.
- Both systems disaggregate the VIS-NIR sensor from NOAA's highest priority cross-track infrared and microwave sounders.

Fig. 6 also illustrates the two costs of sharing authority. The first cost is induced by limiting the size of the trade space. As shown, if NOAA did not share authority, it would have the autonomy to select any of the systems on its Pareto front, including those with less benefit and cost. However, by sharing authority, NOAA confines its trade space to a region that maximizes these metrics. As discussed previously, when agencies share authority, it is unlikely that they will accept capability reductions later in the program, even if their programs' costs grow significantly. Thus, by sharing authority with either NASA or the DoD, NOAA locks its system into a costly configuration that it will be forced to preserve for the remainder of the program.

The second cost is induced specifically by sharing authority with the DoD, since the joint NOAA-DoD systems are costlier than even the most expensive systems on NOAA's Pareto front. The cost differential is induced by the agencies' non-synergistic requirements, which drive the configuration of their potential joint systems to differ from NOAA's high-benefit systems in the following ways:

- Systems with high NOAA and high joint benefit occupy orbits with both afternoon and mid-morning RAAN; however, in addition to these orbits, joint NOAA-DoD satellites all include a third orbital plane with an early morning RAAN.
- Of the NOAA systems that do fly satellites in the early morning orbits, most satellites are composed of only one or two instruments. In contrast, in the high-benefit joint systems, four to five instruments are assigned to spacecraft in the early morning orbital plane.
- Pareto optimal NOAA systems tend to fly multiple satellites in a train formation in a 13:30 orbit. In contrast, a greater majority of the Pareto optimal joint systems fly monolithic satellites in each orbital plane.

Although sharing authority with either NASA or the DoD increases the overall cost of NOAA's system, if the agencies share budget responsibility (as recommended by the principles), the joint system's cost to NOAA will be significantly reduced. In addition to aligning budget and mission responsibility, the principles recommend that each agency's expertise be commensurate with its authority. Regardless of whether NOAA partners with NASA or the DoD, it is at risk for violating this principle because it lacks the technical expertise that resides in the other organizations, which have considerable experience developing space systems. To insure that potential partners do not exploit this expertise differential in order to prioritize their unique missions, NOAA could supplement its in-house expertise with greater support from external organizations such as Federally Funded Research and Development Centers (FFRDCs).

Finally, when selecting a joint program form, NOAA should only consider form Alpha if it partners with the NASA, since the agencies' requirements are synergistic and harder to decouple into components that can be managed separately. Because NOAA and the DoD's requirements are non-synergistic, it could consider using form Eta in addition to form Alpha. For example, NOAA could assume authority and responsibility for developing the cross-track infrared and microwave sounders while the DoD could take the conical microwave imager-sounder. Because both agencies' missions use the VIS-NIR sensor, they should manage it jointly or consider strategies to modularize the instrument into components that separate the agencies' missions and can be managed independently. Again, using form Delta is not recommended.

C. Step 3: Assess the Costs of Delegating Authority

If NOAA shares authority with either NASA or the DoD, it accepts the cost of developing a system that meets both agencies' requirements and the risk that if the program's costs grow, it will be unable to reduce the joint system's capabilities to cut costs. If these costs and risks are unacceptable to NOAA, it can consider delegating authority to either agency; by doing so, NOAA can select a lower benefit, lower cost system, and maintain the option of changing that system's capabilities later in the program.

As discussed above, when selecting a joint program form that delegates authority, government decision-makers need to understand the relationship between agencies' requirements. Since NOAA and the DoD have non-synergistic requirements, as long as NOAA selects a system that does not maximize both agencies' benefit, the DoD can serve as a pure acquisition agent, because it derives little benefit from NOAA's system. As a result, NOAA should hold full budget responsibility for the system and both forms Gamma and Kappa can both be used. NOAA will not need to enhance its in-house technical expertise significantly because it is unlikely that its acquisition agent will use an expertise differential to prioritize its own mission, since its mission is not executed by NOAA's system. Of course, given the DoD's myriad of other missions, it is unlikely that it will be willing to serve as an acquisition agent. As an alternative, NOAA could consider using an FFRDC to fill that role.

Since NOAA and NASA have synergistic requirements, NASA cannot serve as a pure acquisition agent because it derives benefit from NOAA's systems. To guard against NASA taking action to prioritize its mission over NOAA's, NOAA could select a system that minimizes benefit to NASA: although this seems counter-intuitive, doing will help NOAA maintain organizational stability and insure that NASA will be unable take action to prioritize its mission over NOAA's. However, because the agencies have synergistic requirements, finding systems that minimize one agency's benefit while maximizing the other's is a challenge; Fig. 7 identifies candidate systems on NOAA's fuzzy cost-benefit Pareto front that are also on a Pareto front that minimizes NASA's benefit while maximizing NOAA's. While none of these systems include JPSS, alternative systems that provide < 0.9 benefit to NOAA have the following characteristics:

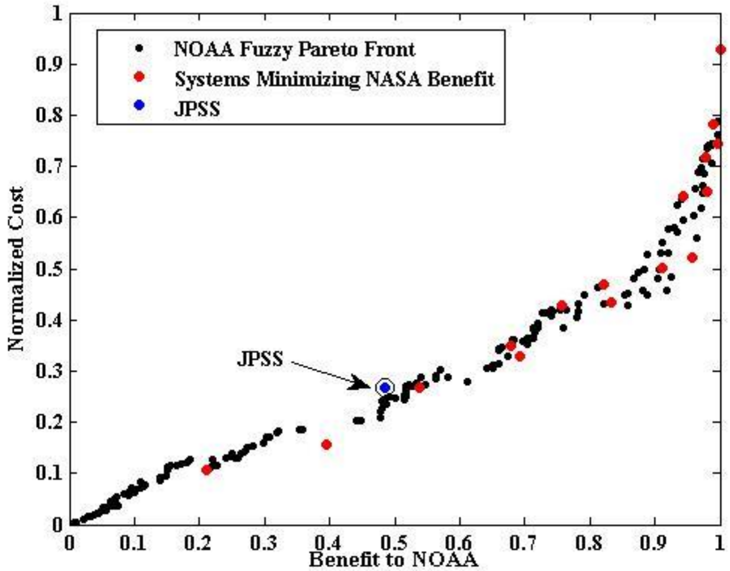

Figure 7. System Options when Delegating Authority to NASA

- Each system includes the cross-track microwave sounder and the infrared sounder.
- Most systems also include the VIS/NIR sensor, although several select a sensor that is less capable than NOAA's current sensor.
- The systems include, at most, only one sensor that's primary purpose is contributing to NOAA and NASA's climate mission.

Regardless of the system that NOAA selects, in accordance with the principles, NOAA should require NASA to contribute some funding so that the agency's budget and mission responsibilities are aligned. For example, Fig. 7 also identifies NOAA's current program, JPSS. JPSS generates a benefit score of 0.49 to NOAA and 0.39 to NASA. To align the agencies' mission and budget responsibilities, NOAA could contribute approximately 55% of the budget, while NASA contributes 44%: currently, NOAA funds 100% of the program. Furthermore, it is critical that NOAA enhance its current technical expertise so that it can effectively oversee NASA and ensure that its missions are appropriately prioritized. With regards to joint program forms, form Beta is recommended, while form Epsilon and Theta are not. Finally, regardless of whether NOAA decides to partner with NOAA or the DoD, as discussed above, it should budget for the conservative development process that each agency will execute in an attempt to regain some of their autonomy from NOAA.

V. Conclusions

By applying the principles for architecting joint systems to NOAA's low-earth orbiting weather satellite program, we identified the costs and risks of each potential partnership and we recommended appropriate joint program forms. In doing so, we noted several misalignments that exist in NOAA's current JPSS program and made the recommendation that if NOAA continues its partnership with NASA, it should select a system that minimizes benefit to NASA, should require NASA to contribute budget, and should enhance its own technical expertise. Thus, applying the principles allowed us to gain new insight into structure of a current joint program and most importantly, to identify strategies to reform it in the future. We hope that by following this example, future research can apply our principles and an understanding of the Agency Action Model to study cost growth on other joint programs and to identify reforms or future joint program forms that align the partnering agencies' budget, authority, responsibility, and expertise.

Past studies of joint programs have generated excellent lessons learned and guidelines for future programs (e.g. Refs (5, 20)) and our principles do not replace these resources. Instead, the principles should be applied *before* establishing a joint program and used to help decision-makers reason through the costs and risks of each potential partnership and joint program form. Once a partner and form have been selected, we encourage the joint program to capitalize on the resources cited above. Finally, even if current joint programs are applying best practices, we believe that the principles can be used as a tool to identify future reforms that can improve the alignment of responsibility, authority, budget, and expertise between partners and thus, can reduce joint program cost growth in the future.

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