CENTER FOR SPACE POLICY AND STRATEGY

JUNE 2020

FROM THE GROUND UP: GETTING TO SPACE WITH THE RIGHT CONSTRUCTION PROJECT DELIVERY TYPE

VERA L. SCHEIDLINGER, MATTHEW F. MARSHALL, AND J. DENISE CASTRO-BRAN
THE AEROSPACE CORPORATION

AEROSPACE

VERA L. SCHEIDLINGER

Vera L. Scheidlinger is a project leader in Enterprise and Technology Assessments within The Aerospace Corporation’s Civil Systems Group. She leads independent and cross-cutting programmatic assessments in support of civil and commercial customers, including NASA, the National Science Foundation, and the National Academies of Science. She also supports strategic efforts to modify and apply Aerospace’s existing programmatic assessment expertise to a non-space portfolio. Prior to joining Aerospace, Scheidlinger was a civilian program manager leading a wide range of U.S. Air Force aerospace acquisition, testing, and integration efforts.

MATTHEW F. MARSHALL

Matthew F. Marshall is the director for Enterprise and Technology Assessments within The Aerospace Corporation’s Civil Systems Group. He is responsible for developing and applying Aerospace’s expertise in programmatic, technical, and cost assessments to a non-space portfolio. Marshall has led and participated in numerous studies and analyses related to systems engineering, technical, and cost assessments. He led the ground concept evaluations for the Astro 2020 Decadal Survey in Astronomy and Astrophysics as part of the technical risk and cost evaluation team. His team has conducted a number of technical assessments of NASA environmental test facilities. Prior to joining Aerospace, Marshall contributed his systems engineering expertise to several civil space programs, in particular NASA's space station program and the Cassini mission to Saturn.

J. DENISE CASTRO-BRAN

Denise Castro-Bran is the director of the Systems and Operations Assurance Department within The Aerospace Corporation’s Engineering Technology Group (ETG), Mission Assurance Subdivision. She is a registered architect with experience that spans more than 25 years in the development of national space and defense related ground facilities and infrastructure. Her expertise includes master project planning and programming, facilities design and project management, cost estimating and scheduling, risk assessments, and systems anomaly resolution.

ABOUT THE CENTER FOR SPACE POLICY AND STRATEGY

The Center for Space Policy and Strategy is dedicated to shaping the future by providing nonpartisan research and strategic analysis to decisionmakers. The center is part of The Aerospace Corporation, a nonprofit organization that advises the government on complex space enterprise and systems engineering problems.

Contact us at www.aerospace.org/policy or policy@aero.org

AEROSPACE

Summary

Every major aerospace effort is built, tested, launched, and controlled in a ground-based facility. When planning to build or renovate these facilities, the *project delivery type* is an important element that needs to be considered. The project delivery type is the overarching method or approach to organizing the components needed to design and build a facility. While the correct project delivery type can support the overall design and delivery of the project, the wrong project delivery type can result in significant cost and schedule delays and performance issues. To achieve the nation's goals in space, relevant agencies and organizations need to be able to build a successful infrastructure on the ground; selecting the correct project delivery type is one of the most fundamental decisions of that effort. After providing a brief overview of three competing project delivery types and some current policy, this paper explores how each delivery type has various elements that can advantage, or disadvantage, the owning government agency and the success of a project. A project's success depends on weighing its goals and choosing the right project delivery type to support those goals. Improved understanding of project delivery types will result in more ground-based projects successfully contributing to the nation's goals in space.

Introduction

Space Command. Space Force. A New Race to the Moon. Mars Sample Return. It's an exciting time to be involved in space acquisitions with these and many other major efforts on the horizon.

As attention is focused on payloads leaving the earth, it's important to remember the terrestrial side of the space enterprise. Every major space asset is built, tested, launched, and controlled in one or more of the ground-based facilities. These satellite processing facilities, environmental test chambers, test stands, mobile launchers, ground control stations, command and control centers, and data processing centers are an integral part of the space enterprise, and their success can have a huge impact on the success of the total system architecture.

While many variables can impact the success of a facility or infrastructure project, one often overlooked element is the *project delivery type* (also called *project delivery method*). The project delivery type is the approach or method used to organize all the components needed to design and build a facility and can include management of contractors, architects, and consultants; sequencing of operations; and the actual execution of design and construction. How much collaboration exists between the team that designs the facility and the team that builds it? Who is responsible for design issues—contractors, designers, or the government agency that owns the facility? Can construction begin while final designs are ongoing? How many contract efforts must the government agency manage? These decisions can affect the cost and schedule of a construction project as well as the efficiency of operations once the facility is complete.

The successful development and delivery of a ground-based facility in the space enterprise can depend on using the right project delivery type. Conversely, the quality of these key ground assets can be negatively affected if the delivery type increases cost and delivery schedule. Choosing the right project delivery type allows a space program's ground assets to deliver timely, cost-effective support for its entire operational life. However, choosing the wrong project delivery type can undermine a program's efficacy and allow an overlooked detail on the ground to ultimately affect mission success. Ground-based facilities or infrastructure projects undertaken in support of the nation's new goals in space will vary widely; government agencies and decisionmakers must understand the characteristics of different project delivery types and how their advantages and disadvantages affect the goals of a specific project. In order to achieve big goals in space, the nation needs to get it right on the ground first, and an improved understanding of project delivery types will result in more ground-based projects successfully contributing to the nation's goals in space.

Major Project Delivery Types

The project delivery type is somewhat comparable to the acquisition strategy planning process for space or weapons systems. The three major project delivery types are:

1. Design-Bid-Build (DBB)
2. Design-Build (DB)
3. Construction Manager At Risk (CMAR)

While DBB is traditionally the most common project delivery type, some state and federal agencies are beginning to more aggressively explore the potential benefits of DB and CMAR methods depending on the nature of the project. Each one results in variable outcomes in four areas:

1. The number of contracts executed by the facility owner (i.e., the government agency)
2. The roles and responsibilities of each participant in the facility project
3. The point in which the contractor joins the project
4. The ability to conduct design and construction activities simultaneously

Each project delivery type has strengths and weaknesses in these four areas. Table 1 summarizes the relevant differences for each project type, and a detailed discussion follows.

Design-Bid-Build (DBB)

DBB is the most traditional project delivery type in the U.S. construction industry and is often referred to as a "three-step" process. First, the design firm is hired to deliver a "complete" design, meaning that all relevant calculations, analyses, reports, specifications, and drawings have been reviewed and approved by the owner. The owner (i.e., the

Table 1: Overview of Main Project Delivery Types			
	DBB	**DB**	**CMAR**
Number of contracts executed by owner (gov't agency)	**Two separate contracts:** one with a design firm and one with a construction firm	**One contract** with a design-build firm for both design and construction activities	**Two separate contracts:** one with a design firm and one with the construction manager
Roles and responsibilities	**Owner:** hires a design firm and a construction firm; has complete control over design **Design firm:** delivers 100 percent complete design documents **Construction firm:** completes construction according to design documents	**Owner:** hires a design-build firm; no design and construction risk **Design-build firm:** manages the contracts and communication with other subcontractors and suppliers	**Owner:** hires a design firm and a construction manager; some responsibility for design problems **Design firm:** responsible for design documents; provides early budget information to construction manager **Construction manager:** responsible for project coordination and the construction
Point at which the contractor joins the project	After the design process is complete	Before the design process is complete	Before the design process is complete
Ability to conduct concurrent activities	Not possible	Possible (main characteristic of this project delivery type)	Possible

government agency) then solicits bids from construction firms (also called *general contractors*) based on the completed design, and, finally, the actual construction is performed by the selected general contractor. Figure 1 demonstrates the sequential timeline of a typical DBB project.

Using DBB, the government agency must manage two separate contracts for the facility project: one with a design firm and one with a construction firm. The design team and the builder have no contractual obligation to each other; while there may be communication between the two, each company only reports to the government project manager (see Figure 2). Using DBB can be highly competitive since typically the lowest reasonable construction bid is accepted.

Because DBB follows a methodical, incremental process, using it can help mitigate some of the risks associated with an uncertain project scope by ensuring that all requirements are known and documented before construction starts. For example, DBB might work well for a complex, one-of-a-kind environmental test chamber with undefined calibration and control requirements. It is not well suited for projects with significant time constraints that prioritize schedule over performance or budget.

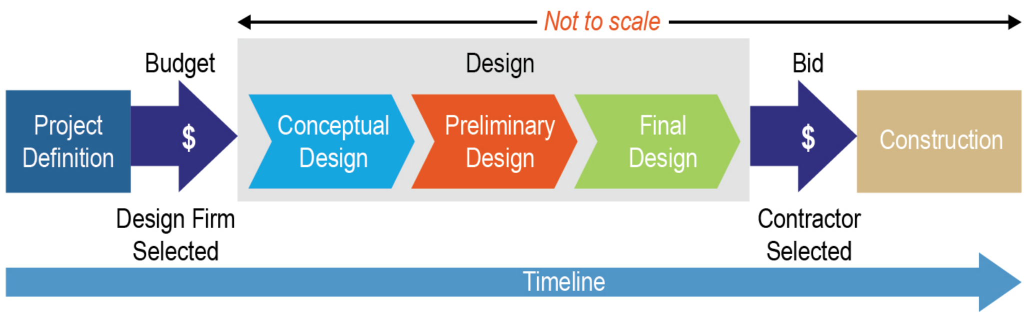

Figure 1: Design-Bid-Build process.

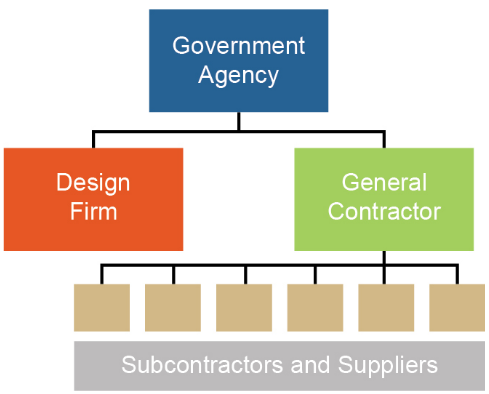

Figure 2: Design-Bid-Build contractual relationships.

Design-Build (DB)

DB is growing in popularity due to its more collaborative nature and potential to "fast-track" or compress design and construction schedules. The government agency hires a single firm to perform both the design and construction of a facility. Construction can start with conceptual and preliminary designs and does not need to wait for them to be fully reviewed and approved. Figure 3 demonstrates the simultaneous design and construction activities of a typical DB project.

With a DB project delivery method, the government agency responsible for the facility only has to manage one contract for both design and construction activities (see Figure 4). This contract is with a design-build firm that either contracts out to a separate design firm and general contractor or does all the work in-house. Contract awards typically consider not just cost but also the experience and qualifications of bidders. In either situation, the government project manager only has the one point of contact with the design-build firm, which then manages the contracts and communication with other subcontractors and suppliers.

The contractor becoming involved much earlier in the lifecycle, before the design is even finalized, allows for higher levels of collaboration between designers and contractors during the design phase. Additionally, if the schedule is a main driver, using the DB delivery type confers the advantage of concurrent design and construction processes.

However, it could be risky to proceed with construction if there's a good chance that the design or requirements of a project will change significantly. For this reason, the DB type is not well suited for unique types of projects that expect late-add design changes caused by evolving mission requirements, requirements that are difficult to outline in a written scoping document, or significant unknown or unidentified interface needs. For example, DB might work best for a modification to an existing mission control center, where the requirements are standard and the interfaces are known.

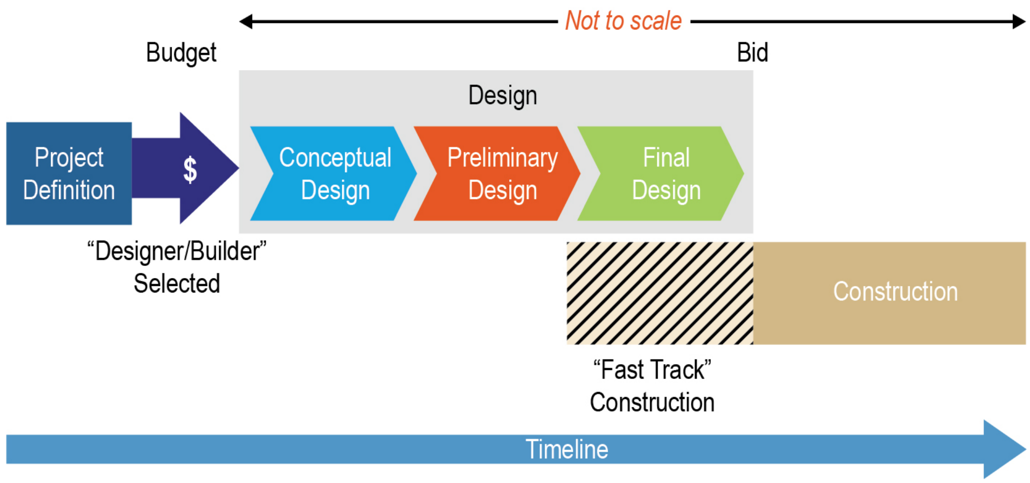

Figure 3: Design-Build process.

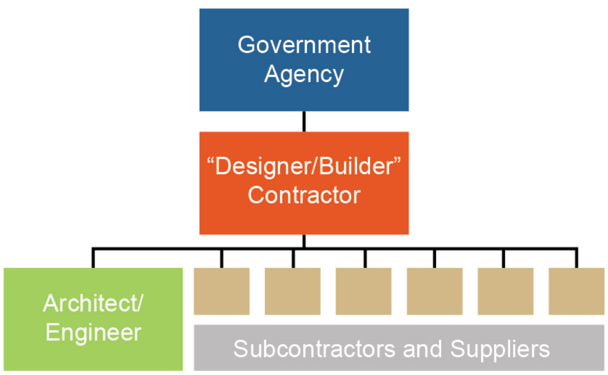

Figure 4: Design-Build contractual relationships.

Construction Manager at Risk (CMAR)

A third popular project delivery type is CMAR. While construction managers can play a variety of roles in many project delivery types, CMAR is characterized by the contractual relationship between the relevant government agency and the construction manager, who is ultimately responsible for the final cost and schedule of the project.

After an initial project definition period, a design firm is selected by the government agency to begin the preliminary design process. However, prior to the completion of the design phase, the construction manager is hired as both the project coordinator and the general contractor. Similar to DB, CMAR projects also allow for simultaneous design and construction activities (see Figure 5).

With a CMAR project delivery method, the government agency responsible for the facility has two separate contracts to manage: one with the design firm and one with the construction manager (see Figure 6). Like a DBB project, the design team and the construction manager do not have a contractual obligation to each other and only report to the government project manager. However, since the construction manager is hired before the design process is complete, there is opportunity for collaboration between them and the design firm.

CMAR is best suited for projects that require multiple phases of separate construction activities, as many complex space facilities do. Using CMAR allows the construction manager to act as the enduring project coordinator across each separate construction effort. And its concurrent design/construction aspect works well for projects with a tight delivery schedule. Therefore, CMAR might work best for a multi-phased improvement effort at an existing launch range, where the requirements have been adequately captured in a scoping document, but implementation is spread across multiple design and construction phases.

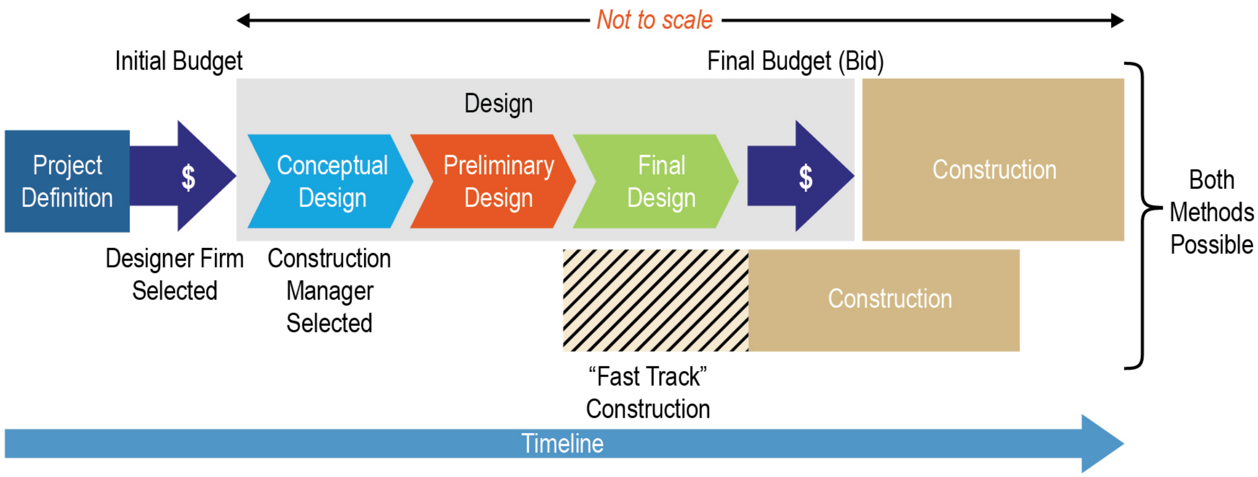

Figure 5: Construction Manager at Risk process.

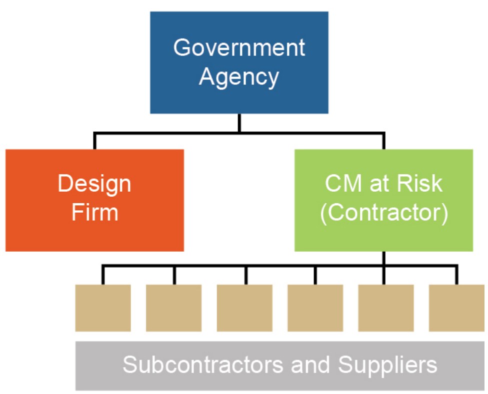

Figure 6: Construction Manager at Risk contractual relationships.

Current Federal Policy

While one might expect government requirements regarding project delivery type to be very restrictive, they actually provide significant flexibility and variability in what project delivery type is ultimately chosen. Prior to 1985, the military services were required to utilize the "traditional" DBB project delivery type for all infrastructure or facility construction projects, except for family housing. From 1985 to 1991, this policy requirement was slightly relaxed, and each military department was able to utilize the DB project delivery type for up to three projects per year. This three-per-year limit was lifted in 1992, and in 1996 authorization was granted for all executive agencies to use the DB delivery method with the passage of the Clinger-Cohen Amendment.[1] While DBB projects are still the most common across the public and private sectors, U.S. government agencies are no longer *required* to use it. Under this amendment, the reformed Federal Acquisition Regulation (FAR) does not mandate one project delivery type; however, if the DBB type, or "another acquisition procedure authorized by law," is not used, FAR Part 36.104 says DB shall be used.[2] The FAR does not mention CMAR delivery types specifically. FAR Subpart 36.3 goes on to describe the policies and procedures associated with implementing the DB project delivery type. The contracting officer must determine that the method is appropriate based on certain criteria (see sidebar on the following page).

FAR Subpart 36.3 Criteria for Determining Project Delivery Type[3]

- Three or more offers are anticipated.
- Design work must be performed by offerors before developing price or cost proposals, and offerors will incur a substantial amount of expense in preparing offers.
- The following criteria have been considered:
  - The extent to which the project requirements have been adequately defined.
  - The time constraints for delivery of the project.
  - The capability and experience of potential contractors.
  - The suitability of the project for use of the two-phase selection method.
  - The capability of the agency to manage the two-phase selection process.
  - Other criteria established by the head of the contracting activity.

Many of the infrastructure and facility projects associated with the "new space race" will fall under the purview of the Department of Defense (DOD) military construction program (MILCON), which provides further guidance on the requirements in the FAR. The DOD directive for MILCON does not contain any reference to project delivery types.[4] However, the DOD fiscal year 2021 budget request includes $88 million in funding for construction of the Consolidated Space Operations Facility in Colorado Springs, Colorado, which will be awarded as a DBB effort—a traditional approach. Design and some construction work have already begun using FY20 funding.[5]

Under DOD's MILCON program, some of the agents for design and construction are the Naval Facilities Engineering Command (NAVFAC) and the U.S. Army Corps of Engineers (USACE); these two organizations differ in prescribing approaches to project delivery type.[7] For example, since 2007, NAVFAC has been following a policy that mandates the use of the DB project delivery type on 75 percent of capital improvement projects costing more than $750,000.[8] On the other hand, the USACE regulation for DB contracting does not contain any such specific restrictions, limitations, or guidance. The regulation only states that "USACE commands will consider and evaluate objectively the project requirements, industry capabilities, and the executing USACE organization's capabilities as part of determining the most appropriate delivery method for engineering and construction projects."[9] The USACE regulation includes a short list of acquisition planning factors to be used as part of this evaluation (see sidebar below).

NASA's policy directive for the design and construction of facilities does not reference project delivery type at all. However, the mobile launcher needed to assemble and launch the Space Launch System (SLS) rocket was recently awarded as a DB effort.[10]

It is worth noting that none of these policies reference CMAR; as a newer project delivery type, it does not appear to be in wide use by many

U.S. Army Corps of Engineers (USACE) Acquisition Planning Factors[6]

- Whether customer requirements have been fully defined (maturity of requirements)
- Size and complexity of the project
- Relevant quality requirements
- Time constraints
- Capabilities and experience of potential contractors
- The executing USACE organization's capabilities and experiences with the proposed delivery method

government agencies. However, the Office of Veterans Affairs has begun encouraging the use of a collaborative project delivery type similar to CMAR.[11]

As this brief survey shows, NAVFAC's policy toward project delivery type is the most prescriptive, but it still allows the government agency some ability to choose one project delivery type over another. The other relevant policies are more flexible and give government agencies a significant amount of leeway in selecting the appropriate project delivery type for their effort. In turn, agencies can focus on other project characteristics that may have a greater impact on which project delivery type will best support the success of their ground-based effort.

Other Policy Considerations

Traditional vs. Novel. Some government agencies may hesitate to utilize DB or CMAR simply because they are "not traditional," or agency personnel may not understand how to best leverage their unique characteristics to the agency's advantage. On the other hand, increased innovation requires new approaches.

Competitiveness. If encouraging competition is a key part of the acquisition strategy, then a DBB project delivery type can be more attractive since the construction contract is typically awarded based simply on the lowest bid, unlike a DB contract which considers past performance and specific qualifications.

Government Staffing. DBB projects require two separate contracts, hence an increased number of government employees to manage them. Using a DB type would mean a smaller staff, which may or may not be desirable. CMAR projects typically require the least number of agency employees, since the construction management firm can expand to address the project's staffing needs.

Getting it Right

Just as each project delivery type has specific advantages and disadvantages in terms of cost, schedule, or performance, each federally funded facility or infrastructure project has specific characteristics, goals, and requirements. For example, a one-of-a-kind ground control station might have unique tracking and antenna requirements, or a data processing center may only need a standard building to house computing equipment.

There is no one perfect project delivery type; the "best" project delivery type will depend on the success criteria the government agency is attempting to influence. What level of risk is a government agency willing to accept in order to control the design and construction of a complex, classified ground control station? What trades can be made when balancing the cost of a deep space communication system versus the cost of extended on-orbit science? What amount of schedule control is needed when launching a technology demonstration mission versus an inter-planetary mission? Will changing the concept of operations (CONOPS) or mission requirements for processing capacity drive changes to the facility design? These questions and more must be asked in order to get it right on project delivery type. Table 2 gives an overview of these considerations with further discussion below.

Risk and Control

First, the central concept a government agency must consider is the amount of control it requires on the project, and the corresponding cost and schedule risk it is willing to accept. Is the agency buying a complex, first-of-its-kind project that requires complete and constant government oversight? Or, is the agency pursuing the modification or upgrade to an existing facility, such that it can delegate control

Table 2: Project Success Criteria and Project Delivery Type			
	DBB	**DB**	**CMAR**
Risk and control	The government agency has control over both the design process and the actual construction. The government agency bears risk associated with incomplete or inadequate design documents.	The government agency delegates both the design and construction process to the design-build firm, which then assumes the risk for design and construction.	The construction manager bears the risk of completing the project within budget and on schedule, but only provides an advisory role to the government agency during the design process.
Cost estimation and control	Can result in a lower cost at the time of award because the open competition invites many proposals. The overall project price isn't available until after the design process is complete and contractors bid for the project. Can result in higher cost at completion of construction due to susceptibility to change orders.	Early commitment to an overall project price allows the government agency to start accurately budgeting for the entire lifecycle of the project. Difficult for a construction team to accurately price a project based on an incomplete design, so bids may include more contingency dollars.	The general contractor provides a guaranteed maximum price before the design is complete, allowing the government agency to lock in total cost before construction starts. The government agency may have to compensate the construction manager for their assumption of the design and construction risks.
Schedule estimation and control	Sequential and deliberative design-bid-build process results in longer schedule durations.	Ability to fast-track: Design and construction phases occur in parallel, so some construction activities can start before the design is complete.	Ability to fast-track: Design and construction phases occur in parallel, so some construction activities can start before the design is complete.
Change orders	More susceptible to change orders during construction due to lack of collaboration during the design phase.	Less susceptible to change orders due to more collaborative environment within the design-build team.	Less susceptible to change orders because the construction manager is part of the early design process.
Collaboration	Not collaborative. The construction firm does not have the opportunity to get acquainted with the design team prior to the start of construction.	Highly collaborative. The contractor and the designer are typically on the same team, which decreases their incentive to blame each other for design or construction problems.	Highly collaborative. The construction manager can work with the design team while the design is still being finalized to avoid any potential design issues and ensure constructability.

to a design-build firm? Is the agency willing to bear the responsibility for any potential cost, schedule, and performance issues?

The three main project delivery types exist on a continuum of risk and control (see Figure 7); the government agency must decide what amount of risk, and related control, it is willing to accept, and then choose the proper project delivery type accordingly. The "best" project delivery type will depend on the success criteria of the government agency, and the level of risk and control over cost and schedule are two main considerations for any space-supporting infrastructure or facility projects.

The traditional DBB project delivery type provides the government agency with the greatest amount of control, in that it has direct contracts with both the design firm and general contractor. But DBB also gives the government agency the greatest amount of risk because it is responsible for the negative impacts caused by incomplete or inadequate designs. The general contractor typically bears little of the risk if there is a construction issue due to design flaws. Using DBB in the space enterprise would be appropriate for the construction of a classified ground control station that requires complete and constant government oversight.

The DB project delivery type provides the government agency with the least amount of control because the entire process is delegated to a design-build firm. In this way, DB also gives the government agency the least amount of risk because the design-build firm bears all the risk for cost growth and can be penalized for schedule or performance issues. This arrangement is best suited for projects with simple designs or requirements, where the government agency is willing to relinquish control of the project design. Using DB in the space enterprise would be appropriate for a standard upgrade to an existing rocket propulsion test stand.

Between these two extremes lie CMAR projects, where government agencies hold certain amounts of control in that they have contracts with both the design firm and general contractor. However, the amount of risk to government agencies is minimized as the construction manager is responsible for completing the project on budget and on schedule. The construction manager also has a relationship with the design firm and can influence both government requirements and the design itself. This arrangement is best suited for projects with tight schedule constraints. Using CMAR in the space enterprise would be appropriate for the construction of a standard satellite processing facility that is on the critical path for a national security mission.

Cost Estimation and Control

Cost is a significant driver for a project, but it can have a shared risk and be controlled. Accurate initial cost estimates are important so that an agency can accurately manage its entire budget; cost control during execution is also important to demonstrate that an agency is being a good steward of taxpayer dollars.

The initial cost estimation for a DBB project can be tricky. DBB projects will not have a final cost until

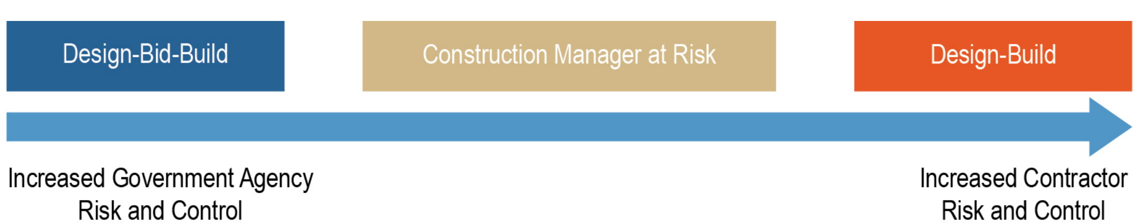

Figure 7: Risk and Control Continuum of Various Project Delivery Types

the design process is complete and the final construction bid is accepted. A government agency must invest a significant portion of time and money before knowing the total cost. If the total cost exceeds the allotted budget for the project, costly redesign might be needed, or the project might even be abandoned. However, DBB projects are usually open competition and tend to attract numerable construction bidders who compete to submit the lowest bid for approval without having the uncertainty of a simultaneous design phase. Cost control during execution is important to demonstrate that an agency is being a good steward of taxpayer dollars. Because DBB construction contracts are typically "lump sum" or fixed price, if construction firms save money during execution, the money is not returned to the government agency. If problems arise during construction due to an issue with the design, the government will be responsible for bearing those cost impacts.

When estimating DB projects, the design-build firm typically provides a lump sum design and construction cost at the time of award; this early commitment to a guaranteed maximum price allows the government agency to start accurately budgeting for the entire lifecycle of the project. However, since DB projects start construction before the design is complete, estimating costs can be difficult for the construction team. This design uncertainty can result in higher-than-normal bids, which may include contingency dollars for things such as design development risks or unforeseen construction risks. However, DB project bids typically use a guaranteed maximum price so "budget creep" is not a concern for the government agency. Controlling cost in DB projects may be possible due to the close coordination between the design and construction teams during the ongoing design process; change orders are less frequent (more on that below). When using the DB delivery type, costs of the simultaneous design and construction processes can also be controlled because the government agency considers qualifications and experience of bidders (opposed to DBB's open competition), so overcoming challenges in materials and installation, for example, is usually easier and, hence, cheaper.

With CMAR projects, the government agency has a good cost estimate at the early stages in the project because the general contractor provides a guaranteed maximum price before the design is complete, similar to the DB delivery type. This means that the general contractor must have the knowledge and relevant experience to estimate correctly and still make a profit. There is a mix of uncertainty in that the design plans are not yet finalized at the time of construction bids; yet, the collaboration between the general contractor and the design firm can result in lower bids and have fewer built-in contingency costs. This also means the construction manager can control costs better because they have a better design that may be easier to build and may use cheaper materials. Moreover, the government agency passes on the burden of risk to the general contractor, which reduces the overall cost of a project.

Research shows a mixed bag of cost success according to project delivery type. A 2003 study showed that DB projects had less cost creep—75 percent of DB projects were completed within 5 percent of the original budget, compared to only 63 percent of traditional DBB. [12] This could be due to the cost impacts of change orders, discussed below. The same study found DB projects were 13 percent cheaper than DBB projects overall. Meanwhile, a 2007 study on military construction found that there was no significant difference between project delivery types when it came to cost. [13] Clearly more research is needed, specifically for recently built, renovated or planned space enterprise ground facilities.

The development and operations of ground-based infrastructure are often just part of a larger space system architecture that must be adequately funded over its entire lifecycle. Accurate cost estimates for a facility or infrastructure project early in the acquisition process can help senior leaders better plan and manage the total funding required for their entire portfolio. For example, if the design and construction of a deep space communication system costs more than its original budget, funding for the in-space science portion of the mission may have to be decreased. Additionally, controlling the cost of the project throughout its lifecycle can reassure watchdogs and taxpayers that funding is being utilized correctly. Therefore, government agencies should carefully consider the cost-related benefits and disadvantages of each project delivery type.

Schedule Estimation and Control

The relationship between the schedule and cost is well known, but when deploying national space assets, the schedule can often take precedence. As stated above, ground-based infrastructure is often part of the larger space system architecture, so the schedule can be a major factor in the timely operation of the overall architecture. As with cost, it can have a shared risk and be controlled depending on which project delivery type is used.

When estimating the schedule, traditional DBB projects are often characterized by longer schedule durations because of their linear, sequential nature, so government agencies should be certain they have the time and political capital to invest in DBB projects. Developing and delivering 100 percent design solutions for complex space systems is time consuming, especially if the total system CONOPS is under development as well. Additionally, as the construction firm does not collaborate in the design phase and is not selected until design documents are 100 percent complete, there can be an extended transition time from the design phase to the start of construction. The "fast track" characteristic of DB or CMAR projects may be more desirable for some ground-based space assets, especially for missions with significant schedule constraints. One study found that the entire project development lifecycle (design and construction) of DB projects was 30 percent faster than traditional DBB projects; additionally, the construction-only phase of these DB projects was seen to be 12 percent faster than traditional DBB projects.[14]

Controlling the schedule can be difficult, especially if there are changing requirements dictated by new technologies or evolving threats, which are common in the space enterprise. These are dealt with more easily and cheaply using concurrent design and build processes found in DB and CMAR delivery types. Research indicates that there are more schedule benefits associated with delivery types like DB and CMAR. In a 2006 report by the National Cooperative Highway Research Program (NCHRP), researchers found that traditional DBB projects tended to have the greatest average time growth.[15] A 2013 Government Accountability Office (GAO) report cited a handbook from the Office of Veterans Affairs that found DB projects can save approximately six months of schedule time over DBB projects.[16] However, a different study found that MILCON projects built using the DB project delivery type may experience *greater* contract schedule growth than projects using DBB.[17] This difference should be an area of further research.

Since infrastructure and facility projects are often one part of a larger system architecture, the success of the entire system may depend on the development and delivery of these ground-based assets on a timely and accurate schedule. For example, some inter-planetary missions must hit a specific launch window that opens only every five years, so the mission control center must be completed on time. In those cases, government agencies should utilize the project delivery type that supports on-time delivery over other considerations.

Change Orders and Collaboration

Change orders are costly, time consuming changes to a completed design that are necessary for the successful construction of a facility. They could involve material, engineering, environmental impact, or other needs. Change orders can negatively affect many parts of a project, resulting in budget overruns, schedule delays, and increased hostility between the various stakeholders.

The traditional DBB delivery type plays it safe in one regard by providing the chosen construction firm with a 100 percent completed, fully scoped design. Unlike the fluid, ongoing design process of DB and CMAR, traditional DBB projects may appear less susceptible to changes, but they lack something the other project delivery types have: collaboration.

More collaboration between the designer and the contractor in the design phase has been found to result in fewer change orders during construction, leading to lower cost growth and less schedule slip. Increased collaboration can lead to more trust between designer and builder, and a better design that is more constructible in terms of materials, logistics, and resources. DB and CMAR projects are more collaborative in the design phase and tend to have fewer change orders than DBB projects.

Indeed, a 1998 study found that, traditional, noncollaborative DBB projects experienced 5 percent *more* change orders than DB projects;[18] this finding was supported by a 2007 study as well.[19] Additionally, the highly collaborative delivery types have more stability in cost estimates and lower overall costs. A 2012 study on the cost impacts of project delivery type found that cost prediction and cost performance was more reliable for collaborative project delivery types like DB and CMAR. The study indicates that projects built collaboratively cost 1.5 percent less than projects built with the traditional DBB model. It also noted that cost performance was more reliable due to the lower number of change orders in collaborative projects.[20]

However, there is a potential drawback to DB and CMAR delivery types with regard to change orders. While starting construction of a facility *before* designs are finalized can result in time savings, incremental changes to immature project requirements, CONOPS, or interfaces can also require change orders, causing significant schedule delays or cost growth during the construction process. When using DB or CMAR, it is important for the government agency to develop and provide early and clear definitions of the most important design and performance requirements.

It is also important to remember that sometimes changes are inevitable, especially when dealing with state-of-the-art technology, changing CONOPS, or unique requirements—all elements common to space projects. New communication technologies drive changes to a command and control center; on-orbit resiliency must be improved to address changing threats; future project funding is diverted to other, more pressing agency needs; a commercial entity develops a ground system for less than the cost to build a bespoke government system; a retiring program's ground assets need to be repurposed efficiently—the list goes on. Government agencies responsible for extensive facility or infrastructure projects should carefully review the impact of their preferred project delivery type on levels of collaboration and the potential number of change orders and how they might affect the lifecycle of the project.

Recommendations for Future Research

As space organizations continue to take stock of their existing infrastructure and changing requirements, there may be a desire to implement a one-size-fits-all policy decision concerning project delivery types. However, not all projects are the same, and the selection of the relevant project delivery type should be undertaken with care and deliberation. While the above can help lay out the advantages and disadvantages of each project type, it is not detailed enough to inform a government agency what the right type is for any specific project. Three areas of further research could help: (1) lessons specifically from space-related infrastructure and facilities, (2) a set of common guidelines, and (3) a better understanding of why project types were chosen, especially when the project type does not seem the best choice for the project.

To gather lessons learned, a key area of study would be to expand existing research on commercial, military, and transportation projects into the realm of space-related infrastructure and facility projects. While some space-related ground projects may include features common with other facility projects, such as the integration of vertical and horizontal elements needed for satellite testing facilities and mobile launchers, they will also have unique features or success criteria that could affect the appropriate project delivery type.[21] Relevant governmental organizations, including USACE, NAVFAC, and NASA, as well as their commercial partners, could be surveyed for more industry-specific results and lessons learned. The results of these surveys could support the development of a consolidated database of federal projects that could be a resource for future government facility project managers as they embark on new and challenging infrastructure projects needed to support the terrestrial side of the space enterprise.

Another area deserving of further research is in the development of a set of common guidelines that could be used by government agencies as they evaluate the characteristics of each project delivery type and select the most appropriate method for their project and success criteria. In 2009, the Federal Transit Administration sponsored the development of a guidebook to support transit agencies as they evaluate and select the most relevant project delivery type for their projects. The guidebook provides a three-tiered selection framework, starting with the qualitative documentation of the advantages and disadvantages of each relevant project delivery type. The guidebook also offers a weighted-matrix approach and methodology for a risk analysis evaluation.[22] A similar guidebook for agencies involved in space-related infrastructure and facilities projects could help identify the most relevant project delivery type based on project characteristics, risk levels, and cost and schedule constraints. This resource would be extremely beneficial, supplementing the limited guidelines in the FAR and helping to avoid the "one-size-fits-all" mandate approach so common in government acquisitions.

Lastly, there should be additional research on the decision process that drives the current selection of project delivery types. While this paper cites research that has been done on the cost and schedule benefits of each type of project delivery method, less research has been done on *why* different delivery types are selected. A misunderstanding of the advantages and risks of each delivery type or an over-emphasis on perceived cost or schedule savings over other relevant project success criteria could affect the selection. Future research could illuminate what factors affect the decision process, so that better review guidelines could be implemented. This would encourage agencies to conduct an adequate review prior to selecting a project delivery type for their terrestrial space enterprise acquisition efforts.

As the United States embarks on the many infrastructure projects needed to support new and expanding space efforts, the research outlined above could help government agencies identify the best project delivery type for their tasks.

Conclusion

As new strategic plans for space transition into programs of record, it is important to consider all aspects of proposed architecture—not just the new rockets needed to send humans to Mars, but also the facilities and infrastructure needed to build, test, and launch those rockets.

Project delivery type is a key element that can affect the efforts to construct or refurbish these facilities. When selected and implemented correctly, the project delivery type can support project goals and ensure a successful project is delivered on time and within budget. However, the wrong delivery method can negatively affect the cost and delivery schedule of a project, potentially delaying key parts of the new space enterprise.

If schedule and on-time delivery is of the utmost concern, DB and CMAR may be the best options. Both delivery types have the ability to combine design and construction phases, resulting in a shorter overall schedule. This characteristic can be beneficial for projects with a tight delivery schedule, such as the range control infrastructure needed to support an inter-planetary launch.

If budget control is the most important project goal, DB and CMAR may also be the best option. DB projects typically provide an early commitment to a guaranteed maximum price, which allows the government agency to start accurately budgeting for the entire lifecycle of the project. Similarly, the general contractor on CMAR projects provides a guaranteed maximum price before the design is complete, so the government agency has a good cost estimate during the early stages of the project lifecycle. For an experimental mission that is simply feeding into potential later missions, keeping a ground control station within budget may be more important than getting it done on time.

If a project is highly complex with multiple unknown design elements, DBB may be the best option. Because the DBB project delivery type follows a methodical, incremental process, it can help mitigate some of the risks associated with an uncertain project scope. This characteristic could be relevant for complex or unique projects with evolving mission requirements and unknown interfaces, such as the contamination control facility that will be needed to store the first rock samples gathered on Mars and test them for signs of ancient life.

There is no one perfect project delivery type, so it is important that government agencies are able to select the right project delivery type based on their specific project requirements, instead of being pushed into a one-size-fits-all option. As launch folks like to say, "The payload is important, but you can't get there without the ride." Similarly, while sending humans to Mars is exciting, this nation will never get there without a good terrestrial foundation. Improved understanding of project delivery types will result in more ground-based projects successfully contributing to the nation's goals in space.

References

[1] Mouritsen, John W., "An Empirical Analysis of the Effectiveness of Design-Build Construction Contracts Based on Projects Executed by the Naval Facilities Engineering Command," August 1993 and Thomas, Stephan R., Candace L. Macken, Tae Hwan Chung, and Inho Kim, "Measuring the Impacts of the Delivery System on Project Performance – Design-Build and Design-BiDBuild," November 2002.

[2] Federal Acquisition Regulation (FAR) Part 36 – Construction and Architect-Engineer Contracts, https://www.acquisition.gov/content/part-36-construction-and-architect-engineer-contracts#id1617MD0I0DP (accessed 1/24/2020).

[3] Federal Acquisition Regulation (FAR) Subpart 36.3 - Two-Phase Design-Build Selection Procedures, https://www.acquisition.gov/content/part-36-construction-and-architect-engineer-contracts#i1078838 (accessed 1/24/2020).

[4] Department of Defense, "Directive: Military Construction, Number 4270.5," August 31, 2018.

[5] Erwin, Sandra, "U.S. Space Force, Space Command to get state-of-the-art facility in Colorado," Space News, February 11, 2020, https://spacenews.com/space-operators-to-get-state-of-the-art-facility-in-colorado/ and https://govtribe.com/opportunity/federal-contract-opportunity/consolidated-space-operations-facility-w9128f19sm011 (accessed 2/12/2020).

[6] Department of the Army, U.S. Army Corps of Engineers, "Contracts, Design-Build Contracting, Regulation No. 1180-1-9," March 31, 2012.

[7] The Air Force, Intelligence Community, and some other agencies have their own processes, not covered in this paper.

[8] Cantrell, Kim S., "Analysis of design-build processes, best practices, and applications to the Department of Defense," June 2006, downloaded from NPS Archive: Calhoun (accessed 1/27/2020).

[9] Department of the Army, U.S. Army Corps of Engineers, "Contracts, Design-Build Contracting, Regulation No. 1180-1-9," March 31, 2012.

[10] NASA Policy Directive, "Design and Construction of Facilities, NDP 88.20.2E," July 15, 2019 and http://www.fbodaily.com/archive/2019/07-July/20-Jul-2019/FBO-05375345.htm (accessed 1/27/2020).

[11] United States Government Accountability Office, "VA Construction, Additional Actions Needed to Decrease Delays and Lower Costs of Major Medical-Facility Projects," GAO-13-302, April 2013.

[12] Molenaar, Keith R. and Sidney Scott, "Examining the Performance of Design-Build in the Public Sector," *Design-Build for the Public Sector*, 2003.

[13] McWhirt, Darren D., "A comparison of design-biDBuild and design-build project delivery methods on military construction projects," 2007.

[14] Molenaar, Keith R. and Sidney Scott, "Examining the Performance of Design-Build in the Public Sector," *Design-Build for the Public Sector*, 2003.

[15] Scott, Sidney, Keith R. Molenaar, Douglas D. Gransberg, and Nancy C. Smith, Transportation Research Board of the National Academies, National Cooperative Highway Research Program, "Best-Value Procurement Methods for Highway Construction Projects," NCHRP Report 561, 2006.

[16] United States Government Accountability Office, "VA Construction, Additional Actions Needed to Decrease Delays and Lower Costs of Major Medical-Facility Projects," GAO-13-302, April 2013.

[17] McWhirt, Darren D., "A comparison of design-biDBuild and design-build project delivery methods on military construction projects," 2007.

[18] Konchar, Mark and Victor Sanvido, "Comparison of U.S. project delivery systems," *Journal of Construction Engineering and Management*, Volume 124, Issue 6, December 1998.

[19] McWhirt, Darren D., "A comparison of design-biDBuild and design-build project delivery methods on military construction projects," 2007.

[20] Kulkarni, Aditi, Zofia K. Rybkowski, and James Smith, "Cost Comparison of Collaborative and IDP-Like Project delivery Methods versus Competitive Non-Collaborative Project Delivery Methods," *Proceedings of the 20th Conference of the International Group for Lean Construction*, July 2012.

[21] Touran, Ali, Douglas A. Gransberg, Keith R. Molenaar, Kamran Ghavamifar, D.J. Mason, and Lee A. Fithian, Transportation Research Board of the National Academies, Transit Cooperative Research Program, "A Guidebook for the Evaluation of Project Delivery Methods," TCRP Report 131, 2009.

[22] Touran, Ali, Douglas A. Gransberg, Keith R. Molenaar, Kamran Ghavamifar, D.J. Mason, and Lee A. Fithian, Transportation Research Board of the National Academies, Transit Cooperative Research Program, "A Guidebook for the Evaluation of Project Delivery Methods," TCRP Report 131, 2009.