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An Approximate Dynamic Programming Approach for Weapon System Financial Execution Management

Erich Morman—is an assistant professor at the Naval Postgraduate School in the Defense Resources Management Institute (DRMI). He received a BA in mathematics and economics (1996) from the University of Dayton, and an MS in systems engineering and operations research (2003) and a PhD in systems engineering and operations research (2013) from George Mason University. Prior to joining DRMI, Dr. Morman spent 17 years with the Missile Defense Agency (MDA) supporting various weapon system program offices in the area of Planning, Programming, Budgeting, and Execution (PPBE). While working for the MDA, he completed his dissertation, which focused on applications of reinforcement learning algorithms to improve fiscal year cash allocation decisions. Additionally, Dr. Morman spent nearly two years as a support contractor for the DoD's Suicide Prevention Office (DSPO) conducting measures of effectiveness and data analysis. [edmorman@nps.edu]

Jefferson Huang—is an assistant professor in the Operations Research Department at the Naval Postgraduate School. Prior to joining NPS in 2018, Dr. Huang was a postdoctoral associate with the School of Operations Research and Information Engineering at Cornell University. He received a PhD in applied mathematics in 2016 from Stony Brook University, with a dissertation on the computational complexity of algorithms for Markov decision processes. Huang also holds an MS in transportation from the Massachusetts Institute of Technology and a BS in civil and environmental engineering from the University of California at Berkeley. His research interests include applied probability, optimization under uncertainty, and operations management. [jefferson.huang@nps.edu]

Abstract

A fiscal year (FY) starts on 1 October and runs to 30 September of the following year. During this time frame, a Department of Defense (DoD) weapon system program office allocates financial resources to vendors working various projects. As the calendar gets closer to 30 September, program offices undergo a FY closeout review. During this time, considerable energy is invested in assessing cash utilization levels (disbursements) and taking corrective actions related to projects that are not sufficiently spending their allocated funds. Since the DoD operates under a use-or-lose budgetary environment, projects that are behind in meeting their spending goals are at risk of losing a portion, if not all, of their unutilized allocated funding. This financial closeout process is an annual tradition that involves considerable time and resources. The purpose of this research is to assess the viability of using approximate dynamic programming (ADP) to create and manage financial execution plans throughout the FY. The research examines the difficulties of adopting ADP as an execution management tool as well as the potential this methodology has for reducing the total amount of unspent money a program office has on hand during the FY closeout period.

Introduction

As with most public sector organizations, Department of Defense (DoD) money that is managed by weapon system program offices contains an expiration point. Dollars not spent or utilized within a defined timeframe are taken away and are no longer available as a resource to pay for support projects or activities. Organizations that manage money with this type of constraint are operating with what is informally referred to as a use-or-lose budget. Functioning under this framework, weapon system program managers and their financial officers must consider how to strategically allocate funding over an annual time horizon that balances between the immediate day-to-day cash allocation decisions and the aggregate



long-term impact these decisions will have on the program office's fiscal year (FY) financial closeout position.

Although a weapon system program manager (PM) is ultimately tasked with efficiently and effectively delivering a weapon system platform or capability, it is the responsibility of their business financial manager (BFM) to ensure that the flow of financial resources is conducted in a manner that complements the PM's mission. While analyzing FY2012 DoD budget data, Conley et al. (2014) point out that the rate of spending as measured by expenditure rates across the DoD was declining for several years prior. The report highlights how spending benchmarks issued by the Office of the Secretary of Defense (OSD) are based on 30 years of financial execution history. Theoretically, this means that DoD spending benchmarks are correlated to the work schedules and associated spending patterns that are emblematic of the acquisition efforts within a typical DoD weapon system program office. However, the actual acquisition experience for each weapon system program is unique and always evolving, compounding the difficulties faced by PMs, BFMs, and their staff.

Serving as additional evidence that there are cash flow problems within the DoD, a 2013 Defense Acquisition University (DAU) study provides a summary of survey results from 229 DoD personnel that responded to questions regarding the top challenges they see as factors impeding cash flow and hindering the ability of a program office to meet OSD's spending benchmarks (Tremaine & Seligman, 2013). In their report, they provide a summary of key factors that program offices indicate are barriers to improving spending efficiency. The report highlights a myriad of growing challenges and endogenous issues that DoD personnel working in a weapon system program office contend with on a routine basis. The following is a short list of standard problems that are impediments and bottlenecks to efficiently allocating and spending money in a timely manner:¹

- The more routine use of continuing resolution authorities (CRAs) by Congress to issue yearly budgets through multiple installments
- Congressional marks or program cuts
- Delays in contract negotiations and awards
- A high volume of contract modifications related to warfighter requirement changes
- Constant rotation or shortages of key program office personnel
- Complications with getting funding documents issued and approved in a timely manner
- An inability to obtain timely data on contractor outlays or expenditure positions

¹ The list includes items from the survey results of Tremaine & Seligman (2013) as well as factors mentioned in Cooley & Ruhm (2014). Some of the additional items contained in the list are from the author's first-hand knowledge of working directly for DoD weapon system program offices for 15 years.



A question to consider is whether or not DoD financial execution performance has improved at all over the past five to six years since the publication of the Conley et al. (2014) and Tremaine & Seligman (2013) reports. However, it is difficult to find open-source data or information that suggests that weapon system expenditure performance is improving. Rather, popular press headlines that currently occur during the traditional annual FY closeout period suggest that efficient cash flow remains a problem and is becoming worse (Mehta, 2018; Moritz-Rabson, 2018).

In this study, we look to the use of ADP as a solution approach to the financial execution problem for weapon system program offices. Fundamentally, the financial execution problem confronted by program offices is a dynamic sequential resource allocation problem, where the resource variable in question is the amount of cash that is committed to projects on a daily basis. Although use-or-lose budget resource problems are not explicitly addressed, there are a number of publications that highlight ADP's applicability to solving other types of resource allocation problems. ADP contains a number of features that make it an attractive tool for the financial execution challenges of weapon system program offices that are operating with use-or-lose budgets. First, ADP is a well-established prescriptive analytical tool. It is designed to create a sequential decision-making policy. In the case of the financial execution problem, a program office must consider a cash allocation policy over a fiscal year that provides an appropriate level or installments of funding to projects that minimize the amount of vulnerable end-of-year money. Second, ADP "learns" a financial execution policy by iteratively interacting with the decision environment. Lastly, the ADP methodology can be adjusted to incorporate the uncertainty and stochastic information of separate program offices. In this manner, ADP can be specialized for individual program offices to more readily account for their unique financial challenges and circumstances.

The remainder of the paper is organized as follows. In the following section, we provide a short literature survey that includes background and context information on ADP. After that is an overview of the DoD financial execution process. We provide a dynamic programming formulation of the use-or-lose program office budget problem in the following section, and then a numerical example. The final section includes conclusions and directions for future research.

Literature Review

Dynamic programming has a history as a mathematical tool for modeling and solving sequential decision-making problems that traces back to the 1950s and early 1960s. A number of the seminal works at this time that set the foundations for dynamic programming include publications by Bellman (1954), Bellman (1957), Howard (1960), and Bellman and Dreyfus

(1962). Since then, the dynamic programming field has grown to include newer techniques such as ADP that address the inherent difficulties with using traditional dynamic programming solution approaches and the complexities of real-world problem structures. Unfortunately, as pointed out by Powell (2009), the various sub-communities working to advance dynamic programming concepts use different vernacular and notional symbols to essentially express the same fundamental ideas. For further discussion on relationships between ADP and artificial intelligence, see, for example, Powell (2010), Tsitsiklis (2010), and Gosavi (2009).



Overview of DoD Financial Execution

A program office acquisition environment is interwoven with a number of important schedules and critical timelines. The more prominent time-oriented processes that a PM must adhere to include (1) a schedule for budget preparation, review, submission, and approval; (2) the timeline for prime contract awards or modifications which can include periods for request for proposals (RFPs), time for proposal preparations and responses to proposal questions, review and assessment of submitted proposals, and time for resolving a possible bid protest after a contract award is announced; (3) the fiscal year calendar that involves mid-year financial reviews, end-of-year closeout reviews, and even possible monthly spending benchmark reviews; and (4) programmatic schedules with well-defined milestone review thresholds. Unfortunately, these separate process schedules do not always complement one another or align cohesively in a streamlined method that facilitates the delivery of a weapon system platform.

It's tough to manage an event-driven program in a schedule-driven budget.

—William T. Cooley (Cooley & Ruhm, 2014)

The FY calendar includes important start dates (1 October) and stop dates (30 September) that are necessary for comptrollers and budgetary personnel to track and manage funding that supports the acquisition of a weapon system. However, the fact that the fiscal year calendar starts on 1 October and ends on 30 September has little to do with timing for parts, materials, test events, or other programmatic activities necessary for fielding a weapon system. Nonetheless, the reality is that these dates have considerable influence on when funding is available and the timing of financial commitment actions or cash allocation decisions a program office is likely to take. In the remainder of this section, we take a closer look at different aspects of the DoD financial execution environment: stages of a transaction, appropriation categories, and spending timelines and benchmarks.

Stages of a Transaction

Once a cash determination is made to allocate money for a particular project, the transaction moves through formal DoD financial execution stages. The flow chart in Figure 1 from the Army's financial management operations field manual provides the order of execution stages (Department of the Army, 2014). This financial execution process is the standard used throughout the DoD. The first step is the authorization of a funding transaction. After the appropriate authorization documentation is completed and signed, the funding is said to be committed. Committing dollars is an important first step in the execution process that occurs prior to the actual movement of money to a recipient. This initial stage serves as a cross-check that helps to avoid anti-deficiency violations that result when funding is issued to a contractor or service provider in excess of what is available. Committed dollars are then used to prepare formal and legal contractual obligations between the weapon system program office and a hired vendor. The obligation creates a legal reservation of funds and represents the allocated funds that are available for paying for a project. As work is performed on the project, expenses are accrued. A vendor then provides invoices to the program office for which payment is issued. Once payment is received by the vendor or contractor the funding is considered disbursed. The terms outlays and expenditures can also be used to refer to disbursed funding. Throughout the course of a fiscal year, the financial execution status of a weapon system program office is routinely tracked and assessed. The basis of measurement used to evaluate fiscal year execution is the amount of overall budget that currently resides in each of these respective stages. However, significant attention is paid particularly to the obligation and expenditure positions of a weapon system program. To highlight the magnitude of the amount of funding that



moves through this process each year, the Defense Finance and Accounting Service (DFAS) reported that it paid out \$554 billion in disbursements for FY2017 and \$558 billion in disbursements for FY2018 (DFAS, n.d.).

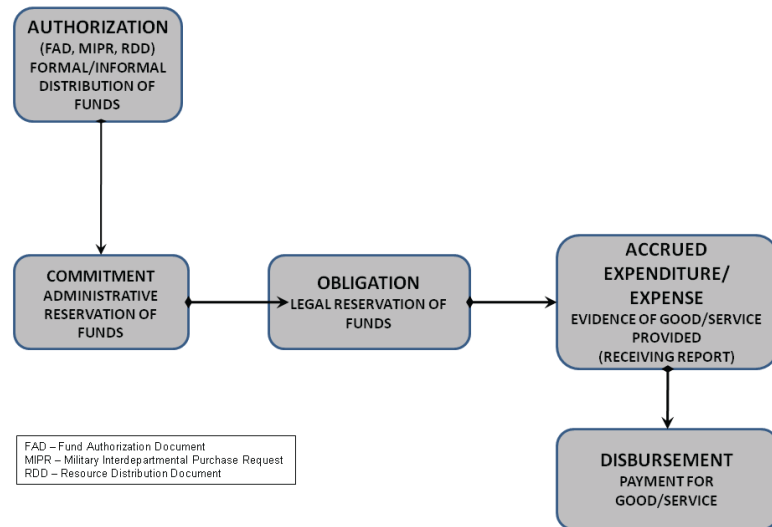


Figure 1. Stages of a Transaction

Appropriation Categories

An additional factor that contributes to the complexity of financial execution at the DoD is the agency's use of different appropriation categories. When creating a budget for a weapon system program office, similar types of projects or work are categorized together in the same appropriation category. Furthermore, the activities of the separate appropriation categories are funded with unique types of money or with what is more commonly referred to as different "colors"-of-money. These categorizations of activities and funding allow regulators, comptrollers, and other oversight officials to have better insight on how money is spent and on what activities constitute most of the defense budget. However, weapon system program managers and their financial staff are now encumbered with the additional responsibility of managing their programs to correct appropriation categories and must account for these delineations when making decisions related to budget preparations, funding requests, and cash allocations. The following is a short summary of the more common appropriations:²

- **Military Personnel (MILPERS):** Funds salary and benefits of military personnel to include active duty, reserve, as well as DoD government civilian employees.
- **Research, Development, Test, and Evaluation (RDT&E):** Funds projects and initiatives that support program research, technology development, engineering development, manufacturing development, and programmatic test events.

² More extensive details regarding what each appropriation category funds can be found in the DoD Financial Management Regulation (FMR) 7000.14-R, Volumes 2a and 2b.

- Procurement: Funds the purchase of military equipment and weapon systems to include the production and fielding costs associated with the assets.
- Operation and Maintenance (O&M): Funds activities directly related to the operations, servicing, and upkeep of fielding military systems and platforms.
- Military Construction (MILCON): Funds construction projects related to buildings, facilities, and property improvement efforts that directly support the operations and maintenance of a fielded weapon system.

Spending Timelines and Benchmarks

Each of the DoD's appropriation categories are subject to guidance regarding the amount of time allowable for moving money through the different stages of a transaction, as described previously. Particular attention is paid to the rate at which funding is obligated and disbursed. Within DoD financial execution, regardless of the appropriation category, money exists in two possible periods: (1) the current period and (2) the expired period. Weapon system program offices must ensure all new obligation actions occur during the current period. The length of the current period is different for each "colors"-of-money or appropriation category. O&M and MILPERS have the shortest current period at one year, RDT&E funding has a two-year current period time frame, the current period for procurement funding can range between three to five years, and military construction has the longest current period at five years. Once the current period for an appropriation has lapsed, the funding moves into an expired period. Irrespective of the appropriation, the expired period lasts for five years once the current period is over. During the expired period, no new obligations are allowed. However, funds that were already obligated during the current period can be expensed and recorded as an outlay. Once the expired period has lapsed, the funding is considered canceled and can no longer be used for obligations or expenditures.

The current period and expired period set strict cash flow stopping points; however, the cash flow performance of a weapon system program office is judged on a continual basis. If for any reason it appears that a program office is falling too far behind in its ability to effectively issue and spend money, it runs the risk of being perceived as having too large of a budget for its mission. Comptroller officials and leadership at a more senior level to the program office have the authority to reallocate funding from underperforming program offices to other program offices or activities. Thus, there is an imperative for program offices to maintain constant vigilance of their financial execution position and to make quality cash allocations to contracts and vendors that will expeditiously accrue and expense their funding allotments.

From the perspective of purely protecting funds in a use-or-lose environment, the sooner money moves through the complete stages of a transaction, the better it is for the program office. Unfortunately, programmatic activities and acquisition initiatives that require funding are not always conveniently timed or necessarily ready to receive funds in a manner that allows program offices to keep pace with the spending benchmarks in Table 1. Furthermore, if a program office expends funding too quickly, it runs the risk of running over its budget before the fiscal year is over. Much like underutilizing funds, overrunning a budget is another financial execution position that a program office needs to avoid and must take into consideration when making cash allocation determinations.



Table 1. DoD Spending Guidance by Appropriation

	Month	RDT&E		Procurement		O&M		MILCON	
		Obl.	Exp.	Obl.	Exp.	Obl.	Exp.	Obl.	Exp.
First Year of Availability	Oct	7.5%	4.6%	6.7%	N/A	8.3%	6.3%	5.4%	1.2%
	Nov	15.0%	9.2%	13.3%	N/A	16.7%	12.5%	10.8%	2.3%
	Dec	22.5%	13.8%	20.0%	N/A	25.0%	18.8%	16.3%	3.5%
	Jan	30.0%	18.3%	26.7%	N/A	33.3%	25.0%	21.7%	4.7%
	Feb	37.5%	22.9%	33.3%	N/A	41.7%	31.3%	27.1%	5.8%
	Mar	45.0%	27.5%	40.0%	N/A	50.0%	37.5%	32.5%	7.0%
	Apr	52.5%	32.1%	46.7%	N/A	58.3%	43.8%	37.9%	8.2%
	May	60.0%	36.7%	53.3%	N/A	66.7%	50.0%	43.3%	9.3%
	Jun	67.5%	41.3%	60.0%	N/A	75.0%	56.3%	48.8%	10.5%
	Jul	75.0%	45.8%	66.7%	N/A	83.3%	62.5%	54.2%	11.7%
Second Year of Availability	Oct	90.8%	57.9%	80.8%	N/A	100.0%	77.1%	67.1%	18.1%
	Nov	91.7%	60.8%	81.7%	N/A	100.0%	79.2%	69.2%	22.2%
	Dec	92.5%	63.8%	82.5%	N/A	100.0%	81.3%	71.3%	26.3%
	Jan	93.3%	66.7%	83.3%	N/A	100.0%	83.3%	73.3%	30.3%
	Feb	94.2%	69.6%	84.2%	N/A	100.0%	85.4%	75.4%	34.4%
	Mar	95.0%	72.5%	85.0%	N/A	100.0%	87.5%	77.5%	38.5%
	Apr	95.8%	75.4%	85.8%	N/A	100.0%	89.6%	79.6%	42.6%
	May	96.7%	78.3%	86.7%	N/A	100.0%	91.7%	81.7%	46.7%
	Jun	97.5%	81.3%	87.5%	N/A	100.0%	93.8%	83.8%	50.8%
	Jul	98.3%	84.2%	88.3%	N/A	100.0%	95.8%	85.8%	54.8%
Third Year of Availability	Oct	100.0%	90.8%	90.8%	N/A	100.0%	100.0%	90.4%	65.5%
	Nov	100.0%	91.7%	91.7%	N/A	100.0%	100.0%	90.8%	68.1%
	Dec	100.0%	92.5%	92.5%	N/A	100.0%	100.0%	91.3%	70.6%
	Jan	100.0%	93.3%	93.3%	N/A	100.0%	100.0%	91.7%	73.2%
	Feb	100.0%	94.2%	94.2%	N/A	100.0%	100.0%	92.1%	75.7%
	Mar	100.0%	95.0%	95.0%	N/A	100.0%	100.0%	92.5%	78.3%
	Apr	100.0%	95.8%	95.8%	N/A	100.0%	100.0%	92.9%	80.8%
	May	100.0%	96.7%	96.7%	N/A	100.0%	100.0%	93.3%	83.3%
	Jun	100.0%	97.5%	97.5%	N/A	100.0%	100.0%	93.8%	85.9%
	Jul	100.0%	98.3%	98.3%	N/A	100.0%	100.0%	94.2%	88.4%
	Aug	100.0%	99.2%	99.2%	N/A	100.0%	100.0%	94.6%	91.0%
	Sep	100.0%	100.0%	100.0%	N/A	100.0%	100.0%	95.0%	93.5%

Table 1 provides DoD spending guidance that serves to assist program offices with determining if their cash flow performance is maintaining an adequate pace. A close examination of the information in Table 1 reinforces the concept that there are different benchmark spending expectations for the different “colors”-of-money. Not shown on the chart is MILPER. Since this appropriation is primarily for salaries, its expenditure cycle occurs at a relatively predictable and standard pace. Also, procurement funding does not show a monthly expenditure rate. Since procurement is used to buy and support the purchase of large weapon systems and platform end items, its expenditures often occur in single large sums, as opposed to small monthly incremental allotments. However, the remaining three appropriations—RDT&E, O&M, MILCON—represent initiatives that a program office could fund and receive outlays against in relatively smaller installment amounts to projects. Table 1 reveals that after the first year of availability, the expectation is that RDT&E funds will be 55% expended, O&M funds will be 75% expended, and MILCON funding will be 14% expended. It is these appropriations that are of interest for use in an



ADP approach for financial execution management. ADP is ideal for either appropriation categories or specific projects where a program office would consider issuing staggered multiple allotments of cash or commitment actions to pay for the activity. This cash allocation approach is one where the program office is attempting to determine if the contractor or vendor will spend the current funds allotted to it before another installment of money is provided.

A Financial Execution Management Model

The following section provides a mathematical formulation for the financial execution problem of weapon system program offices. We define critical variables of the financial execution system and adopt them to a dynamic programming formulation.

At the start of the fiscal year, a budget of bud_i is allocated to each of a finite number I of projects $i \in \{1, \dots, I\}$. During each of a finite number of time periods $t = 1, \dots, T$, each project i has a (random) disbursement need $\widehat{D}_{i,t}$, which must be satisfied from the current “inventory” of funds that have been committed and have become available to project i by period t .

The agency’s objective is to allocate funds in a way that tracks the actual disbursements as closely as possible. This is reflected in the model as follows. For $t = 1, \dots, T$, let $b_{i,t}^c$ denote the total amount committed to project i by the end of period t . In particular,

$$b_{i,t}^c = \sum_{s=1}^t x_{i,s}$$

where $b_{i,s}^c = 0$ for $s \leq 0$. Moreover, we assume that at the start of each period, the agency has a cumulative disbursement schedule $\bar{b}_{i,t}^d = [\bar{b}_{i,t}^d(1), \dots, \bar{b}_{i,t}^d(T)]$ for each project i , where $\bar{b}_{i,t}^d(n)$ denotes the current (i.e., at the end of period t) projected amount of money that project i will need during time n . Once the actual disbursement requirement $\widehat{D}_{i,t}$ for project i during period t is revealed, the disbursements for each project i are updated according to a given function F^d , so that

$$(\bar{b}_{1,t+1}^d, \dots, \bar{b}_{I,t+1}^d) = F^d[(\bar{b}_{1,t}^d, \dots, \bar{b}_{I,t}^d), (\widehat{D}_{1,t}, \dots, \widehat{D}_{I,t})]. \quad (1)$$

At the start of each period $t = 1, \dots, T$, and for each project i , the agency must decide on a total amount x_t to commit. This amount is allocated to the I projects based on fixed allocation rules and is subject to constraints that depend on the cumulative commitments $b_{i,t}^c$ and current disbursement schedule $\bar{b}_{i,t}^d$ for each project i . Given $b_{i,t}^c, \dots, b_{I,t}^c$ and $\bar{b}_{1,t}^d, \dots, \bar{b}_{I,t}^d$, let

$$\chi(b_{i,t}^c, \dots, b_{I,t}^c, \bar{b}_{1,t}^d, \dots, \bar{b}_{I,t}^d).$$



Denote the corresponding set of feasible total commitment amounts x_t . If the agency elects to commit x_t , the cumulative commitments for each project i are updated according to a given function F^c (describing a given allocation rule), so that

$$(b_{1,t+1}^c, \dots, b_{I,t+1}^c) = F^c[(b_{1,t}^c, \dots, b_{I,t}^c), x_t]. \quad (2)$$

If the agency commits x_t at time t , its associated “cost” for that time period is the absolute difference between the cumulative amount committed by the end of time t , and the cumulative projected disbursement by the end of time $t + \alpha_i$ (which is when x_t first becomes available for disbursement), that is,

$$\left| \sum_{i=1}^I b_{i,t-1}^c + x_t - \sum_{i=1}^I \bar{b}_{i,t}^d(t + \alpha_i) \right|.$$

The term α_i is a project specific sensitivity parameter. The choice α_i reflects the number of time periods beyond the current time period t that a program office wants to provide an incremental amount of funding that will sufficiently cover project i costs occurring between time periods t and $t + \alpha_i$.

Formulation as a Dynamic Program

To formulate the agency’s sequential decision problem as a dynamic program, we need to specify the *state variables*, the *decision variables*, the *exogenous information processes*, *transition function*, and the *objective function*.

State Variables: For $t = 1, \dots, T$, the *state* S_t at the start of period t is a pair that includes, for each project $i \in \{1, \dots, I\}$, the values $b_{i,t-1}^c$ (i.e., the cumulative commitment to project i by the end of time $t-1$) and $\bar{b}_{i,t-1}^d$ (i.e., the projected disbursement schedule for project i as of the end of period $t - 1$), that is,

$$S_t = [(b_{1,t-1}^c, \dots, b_{I,t-1}^c), (\bar{b}_{1,t-1}^d, \dots, \bar{b}_{I,t-1}^d)].$$

Decision Variables: For $t = 1, \dots, T$ and $i = 1, \dots, I$ the *decision variable* x_t denotes the amount that the agency commits at the start of time t . If the start at the start of period t is S_t , then x_t is constrained to satisfy

$$x_t \in A(S_t) := \chi(b_{1,t}^c, \dots, b_{I,t}^c, \bar{b}_{1,t}^d, \dots, \bar{b}_{I,t-1}^d).$$

Exogenous Information Process: There is a single exogenous information process $\{\hat{D}_{i,t}\}_{t=1}^T$ associated with each project i , where $\hat{D}_{i,t}$ are simulated actual disbursement requirements for each project i during period t .

Transition Function: Suppose that at the start of period t , the state is S_t . If the decision $x_t = (x_{1,t}, \dots, x_{I,t})$ is made, and the exogenous information for that period is $\hat{D}_t = (\hat{D}_{1,t}, \dots, \hat{D}_{I,t})$, then the state at the start of period $t + 1$ is

$$\begin{aligned} S_{t+1} &= S^M(S_t, x_t, \hat{D}_t) \\ &= [(b_{1,t}^c, \dots, b_{I,t}^c)(\bar{b}_{1,t}^d, \dots, \bar{b}_{I,t-1}^d)] \end{aligned}$$



$$= \left[F^c \left((b_{1,t-1}^c, \dots, b_{I,t-1}^c), x_t \right), F^d \left((\bar{b}_{1,t-1}^d, \dots, \bar{b}_{I,t-1}^d), (\hat{D}_{1,t}, \dots, \hat{D}_{I,t}) \right) \right],$$

where F^c and F^d come from (2) and (1), respectively. Figure 2 depicts the relationship that exists between the *state variables* S_t , *decision variables* x_t , and *exogenous information process* $\hat{D}_t$. At the beginning of a time period t , the financial execution status of a program office is captured by S_t which includes the cumulative commitment amounts and project disbursement schedules for each project i . At this point, exogenous information $\hat{D}_t$ regarding the previous time period's disbursements is revealed. The decision process utilizes information from the state position S_t and exogenous information $\hat{D}_t$ to select a commitment action x_t regarding the amount of additional incremental funding to allocate to each project i . This commitment action x_t , along with our knowledge regarding the current actual project disbursement amounts $\hat{D}_t$, allows our decision system to step forward one time period and into the next state position S_{t+1} , which contains updated information regarding our program office's cumulative commitment amounts and project disbursement schedules. The process continues for a pre-defined limited number T of time periods or decision periods t .

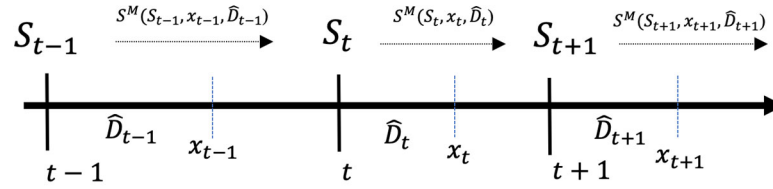


Figure 2. State-to-State Transitions

Objective Function: Suppose that at the start of period t , the state is S_t and the decision x_t is made. Then the corresponding *contribution* of period t is

$$\hat{C}(S_t, x_t) := - \left| \sum_{i=1}^I b_{i,t-1}^c + x_t - \sum_{i=1}^I \bar{b}_{i,t-1}^d (t + \alpha_i) \right|. \quad (3)$$

The objective is to find a policy that maximizes the expected total contribution over the T periods, that is, a policy that maximizes

$$\mathbb{E} \left\{ \sum_{t=1}^T \hat{C}(S_t, x_t) | S_0 \right\}.$$

Cash Allocation Example

We now consider the simple case of allocating funding for a single project with a total project budget $bud_1 = 27$. We define the time period t as a month and consider the cash allocation process for this single project over a fiscal year horizon $T = 12$ months. The choice of t reflects the frequency of how often a program office wants to assess their financial execution status and make an allotment of funding decision x_t across all the projects within their budget. Additionally, we'll select $\alpha_1 = 2$, to indicate that the program office wants to consider funding allotments in amounts that cover three-month time frames. An initial cumulative disbursement schedule $b_{i,t}^d$ is created from either a direct vendor quote, similar work completed in the past, or from any other viable technique available to the program office that can be used to create an initial spend plan forecast. For our single

project, we'll assume the following cumulative disbursement schedule in millions of dollars (\$M):

$$\bar{b}_{1,1}^d = [0,0,0,3,6,9,12,15,18,21,24,27].$$

This disbursement profile represents a project that starts work in the fourth month of the fiscal year, January, and requires \$3M per month for the remainder of the fiscal year.

Let's consider a case where the decision system arrives at time period $t = 4$, January, with $S_t = (6, [0,0,0,3,6,9,12,15,18,21,24,27])$. At this point, \$6M are committed to the project and \$0M are disbursed. The decision system makes a commitment action according to (3). Given that $\alpha_1 = 2$, the next allocation of funding will attempt to bring the current total committed funding level $b_{1,4}^c$ up to a level that matches as close as possible the estimated cumulative disbursement amount for March (time period $t + 2$). In our example, we'll assume that the choice for the next allotment of funding is \$3M. The decision system moves into the next time period, $t = 5$, February. At this point, exogenous information is revealed regarding actual disbursements that occurred in time period $t = 4$. This information is then used to create an updated cumulative disbursement schedule. For example, if the actual disbursement amount in January was only \$1M as opposed to the anticipated \$3M that was expected, an updated disbursement schedule might look like the following

$$\bar{b}_{1,5}^d = [0,0,0,1,3,6,9,12,16,20,24,27].$$

The implication is that the contractor supporting the work fell behind schedule during the month of January; however, the updated cumulative disbursement schedule indicates a belief that the contractor will be able to make up the additional work prior to the end of the fiscal year and will still require a full \$27M to pay for the project prior to the end of the 12-month period.

Curse of Dimensionality

One drawback of using the dynamic programming formulation for solving the financial execution problem is that it suffers from the "curse of dimensionality," which is a common issue for many optimization modeling approaches. Using the single project scenario described in the previous section, we can consider the computational demands of our decision system based on the size of the action space x_t and state-space S_t . In order to determine these dimensions, we will first need to make an assumption about the discretized amount with which our project receives and disburses dollars. For simplicity, we assume money is received and spent to the nearest \$1M increment. Additionally, we need to make another assumption about the range of variability that can occur with our simulated exogenous data $\hat{D}_{1,t}$. In this case, we'll assume that disbursements can occur with variability of +\$2M to -\$2M, above and below the forecasted amount for a given time period t . Given these parameters, we can now calculate both the sizes of both the action-space and state-space.

Given that the project receives money to the nearest \$1M increments, this means that for each time period t , there are 28 possible commitment or de-commitment actions to our \$27M project. De-commitment actions are allowed as long as sufficient funding remains committed to the project to cover all expenses (disbursements) that have occurred to date. The state-space is defined as the combination of our cumulative commitment amount $b_{1,t}^c$ and disbursement schedule $\bar{b}_{1,t}^d$. For the \$27M project, there are 28 possible values for the



scalar $b_{1,t}^c$. Furthermore, since we are anticipating disbursements to occur in nine out of our 12-month time frame, there are 5^9 possible vectors combinations for $\bar{b}_{1,t}^d$, and when combined with the 28 possible values of $b_{1,t}^c$ means that there are over 54 million state-space possibilities. Even for this single project situation, to model all possible outcomes for all the possible state-action pairings is computationally intractable. This difficulty is further exacerbated when we consider budget scenarios that examine multiple projects simultaneously.

As an alternative, we consider using an approximate dynamic programming (ADP) modeling approach to the financial execution problem. ADP allows us to estimate a “good” decision-making solution without having to explicitly enumerate and calculate the values of all possible action-outcome pairings. Rather, it provides a means of approximating state-space values through the use of Bellman’s formula:

$$V_t(S_t) = \max_{x_t} (\hat{C}(S_t, x_t) + \gamma \mathbb{E}\{V_{t+1}(S_{t+1})|S_0\}).$$

Bellman’s formulation contains two components. It retains the *contribution* from the previously stated objective function, $\hat{C}(S_t, x_t)$, and combines with it a discounted expected value of the state the decision system arrives at as a result of the action x_t taken at time period t . Through the use of simulation, the ADP approach allows us to approximate or “learn” the values of state-spaces in our decision system. As a result, the ADP algorithm can generate a cash allocation policy that directs a program office to allocate funding during each time period t to successively move the decision-maker from one high valued state-space (financial execution position) to another high valued-state space position. Therefore, the cash allocation policy generated by the ADP algorithm will balance between allocation decisions taken earlier in the FY with those generated later, creating a sequential cash allocation policy that limits that amount of over-committed funding without shortchanging funding for projects.

Conclusion

This paper presents a framework for integrating ADP as a solution approach to DoD financial execution management. At the end of each FY, millions of unspent dollars are returned by weapon system program offices to DoD comptrollers as a result of use-or-lose budget environments. Currently, traditional FY cash allocation strategies implemented by program offices are myopic and risk projects receiving more funding than what can be spent within the FY calendar. ADP offers an alternative analytical tool that creates a sequential cash allocation plan balancing between the current allotment of funding to a project and the final end of year financial position of a project.

The next steps of this research involve testing the ADP algorithm in a theoretical DoD financial execution construct. ADP is a solution approach that contains flexibility that allows its structure to be modified to accommodate different parameters and facets that are unique to separate program offices. Further work will focus on experimenting with three of our ADP problem variables and determining how they can be used to customize our ADP algorithms. First, we will consider how different definitions of the epoch period t will impact the effectiveness of our model. In the example provided, t represented making a cash allocation decision, x_t , every month. Other options for t can include weekly or daily epochs. One rationale for changing the definition of t is to be able to better align it to the actual decision periods used by program offices. Another reason would be to evaluate to what extent making more cash allocation or fewer cash allocation decisions over a FY has on the



objective of reducing the total amount of vulnerable end of year overcommitted funding. Another feature to closely examine is the sensitivity variable α_i . The value α_i is a parameter that establishes how many time periods, t , into the future the current allotment of cash will be able to pay for project disbursements. In the above example, we defined $\alpha_i = 2$, meaning that our objective function formulation would pick cash allocation amounts that funded projects for the next three months. Realistically, this value would be dynamic and not static; its value would be dependent on the point in time in the fiscal year in which a cash allocation decision is being made. If it is early in the FY, program office may be comfortable with setting α_i at a larger value given that the contractor has a longer time period before the end of the FY to utilize the money, and then slowly reducing the parameter α_i as the FY calendar starts to approach the end of the year. Another strategy to use if the program office is operating under a CRA is to set α_i to the length of time of the CRA. Under this scenario, program offices are aligning a project's cash allocation with the CRA timeframe. Lastly, we look to consider different ways of defining the exogenous data $\widehat{D}_t$. At the start of each time period t , the ADP model simulates a sample of exogenous data $\widehat{D}_t$ and uses the information to define the current period's state-space S_t . The variable $\widehat{D}_t$ represents both the expenses (i.e., disbursement information) that occurred for a project in the previous time period along with the strategy for how this information is used to update the cumulative disbursement schedule $\bar{b}_{i,t}^d$. To provide more fidelity to the ADP model, $\widehat{D}_t$ can be uniquely defined for each project. For example, $\widehat{D}_t$ would take into consideration any available historical spending data on the project as well as subject matter expert input specifically related to the execution management of the project.

Reference List

- Bellman, R. (1954). The theory of dynamic programming. *Bulletin of the American Mathematical Society*, 60(6), 503–515.
- Bellman, R. (1957). *Dynamic programming*. Princeton, NJ: Princeton University Press.
- Bellman, E., & Dreyfus, S. (1962). *Applied dynamic programming*. Princeton, NJ: Princeton University Press.
- Cooley, W. T., & Ruhm, B. C. (2014). *A guide for DoD program managers*. Fort Belvoir, VA: Defense Acquisition University Press.
- Conley, K. M., Dominy, J. R., Kneece, R. R., Jr., Mandelbaum, J., & Whitehead, S. K. (2014). *Implications of DoD funds execution policy for acquisition program management*. Alexandria, VA: Institute for Defense Analysis.
- Defense Finance Accounting Service (DFAS). (n.d.). Agency overview. Retrieved from <https://www.dfas.mil/pressroom/aboutdfas.html>
- Department of the Army. (2014). *Financial Management Operations* (FM 1-06). Retrieved from https://armypubs.army.mil/epubs/DR_pubs/DR_a/pdf/web/fm1_06.pdf
- Gosavi, A. (2003). Reinforcement learning: A tutorial survey and recent advances. *INFORMS Journal on Computing*, 21(2), 178–192.
- Howard, R. (1960). *Dynamic programming and Markov processes*. Cambridge, MA: MIT Press.
- Mehta, A. (2018, October 1). DoD hands out \$7.54 billion in year-end contract bonanza. *DefenseNews*.



- Moritz-Rabson, D. (2018, September 28). Pentagon rushes to spend billions before end of month. *Newsweek*.
- Powell, W. B. (2009). What you should know about approximate dynamic programming. *Naval Research Logistics*, 56, 239–249.
- Powell, W. B. (2010). Merging AI and OR to solve high-dimensional stochastic optimization problems using approximate dynamic programming. *INFORMS Journal on Computing*, 22(1), 2–17.
- Tremaine, R. L., & Seligman, D. J. (2013). OSD's obligation and expenditure rate goals: An examination of the factors contributing to the interference. Fort Belvoir, VA: Defense Acquisition University.
- Tskitsiklis, J. N. (2010). Perspectives on stochastic optimization over time. *INFORMS Journal on Computing*, 22(1), 18–19.





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