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A model for understanding and managing cost growth on joint programs☆

Morgan Dwyer[a,*], Zoe Szajnfarber[b], Bruce Cameron[a], Edward Crawley[a,b]

[a] Massachusetts Institute of Technology, 77 Massachusetts Ave. 33-409, Cambridge, MA, 02139, USA
[b] The George Washington University, 1776 G St NW Suite 101, Washington, DC, 20052, USA

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ABSTRACT

Although joint programs are typically established to save the government money, recent studies suggest that instead of reducing program cost, jointness may actually induce cost growth. Motivated by three case studies that explored the cost of acquiring systems jointly, this paper presents a model that explains why joint programs often experience large cost growth and how jointness itself may induce it. Specifically, our proposed Agency Action Model suggests that on joint programs, the collaborating agencies' institutional interest in retaining or regaining their autonomy induces cost growth. After explaining the basic components of the model, we demonstrate its ability to explain the cost growth observed in our case studies. Finally, we use the model and our case study data to generate recommendations for managing joint programs in the future.

1. Introduction

Joint acquisition programs—which are executed collaboratively by more than one government agency or military department—enable the government to design for interoperability, to leverage a particular agency's unique technical capabilities, and to benefit from mission and technical synergies [1–7]. In addition to these benefits, theoretically, joint programs also reduce cost by sharing development, production, and operations costs across multiple agencies [1–9]. Importantly, despite their cost savings potential, evidence suggests that joint programs experience greater cost growth than non-joint programs [1–6,10] and that it may be more cost effective for agencies to acquire systems independently rather than jointly [1–6]. Despite these findings and the recommendation that agencies should more carefully evaluate future opportunities for jointness [1,5,6], the acquisition community still does not fully understand why joint programs experience large cost growth or how jointness itself may induce it. Absent an understanding of the relationship between jointness and cost, the acquisition community is ill-prepared to prevent cost growth on future joint programs and may be inclined to avoid jointness altogether.

In this paper, we present a model that explains why joint programs experience cost growth and how jointness itself can induce it. With this perspective, we are able to understand what costs are inherent to all joint programs and what costs can be avoided through careful program design. In this way, our model presents a more nuanced understanding of the relationship between jointness and cost and establishes a framework to guide the design of future joint programs. Prior to defining our model, we begin by reviewing the literature and data that motivated it. Next, we continue by defining the model and using our case studies to illustrate its utility. Finally, we conclude by deriving recommendations for future joint programs.

2. Literature review

Our model expands on the idea that four characteristics—hierarchal authority, unique missions, budgets, and expertise—define all government agencies [11–13]. These characteristics are related to agencies' interest in maintaining their autonomy both from elected officials and from each other [12–15]; autonomy refers to an agency's ability to make decisions independently and within its own authority structure. By definition, inter-agency (i.e., joint) activities disturb agencies' hierarchical authority structures and threaten their autonomy to make decisions independently [12].

The uniqueness of an agency's mission is also critical to its autonomy: by executing a unique mission, an agency can eliminate bureaucratic rivals and establish a monopoly over the mission [12,13,15,16]. A key challenge for agencies is ensuring that their jurisdiction matches their mission [13] and that they have full authority to execute that mission; absent a mission-jurisdiction match, agencies may find themselves in conflict with one another [13]. Agencies will also resist new missions that differ significantly from their unique, core mission [17] and will oppose other agencies that attempt to gain

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* Corresponding author.
E-mail address: morgan.dwyer@aya.yale.edu (M. Dwyer).

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jurisdiction over that mission [12]. Also critical to an agency's autonomy is the size of its budget: a large budget signals that an agency's mission is critical to the government and ensures that the agency can continue effectively executing that mission [13,18,19]. Finally, a great source of agencies' power and ability to maintain autonomy comes from their expertise: government bureaucracies are experts on mission execution and it is this expertise—which often only exists within an agency—that provides a significant source of power over elected officials or other agencies [18,20,21].

Using this fundamental understanding of government agencies, our model also draws upon two additional literature streams—bureaucratic politics and principal-agent theory—to connect agency characteristics and behavior. In this section, we review both literature streams and conclude by identifying the gaps that our model addresses. Specifically, we note that existing literature suggests a relationship between agency characteristics and behavior and that our model builds upon this relationship and creates an explicit framework to explain how government agencies behave in joint programs.

2.1. Bureaucratic politics

Bureaucratic politics literature describes a relationship between autonomy—a characteristic that is critical to government agencies—and agencies' behavior on joint programs. For example, according to the "law of inter-organizational conflict," all government agencies are in conflict with one another [12] and are in constant pursuit of autonomy, since autonomy enables agencies to establish a permanent claim over their resources, missions, and jurisdictions by eliminating rival agency threats [12,13]. Furthermore, bureaucratic politics literature suggests that agencies are territorial and imperialistic and that agencies define territories in terms of their missions and jurisdictions, resist encroachment into their territory, and try to invade the territories of others [12].

The "law of inter-organizational conflict" [12] has significant implications for joint acquisition. Specifically, agencies view joint activities as threats to their autonomy and will resist cooperating with other agencies or will define cooperation agreements to protect individual agency autonomy [13]. Furthermore, many authors have noted that agency territoriality induces conflict when agencies interact; for example, joint committees have been described as "the gray and bloodless ground of bureaucratic warfare, a warfare of position, not of decisive battles" [18]. Finally, others have noted that interagency collaboration is "rarely neutral" because it can only occur when one agency gains territory at the expense of another [17]; authors also warn that when agencies coordinate, "the battle for position is never-ending and that it grows more intense as agencies seek to gain control" of their missions, their jurisdictions, and ultimately, of their autonomy [17].

Several authors have analyzed the outcomes of interagency conflicts using a bureaucratic politics framework [14,22,23] which suggests that government decisions are the result of "compromise, coalition, competition, and confusion among government officials who see different faces of an issue" [24]. Others use game theory and liken agency interactions to "bargaining games," where each player acts according to its interest and interactions are structured by power, which is shared by players that have separate responsibilities [24]. Players' ability to reach outcomes that maximize their self-interest depends on their ability to exert power over one another; as one author notes, "the context of shared power but separate judgments concerning important choices determines that politics is the mechanism of choice" [24].

2.2. Principal-agent theory

Unlike bureaucratic politics, which focuses on autonomy from other agencies, principal-agent theory considers agencies' quest to maintain autonomy from elected officials. The general structure of a principal-agent problem has an agent performing a task on behalf of a principal; however, because at least some portion of both actors' self-interest is misaligned, the agent's actions may conflict with the principal's interests [25]. Typically, this conflict results in the agent "shirking" its responsibility to perform the task, even though the principal is paying it to do so [25]. The central problem considered by principal-agent theory is how the principal can insure that the agent completes its task according to the principal's interest, even if that interest conflicts with its own [26,27].

Information asymmetry complicates the principal's ability to resolve this problem. Information asymmetry occurs when the agent possesses expertise on how to execute the principal's task or when it possesses private information on how the task was executed [25]. In the context of public administration, principal-agent problems typically assign the legislature the role of the principal and the bureaucracy the role of the agent [28–30]. Information asymmetry is a particularly salient challenge for this type of principal-agent problem because government agencies exist to provide public services that the legislature cannot [26]. Many authors have analyzed this control problem (e.g., see [28–30]), which is typically managed by monitoring agencies and by levying reporting requirements [31]. Importantly, although most literature focuses on the principal-agent problem between agencies and elected officials, problematic behaviors can occur between any two actors, including agencies that are collaborating on a joint program.

2.3. Literature gaps

Bureaucratic politics and principal-agent theory suggest a relationship between agency characteristics and behavior that can be used to understand joint program outcomes. Importantly, existing literature is largely silent on role that joint organizations and systems play in either enabling or inducing agency actions. By focusing our analysis on those elements, we observe how joint systems and organizations evolve alongside program cost and can be related to agencies' dynamic interactions. Using this unique perspective, we construct a model that defines the joint system and organization as the medium through which costs grow and agencies interact. Our model is distinct from existing literature because it uniquely explains how and why agencies take actions and how those actions translate into cost growth.

3. Methods

To develop our model, we employed a small-N case study design and used a mix of qualitative and quantitative methods. We selected this approach for its ability to develop generalizable, explanatory models [32] and to maintain contextual details [33]. Ultimately, we studied three cases: the National Polar-orbiting Operational Environmental Satellite System (NPOESS), the Defense Weather Satellite System (DWSS), and the Joint Polar Satellite System (JPSS). We used NPOESS as our central case study because it represents a critical test (per [33]) for any model that explains the cost of jointness and because we valued preserving the complexities of its nearly 20-year history over the breadth that could be gained by studying more cases in less detail [34]. We used DWSS and JPSS as plausibility probe cases, which enabled us to refine and generalize our model [35,36] and we selected each case using theoretical sampling [37] and according to its ability to illuminate specific technical and organizational costs that were previously associated with jointness [e.g., see [38–41]].

To study each case, we used semi-structured, qualitative interviews as our primary data source [33,37]. Each interview covered the topics listed Fig. 1, but was specifically tailored to the individual interviewee's unique expertise, experience, and perspective [33]. During each meeting, we asked the interviewee to discuss the decision making process associated with the program activities listed in Fig. 1 [1]. This included recounting the decision point itself, the options and stakeholder preferences for each decision, and finally, how the decision was made, approved, and implemented. We also used interviews to build a

Summary of Interview Discussion Topics

- **System Definition**
  - Convergence Studies
  - Mission Requirements Development
  - Relationship to Heritage Systems
- **System Development**
  - Trade Studies
  - Cost and Schedule Estimation
  - Program Milestones
- **System Integration and Test**
  - Verification and Validation Requirements Development
  - Test Anomaly Root Cause Corrective Action
- **Program Divergence**
  - Trade Studies
  - Program Reviews

Fig. 1. List of interview topics.

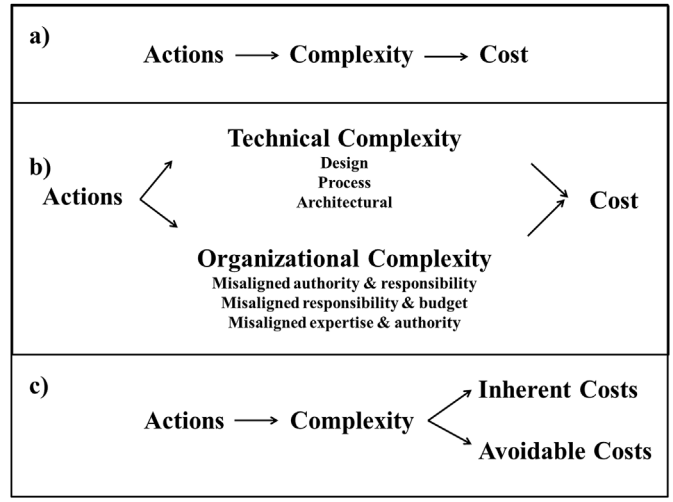

Fig. 2. The agency action model.

detailed timeline of program events and to review and explore the assumptions, motivations, and analysis behind primary source documents. Interviewees were selected from multiple levels in the programs' organizational hierarchies and were distributed equally between the three collaborating agencies and their contractors (as per [37]). Ultimately, 70 people were interviewed and over 95 hours of data were collected. Interview data was triangulated using over 235 primary and secondary source documents [33].

Case study data was analyzed both qualitatively and quantitatively. We began qualitative analysis by constructing an event database to capture key decisions, decision processes, and decision maker involvement [33]. Using the event database as a guide, we employed process tracing [34] to identify decision processes that appeared abnormally inefficient, resource intensive, and complex. After identifying mechanisms for cost growth—or anything that made the systems' costs increase or that hindered the organizations' ability to manage its systems—we found that *complexity* was a useful theoretical construct with which to identify, classify, and organize those mechanisms [1,3,42].

Complexity mechanisms were subsequently assessed using a quantitative framework [1,3,42] wherein the programs' histories were divided into epochs and the programs' evolution was observed across those epochs. Specifically, we represented the programs' systems and organizations—as well as the complexity mechanisms contained within them—using design structure matrices (DSMs). We then used two metrics to quantify the impact of those complexity mechanisms and to observe the evolution of complexity over time. Ultimately, this framework supplemented the detailed, process-centric qualitative data that we collected from each program with the ability to observe the program's evolution: a capability that was critical for developing a dynamic model of cost growth. Finally, using our framework's unique perspective, we employed visual mapping [43] to further abstract the data and to represent the large number of dimensions contained in the quantitative framework in a more concise manner. During the theory building process, the visual codes were rearranged, viewed from multiple perspectives, and augmented as we iterated between qualitative and quantitative data and the emerging theory [44]. For additional description of our research design, data, and analysis methods, please refer to [1].

4. Cost growth induced by agency actions

The model we propose, the Agency Action Model, follows the logic shown in Fig. 2a, where agency actions induce complexity and complexity engenders cost [1,2]. Actions, complexity, and cost all occur within a joint program *form*, which we define in terms of relationships between the agencies in a joint organization, between the organization and the system, and finally, between the missions executed by the system. We begin this section by further describing the three components of a joint program form and by identifying the variations they may take. We continue by describing the latter half of the model and by illustrating the relationship between complexity and cost. Finally, we conclude with a discussion of the entire model and demonstrate how agency actions can induce two types of cost: those that are inherent to all joint programs and cannot be avoided and those that can be prevented via careful design of the joint program form.

4.1. The joint program form

A joint program form is defined by three key relationships: between agencies in the joint organization, between the joint organization and joint system, and between the missions executed by the joint system. Four different relationship types—authority, responsibility, budget, and expertise—are possible and we define these relationships as:

- **Authority**: Having the power to make and sustain decisions related to agency missions.
- **Responsibility**: Being accountable for delivering a technical system that executes agency missions.
- **Budget**: Providing funding to support joint program decisions and to develop a joint system.
- **Expertise**: Possessing the knowledge and experience required to make effective decisions.

Fig. 3 illustrates several options for defining relationships in a joint program form. Note that although Fig. 3 only depicts authority relationships, responsibility, budget, and expertise can be represented using this framework as well. Starting with the relationship between agencies in the joint organization, Fig. 3 shows two options: sharing authority and delegating authority. When agencies share authority, they are equal partners; however, when authority is delegated, the agencies are unequal and one agency serves as a lead that possesses authority over the other. As shown in Fig. 3, both options are identified by the following coding scheme: shared authority (S) and delegated authority (D).

Next, the relationship between the joint organization and system can either be integrated or modular. The relationship is integrated (I) when a single organization holds authority over all of a system's components. The relationship is modular (M) when organizations with equal power retain authority over individual components (or modules). For example, programs with prime contractors have integrated relationships, since the prime contractor retains authority over all

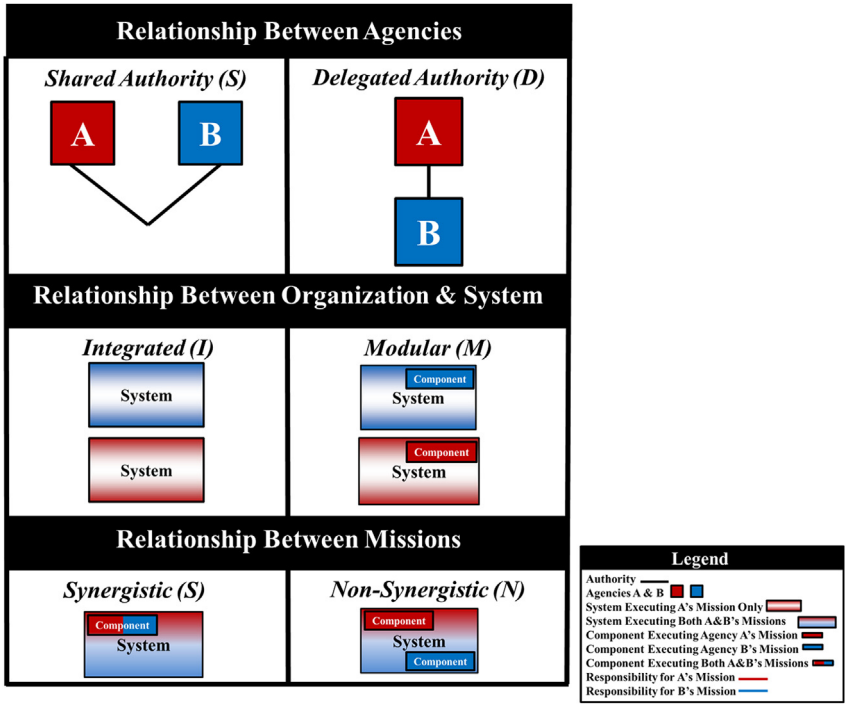

Fig. 3. Joint program building blocks.

subcontractors and associated modules. In contrast, smart phones are developed by modular programs, since phones and applications are managed by autonomous organizations that interact only through a technical interface.

Finally, missions executed by a joint system are either synergistic or non-synergistic. Missions are synergistic (S) if they levy similar requirements that are easily executed by an integrated system. Missions are non-synergistic (N) if they levy dissimilar requirements that are easily decoupled and are best executed using separate components. For example, television's dual missions to project both live broadcasts and DVD material are synergistic because both missions levy similar requirements for visualization and sound. In contrast, a projection mission is non-synergistic with a mission for two-way video communication, since the communication mission levies many requirements that are distinct from a one-way broadcast (e.g., the need for a video camera, microphone, and internet connection).

Fig. 4 shows how to construct basic joint program forms by selecting one option for each relationship; as will be illustrated in Section 5, more complex joint programs can be created by combining basic forms. Additionally, Fig. 4 demonstrates that agency autonomy and authority are a function of a joint program's form. For example, given collaborating agencies A and B, if A delegates authority for a modularized system that executes a non-synergistic mission (form DMN), A's authority and autonomy are maximized, whereas B's are minimized. Conversely, if A and B share authority over an integrated system (forms SIS/SIN), both agencies' autonomy and authority are minimized. As will be discussed below, agency authority and autonomy play a critical role in motivating agency actions that augment joint program forms, that shift the power dynamics between collaborating agencies, and that ultimately induce cost growth; consequently, the initial choice of program form determines a joint program's susceptibility to future cost growth.

4.2. The relationship between complexity and cost

The joint program form serves as the venue in which agencies take actions, actions induce complexity, and complexity engenders cost. In this section, we review another critical component of our model: the relationship between complexity and cost. This relationship is well documented in literature [45–49] and similarly, was apparent in our case study data [1,42]. More importantly, the relationship allowed us to collect data at the level of detail and frequency required to develop our model, since actual cost data was unavailable. Thus, when we discuss the Agency Action Model, we use complexity as a proxy for cost and assert that agency actions induce cost by increasing complexity; similarly, when we state that agency actions induce complexity, we tacitly assert that those actions increase cost as well. In all subsequent discussions, the terms complexity and cost are interchangeable.

Importantly, as shown in Fig. 2b, by using complexity to discuss cost, we are able to further classify and describe specific complexity types. For example, we identified three types of technical complexity: design, process, and architectural [1,3,4,42]. **Design complexity** refers to the technical maturity of a system's components: it increases as technical maturity decreases. Design complexity can be induced when distinct agency requirements converge on single components; when this happens, the joint program's ability to leverage heritage components is limited and new development is required. **Process complexity** refers to constraints or conflicting requirements that are imposed during the system development process. This type of complexity can be induced if a joint system is produced to meet multiple agencies' technical standards which may be contradictory or unnecessarily duplicative. Finally, **architectural complexity** refers to interactions and relationships between components. When agency missions do not entirely overlap, the joint system will contain distinct components to satisfy each agency's unique mission: as the number of components increases, so does architectural complexity. For additional description of technical complexity, please refer to [1,3,4,42].

We observed organizational complexity to be a function of three misalignments between components in an organization and to affect cost by decreasing the efficiency and effectiveness of an organization's decision making processes [1,3,4,42]. For a joint organization to make effective and efficient decisions, first, **authority and responsibility** should be aligned so that agencies can make decisions rapidly. Second, **responsibility 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. When these relationships are misaligned, an organization's

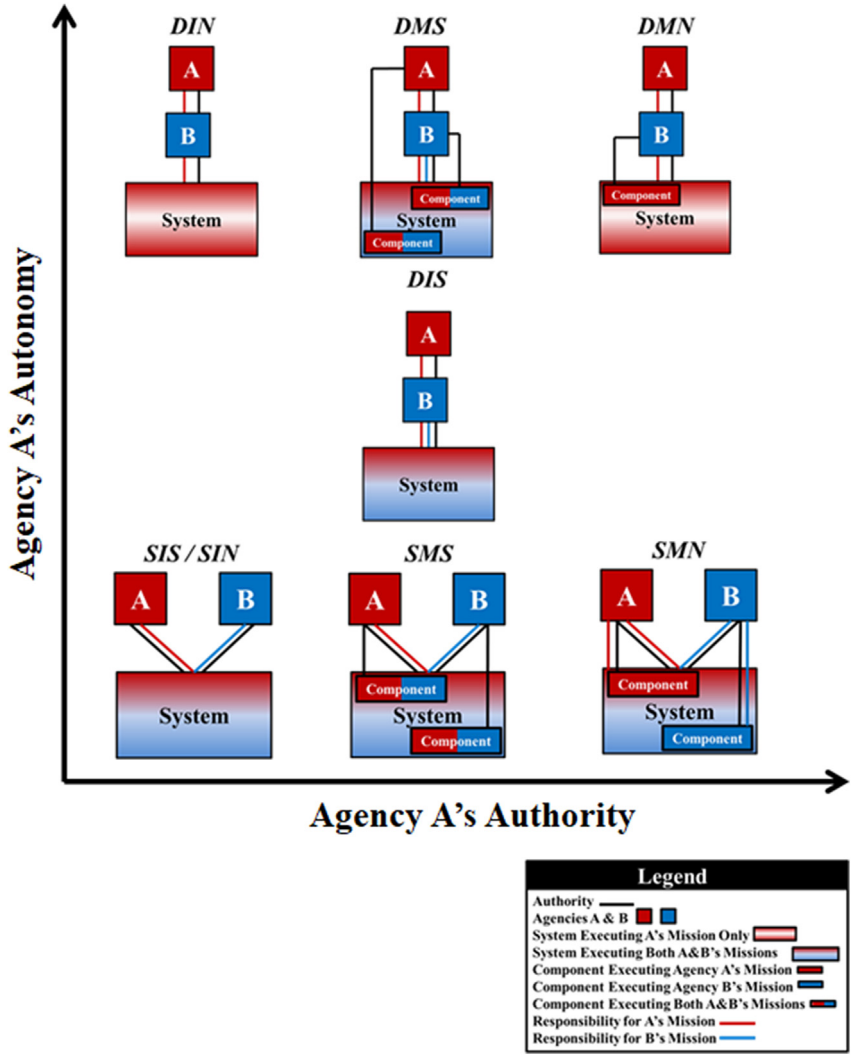

Fig. 4. The relationship between joint program form, authority, and autonomy.

decision quality and efficiency decreases, its complexity increases, and its overhead costs grow. For additional description of organizational complexity, please refer to [1,42].

4.3. The agency actions

With the joint program form and relationship between complexity and cost established, we are now able to explain the dynamics of our model, which derive from our assertion that joint program **cost growth is induced by agency actions to retain or regain autonomy** [1,2]. Autonomy refers to an agency's ability to make decisions independently. Autonomy is closely related to authority, or the power to make decisions. For example, an agency can have authority to make decisions but lack autonomy if it must consult with another agency before making a decision or if another agency can override its decision. As illustrated by Fig. 4, agency autonomy and authority are both determined by a joint program's form.

As discussed above, agency actions to retain or regain autonomy increase joint program costs by inducing technical and organizational complexity. In seeking autonomy, an agency has two key interests:

- To execute its unique mission,
- And to manage its program without interference by other agencies.

By definition, when an agency participates in a joint program, it sacrifices some autonomy and ability to pursue its interests. As a result, our model predicts that all joint programs costs will be affected by agency actions which attempt to maintain or regain autonomy. Importantly, although some agency actions can be expected on all joint programs, others can be prevented through careful program design. Therefore, in our subsequent discussion and as shown in Fig. 2c, we distinguish between costs which are inherent to all joint programs and those which can be avoided by defining an appropriate joint program form.

4.3.1. Agency actions and the costs inherent to all joint programs

Any time agency authority is related, either through sharing or delegating authority, agencies will take action to retain or regain their autonomy; therefore, regardless of a joint program's authority structure, some agency actions and cost growth can be expected. First, when two agencies *share authority,* they each retain some autonomy because neither agency can make 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 technical 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 are cost drivers. Neither agency vetoes its partner's requirements because each agency acts in the same way; as a result, the joint requirement set is a concatenation of each agency's unique and driving requirements. To meet these requirements, design complexity of the joint system increases since new technology must be developed. Architectural complexity also increases because more components are necessary to meet both agencies' requirements than would be required to meet a single agency's requirements alone.

Conversely, when agencies delegate authority, one agency's autonomy is maximized while the other's is minimized. Fig. 4 shows the simplest instance of authority delegation as form DMN where Agency A and B's authority is maximized and minimized, respectively [1,2]. In this scenario, because the agencies are not equal partners, Agency B will take actions to *regain* autonomy by *eroding Agency A's authority*. Again, Agency B's actions are motivated by its interests, which in form DMN, is to execute Agency A's mission without interference. Note that in form DMN, the joint system only executes A's mission; as a result, B's interest is simply to fulfill its delegated role of executing A's mission with minimal interference from Agency A.

To satisfy this interest, Agency B may erode A's authority and regain its autonomy by taking actions to manage the program independently. To do this, B may develop a program plan that explicitly follows all of its internal agency processes and procedures and that employs a conservative budget with more than sufficient margin. In this way, Agency B reduces the frequency with which it will require decision approval from A or will need to request more funding in the case of unexpected cost growth. Therefore, when authority is delegated, it is process complexity—in the form of unnecessarily conservative or unwieldy system development processes—which unavoidably increases joint program technical costs.

Finally, irrespective of the agencies' authority relationship, *both* agency actions, to regain and retain autonomy, induce organizational complexity by creating a slight misalignment between responsibility and authority. This source of complexity is present on all joint programs because individual agencies' mission responsibilities are often derived from separate Congressional committees. Thus, in order to comply with their responsibility to Congress, agencies must independently oversee and perform audits of their joint programs. Therefore, joint program oversight costs increase as a function of the number of agencies that are involved in the program.

4.3.2. Agency actions and avoidable program costs

Our research suggests that the agency actions described above are inherent to all joint programs; as a result, future joint programs can avoid cost growth by recognizing and budgeting for the inherent costs of jointness. In this section, we identify costs which are not inherent and instead, induce unnecessary cost growth that could avoided via careful design of the joint program form. These avoidable costs occur when agencies take actions that increase organizational complexity and that often cause the joint program form to destabilize and evolve. Specifically, avoidable costs are induced when agencies take actions to regain their autonomy that instigate interagency turf wars [12,13,17,18] which can alter the agencies' relative authority and autonomy. When this happens, joint program forms evolve across the authority-autonomy dimensions that are depicted in Fig. 5. As joint programs evolve, agency relationships change and the joint program assumes more complex configurations like forms SMS, DIS, and DMS from Fig. 4. In each of these configurations, key relationships—authority, responsibility, budget, and expertise—are misaligned. As a result, when joint programs take on these forms, organizational complexity induces cost growth by allowing the joint organization to become inefficient and unstable.

Given these conditions, agency relationships are more likely to be dynamic since the agencies can exploit organizational instabilities in order to take actions to regain autonomy. Importantly, regardless of

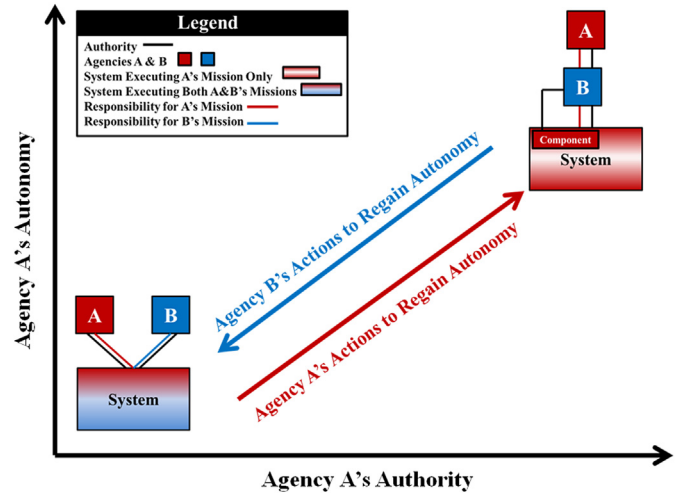

Fig. 5. Actions to regain autonomy.

where a program falls in Fig. 5's spectrum of jointness, the agencies' interest in executing missions without interference remains the same. Faced with interference, an agency will erode the authority of its partner so that it can regain autonomy to execute its mission. Absent interference, an agency will erode its partner's authority by prioritizing its own mission over its partner's.

An agency can erode its partner's authority directly, by second guessing its decisions or by elevating decisions to senior agency leadership 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 expertise 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. In all of these circumstances, the cost of the joint program increases due to inefficient decision making or to decisions that do not appropriately consider cost.

As noted above, agencies can erode partner authority when authority, responsibility, budget, and expertise are misaligned and an organization is unnecessarily complex. However, by aligning these relationships and reducing organizational complexity, a joint program can avoid agency conflict and the instability, inefficiency, and cost growth that it generates. In the next sections, we use data from our case studies to illustrate how organizational misalignments generate unnecessary cost growth and demonstrate how proper alignment can result in less expensive joint programs.

5. Agency Action Model applied: NPOESS, JPSS, and DWSS

Viewed through the lens of the Agency Action Model, cost growth incurred during NPOESS, JPSS, and DWSS can be understood in terms of the collaborating agencies' actions to retain or regain autonomy. NPOESS was a collaboration of Department of Defense (DoD), National Oceanic and Atmospheric Administration (NOAA), and National Aeronautics and Space Administration (NASA) that intended to develop a constellation of environmental monitoring satellites for low Earth orbit.

NPOESS was managed by an integrated program office (IPO) that was staffed by representatives from all three agencies. The IPO reported to the program's executive committee (EXCOM), which was a tri-agency board composed of the NOAA administrator, NASA administrator, and Under Secretary of Defense for Acquisition, Technology, and Logistics. NPOESS was established in 1992 and cancelled in 2010; after NPOESS's cancellation, two follow-on programs were established: DoD's DWSS

and the joint NOAA-NASA JPSS program.

The history of NPOESS, JPSS, and DWSS is too complicated and immense to be covered in detail here. Instead, we begin by reviewing the historical context that is necessary to discuss our model; for additional detail on program history, please refer to [1,50,51]. Next, we continue by illustrating how major program events can be classified in terms of agency actions to retain or regain autonomy. Finally, we conclude by demonstrating how our conceptual model is capable of explaining the cost growth that occurred on NPOESS, JPSS, and DWSS.

5.1. A brief history of NPOESS, JPSS, and DWSS

The history of NPOESS, JPSS, and DWSS can be divided into five epochs, or periods of time when the programs' forms, as defined in Section 4.1, were unique and stable [1,4,42]. In **Epoch 1,** the three agencies shared authority in an oversight board, the EXCOM. Because authority was shared, it was impossible for a single agency to exert authority over its partners: as a result, all agencies had to agree on a decision or no decision could be made. Importantly, although the agencies shared authority, they did not share responsibility, budget, or expertise. Initially, NPOESS was supposed to execute *only* NOAA and DoD's weather missions; therefore, *only* NOAA and DoD funded the program.

Although NOAA and DoD shared mission responsibility and budget, they did not share expertise: unlike DoD, NOAA had no institutional expertise or experience in system acquisition because prior to NPOESS, it relied on NASA to manage its weather satellite programs. In addition to serving as NOAA's acquisition agent, prior to NPOESS, NASA also executed its own climate science mission independently; however, during NPOESS, NASA's climate science Earth Observing Program (EOS) was cancelled and the agency was directed to satisfy its mission using NPOESS's capabilities. Therefore, NASA's role on NPOESS was to provide technical support to NOAA and to seek opportunities to execute its climate science mission.

In **Epoch 2,** a dual risk reduction and climate science program, the NPOESS Preparatory Project (NPP), was established and NASA was assigned to serve as the program's lead. To execute NPP's risk reduction mission and to reduce the risks associated with NPOESS's new technology, NPP planned to host the first copies NPOESS's highest risk instruments on a smaller spacecraft and to test their performance on orbit. NPP's instruments were primarily developed by the IPO and were then integrated by NASA onto a NASA-provided spacecraft. By managing NPP system integration and developing its spacecraft bus, NASA resumed a responsibility that was similar to its previous role as NOAA's acquisition agent. Furthermore, NPP also enabled NASA to preserve the climate science mission that it lost when EOS was cancelled.

In addition to enhancing NASA's role relative to the other agencies, the formation of NPP misaligned mission responsibility, authority, and budget. Because the NPP instruments executed NASA's climate science mission, but NASA did not fund their development, the agency prioritized performance and risk reduction over cost when it made decisions. Importantly, although NASA preferred more expensive decision outcomes, since the IPO directly managed the instrument contracts, NASA held no formal decision authority over the NPP instruments that executed its climate science mission. In order to indirectly manage the instruments, NASA eroded the IPO's authority by using its technical expertise to second guess IPO decisions and by raising unsatisfactory decision outcomes to the EXCOM, the only decision body that had authority over both the IPO *and* NPP. As a result, the decision-making process was so slow and onerous that it impacted the program's cost and schedule.

Given the cost growth and schedule delays that occurred in Epochs 1 and 2, NPOESS breached the Nunn-McCurdy threshold and in **Epoch 3**, had to reduce its costs by restructuring. Because the Nunn-McCurdy Act applies specifically to DoD, that agency lead the reform process. One of DoD's most significant changes was establishing a new Program Executive Officer (PEO) to be the single decision-maker capable of adjudicating issues that affected both the IPO and NPP. As discussed above, without a PEO, when joint IPO-NPP technical issues could not be resolved by the programs' engineers, they had to be elevated to the EXCOM. By delegating authority to a PEO, issues would be resolved more efficiently since they could bypass the EXCOM, which met infrequently and required tri-agency consensus. DoD also reduced cost by removing several of NASA's climate science instruments from the program.

By establishing a PEO, the Nunn-McCurdy reforms made it possible for a single person to make decisions that favored NOAA and DoD's interests over NASA's. In an attempt to mitigate the risk that its climate mission would be deprioritized, in **Epoch 4,** NASA eroded the PEO's authority by sending its own civil servants to work in NOAA management. Because the PEO was officially a NOAA employee, the NASA transplants in NOAA management were able to use their relationship with the PEO to influence his/her decisions and to ensure that they favored NASA's missions. Ultimately, by eroding the PEO's authority, NASA's actions misaligned authority, responsibility, and budget within the program's senior management, stalled decision making, and allowed decisions to favor NASA's missions even though NASA did not contribute to NPOESS's budget. NASA's influence also enabled its prized climate instruments to be added back to the program.

Finally, in **Epoch 5,** NPOESS was cancelled and replaced with the JPSS and DWSS programs. Specifically, NASA gained full authority to execute NPP and the authority to serve as NOAA's sole acquisition agent for its follow-on JPSS program. Interestingly, even without DoD, NOAA and NASA continued to struggle for control of the program and established separate program offices to manage the new joint program. As result, the JPSS organization that replaced NPOESS contained many of the same misalignments as NPOESS; for example, the dual NOAA-NASA program offices misaligned authority and responsibility. Budget and responsibility also remained misaligned, since JPSS executed NASA's climate mission but NASA did not contribute to the program's budget. In contrast, once DoD was freed of its collaboration with NOAA and NASA, it determined that NPOESS's instruments were too expensive to execute the agency's limited weather mission: since DoD had full jurisdiction over its mission, it responded swiftly and canceled DWSS, only one year after its formation.

To understand why program forms evolved over time, we can use the Agency Action Model to identify agency actions to **retain or regain autonomy** as the root cause for each epoch shift. As shown in Table 1, for each epoch, we are able to identify a specific agency action that augmented the programs' forms, to classify that action in terms of retaining or regaining autonomy, and then link that action to program cost using the six types of complexity that were defined in Section 4.2. As shown in Table 1, all actions increased cost *except* for Action 3, which corresponded to the Nunn McCurdy-mandated reforms; as will be discussed later, although Action 3 did not immediately induce cost, it incentivized subsequent agency actions that did. In the next section, we review the programs' history in terms of the Agency Action framework and demonstrate how each epoch can be described in terms of a joint program form and how each epoch shift can be explained in terms of agency actions to retain or regain autonomy.

5.2. Agency actions and NPOESS, JPSS, and DWSS history

Using the simplest joint program forms shown in Fig. 6, we can model the initial NPOESS program as a cross between forms SIN and DMN. As in form SIN, NOAA and DoD retained some autonomy by sharing authority over the program's missions and as in form DMN, NASA was included in the initial collaboration to supplement NOAA's technical expertise as an advisor. Fig. 7 illustrates the starting point, **Action 1**, where agencies **retained autonomy**, that resulted from the fundamental tension between NASA and DoD's interests: a program form that was a cross between SIN and DMN. As shown, in addition to

Table 1
Mapping actions to Complexity.

#	Case Study Action	Actions		Technical Complexity			Organizational Complexity		
		Retain	Regain	Design	Process	Architectural	Authority & responsibility	Authority & expertise	Budget & respnsibility
1	Agencies share authority in the EXCOM	X		+		+	+	+	+
2	NASA formalizes role on the program		X		+		+	+	+
3	DoD delegates authority to a PEO		X	-		-	-		
4	NASA erodes the PEO's authority		X		+		+		+
5	NASA & the DOD separate their authority		X	+	+	+		+	+

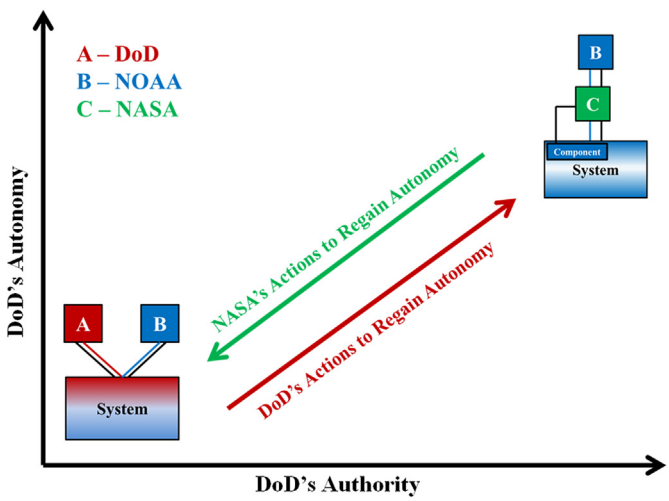

Fig. 6. Case study initial conditions.

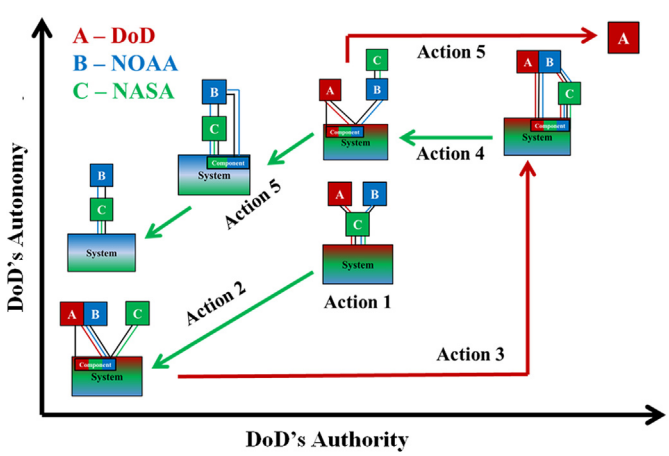

Fig. 7. Case Study Actions.

executing both NOAA and DoD's missions, the NPOESS system executed NASA's climate science mission as well. Importantly, even though the system executed NASA's mission, the agency's initial program management role was limited; as a result, NASA was incentivized to regain its autonomy and to use its technical expertise to prioritize its climate science mission. Since NASA did not contribute to the program's budget and NOAA's technical expertise was not commensurate with its authority over the program, the initial joint organization did not provide the necessary checks and balances to disincentive NASA from pursuing its autonomy.

Action 2, which allowed NASA to **regain autonomy** via the NPP program, reduced DoD's autonomy by requiring it to consult with *both* NOAA and NASA when it made decisions. In contrast, NASA gained autonomy because NPP formalized its role in NPOESS and justified its right to share authority with the other agencies. Importantly, the organization that was created to execute NPP did not foster effective authority sharing; instead, by misaligning NASA's mission responsibility for NPP and its authority over NPP's instruments, it incentivized NASA to take actions to regain autonomy by eroding its collaborators' authority. NASA's actions were particularly effective because it did not have budget responsibility for the larger NPOESS mission and because its representatives to the program had greater technical expertise than the IPO's staff.

With **Action 3**, the Nunn-McCurdy certification, **DoD regained autonomy** by delegating authority over NASA's NPP program to a PEO and it better aligned its weather mission with its jurisdiction by eliminating NASA's climate science instruments. Despite its post Nunn-McCurdy reforms, as shown in Fig. 7, the critical misalignment between NASA's authority and responsibility for NPP persisted and continued to enable NASA to take actions that eroded its partners' authority. NASA was further able to erode DoD's authority with Action 4, which transferred NASA civil servants into NOAA management. By taking this action, NASA created an alliance with NOAA and redefined the existing bureaucratic turf war as a new battle with two agencies against one. Ultimately, NASA won its battle against DoD when NPOESS was cancelled and the President terminated DoD's involvement in NOAA and NASA's follow-on program.

As a result of NPOESS's cancellation (**Action 5**), **DoD regained full autonomy** and authority over its new DWSS system and NOAA and NASA renewed their struggle for autonomy and authority over JPSS. This resulted in the brief period shown in Fig. 7—where NOAA held authority over the JPSS ground segment—but quickly transitioned to the final form, where NOAA was the lead agency but NASA retained direct implementation authority over the JPSS system. Although JPSS was established to correct the flaws in NPOESS, because NOAA lacked expertise commensurate with NASA's and NASA provided no budget for JPSS, NASA continued eroding NOAA's authority by using its implementation authority to prioritize its own mission over NOAA's.

Thus, using the Agency Action Model, we can trace the evolution of NPOESS, JPSS, and DWSS according to NASA and DoD's actions and the agencies' interest in retaining and regaining autonomy. Importantly, as shown in Table 1, each action can be connected—either directly or indirectly—to specific types of complexity that engendered cost growth. Thus, we see that jointness induced cost growth on NPOESS, JPSS, and DWSS because the collaborating agencies' institutional interests in retaining or regaining autonomy drove complexity into the programs' systems and organizations. Importantly, by viewing the programs through the lens of the Agency Action Model, we are able to attribute cost growth to poorly designed joint program forms which left the agencies' interests unchecked and made their cost-inducing actions possible. In the next section, we will illustrate how, given the agencies' natural pursuit of autonomy and the program forms' inability to disincentive agency actions, the cost inducing actions of the NPOESS,

JPSS, and DWSS programs were not only possible, they were inevitable.

5.3. The inevitability of agency actions and cost growth on NPOESS, JPSS, and DWSS

As shown in Fig. 7, the NPOESS program concluded with both NASA and the DoD's authority and autonomy maximized and with significant cost growth occurring along the way. Given this outcome, both academics and policy makers are right to question whether all joint programs are doomed to serve as battlefields for bureaucratic turf wars in the way that NPOESS and JPSS were. Theory suggests that agency actions are motivated by institutional interest and therefore, none of the actions described above are unexpected. However, closer inspection of the joint program forms reveals that they left agencies' institutional interests unchecked. By ineffectively balancing agencies' individual mission interests with authority or budget responsibility, the programs allowed agencies to struggle for power. When one agency triumphed, its action drove complexity into the joint organization and system and increased the programs' costs. Therefore, if the joint programs had appropriate checks and balances to control the agencies' institutional interests, they may have prevented the evolution towards increased complexity and cost. In this section, we demonstrate how the Agency Action Model can be used to appreciate the inevitability of cost growth in the absence of institutional checks and balances.

Two key characteristics defined the organization that was established by Action 1: shared authority and a misalignment of responsibility and budget. First, NOAA, NASA, and DoD shared authority over a system that executed NOAA and DoD's non-synergistic weather missions; authority sharing and differing requirements unavoidably increased NPOESS's technical costs. But the misalignment of responsibility and budget, induced by including NASA on the EXCOM but not requiring it to fund the program, induced costs that could have been avoided. Specifically, the initial organization created a classic principal-agent problem, where NASA was an agent tasked with providing technical expertise for NOAA, its principal.

Despite being an agent, NASA exerted considerable power over its principal. For example, NASA exercised the power of its expertise during the requirements generation process: since NASA had previously served as NOAA's acquisition agent, NOAA defaulted to NASA's technical recommendations. Therefore, even though NASA did not formally levy requirements on NPOESS, it actively participated in the requirements development process as an agent working on behalf of its principal. Importantly, because NASA's institutional interest was partially aligned with NOAA's (i.e., their requirements were synergistic), NOAA did not immediately notice that it was the agent and not the principal that was driving the requirements definition process. The joint organization provided no check to NASA's pursuit of institutional interest because NOAA lacked the necessary expertise to question NASA's recommendations and because NASA had no budget responsibility for the program. The result was a set of requirements that more closely resembled NASA's EOS program than it did NOAA or DoD's heritage systems; of course, the difference between EOS and NPOESS was that NASA paid for EOS.

Next, the organization created after Action 2 contained a fundamental flaw, the misalignment of responsibility and authority, that provided a mechanism for NASA to openly and detrimentally pursue its interests. Ultimately, it was the interface between the IPO and NPP that crippled the organization's ability to make effective and efficient decisions by requiring decisions which could not be resolved by engineers to be elevated to the EXCOM. The IPO-NPP interface also created a second principal-agent problem between NPP and the IPO. The NPP program office was the agent executing the IPO's risk reduction mission. However, NPP exerted considerable control over its principal by using the technical expertise of NASA's engineers to erode the authority of the IPO and its contractors. By eroding their authority, NASA was able to sway decisions to favor its institutional interest, which primarily focused on executing NPP's climate science mission. NASA's actions were unchecked by budget responsibility, since it did not fund NPP's instruments and therefore, did not have to pay for decisions that the IPO made regarding them.

Again, the joint organization could have been designed to check NASA's institutional interest. For example, a risk reduction program could have been formed *within* the IPO and designated to be subordinate to it. This would have integrated the agencies' responsibility and authority and prevented NASA from eroding the IPO's authority and from seeking EXCOM intervention when it could not sway decisions in its favor. Alternatively, NASA could have been awarded full authority and the budget to develop and field the first copies of each instrument. In this way, NPP could have been similar to the Operational Satellite Improvement Program (OSIP) that was cancelled before NPOESS.

Despite Action 3's attempt to shift power away from NASA and back to NOAA and DoD, it failed to augment the flawed organizational interface between the IPO and NPP; as a result, the principal-agent problems discussed above persisted and continued to destabilize the program and induce cost growth. These problems were exacerbated by Action 4, when NASA personnel transferred into NOAA and eroded the PEO's authority: essentially, at this point in the program, the agent became the principal.

Even after NPOESS's cancellation, the fundamental principal-agent problem between NOAA and NASA remained. NASA used the power of its expertise to claim authority over JPSS's space *and* ground segments and to justify many costly changes to the JPSS system. Because NOAA lacked sufficient expertise to question NASA's decisions, in most cases, NOAA simply defaulted to them. As on NPOESS, NOAA and NASA's mission interests were synergistic; therefore, NASA's decisions often benefited NOAA, even though they may have cost more money than NOAA would have spent independently. Again, NASA's primary institutional interest was climate science and in developing a system to succeed EOS and NPP; as on NPP, NASA held no budget responsibility for JPSS.

Thus, for every action, with the partial exception of Action 1, misalignments between agency authority, responsibility, budget, and expertise resulted in principal-agent problems where the agencies exploited organizational weaknesses to pursue their own interests. Oftentimes pursuing individual interests induced cost growth by instigating conflict between the agencies which took the form of slow and acrimonious decision making: for example, simple technical decisions that should been made in a lab were instead elevated to agency leadership for arbitration. Cost growth was also induced when agencies were able to use their technical expertise to erode the authority of less expert agencies and to sway decision outcomes in their favor. Finally, when agencies were not financially responsible for decisions, they did not adequately consider costs when making decisions; as a result, costs grew unnecessarily. In the next section, we suggest that future joint programs can avoid the cost growth experienced on NPOESS, JPSS, and DWSS by ensuring that **responsibility, authority, budget, and expertise are aligned** in the joint program form.

6. Managing cost growth on future joint programs

In addition to explaining the epoch shifts and cost growth that occurred on NPOESS, JPSS, and DWSS, we can also use the Agency Action Model to generate recommendations for future joint programs. Specifically, the prior section demonstrated that absent institutional checks and balances to disincentive agencies from taking action, joint program costs will grow when agencies take actions that augment their program forms and that induce organizational and technical complexity. In this section, we suggest that by ensuring that **responsibility, authority, budget, and expertise are aligned** in a joint program's form, one ensures that the program will be affected only by the inherent costs of jointness.

6.1. Managing the inherent costs of jointness

As discussed in Section 4.3, some costs are inherent to all joint programs and cannot be avoided. The first type of inherent cost occurs when agencies share authority (i.e., forms SIS/SIN and SMN) and levy requirements that increase the technical complexity of the system. The second type of inherent cost occurs when agencies delegate authority (i.e., forms DMN and DIN) and the acquisition agent's management of the program induces process complexity. The final unavoidable cost is organizational complexity that is induced when agencies' authority and responsibility is related in a joint program but agencies maintain separate ties to external oversight organizations.

To avoid lifecycle cost *growth*, we recommend that future joint programs should anticipate and incorporate these costs into their initial baseline budget. By doing so, programs' initial cost estimates will increase but their *risk* of experiencing cost growth will decrease. More work is needed to quantify inherent costs and to determine how much programs should budget to account for this cost, but for initial estimates of technical and organizational costs, please refer to [3,52–55].

Finally, the joint program forms in Fig. 4's corners (SIS/SIN, SMN, DMN, and DIN) completely align authority and responsibility. Assuming that the corner forms *also* align responsibility with budget and authority with expertise, they provide sufficient checks and balances to deter cost-inducing agency actions. As a result, these forms are stable and should remain constant throughout a program's lifecycle. As will be discussed next, program forms that do not sit in Fig. 4's corners are unstable and will evolve as agencies struggle for power and program costs increase.

6.2. Preventing the avoidable costs of jointness

In addition to the inherent costs of jointness, programs are also at risk for avoidable costs that can be identified and managed by selecting an appropriate joint program form. In particular, forms DMS and SMS in Fig. 4 are unstable because authority and responsibility are misaligned and the “mirror” (as per [56–58]) between the system and organization is broken. In SMS, the agencies *share authority* for the overall system, but the program is *modularized* and authority for the system's components is delegated to different agencies. An example SMS-type program might use a dual-agency board for important programmatic decisions but assign only one agency authority over key component contracts. In DMS, a lead agency delegates authority for the majority of the system, but retains authority over one component that executes both agencies' missions. Importantly, in both SMS and DMS, individual agencies hold authority over components that execute both agencies' missions; this occurs when agency missions are *synergistic* and it is difficult to decouple the requirements they levy on the system.

In both instances, Agency B loses the autonomy to manage a component that executes its mission; as a result, Agency B will take action to regain that autonomy. 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 and authority or budget and responsibility are misaligned in the joint organization. For example, if B has greater expertise than A, it can second guess all of A's 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. The outcome of these actions is similar to what was observed between the IPO and NPP: the program's decision making process becomes slow, acrimonious, and unnecessarily costly. To avoid these unnecessary costs, we recommend that joint programs avoid employing forms like SMS and DMS, where modular programs are used to execute synergistic missions. Instead, **we suggest that in order to align authority and responsibility, joint programs should delegate authority for their system's modules *only* when the collaborating agencies' missions are non-synergistic**. Integrated programs can be used to execute *either* synergistic or non-synergistic missions.

Fig. 4's middle joint program (DIS) also contains an important characteristic: delegated authority and synergistic missions. In this program, Agency A delegates its implementation authority to Agency B, which acts as an acquisition agent for the system. However, unlike the pure acquisition agent role shown in forms DIN and DMN, in DIS, Agency A's system also executes B's mission. In this form, Agency A is at risk that B will use its implementation authority to prioritize its own mission over A's. Agency A is particularly at risk if B has greater expertise than A or if B does not contribute some of the program's budget (i.e., a misalignment of expertise with authority and budget with responsibility). Therefore, the middle program form faces a risk of cost growth due to a principal-agent problem, where the agent's actions to prioritize its own mission can hinder the principal's mission and increase its cost; we observed this type of cost growth in NASA's management of NPP and JPSS.

To combat the principal-agent problem that is present **in joint programs with delegated authority and synergistic missions, agencies should either avoid forms similar to DIS or be sure to align responsibility with budget and expertise with authority**. Specifically, the subordinate agency should contribute to the program's budget; this will balance its interest in prioritizing its own mission at the lead agency's expense. Additionally, the lead agency's expertise should be enhanced so that it can more effectively monitor the subordinate's actions and insure they are consistent with its interests. Essentially, by aligning budget with responsibility and authority with expertise, the subordinate agency is transformed into a more honest broker and the lead agency is transformed into a smarter buyer. This alignment of budget with responsibility and expertise with authority will allow future joint programs that use DIS-like forms to avoid the cost growth that occurred on both NPOESS and JPSS.

7. Conclusions

In the proceeding sections, we introduced the Agency Action Model and demonstrated how it can be used to both explain past programs and to prevent future cost growth. The Agency Action Model suggests that jointness induces cost growth by increasing the complexity of joint systems and organizations and that complexity is induced when agencies take actions to regain and retain their autonomy. Using data from our case studies, we illustrated how the evolution of NPOESS, JPSS, and DWSS can be understood in terms of the agencies' pursuit of autonomy and noted instances where cost growth could have been avoided.

We also used the model to assess the potential for cost growth in each of Fig. 4's joint program forms. In doing so, we identified the inherent costs of jointness and recommended that future programs anticipate and budget for these costs. We also identified avoidable costs that can be mitigated by carefully selecting a joint program form. Specifically, we recommended that cost growth can be avoided by insuring that authority, responsibility, budget, and expertise are aligned within the joint system and organization. Finally, we provided specific recommendations that future joint programs can use to select a program form.

Ultimately, we hope that the Agency Action Model provides a framework which can be used to guide future decisions to establish joint programs. The case studies that motivated the Agency Action Model illustrated the ways in which joint programs face greater risks for cost growth. Importantly, rather than simply recommending that agencies avoid future joint partnerships, our model provides a means to understand, characterize, and manage the risks associated with them. We hope our model may also provide a framework that is useful for organizing continuing research on joint or international programs, since an improved understanding of these complex and challenging endeavors will improve our ability to mitigate cost growth in the future.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.actaastro.2018.07.004.

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Dr. Morgan Dwyer—Morgan completed this work as part of her PhD in Technology, Management, and Policy at MIT. Prior to MIT, Morgan received a B.S. in Astronomy & Physics from Yale and an M.S. in Aeronautics & Astronautics from Stanford. Morgan currently works in national security in Washington D.C.

Dr. Zoe Szajnfarber—Zoe is an Associate Professor of Engineering Management and Systems Engineering at the George Washington University. Her research seeks to understand the fundamental dynamics of innovation in technology-intensive organizations. She received her bachelor's degree in Engineering Science from the University of Toronto, a dual master's degree in Aeronautics & Astronautics and Technology Policy and a PhD in Engineering Systems, all from MIT.

Dr. Bruce Cameron—Bruce is a Lecturer in Engineering Systems at MIT and a consultant on platform strategies. At MIT, Bruce ran the MIT Commonality Study, a 16-firm investigation of platforming returns. His current clients include Fortune 500 firms in high tech, aerospace, transportation, and consumer goods. He holds an undergraduate degree from the University of Toronto and graduate degrees from MIT.

Dr. Edward Crawley—Edward is the Ford Professor of Engineering at MIT where his research focuses on system architecture and decision support for the design of complex systems. From 2011 to 2016, Edward was also the Founding President of the Skolkovo Institute of Science and Technology. He holds undergraduate and graduate degrees from MIT.