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Probabilistic Schedule Risk Modeling and Advanced Timeline Visualization for the U.S. Military Academy's Academic Building Upgrade Program

Georgia Brownfield, Tyler de Leon, Robert Ferris, Amy Miseli, Emma Sy, and Courtney Razon

Department of Systems Engineering, United States Military Academy, West Point, New York 10996

Corresponding author's Email: gzbrownfield2003@gmail.com

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Abstract: The Academic Building Upgrade Program (ABUP) is the United States Military Academy's (USMA) long term, highly interdependent initiative to modernize academic infrastructure, with the demolition and construction of Thayer Hall as its focal point. Because Thayer Hall supports nearly all academic departments, its demolition requires coordination of multiple renovations, relocations, and infrastructure projects across the installation. This study assesses the probability that the demolition of Thayer Hall can begin in January 2027 and that construction can begin in June 2028, and identifies actions necessary to reduce schedule risk. This research produced a system-level dependency map, Monte Carlo Simulation (MCS), and sensitivity analysis to quantify uncertainty and evaluate thousands of potential timelines. Results reveal the likelihood of achieving the target dates, identifies primary drivers of delay, and provides a tool to clearly communicate the complex timeline to stakeholders at all levels.

Keywords: Monte Carlo Simulation, Infrastructure Modernization, Schedule Risk Analysis, Timeline Visualization

1. Introduction

1.1 Background

The mission of The United States Military Academy (USMA) is to "build, educate, train and inspire the Corps of Cadets to be commissioned leaders of character committed to the Army Values and ready for a lifetime of service to the Army and Nation" (United States Military Academy, 2026). Established in 1802, USMA's historic academic facilities have served generations of cadets, but many have aged to the point that substantial modernization is required to ensure West Point remains a leading institution of academic excellence. As a result, USMA has initiated a multi-building renovation effort across campus, a complex undertaking made even more challenging by the need to sustain USMA's critical mission set. As the Director of Strategic Resources in the USMA G5, LTC Dennis Sugrue is at the center of the multi-building renovation and construction and serves as the primary stakeholder. He identified several areas in which he could use technical and analytical assistance. Given the complexity and interdependence within many buildings in ABUP, communicating the dynamic construction schedule and its impacts on academics is imperative. One research objective is effectively and efficiently communicating the complex timeline to varying levels of USMA stakeholders. Additionally, the timeline needs to factor in common construction delays encountered on historic or older campuses including weather, site-management setbacks, and restricted site access (Lessing & Thurnell, 2017). Thus, a second research objective is to develop a model that quantifies schedule risk by incorporating both general construction-related uncertainties and uncertainties unique to ABUP.

ABUP comprises of multiple buildings across USMA, with the principal effort centered on Thayer Hall. ABUP intends to demolish Thayer Hall and build a state-of-the-art facility that will become the "hub" for USMA's humanities disciplines (United States Military Academy, 2022). Because Thayer Hall serves as the mainstay for nearly every department's teaching needs, the loss of this space significantly hinders the ability to conduct uninterrupted teaching operations. Numerous infrastructure renovations, departmental relocations, and construction projects must be completed prior to Thayer Hall demolition to ensure adequate teaching and departmental space is available once the building is no longer operational. Other universities undergoing similar construction projects have adapted by implementing virtual classes or increasing options for evening classes (Northern Arizona University, 2019). USMA curriculum is highly

involved, requiring that Cadets take an interdisciplinary course load consisting of physical education, military science, a robust core curriculum, and an academic major of their choice (United States Military Academy, 2026). Because of USMA's commitment to small class size and its unique military mission set, large auditorium-style formats, virtual instruction, or evening classes are not viable options. USMA's goal is to begin demolition of Thayer Hall in January 2027, with construction scheduled to start in June 2028. The stakeholder requires analytical support to evaluate the feasibility of this timeline and generate a visual tool to communicate the complexities inherent in ABUP.

2. Methodology

2.1 Agile Method

Agile methodology served as the project's overarching planning and execution framework. Under this approach, major tasks were subdivided into smaller, more manageable subcomponents and completed iteratively in phases known as "sprints" (Jin, 2017). At the end of each sprint, the team met with the project stakeholder to review completed work, gather feedback, and establish priorities for the next sprint. These iterative meetings served as both sprint reviews and planning sessions, ensuring the ABUP capstone priorities remained aligned with stakeholder needs and maintained a clear direction throughout the project.

2.2 System Decomposition & Dependency Mapping

The team began by identifying all infrastructure renovations, departmental relocations, and construction projects within ABUP. To understand the relationships and interdependence within the system, the team conducted a thorough assessment of each component, its timeline, and all prerequisite activities. With this, the team created a dependency map beginning with current construction through the completion of the final building as seen in Figure 1.

Because the demolition of Thayer Hall relies on the completion of multiple upstream construction projects, it is imperative to understand the relationships and interdependencies between each project. Dependencies were identified by ordering all projects by start date and determining which buildings depend on the completion of others. The start dates for dependent buildings and associated departmental moves were then adjusted to align with the completion dates of their preceding buildings. Lastly, final adjustments were made for non-academic building projects with associated dependencies such as the steam pipes, barracks renovations, and receipt of funding. With all the information available, the team connected and annotated each building with information that could prevent a follow-on building from starting, thus creating the dependency map as shown in Figure 1. This dependency map enables the stakeholder to quickly understand the relationships between building and identify factors that could delay the start of Thayer Hall.

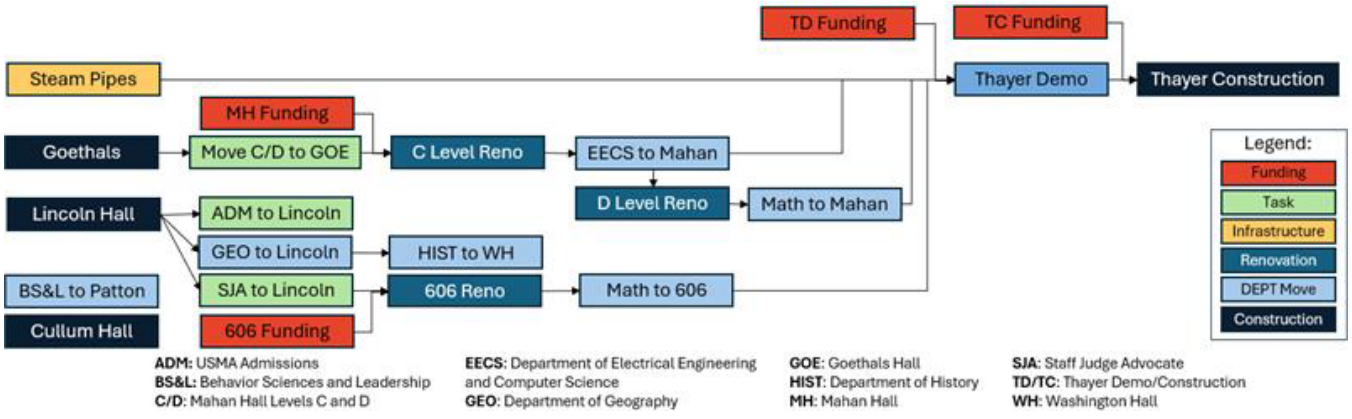

Figure 1. Dependency Map

2.3 Monte Carlo Simulation

Every building within the ABUP renovations has its own unique renovation tasks which carry potential causes for delay and uncertainty. Monte Carlo Simulation (MCS) is a widely used probabilistic modeling technique that quantifies

uncertainty by simulating thousands of possible costs, schedule, and performance outcomes (Kwak and Ingall, 2007). Given the inherent risk within ABUP, forecasting these uncertainties is essential for enabling stakeholders to make informed decisions and ensure successful project execution. The team created a MCS to model thousands of possible ABUP timelines and estimated the probabilities of Thayer Hall demolition beginning in January 2027 and Thayer Hall construction beginning in June 2028.

To model the construction duration for each project within ABUP, the team used a triangular distribution. A triangular distribution is commonly used when a fully specified probability distribution is not available; it relies on three parameters: the minimum value, the most likely value, and the maximum value and are simple enough to run large-scale simulations with MCS efficiently (Johnson, 2002). ABUP subject matter experts (SMEs) provided the minimum, most likely, and maximum number of days to complete construction for each project within ABUP.

As seen in Figure 1, several projects depend both on the completion of other projects and the receipt of funding. To represent this constraint, the team used a beta distribution to model the funding receipt for all projects that have not yet started. Using a minimum, most-likely, and maximum value, the beta distribution bounds limits for uncertainty providing a realistic representation of how delays in funds awarded can affect schedule delays for Thayer Hall (Berny, 1989). ABUP SMEs provided the minimum, most likely, and maximum dates for receipt of funding for each project. The team also accounted for the contracting period delay between receiving funding and starting construction. This varied between one and six months, depending on the project. Figure 2 illustrates how the simulation modeled uncertainty in both project duration and funding receipt. It shows the distribution of the duration to complete Thayer demolition across 1,000 iterations, generated using the triangular distribution, as well as the range of possible funding receipt dates for the project, modeled using a beta distribution.

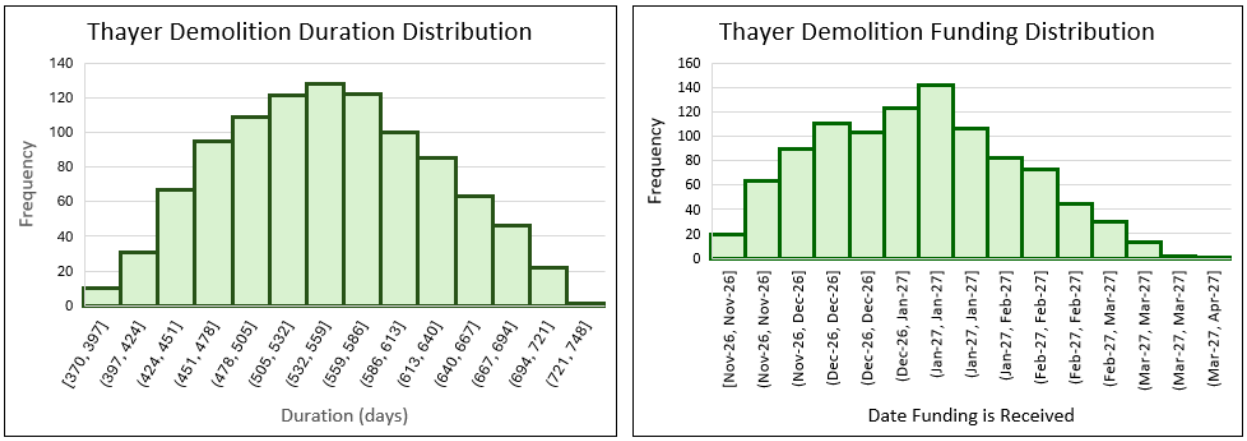

Figure 2. Frequency of Thayer Hall Demolition Duration (left) and Receipt of Funding (right)

With the system dependencies defined and all construction-related uncertainty captured, the team developed a MCS that models all projects within ABUP. The simulation produces 1,000 iterations of project start dates, durations, and completion dates for every project. These results also provide insight into the likelihood of meeting USMA's target dates for Thayer Hall.

3. Results

3.1 Critical Path

Table 1 and Figure 3 summarize the results of the MCS. Table 1 displays the earliest, most likely, and latest start dates for both Thayer demolition and construction. Additionally, Table 1 identifies the project that served as the limiting factor for the start of the Thayer Hall project and quantifies its impact as a percentage of the 1,000 iterations. Figure 3 provides a graphical distribution of the start dates with USMA's target start dates identified by the red dashed line.

The results indicate that the most likely date to start Thayer demolition is April 2027, as seen in Table 1. Although January 2027 was USMA's target start date, the model shows this outcome occurred in only 0.20% of the 1,000 iterations. For Thayer Hall construction, the most likely start date is December 2028, while the probability of starting Thayer Hall construction in June of 2028 is 3.60% as shown in Figure 3.

Table 1 also identifies the key constraints influencing these outcomes. For the Thayer Hall demolition start, 59% of delays are attributed to the steam pipe projects, 40% to the relocation of the Department of Electrical Engineering (EECS) from Thayer into Mahan Hall, 1% to the relocation of the Department of Mathematics to Building 606, and 1% to receipt of funding

for Thayer Hall demolition. In approximately 66% of the simulation iterations, delays to Thayer Hall construction were primarily driven by delays in Thayer Hall demolition, while finding delays accounted for the remaining 34%. Together, Table 1 and Figure 3 show that accelerating the Thayer demolition upstream dependencies will increase the likelihood of meeting the target start dates for both Thayer demolition and Thayer construction.

Table 1. Thayer Demolition and Construction Expected Start Dates and Dependencies

Thayer Demo Start Dates	
Earliest	1/25/2027
Most Likely	4/19/2027
Latest	7/12/2027

Thayer Demo Dependency	
Math into B606	0.40%
Funding	0.90%
EECS into Mahan	39.90%
Steam Pipes	58.80%

Thayer Construction Start Dates	
Earliest	4/7/2028
Most Likely	11/15/2028
Latest	5/22/2029

Thayer Construction Dependency	
Thayer Demo	65.80%
Thayer Funding	34.20%

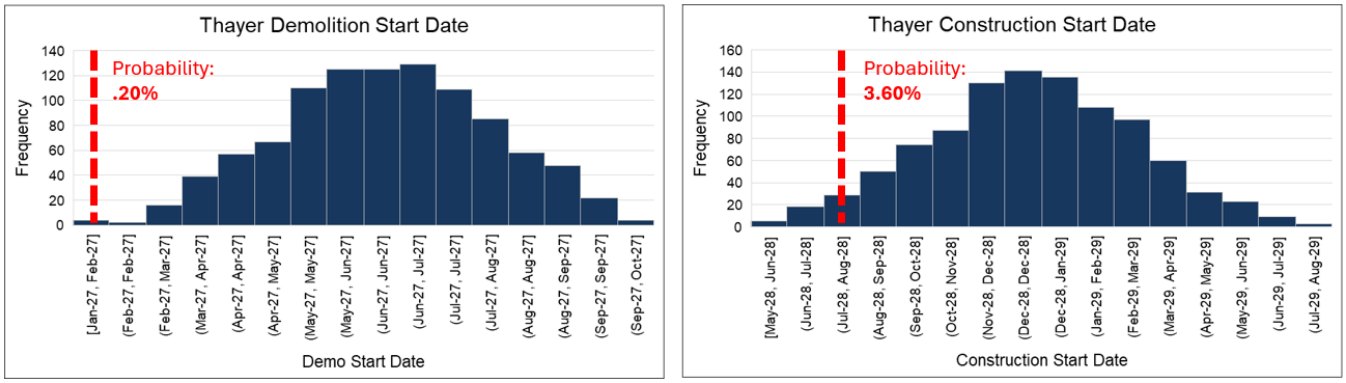

Figure 3. Probabilities of Meeting Critical Start Dates

Table 1 identifies the primary dependencies limiting the start of Thayer Hall demolition: the steam pipe project and moving EECS out of Thayer and into Mahan Hall. The steam pipe project involves replacing all steam pipes under USMA. To do this, all steam pipes are temporarily moved above ground while the underground steam pipes are replaced. The above ground steam pipes limit access to Thayer Hall, restricting the ability of wrecking balls and other critical equipment to begin Thayer Hall demolition. For EECS to vacate Thayer Hall, their assigned space in Mahan Hall must be available. Currently, ongoing departmental moves within Mahan Hall and into Goethals Hall as well as Mahan Hall renovation activities prevent EECS from relocating. With these critical projects identified, the team conducted sensitivity analysis to determine how accelerating both dependencies would improve the likelihood of meeting the ABUP goals, both individually and combined.

3.2 Sensitivity Analysis

Sensitivity analysis determines which dependencies have the greatest influence on the desired completion date. By systematically reducing the duration of the two critical projects, this analysis can arm decision makers with knowledge of how these projects strongly influence the timeline and ultimately the likelihood of meeting USMA's target start dates.

The MCS results identified the steam pipe project as the primary dependency affecting the start date of Thayer Hall demolition. The stakeholder indicated that USMA may be able to reduce the duration of the steam pipe project by adjusting project priorities or allocating additional funding. To evaluate the potential impact on the Thayer Hall demolition start date, the team modeled incremental reductions in the steam pipe project duration ranging from 15 to 180 days to assess the feasibility of meeting USMA's intended timeline. Similarly, the stakeholder indicated that steps could be taken within Mahan Hall, either through revised planning or additional funding, to accelerate the relocation of EECS. To assess the potential impact on the overall schedule, the team modeled an acceleration of EECS's move into Mahan Hall ranging from 15 to 60 days ahead of the baseline schedule.

The team conducted a two-way sensitivity analysis to determine the overall impact on the start date of Thayer Hall demolition. Table 2 provides the two-way sensitivity analysis results. In both tables, the columns display the effect of shortening the steam pipe project duration, shown from left to right. The rows reflect the impact of accelerating the EECS move into Mahan Hall, shown from top to bottom. The top table shows the resulting Thayer Hall demolition start date. The bottom table shows the project that served as the limiting factor. From these tables, the tipping point appears to be the ability to complete the steam pipe project between 90 and 120 days. During this period, the primary limiting factor shifts from steam pipes to

EECS relocation into Mahan Hall, and the projected start date for Thayer Hall is expedited to mid-April 2027. If USMA stakeholders can also shorten the time required to make Mahan Hall available for EECS, the Thayer Hall demolition date can be accelerated further into late March 2027. In the most optimistic scenario where both dependencies are reduced to their minimum feasible durations, Thayer Hall demolition can begin in early March 2027.

Table 2. Sensitivity Analysis

EECS Move (# days early)	Steam Pipe Project Duration (# days earlier)											
	-15	-30	-45	-60	-75	-90	-105	-120	-135	-150	-165	-180
-15	6/4/2027	5/25/2027	5/16/2027	5/11/2027	4/30/2027	4/26/2027	4/19/2027	4/13/2027	4/10/2027	4/6/2027	4/2/2027	4/2/2027
-30	5/31/2027	5/24/2027	5/10/2027	5/4/2027	4/26/2027	4/20/2027	4/15/2027	4/9/2027	3/31/2027	3/27/2027	3/27/2027	3/22/2027
-45	5/28/2027	5/17/2027	5/11/2027	5/1/2027	4/24/2027	4/15/2027	4/10/2027	4/1/2027	3/27/2027	3/22/2027	3/17/2027	3/14/2027
-60	5/28/2027	5/17/2027	5/5/2027	4/30/2027	4/20/2027	4/11/2027	4/3/2027	3/29/2027	3/21/2027	3/16/2027	3/12/2027	3/6/2027

EECS Move (# days early)	Steam Pipe Project Duration (# days earlier)											
	-15	-30	-45	-60	-75	-90	-105	-120	-135	-150	-165	-180
-15	Steam Pipes	Steam Pipes	Steam Pipes	Steam Pipes	Steam Pipes	Steam Pipes	EECS into Mah	EECS into Mah	EECS into Mah	EECS into Mah	EECS into Mah	EECS into Mahan
-30	Steam Pipes	Steam Pipes	Steam Pipes	Steam Pipes	Steam Pipes	Steam Pipes	Steam Pipes	EECS into Mah	EECS into Mah	EECS into Mah	EECS into Mah	EECS into Mahan
-45	Steam Pipes	Steam Pipes	Steam Pipes	Steam Pipes	Steam Pipes	Steam Pipes	Steam Pipes	EECS into Mah	EECS into Mah	EECS into Mah	EECS into Mah	EECS into Mahan
-60	Steam Pipes	Steam Pipes	Steam Pipes	Steam Pipes	Steam Pipes	Steam Pipes	Steam Pipes	Steam Pipes	Steam Pipes	EECS into Mah	EECS into Mah	EECS into Mahan

3.3 Visualization and Decision Insight

A concurrent objective of this project is to effectively and efficiently communicate the complex timeline to key ABUP constituencies. At the beginning of this project, the stakeholder relied on two simplified PowerPoint slides to convey the plan. These slides were insufficient for explaining project interdependencies, timeline projections, classroom impacts, funding considerations, building-specific requirements, and departmental moves. To improve communication, the team incorporated the dependencies and individual project timelines into a comprehensive visualization tool.

The primary visualization method and tool of choice for this project is Microsoft Visio. Figure 5 provides the Visio as of March 13, 2026. Microsoft Visio allows for a low-level of detail from afar with increasing details as the user reads more into it. The team designed the visualization to include critical information such as the amount of classroom space available, number of auditoriums, funding types, and key milestones. Each project duration is communicated using swim lanes to include information relating to department moves, classroom allocations, and the level of operations of buildings every year to prevent cluttering in the main timeline. At the stakeholder's request, the dates presented reflect USMA's current planned schedule, which is required for briefing senior leaders. However, the timeline highlights the potential schedule risk incurred from the steam pipe project and the upstream factors leading to the inability of EECS to move into Mahan Hall. This visualization tool enables USMA to brief a broad audience from senior leaders who need a bottom-line summary to engineers who require detailed milestones, ensuring consistent, accurate communication of the ABUP timeline.

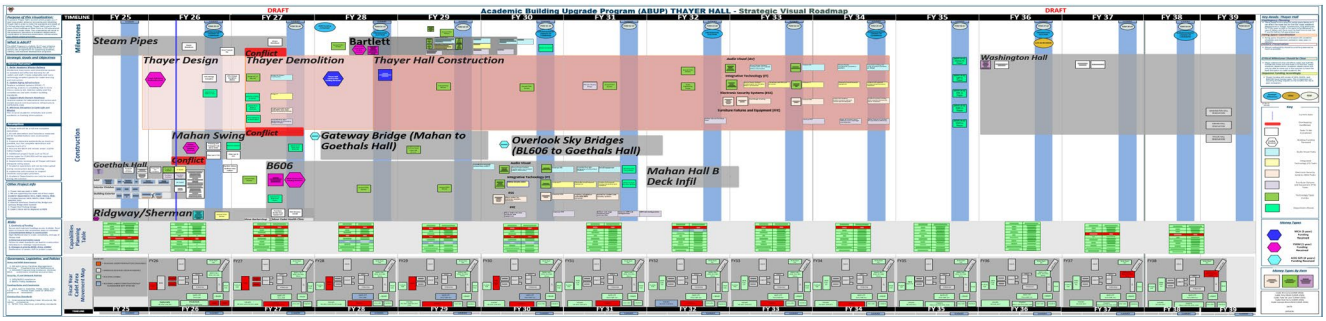

Figure 5. Timeline Visualization

4. Discussion

4.1 Interpretation for Stakeholders

This research provides stakeholders with valuable insight and decision space regarding the probability of achieving USMA's target timeline. While the likelihood of meeting these dates is currently scheduled is low, the analysis highlights several opportunities to move closer to meeting the target dates. The analysis identified the steam pipe project as the primary limitation and demonstrates how adjustments to that project can directly affect Thayer Hall start dates. If stakeholders can

allocate additional funding or reprioritize activities to reduce the steam pipe project timeline, the Thayer Hall demolition start date can move closer to the USMA's target date. A secondary limitation is the relocation of EECS from Thayer Hall to Mahan Hall. The analysis shows that by exploring options to accelerate the EECS move can allow Thayer Hall demolition to begin closer to the target date. The dependency map shown in Figure 1 identifies the critical projects required for EECS occupancy, including the completion of Goethals Hall and receiving funding for Mahan Hall renovation. Understanding these dependencies provides USMA with multiple opportunities to strategically allocate funds or adjust priorities. Improvements or efficiencies in the critical projects will have a meaningful downstream effect on both the Thayer Hall demolition and Thayer Hall construction start dates.

4.2 Limitations

While the MCS and sensitivity analysis provided valuable insights, several limitations exist between the model and the static visual timeline. Because static visualization does not update dynamically, the resulting schedule uncertainty is not automatically integrated into the visual timeline—these changes must be made manually. Future research could advance this work developing an interface that automatically incorporates MCS and sensitivity analysis outputs into the timeline. This would allow users to adjust one aspect of a project and immediately observe the impact on the overall timeline. Another limitation involves inputs for the MCS. The triangular and beta distribution parameters were based on estimates provided by SMEs, meaning they are still subject to errors or inaccuracies due to potential bias. Improving the accuracy and granularity of the underlying data would help produce probability distributions and more closely model real-world performance.

5. Conclusion

In summary, this research demonstrates that the probability of Thayer Hall demolition beginning by January 2027 and Thayer Hall construction beginning in June 2028 is low. Due to the numerous dependencies within this complex program, upstream delays will likely push these start dates beyond the USMA's target dates. However, this research identified the critical projects causing these delays and offers updated most likely Thayer Hall demolition start dates if USMA can allocate resources or adjust priorities to reduce the duration of these critical projects. Additionally, the team created a visualization tool to enable the stakeholders to communicate the ABUP timeline to a variety of stakeholders from USMA leadership to project engineers. This work demonstrates how systems engineering and probabilistic modeling can transform schedule uncertainty into actionable insights for complex institutional infrastructure programs.

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