

Applying Army Doctrine to Engineering: Is That Complex?

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Applying Army Doctrine to Engineering...is that complex?

The requirement to include “complex engineering problems” was added to the ABET student outcomes for engineering programs in 2019. ABET provides several characteristics that governs what constitutes a complex engineering problem: involving wide-ranging or conflicting technical issues, having no obvious solution, addressing problems not encompassed by current standards and codes, involving diverse groups of stakeholders, including many component parts or sub-problems, involving multiple disciplines, or having significant consequences in a range of contexts. (ABET, 2019-2020). The Civil Engineering Professional Practice and Applications course at the United States Military Academy integrates the military and civil engineering professions by applying a doctrinal military ‘design process’ to address complex civil engineering problems. This design process is known as the Army Design Methodology (ADM) and it applies critical and creative thinking to understand, visualize, and describe complex problems and approaches to solving them. The purpose of this paper is to describe the ADM and how it is incorporated into the course, and to provide an assessment related to student learning outcomes.

Introduction

The mission of the United States Military Academy (USMA) has evolved since the institution's inception in 1802 [1]:

To educate, train, and inspire the Corps of Students so that each graduate is a commissioned leader of character committed to the values of Duty, Honor, Country, and prepared for a career of professional excellence and service to the Nation as an officer in the United States Army.

The Department of Civil and Mechanical Engineering is one of 13 departments at the Academy, and both the civil and mechanical engineering programs are accredited by ABET Inc. The mission of the Department of Civil and Mechanical Engineering parallels the Academy's mission, while focusing on educating and inspiring students in the fields of civil and mechanical engineering [2]:

Educate, develop, and inspire agile and adaptive leaders of character who design and implement innovative solutions and win in complex environments as trusted Army professionals.

The civil engineering program is aligned with the seven ABET [3] student outcomes found in Criterion 3 (Student Outcomes) to achieve the mission and meet accreditation requirements:

Our students upon graduation:

- 1. an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics*
- 2. an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors*
- 3. an ability to communicate effectively with a range of audiences*
- 4. an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts*
- 5. an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives*
- 6. an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions*
- 7. an ability to acquire and apply new knowledge as needed, using appropriate learning strategies.*

The term “complex” appears in both the department mission statement as well as in the first student outcome. For the purpose of this paper, the ABET [3] definition of “complex engineering problems” is used to describe complex, specifically: “Complex engineering problems include one or more of the following characteristics: involving wide-ranging or conflicting technical issues, having no obvious solution, addressing problems not encompassed by current standards and codes, involving diverse groups of stakeholders, including many component parts or sub-problems, involving multiple disciplines, or having significant consequences in a range of contexts.”

Army Design Methodology

While the Army Design Methodology (ADM) is fully described in Army Techniques Publication 5-0.1 “Army Design Methodology” [4], a basic overview is provided to give context for this paper. The ADM is a methodology for applying critical and creative thinking to understand, visualize, and describe unfamiliar problems and approaches to solving them. The ADM enables commanders and staffs to think about a situation in depth and develop more informed approaches to solve or manage problems. The ADM is an iterative process of framing an operational environment, framing the problem(s), and developing solutions or operational approaches, as shown below in Figure 1.

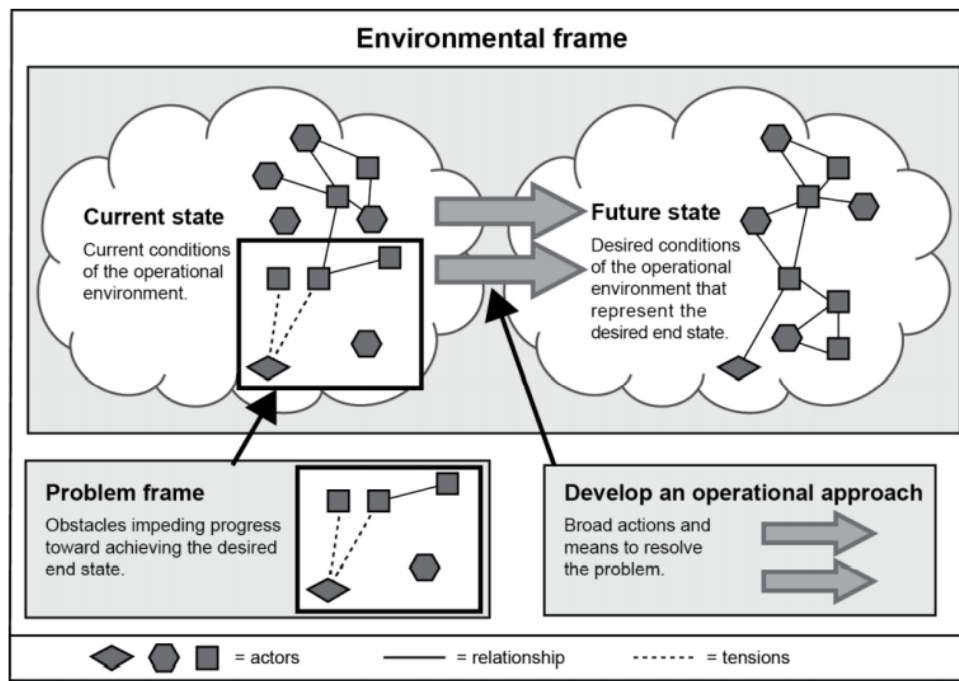


Figure 1: Army Design Methodology

The first step of the ADM is to develop an Environmental Frame, which describes and depicts the context of the operational environment—how the context developed (historical and cultural perspective), how the context currently exists (Current State), and how the context could trend in the future (Future State). The Current State involves both a narrative and a graphic that answers questions such as:

- What is going on in an operational environment?
- Why has this situation developed?
- Who are the relevant actors (note – actors can be viewed as stakeholders)?
- What is causing conflict among relevant actors?
- What are the strengths and weaknesses of the relevant actors?

Once the Current State has been described, a series of questions can be considered to develop the Future State, such as:

- Why is the situation (or the projected future situation) undesirable?
- What is the direction and guidance of higher authorities pertaining to the situation?
- What future conditions need to exist for success?

Identifying and understanding problems is essential to solving or addressing them. As the Current State is developed, there are often tensions (frictions, conflicts, and competitions) between relevant actors including geographic, demographic, economic, religious, and resource consumption trends. Combined, these tensions represent a set of interrelated problems (a system of problems) requiring resolution. With an understanding of the operational environment and associated problems, the commander and planning team consider an operational approach—the broad general actions and means to solve or manage identified problems.

Methodology

The ADM is incorporated into CE401 (Civil Engineering Professional Practice and Applications), a senior level one semester course, by applying a doctrinal military ‘design process’ to address complex civil engineering problems. The ADM is used in three different contexts, with varying degrees of application, to support several of the course objectives:

1. Describe challenges facing civil engineers in professional practice now and in the future.
2. Develop short-term and long-term professional goals, to include consideration of continuing education, and professional registration.
3. Apply the American Society of Civil Engineers Code of Ethics to the solution of ethical problems confronting a practicing engineer.
4. Communicate effectively in writing.
5. Explain the principles of sustainability.
6. Identify, analyze and address complex engineering problems that may include global, cultural, social, environmental, economic, and other factors.

Context 1 - Citizen Jane:

Students are introduced to the ADM, including Figure 1, and how it is similar and different to other problem-solving methodologies they are familiar with. Students watch and discuss portions of *Citizen Jane: Battle for the City* [5], a documentary that describes the struggle in the 1960s between Jane Jacobs, a writer and urban activist, and Robert Moses, an urban planner and master builder. Moses wanted to construct new highways through parts of New York City that would have required the destruction of neighborhoods and parks. Jacobs led the fight against Moses and was ultimately successful in preventing some of his plans from occurring. The intent of using the documentary is to provide an example of what a complex civil engineering problem look might look like, through the lens of the ADM’s Current State. The discussions are centered around the diverse group of actors (stakeholders), their relationships, and their differing interests and desires. The class essentially develops the narrative portion of a Current State from an ADM perspective. Although not part of the *Citizen Jane* documentary, the class also discusses how some of the same challenges might be present within some of the ideas outlined within ASCE’s Future World Vision.

Context 2 - Missouri River Case Study:

Students dive deeper into the ADM by conducting a case study of the Missouri River that includes several stakeholders north and south of the Gavins Point Dam, near Yankton, South Dakota. The case study examines the complex problem created by the drought conditions in 2004, when it was all about who gets the water and the wide ranging and conflicting interests on engineering, environmental and social issues with no obvious solution.

Students have four requirements associated with the case study. Their first requirement is to prepare a 500-600 word narrative describing the roles, interests and relationships of at least five of the stakeholders from the list below.

- Native Americans (north of Gavin's Point)
- Farmers (south of Gavin's Point)
- Barge Industry (MO and MS Rivers)
- Environmentalist
- Recreation (north of Gavin's Point)
- Hydropower (north of Gavin's Point)
- Water Supply and Nuclear Power Plants (south of Gavin's Point)
- Congress (SEN Bond (MO) and SEN Daschle (SD))
- States (MO, SD, ND, MT)

The stakeholders are then discussed in class so everyone has a shared understanding of all the key stakeholders.

The second requirement is for students to provide an initial assessment of the Current State (based on 2004) of the Missouri River Basin using the ADM. The Current State include a 400-500 word narrative and a graphic depiction (map), along with some guidelines for each:

Narrative should tell a story and address the following questions:

- Briefly describe the river basin including its hydrology. What has changed based on the addition of dams and the navigation channel?
- Who are the relevant stakeholders and why?
- Who are the relevant federal agencies and why?
- What are the relationships between the players?
- What is the guidance from the White House? Congress? States?
- What are the key challenges, laws, and policies impacting the situation?

Graphic Depiction (on provided Missouri River Basin Template)

- Highlight the location of Gavin's Point Dam
- Depict the stakeholders and their relationships with other stakeholders
- Every actor from the template must be located on the map. Use the map to depict spatial positioning between actors
- Highlight the location of the dams and navigation channel

Two to three students are asked to present their Current States to the class. As with the stakeholders, the Current State is discussed to ensure all students gain an appreciation for the

circumstances which made this a complex problem. Additionally, an “approved” Current State is provided to the entire class so there is a common operating picture as the case study moves forward.

Groups, representing most of the previously mentioned stakeholders and the US Army Corps of Engineers (USACE), are used for the last two requirements of the case study. The USACE is added as a stakeholder because they are responsible for operating the Missouri River. The third requirement is for each group to build upon the Current State and develop an Environmental Frame, which includes identifying problems with the Current State and describing the group’s desired end state. Groups are also required to explain how they would shape and integrate their approach to bring the situation closer to their desired Future State.

Students can develop their communication skills as they role play the various stakeholders in two mock town hall meetings conducted by USACE. Town halls are commonly used to provide information and to collect input from various stakeholders. One town hall is conducted north of Gavin’s Point in Pierre, SD, and the other south in Jefferson City, MO. The attendees at each town hall are outlined in Table 1 below:

Table 1: Town Hall Stakeholders

Pierre, SD (north of Gavin’s Point)	Jefferson City, MO (south of Gavin’s Point)
USACE – Omaha District	USACE – Kansas City District
Congressional Staffer (SEN Daschle’s office)	Congressional Staffer (SEN Bond’s office)
Environmentalists	Environmentalists
Native Americans	Farmers
Recreation Industry	Barge Industry
Hydro-Electric Power Industry	Nuclear Power Plant Industry

Students generally enjoy the town halls and do a great job enthusiastically role playing the various stakeholders they represent; thus, further highlighting the various complexities associated with the case study.

Context 3 - Green Brook Flood Mitigation Project

The final use of the ADM in CE401 involves the Green Brook Flood Mitigation Project, which is a current USACE project. The Green Brook Sub Basin is located within the Raritan River Basin in north-central New Jersey in the counties of Middlesex, Somerset and Union. It encompasses 13 municipalities and drains approximately 65 square miles of primarily urban and industrialized area. For the majority of the project area, the most damaging floods of record resulted from storms in 1973 and 1999 and resulted in eight deaths. The \$1.14B project began in 1999, is being funded incrementally, and is cost shared (75% Federal and 25% State of NJ). To date, slightly over 30% of the Federal funds have been received; therefore, the project is expected to continue for many years. [6]

At this point in the course, students are ready to apply the ADM. Students are provided several references and encouraged to research USACE's website associated with the Green Brook Project as they individually develop a Current State. Once the Current States have been developed and discussed in class, students are formed into groups of 3-4 and are told they will assume responsibility for the Green Brook Project and they must conduct a battle handover with the current project team and brief the New York District Engineer, or his representative near the end of the semester. In addition to the project documents they have already researched, students conduct site visits and meeting with the current project team to synthesize a wide variety of information pertaining to the project. The final step is for them to conduct a briefing to the USACE New York District Commander, or his designated representative (i.e. one of the instructors). Although not available in 2020 due to COVID response efforts, the District Commander received briefings from two or three teams previously. The briefings are conducted using the framework of the Current State and provide both confidence and relevance to using the ADM to address complex problems.

Wrap-Up Comments and Thoughts Moving Forward

CE401 was initially taught in 2019, so we are currently in the third offering of the course. The instructor team used feedback gained in 2019 to make some adjustments to case studies, and feel they are more appropriately scoped based on how the semester went and the qualitative feedback from 2020 that pertained specifically to the use of the ADM:

- It was a great course that looked at understanding complex problems.
- CE401 was great because our whole year of Civil majors was able to have class together. I also enjoyed the practical examples we went through that our instructors had commanded through. This led to great professional development experiences.
- Every instructor came to each class with great enthusiasm. They always exhibited extensive knowledge for the lesson material, coupled with real-world examples and experiences. I enjoyed attending this class.
- I absolutely loved CE401 and hope that this course remains relatively the same in the future. My hope is that the department of CME continues to re-emphasize the importance of engineers in society and how much we do in the background to solve the world's most complex engineering problems.
- I liked the mock Townhall meetings, and especially enjoyed the opportunity to wear a suit to class.
- At first, I thought the examples (Green Brook, Missouri River basin) were a little above our pay grade, but I really enjoyed the confidence gained in doing these examples.
- This course allowed me to solve real world problems and gave me a new look into engineering.

The graded events associated with each case study were used as direct indicators to contribute to the formal assessment of several course objectives, as described earlier in the Methodology section. The results for 2020 are shown below, which are similar to those from 2019. The instructor team assessed that all course objectives were solidly met, based on the USMA CE Program's course assessment criteria below, and as shown in Table 2:

Course Assessment criteria for Course Objectives:

- 1= Objective Not Met.** Objective clearly not met, most (75%) of the students did not achieve it.
- 2= Objective Marginally Met.** Objective met by half the students or minimally by most.
- 3= Objective Satisfactorily Met.** Objective clearly met by a solid majority (70%) of students.
- 4= Objective Solidly Met.** Objective clearly met by the vast majority (90%) of students.
- 5= Objective Clearly Met.** All students have achieved the objective and can demonstrate it.

* The definition of “meeting a course objective” is achieving a “C” level (70%) on the task.

Table 2: CE401 Course Assessment for 2020

Course Objective	Assessment	How Evaluated and Remarks
a. Describe challenges facing civil engineers in professional practice now and in the future.	4	All graded events in the course address this objective and students solidly met the requirements.
b. Develop short-term and long-term professional goals, to include consideration of continuing education, and professional registration.	4	This specific course objective is only directly addressed by the Career Paper, but is part of several discussions during the course.
c. Apply the American Society of Civil Engineers Code of Ethics to the solution of ethical problems confronting a practicing engineer.	4	This objective is addressed directly by the ethics paper and is included throughout the discussions associated with complex engineering problems.
d. Communicate effectively in writing.	3	The course includes several writing events, which are used in this assessment. Although a significantly less percentage would be classified as really good writers, more than 80% are clearly effective writers.
e. Explain the principles of sustainability.	4	There is only one requirement that currently addresses this objective, but it is sufficient to assess the students at 90% achievement.
f. Identify, analyze and solve complex engineering problems that may include global, cultural, social, environmental, economic, and other factors.	4	A significant portion of the course is designed to address this objective and the students were assessed as solidly achieving success in the objective.

Many of the graded events associated with the case studies in CE401 were also used as direct indicators for five of ABET Student Outcomes. The graded events are simply listed below. The overall attainment of each Student Outcome is contained in the program assessment and also includes other direct and indirect indicators; thus, that assessment is outside the scope of this paper.

SO #2: an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors;

- Army Design Methodology Background Paper
- Missouri River Case Study – Stakeholder Analysis
- Green Brook Case Study – Background and Stakeholder Analysis

SO #3: an ability to communicate effectively with a range of audiences;

- Army Design Methodology Background Paper
- Missouri River Case Study – Stakeholder Analysis
- Missouri River Case Study – Current State Analysis Presentation
- Green Brook Case Study – Background and Stakeholder Analysis
- Green Brook Case Study – Final Battle Handover Presentation

SO #4: an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts;

- Army Design Methodology Background Paper
- Missouri River Case Study – Stakeholder Analysis
- Green Brook Case Study – Background and Stakeholder Analysis

SO #5: an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives;

- Green Brook Case Study – Final Battle Handover Presentation

SO #7: an ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

- Sustainable Engineering Background and Problem Paper
- Army Design Methodology Background Paper

Overall, this class takes an interdisciplinary approach that integrates a methodology from the military profession into the context of complex civil engineering problems. It is a course that reinforces the technical skills and develops the operational skills students will need to address these multilayered, deep civil engineering problems. We feel it is important to educate and inspire our students to be ready to apply the Army Design Methodology to any complex problem, as we want them to instinctually develop an understanding of a problem *before* they try to solve it.

References

- [1] United States Military Academy (2020). *Mission Statement*. Accessed Jan 1, 2020. <https://www.westpoint.edu/>
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- [3] ABET, Inc. (2019). *Criteria for Accrediting Engineering Programs: Effective for Reviews During the 2019-2020 Accreditation Cycle*. ABET, Baltimore, MD.
- [4] Army Techniques Publication 5-0.1, “Army Design Methodology” July 2015. <https://armypubs.us.army.mil/doctrine/index.html>
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