NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

MODELING THE ARMY'S MODERNIZATION STRATEGY IN RESPONSE TO FISCAL CONSTRAINTS: A LINEAR PROGRAMMING APPROACH

by

Kert St. John

June 2021

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REPORT DOCUMENTATION PAGE			*Form Approved OMB No. 0704-0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington, DC 20503.			
1. AGENCY USE ONLY ***(Leave blank)***	**2. REPORT DATE** June 2021	**3. REPORT TYPE AND DATES COVERED** Master's thesis	
4. TITLE AND SUBTITLE MODELING THE ARMY'S MODERNIZATION STRATEGY IN RESPONSE TO FISCAL CONSTRAINTS: A LINEAR PROGRAMMING APPROACH			**5. FUNDING NUMBERS**
6. AUTHOR(S) Kert St. John			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000			**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A			**10. SPONSORING / MONITORING AGENCY REPORT NUMBER**
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.			
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release. Distribution is unlimited.			**12b. DISTRIBUTION CODE** A

13. ABSTRACT (maximum 200 words)

In 2018, the Army Futures Command (AFC) was established to modernize the Army and ensure the Army and its soldiers outmatch their adversaries in future conflicts. The Army's modernization efforts include eight priorities encompassing 34 programs. The challenge Army senior leaders face is determining the overall modernization strategy that will maximize future total operational benefit when faced with budgetary constraints.

The primary aim of this project was to determine the maximum total operational benefit subject to a fixed year budget constraint. First, we reviewed the DoD's budget and acquisition process. From this analysis, we formed a methodology incorporating the Planning, Programming, Budgeting, and Execution (PPBE) process with the defense acquisition strategy timeline. We then generated a five-year fixed budget constraint derived from the Future Years Defense Program (FYDP) budget projection. Finally, we implemented a linear programming model to compute the maximum operational benefit subject to our fixed budget constraint. The model results outline the impact potential budgetary constraints have on the total operational benefit. By varying the range of budget constraints from 100% funded to 50% funded, we used sensitivity analysis to determine the impact on specific programs. Our model results will assist Army senior leaders to make more informed decisions regarding the allocation of resources to fund current and future modernization programs.

14. SUBJECT TERMS Army, Army acquisition strategy, Army budget, Army Futures Command, Army Modernization Command, FYDP, Futures Years Defense Program, PPBE, Planning Programming Budget and Execution, budget constraint, optimization, linear programming			**15. NUMBER OF PAGES** 95
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT** UU

NSN 7540-01-280-5500 Standard Form 298 (Rev. 2-89) Prescribed by ANSI Std. 239-18

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN APPLIED MATHEMATICS

from the

NAVAL POSTGRADUATE SCHOOL
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In 2018, the Army Futures Command (AFC) was established to modernize the Army and ensure the Army and its soldiers outmatch their adversaries in future conflicts. The Army's modernization efforts include eight priorities encompassing 34 programs. The challenge Army senior leaders face is determining the overall modernization strategy that will maximize future total operational benefit when faced with budgetary constraints.

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List of Acronyms and Abbreviations

AFC	Army Futures Command
AMA	Army modernization analysis
ASL	Army senior leaders
BES	budget estimate submission
CBO	Congressional Budget Office
CCMD	combatant commanders
cPROBE	program optimization and budget evaluation
CRS	Congressional Research Service
CSP	cost, schedule, and performance
DAS	defense acquisition system
DOD	Department of Defense
DPG	defense planning guidance
DRFPRD	development request for proposal release decision
DSS	decision support system
FAR	Federal Acquisition Regulation
FCS	Future Combat Systems
FY	fiscal year
FYDP	future years defense program
GAO	Government Accountability Office

GDP	gross domestic product
GSA	General Services Administration
IPL	integrated priority list
JCIDS	joint capabilities integration and development system
JSF	Joint Strike Fighter
LCCE	life cycle cost estimates
LOE	line of effort
LRIP	low-rate initial production
MDA	milestone decision authority
MDAP	major defense acquisition program
MDD	materiel development decision
MSA	material solution analysis
NDS	National Defense Strategy
OCO	Overseas Contingency Operations
OSD	Office of the Secretary of Defense
PB	President's Budget
PBD	program budget decision
PDF	probability density function
PM	project manager
POM	program objective memorandum
PPBE	planning, programming, budgeting, and execution
PPBS	planning, programming, and budgeting system

RAP	resource allocation process
RCM	resource coefficient matrix
RDTE	Research Development Testing and Evaluation
SARs	Selected Acquisition Reports
SECDEF	Secretary of Defense
SME	subject matter experts
TOA	total obligation authority
TRAC	The Research and Analysis Center
USC	United States Code
USD(C)	Under Secretary of Defense (Comptroller)

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Acknowledgments

I would like to express my deepest appreciation and gratitude to my thesis advisor, Professor Hong Zhou, for her guidance and support during my graduate studies. I would also like to thank my second reader, Major Jenifer McClary, for her patience and encouragement during the preparation of this thesis. I am also indebted to Captain John Lee and Major David Black for their valuable suggestions and insights on the topic.

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CHAPTER 1:
Introduction

The Department of Defense (DOD) overall mission is to provide the required combat ready forces to deter war and protect the security of our nation [1]. With the ever-changing global threat and the shift in policy outlined in the 2018 National Defense Strategy (NDS), the United States has made significant changes in force structure in an attempt to balance the combat readiness with short-term operational objectives.

As the previous Secretary of Defense (SECDEF), Mark Espers' top priority was to implement the 2018 NDS emphasizing the Great Power Competition among the United States, China, and Russia and acknowledged the increasingly complex global security environment. To succeed in this ever-changing environment, Mark Esper outlined three lines of effort [2]. The number one line of effort (LOE) is to improve the lethality and overall readiness of our force, which leads to a greater investment in force modernization.

This thesis focuses on the challenges senior military leaders face when determining the specific acquisition programs to be requisitioned and the allocation of resources among priority theaters of operation. We will provide background on the Army Futures Command (AFC) and the current decision making model used to compute total operational benefit of major defense programs. Then, we will integrate the planning, programming, budgeting, and execution (PPBE) process and the defense acquisition process to derive a five-year budget constraint. Finally, we will create an optimization model to implement the five-year budget constraint variable in order to inform Army senior leaders (ASL) of the optimal program selection that maximizes total operational benefit.

1.1 Thesis Organization

This thesis has five chapters. The first chapter provides the purpose of the research, introduces AFC, and presents Army modernization analysis (AMA) problem statement and issues for analysis. Chapter 2 provides an in-depth analysis of DOD budget formulation process and the defense acquisition strategy. Chapter 3 describes the methodology used in formulating the five-year budget constraint variable and outlines the concept of applying future years defense program (FYDP) within an optimization model. We then develop a linear programming model and implement the budget constraint methodology to create a linear program that maximizes operational benefit subject to a five-year budget constraint. Finally, we conduct sensitivity analyses to determine the boundaries of total operational benefit based on a range of budget constraint variables. In Chapter 4, we present the results and then compare these results to that of an annual budget constraint. Chapter 5 concludes with a summary of findings and future research recommendations to continue developing AMA's trade-space tool.

1.2 Purpose of Research

Total military expenditures for 2020 exceeded $700 billion and have steadily increased since 1960 [3]. However, when compared to the percent of gross domestic product (GDP), total military expenditures have steadily declined, as shown in Figure 1.1 [3].

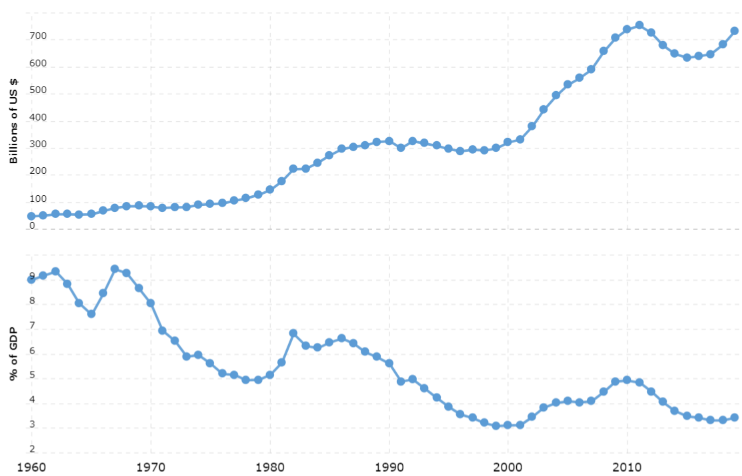

Figure 1.1. Defense Budget vs. GDP. Source: [3].

In 2020, DOD's major acquisition strategy accounted for over $71 billion of military expenditures [4]. Fiscal year (FY) 2021 estimated expenditures are $61 billion, a decrease of over 16% [4]. This thesis will focus on the challenging task of allocating resources to fund current and future modernization programs based on projected budget constraints. We will overview DOD's acquisition strategy, examine the impact of budget constraints, and discuss the long-term implications of current budgetary policy. Then we will create a budget constraint variable by blending the programming and planning phases of the PPBE process with the FYDP and the defense acquisition process. Then we incorporate the budget constraint in a linear programming model to compute total operational benefit subject to a budget constraint.

1.3 Army Futures Command

Army Futures Command was established in 2018 in an effort to strategically align and create a clear modernization strategy by focusing on transforming the Army's modernization enterprise to give the Army a competitive advantage over possible future adversaries [5]. AFC is unique in its mission as the emphasis is on future readiness of our forces and not the current global environment facing combatant commanders (CCMD).

Prior to establishing AFC, in 2003 the Army's principal modernization program was Future Combat Systems (FCS). FCS was the most ambitious and far-reaching modernization program since World War II [6]. FCS was envisioned to field a system of systems for an entire brigade that included new manned and unmanned vehicles capable of communicating across complex battlefield networks. However, in 2009, the Pentagon cancelled the FCS program due to its questionable survivability. Some efforts were developed into follow-on programs, but the overall FCS was deemed a complete failure and cost tax-payers billions of dollars [6].

1.4 Army Modernization Analysis Problem Statement

Army Futures Command faces many challenges; not only must the command overcome previous failures, but current and future budgetary constraints will have a significant impact on program decisions. ASL have the ominous task of predicting the equipment required to ensure the United States maintains a favorable balance of power. At this time, AFC has eight priorities:

1. Long-Range Precision Fires,
2. Next-Generation Combat Vehicle,
3. Future Vertical Lift,
4. Network CFT,
5. Position Navigation and Timing,

6. Mobile and Expeditionary Army Network,
7. Air and Missile Defense, and
8. Soldier Lethality. [7]

Army Modernization Analysis was established by The Research and Analysis Center (TRAC) after an analysis was completed supporting the Army modernization forums and program objective memorandum (POM). Currently, AMA is analyzing 34 programs over eight portfolios across two theaters.

Evaluating competing programs creates a challenge as we are targeting future capabilities that do not currently exist. The majority of these capabilities benefit combat operations of varying degree of intensity. AMA has relied upon the input from subject matter experts (SME) to establish an operational benefit value referred to as the total operational benefit. The operational benefit values are provided in A and are computed at three funding levels: 100%, 50%, and 0% for each theater.

Army Modernization Analysis has analyzed the requirements for each theater in order to determine the minimum operational requirements. AMA then consulted with ASL to determine the operational benefit of each program for each theater. Each program has unique advantages/disadvantages depending on the area of operations. Table 1.1 displays the operational benefit of three programs for Theater A and B at each funding level. As the number of programs increase, so does the complexity of the analysis.

Table 1.1. Operational Benefit by Theater

	Theater A			Theater B		
	0%	50%	100%	0%	50%	100%
Program 1	0	51	65	0	43	57
Program 2	24	61	78	17	47	59
Program 3	24	48	58	10	25	33

In a system with no constraints, we can easily determine the current/future requirements and estimate required funding. However, if funding for current or future acquisitions is constrained, there will be a trade-off between what can be acquired, when to acquire the program, and what theater has fielding priority. This leads us to AMA's problem statement and issues for analysis.

Problem Statement:

- Rank priority modernization programs to maximize operational benefit to the future force subject to cost/budget constraints.

Issues for Analysis:

1. What is the cost of priority modernization programs and their supporting key enablers?
2. What is the optimal funding mix for priority modernization programs to maximize operational benefit within budget constraints?

This thesis will attempt to answer the second issue by creating a five-year budget constraint variable. Then, using this constraint, we will compare the computed operational benefit over a threshold of budget decrements from 0% to 50%.

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CHAPTER 2:
DOD's Budget Formulation and Acquisition Strategy

2.1 Overview

This chapter describes DOD's budget formulation process and the Defense acquisition strategy and how they are incorporated into the president's annual budget. We then highlight the long-term challenges of providing CCMD the most technologically advanced equipment to defeat our adversaries.

2.2 DOD Budget Formulation and Contract Spending

DOD is the largest government agency in the United States. The primary components include four services with over 1.4 million service members and over 700,000 civilians [8]. Providing funding for such an enormous force is extremely complex. DOD created the decision support system (DSS), consisting of three key support systems: PPBE, joint capabilities integration and development system (JCIDS), and the defense acquisition system (DAS), as shown in Figure 2.1.

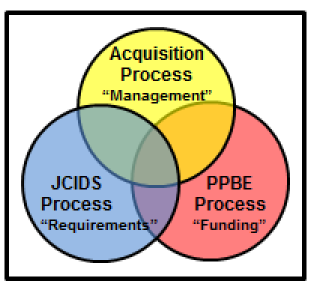

Figure 2.1. Decision Support System. Adapted from [9].

As the cornerstone of defense acquisitions, these support systems work together to ensure efficient and timely decision making, while supporting the warfighter. In this section, we will focus on the PPBE process and how this integrates with the DAS to provide funding for validated DOD acquisition programs.

In 1960, former SECDEF Robert McNamara initiated the planning, programming, and budgeting system (PPBS) to assist the SECDEF with making decisions and to ensure the appropriate allocation of financial resources. In 2003, this concept was changed to PPBE to give additional emphasis on managing the timely execution of appropriated funds.

PPBE has four distinct but interrelated phases and is an ongoing iterative process used by DOD to allocate, acquire, and analyze financial resources. The end state of the PPBE process is to provide the most efficient means possible to support the DOD and provide operational CCMD with an appropriate mix of personnel, equipment, and support. One primary output from the Planning, Programming, and Budgeting phases is the defense portion of the President's Budget (PB) which outlines a specific dollar amount for defense acquisition programs.

Next, we will review each phase of the PPBE process and the function of each phase, as displayed in Figure 2.2.

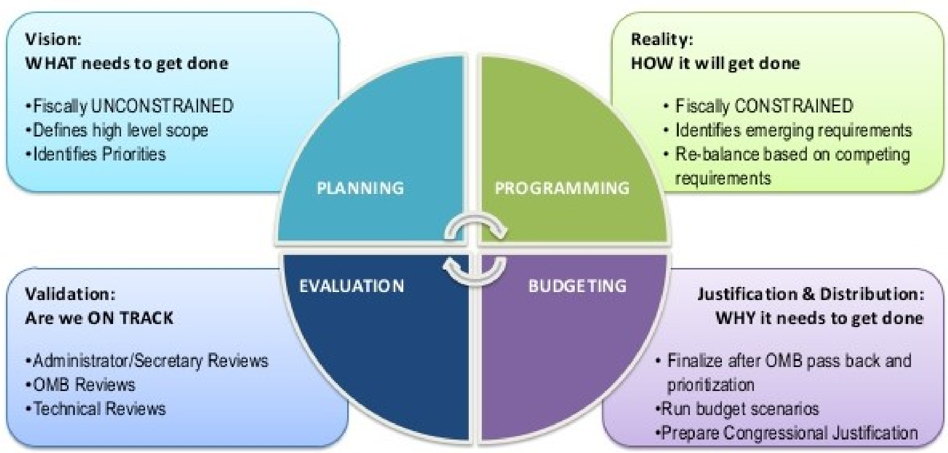

Figure 2.2. Planning, Programming, Budgeting, and Execution process. Source: [10].

2.2.1 Planning

Planning is the first step in the resource allocation process (RAP) and begins approximately 18 months prior to the Fiscal Year of the requested funds. The planning phase is initiated once the SECDEF issues the defense planning guidance (DPG); the source document that all budget estimates are prepared. The DPG is a compilation of defense strategy, force structure, funding strategy, and fiscal guidance.

The planning phase focuses on estimating all resource requirements over the next two to five years (two to seven years for force structure). However, for strategic guidance, the Army breaks the planning phase into three terms: near, mid, and far. Near-term planning extends out six years, mid-planning extends out 16 years, and far-planning extends 25 years into the future [11].

In order to validate requirements, Military departments submit requests through the budget estimate submission (BES) process directly to the Office of the Secretary of Defense (OSD) while CCMD submit high priority requirements via the integrated priority list (IPL). All requirements are then vetted through three high level OSD decision making forums where a determination is made, based on current budgetary constraints, for the preferred force structure, weapon systems, personnel, and sustainment.

2.2.2 Programming

Programming is the process of allocating resources to the requirements agreed upon during the planning phase. This is referred to as a "Cost Out" of force requirements. During the programming phase, alternatives are analyzed to determine various trade-off options based on resource implications. The program timeline includes the budget year and the following five years. This process allows the President and SECDEF to be aware of long-term implications current decisions will have on the future defense strategy.

During the programming phase, each DOD component develops their POM. The POM is a comprehensive outline of requested programs that includes a timeline detailing the components proposed resource allocation over this five-year period. OSD is responsible for combining the POM into a comprehensive defense proposal. Based on the five-year POM, the FYDP is developed and updated to identify potential funding shortages.

Once ASL authorize a program, the program will transition from the programming to budgeting phase. To visualize the process, Figure 2.3 displays the POM 21-25, the five-year Army FYDP, as a loaf of bread divided into five slices representing one year of the POM [11]. Once the budget preparation begins, the first slice is moved from programming to join the year of execution slice, fiscal year (FY)2020, as an appropriation. We then add another slice (year) at the back end and the POM/BES process repeats.

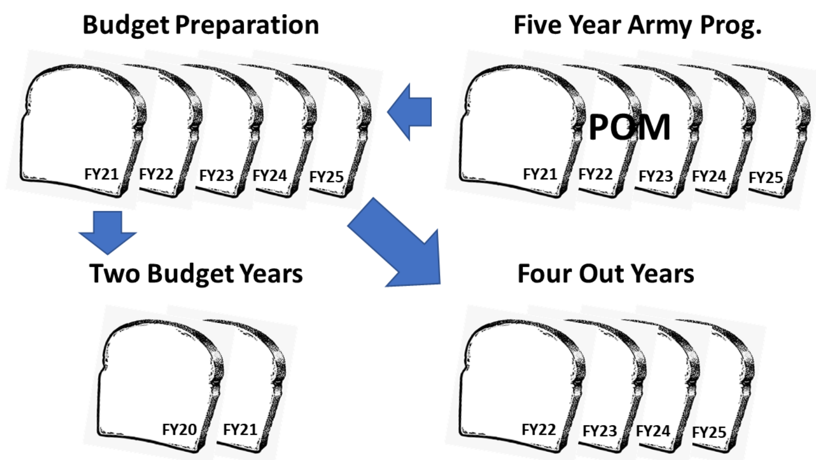

Figure 2.3. Program and Budget Loaf of Bread Visualization. Adapted from [11].

2.2.3 Budgeting

The Budgeting phase is coordinated by the Under Secretary of Defense (Comptroller) (USD(C)) and focuses on the first two years of a program's budget. A budget analyst within the USD(C) office will review all requests focusing on the following four aspects:

1. Correct "color of money" has been requested,
2. Feasibility of the total cost estimate,
3. Efficiency of proposed resource allocation, and
4. Proper phasing of program expenditures.

The phasing of program execution has a direct impact on acquisition programs and influences the development of the FYDP (discussed in Section 2.2.5). Once requests have been reviewed and approved, they are included in a final program budget decision (PBD) to be reviewed by the SECDEF prior to inclusion in the PB.

2.2.4 Execution

The Execution phase focuses on current year budget execution. Recently, there more emphasis has been on reviewing current and prior year execution to ensure funds have been utilized correctly and abide by the three principles of fiscal law: time, purpose, and amount.

During the execution phase, the total obligation rate is compared to the approved resource allocation timeline to verify funds are being executed as requested. Once verified, obligations are scrutinized to determine whether funds are being executed according to the components POM. Any discrepancies are reviewed in order to adjust program spending to meet stated objectives. As we will highlight, this is increasingly important with the DAS. We will provide examples of major programs that have exceeded both projected costs and schedules of completion and then review the impact these programs had on future allocation of FYDP.

2.2.5 Future Years Defense Program

The FYDP is developed during the Programming phase of PPBE and updated during the Budgeting phase prior to inclusion in the PB. According to DOD regulation, FYDP is a series of reports that record and display resource decisions and is an important segment of the PPBE's process [12].

The FYDP is a five-year process that includes the current budget year and the next four years of requested resources in order to project required funding. FYDP is updated twice a year to allow components some flexibility to adjust requirements as priorities change. This flexibility assists major acquisition programs that utilize multiple appropriations to shift requirements to the appropriate funding source. This also allows analysts to identify programs over/under budget so funding can be reallocated from under executed programs to programs exceeding budget within the same appropriation.

In summary, the PPBE process identifies needs, determines/allocates resources, monitors execution, and authorizes the program budget while the FYDP spreads the funding over the five-year period.

2.3 DOD's Acquisition Strategy

In this section, we will highlight the importance of DOD's acquisition strategy and outline the acquisition process. Then we will discuss how the acquisition strategy is incorporated into FYDP to allocate resources for major defense programs that consist of multi-year outlays.

2.3.1 Background

According to a Congressional Research Service (CRS) report, DOD's acquisition process is extremely complex and may not produce systems that meet the projected costs or expected performance [13].

A recent example of a program that severely exceeded the cost and schedule parameters compared to the initial program requests is the Joint Strike Fighter (JSF) program (F-35). The JSF is DOD's largest acquisition program with total acquisition costs over $400 billion compared to the $330 billion estimate. The total cost estimate for operating and support is near $1 trillion [14]. This program highlights the challenge of forecasting resources for major acquisition programs and how severe cost/schedule variances will inevitably impact competing programs over multi-year periods.

The FYDP is designed to capture cost variances early to allow funding to be reallocated or reprogrammed to meet changing priorities. Annually, the DOD releases the Selected Acquisition Reports (SARs) that provide a comprehensive summary of the major defense acquisition program (MDAP)'s current estimates. The SARs are prepared in conjunction with the PB. Based on DOD's 2019 comprehensive SARs, the DOD had 87 active programs with a total estimated cost over $2 trillion [15]. The Army's acquisition program accounts for over $215 billion of these anticipated expenditures.

2.3.2 Defense Acquisition System

A distinguished Harvard industrial engineering expert once described the DOD acquisition system as the most complex industrial process in the world [16]. Figure 2.4 displays the defense acquisition life-cycle which has been termed the defense acquisition "Horse Blanket" due to its complexity.

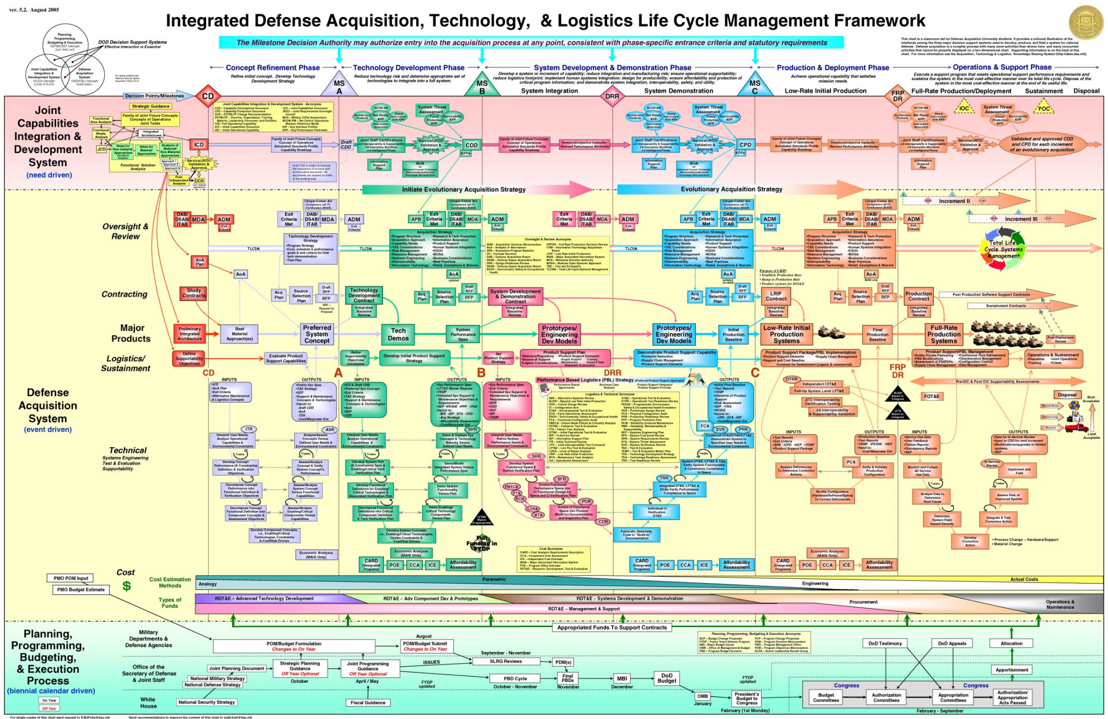

Figure 2.4. Acquisition Life Cycle **"Horse Blanket."** Source: [17].

The DAS is the management process for all DOD acquisition programs [9]. Within DAS, there are six adaptive acquisition pathways.

1. Urgent Capability Acquisition,
2. Middle Tier of Acquisition,
3. Major Capability Acquisition,
4. Software Acquisition,
5. Defense Business Systems, and
6. Acquisition of Services.

This research focuses on Pathway 3, the Major Capability Acquisition pathway.

Each acquisition program will be appointed a project manager (PM) who is responsible for all program objectives. The PM has decision-making authority and is responsible for the overall cost, schedule, and performance (CSP) of a program. Each PM should be a SME of the program and understand the DAS. The DAS is composed of milestones and phases that contain major activities and decision points.

The five phases in the Defense Acquisition Process are:

1. Material Solution Analysis,
2. Technology Maturation and Risk Reduction,
3. Engineering and Manufacturing,
4. Production and Deployment, and
5. Operations and Support.

The three major milestones in the Defense Acquisition Process are: [13]

1. Milestone A approves entry into the Technology Maturation and Risk Reduction phase.
2. Milestone B approves entry into the Engineering and Manufacturing Development phase.
3. Milestone C approves entry into the Production and Deployment phase.

The four decision points in the Defense Acquisition Process are:

1. Materiel Development Decision (MDD) establishes entry point for a program.
2. Capability Development Document Validation (CDDV) validates requirements are technically achievable, affordable, and testable.
3. Development Request for Proposal Release Decision (DRFPRD) is the point where the milestone decision authority (MDA) approves the acquisition strategy and the request for proposal prior to Milestone B.
4. Full-Rate Production Decision Review authorizes entry into full-rate production.

The defense acquisition decision points, milestones, and phases are displayed in Figure 2.5.

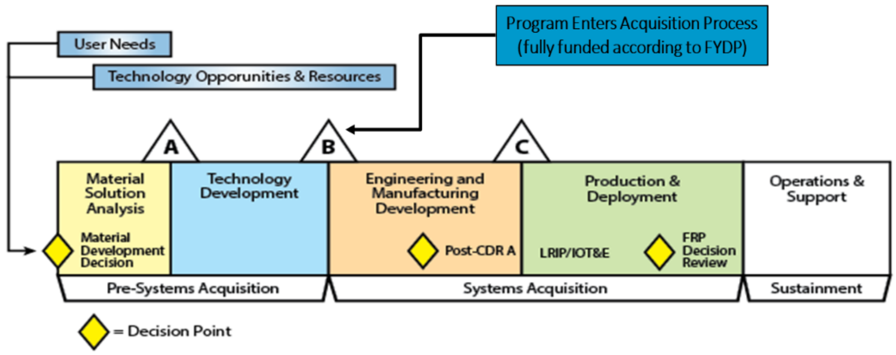

Figure 2.5. Acquisition Decision Points and Phases. Adapted from [9].

A program is identified in one of two ways: a capability gap or an opportunity to take advantage of an advancement in a technological process. In either case, a formal decision is made on whether to proceed. Once a program has authorization to proceed, the MDA renders a positive materiel development decision (MDD) which establishes the entry point for the program and the material solution analysis (MSA) phase referred to as the analysis of alternatives. In this phase, the acquisition strategy, or business plan for developing the system, is created.

The program now enters Milestone A where the MDA will review the results of the program. If all documents reflect an acceptable program with an executable budget, the MDA will release an acquisition decision memorandum, authorizing the program to proceed to the Technology Maturation and Risk Reduction phase. After a capability development document review and a validation of performance requirements, the MDA reviews the overall game-plan for phase three, Engineering and Manufacturing. This decision point is referred to as the development request for proposal release decision (DRFPRD) and is the critical decision point during the acquisition program since this creates the foundation for everything that follows and changes after this review can be difficult and costly to make.

Our analysis begins once a program achieves Milestone B as this is when the program enters the acquisition process. At this point in the acquisition life-cycle, a program must be fully funded according to the FYDP [18]. During the third phase, the final design is put in place and the program must demonstrate it is interoperable and supportable. During the fourth phase, low-rate initial production (LRIP) is initiated until initial operational testing and evaluation is complete. Once testing is complete and satisfactory, Full Rate Production will commence which could take years to complete.

The final phase is Operations and Support (to include disposal costs). This is often the most expensive phase and often overlooked during the cost estimation process. Figure 2.6 details the Acquisition life cycle of a weapons system and compares cost versus time for each phase of the acquisition process.

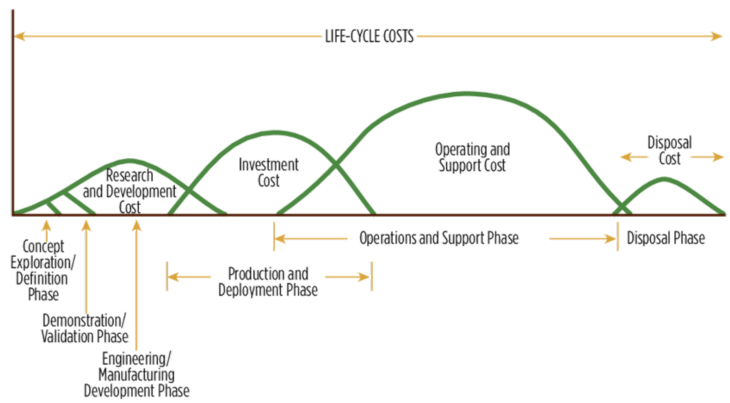

Figure 2.6. Acquisition Life Cycle Costs. Source: [19].

The potential for cost savings must take place early in a program life-cycle. Once a program enters production, significant cost outlays have been absorbed and changing or canceling a program will incur significant costs.

2.3.3 Incorporating Defense Acquisitions and FYDP

In FY 2019, defense contract spending continued to grow but at a slower rate as total defense spending leveled off due to a reduction in Overseas Contingency Operations (OCO) spending [4]. Figure 2.7 displays the FY 2019 total defense contract obligations which increased to $381 billion and accounted for over 55% of DOD's total obligation authority (TOA).

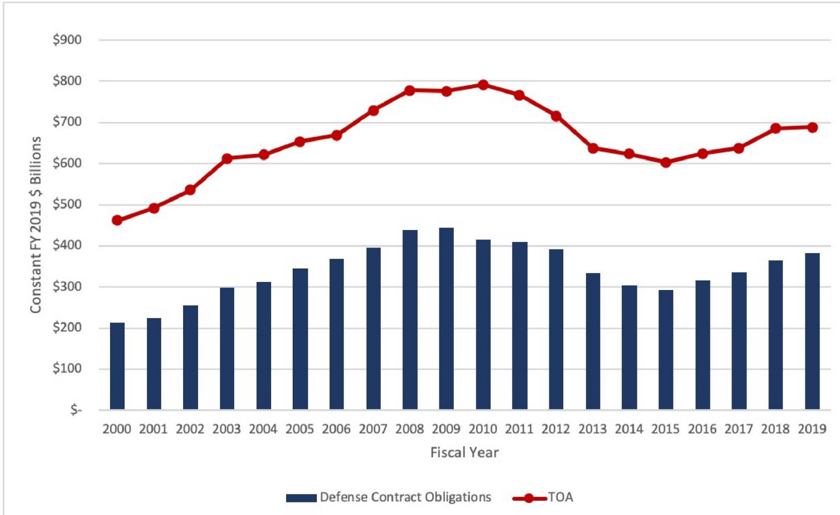

Figure 2.7. Defense Contract Obligations vs. Total Obligation Authority. Source: [4].

Since the last military drawdown in FY 2015, defense contract obligations have increased 31% [4]. According to the Congressional Budget Office (CBO) and details in the FY 2021 FYDP, total funding is expected to be relatively flat through 2025 while personnel and support obligations are expected to rise 10% annually [20]. The CBO also projects the cost of implementing DOD's authorized programs will be 2% higher than current estimates during this FYDP period and 3% higher than estimates over the next 15-years (2021-2035) [20]. Reductions in Army funding coupled with unforecasted increases in obligations will ultimately lead to a strain on available resources.

Figure 2.8 outlines the Army's total budget by resource category. These estimates are used to project available resources across each category through 2030. Since Manpower accounts for over 40% of available resources, any future reduction in Army funding must consider a reduction in Manpower. Otherwise, the Army is at risk of hollowing out the force [21]. The term "hollow force" has been used to characterize forces that appear mission ready but are not trained to standards and lack the proper equipment.

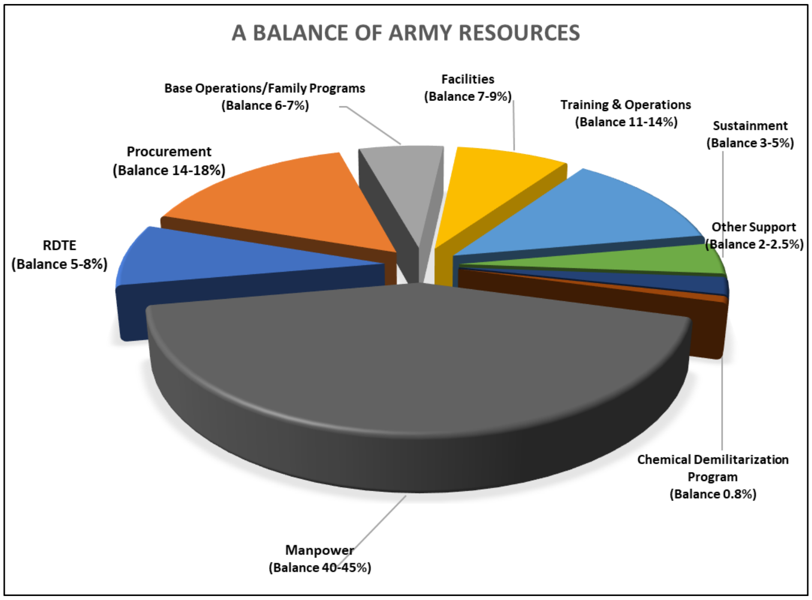

Figure 2.8. Competing Army Resources. Adapted from [21].

A majority of the programs analyzed extend beyond the current FYDP as some programs extend to 2035. Incorporating an estimated budget beyond the FYDP period into an optimization model poses many challenges and uncertainties. In the Methodology chapter, we will outline a strategy where we integrate the FYDP budget into a five-year year budget constraint over a multi-year period.

CHAPTER 3: Data and Methodology

3.1 Introduction

This chapter describes the data used in the model and the concept of integrating a five-year budget constraint into AMA's existing model. First, we highlight some assumptions made during the modeling process and identify the datasets and decision variables. Then we define the model parameters and review AMA's mathematical model used to compute total operational benefit. Finally, we develop our five-year budget constraint variable by integrating cost variables through the development of the POM/BES and FYDP process.

3.2 Assumptions

During the development of the methodology used in our modeling process, we made the following assumptions:

1. Procurement costs are distributed according AMA's procurement timeframe and will not fluctuate throughout the acquisition timeline.
2. Current program cost data is accurate and reflects all risk associated with the procurement of the program.
3. Inflation will not impact the purchasing decisions.
4. All programs are independent (i.e., purchasing Program A has no impact on the decision to purchase any other program).
5. For planning purposes and to maintain consistency with AMA's model, the current budget year is FY 2020 and the execution year is FY 2019.

The first three assumptions will be discussed in more detail in Section 5.2.

3.3 Model Data

Our model consists of data derived from AMA's dataset. Actual program names and values have been altered, but the overall concept mirrors AMA's current study. The existing dataset incorporates 34 programs (program A through AH), over two theaters (theater A and B), with three decision points per theater (funding level of 0%, 50%, or 100%).

3.3.1 Datasets

The four datasets included in the model are the same datasets used in AMA's model. The datasets include the programs, theaters of operation, set of operational metrics, and set of funding levels for the programs, as shown in Table 3.1.

Table 3.1. Datasets

I (sysList)	{1,...,m} set of system (programs)
J (opMets)	{1,...,n} set of operational metrics
T (theaterList)	{1,...,p} set of operational theaters
L (levels)	{0,50,100} set of funding levels for programs

3.4 Mathematical Model

In this section, we will define the model parameters, review AMA's mathematical model, and outline the computation of total operational benefit.

3.4.1 Parameters

Table 3.2 displays the model parameters used in AMA's mathematical equation to compute total operational benefit.

Table 3.2. Data Parameters

$Wt_{j,t}$	weight of each operational score by theater
$OpBenefit_{i,t,l}$	operational benefit score of each theater
Capability Value	operational benefit of each program relative to the user allocation and theater
RCM	operational benefit contribution to each operational measure
Obj Max	maximum score of an operational measure with all capabilities
Obj Min	score of an operational measure with current legacy force structure
MaxVal	maximum possible "Val" score for a given objective, theater.
MinVal	minimum possible "Val" score for a given objective, theater
Value	normalize data for inflation
UserInput	incorporate Program Life Cycle Costs in the model
i	number of programs
j	operational objective (Warfighting Function's)
t	theater of operation

3.4.2 Current Mathematical Model

Under the current TRADES Tool methodology, the user specifies the level of modernization for each program in each theater. Equation (3.1) computes the operational benefit measure for each program, referred to as the **Capability Value** of each theater for a given level of modernization. Formations that are not modernized are equipped with legacy equipment. However, legacy equipment may still have operational value. Equation (3.2) computes the operational benefit contribution (**Val**) for each operational score by multiplying the program level measure by the appropriate line in the **resource coefficient matrix (RCM)**.

$$CapabilityValue_{i,t} = f_{value_{i,t}}(UserInput_{i,t}) \tag{3.1}$$

$$Val_{j,t} = \sum_{i}[\mathrm{RCM}_{j,i} * CapabilityValue_{i,t}] \tag{3.2}$$

Since the operational measure can extend beyond 100%, Equation (3.3) computes the **Obj Scales** value by scaling the **Val** into a range from the **Obj Max** value to the **Obj Min** value. Then, we multiply this factor by the difference of the **MaxVal** and **MinVal** computations. **MaxVal** is the value when all programs are fielded at 100% for a given theater and **MinVal** is the value when no programs are fielded.

$$ObjScales_{j,t} = \frac{Val_{j,t} - MinVal_{j,t}}{MaxVal_{j,t} - MinVal_{j,t}} * [ObjMax_{j,t} - ObjMin_{j,t}] + ObjMin_{j,t} \tag{3.3}$$

Equation (3.4) computes the theater operational benefit score (**Op Benefit**). **Op Benefit** is the weighted sum of each scaled operational measure, where the weights are a value between 0 and 1 and all sum to 1. Finally, Equation (3.5) computes the the total operational benefit (**Total Op Benefit**) which is the weighted sum of each theater's operational benefit score, where the weights of each theater range between 0 and 1 and sum to 1.

$$OpBenefit_{th} = \sum_{j} Wt_j * ObjScaled_J \tag{3.4}$$

$$Total\ Op\ Benefit = Wt_{th_A} * OpBenefit_{th_A} + Wt_{th_B} * OpBenefit_{th_B} \tag{3.5}$$

3.5 Formulation of the Budget Constraint

AMA's TRADES Tool derives all cost data from the program optimization and budget evaluation (cPROBE) environment, an Army G8 budget management database that maintains budget proposals for the current FYDP. These are point cost estimates generated during the initial planning phase of the program (point cost estimates are referenced in Section 5.2) that feed into the FYDP. The MDAP's total annual cost estimate is generated once all costs are distributed across the program's procurement timeline.

AMA's current budget constraint is an initial budget estimate generated during the early planning phase of the MDAP. During the entire procurement timeline, FY 2020 through FY 2035, the budget constraint is fixed.

We propose creating a budget constraint variable by monitoring the program and planning phase and then incorporating the annual POM/BES requests into an annual cost estimate. Figure 3.1 details how the PPBE cycles overlap as each year's POM cycle is evaluated and developed in the current FYDP.

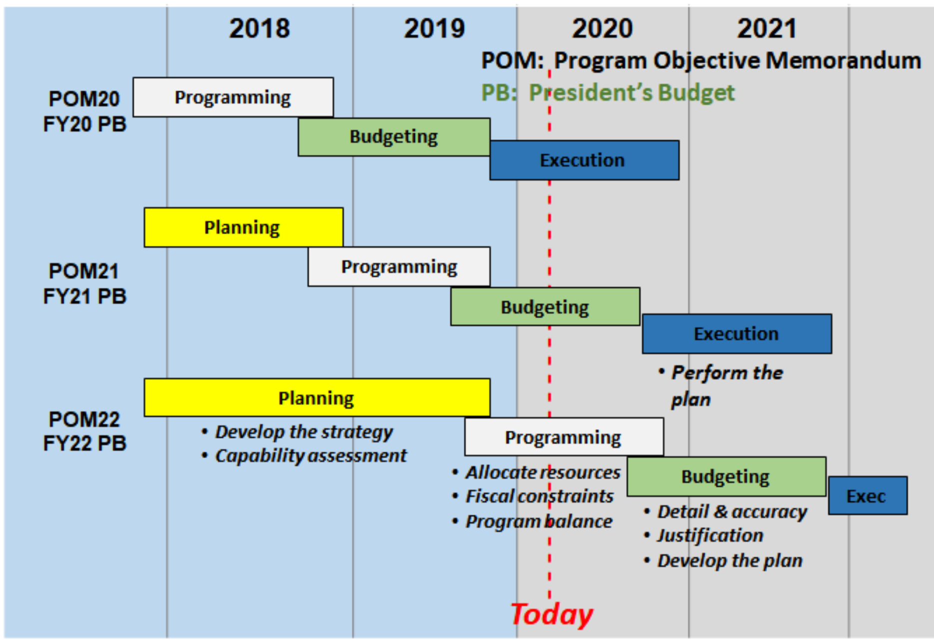

Figure 3.1. PPBE Overlapping Cycles. Adapted from [22].

Figure 3.2 details each step of the PPBE process and illustrates how the planning phase of POM-21 *On-Year* programming extends through 2035.

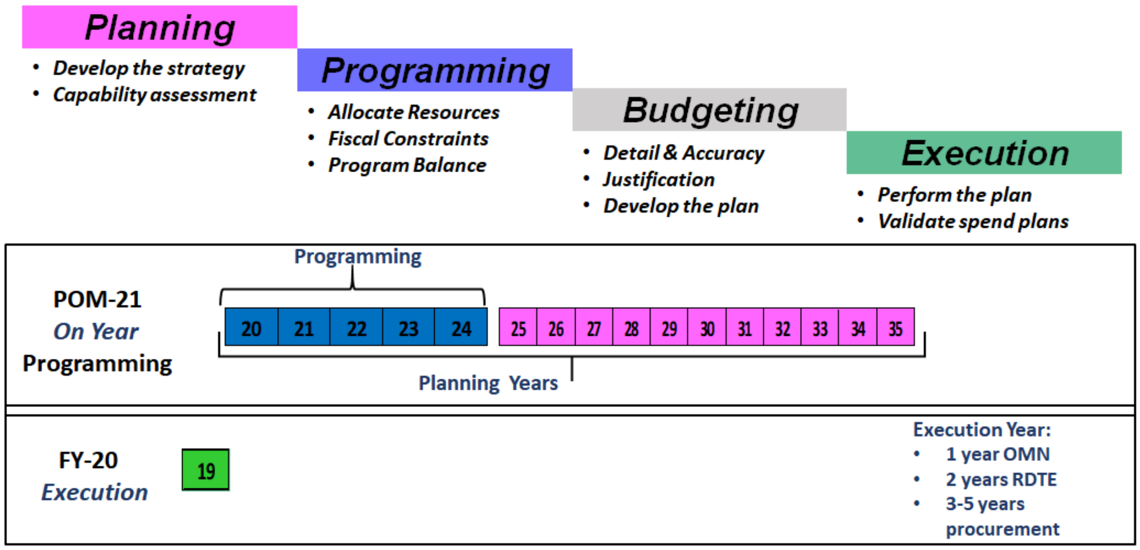

Figure 3.2. PPBE Timeline

Ideally, MDAP will be funded at 100% FYDP and, during the acquisition life cycle, no program would incur a deviation from the projected total cost, nor would the annual cash outlays for any program deviate from the program's proposed spend plan. This would lead to an annual FYDP budget equivalent to the total anticipated obligations for all combined programs. The end result would be 100% funding for both theaters and achieving maximum total operational benefit.

Unfortunately, there are multiple variables influencing a program's cost and proposed budget. In an attempt to create a realistic budget constraint variable that incorporates this risk and uncertainty, we integrate Figures 2.3, 3.1, and 3.2.

The initial five-year budget constraint variables will be derived from the FYDP shown in Figure 3.3.

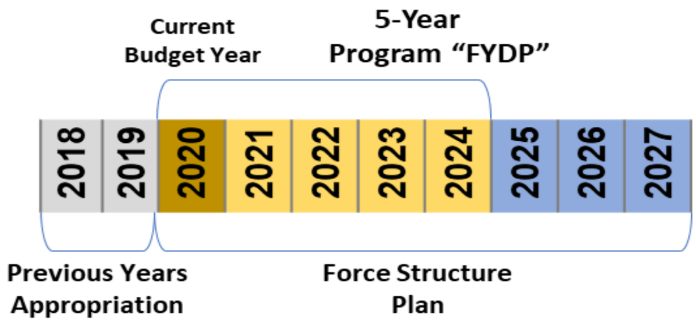

Figure 3.3. FYDP Timeline. Adapted from [23].

This consists of the budget year FY 2020 and the next four years of the FYDP period from FY 2021 through FY 2024. Based on the POM & BES projected obligations, we will then extrapolate an estimated budget for the mid-term planning years, FY 2025 through FY 2035, which extend through AFC's projected acquisition timeline.

Similar to Figure 2.3, the first year of the FYDP will move to the Execution phase and the FY 2025 budget estimate will be included in the FY 2021 five-year budget. This now becomes the second budget constraint variable. We repeat this process each year as shown in Figure 3.4. This cycle produces 12 five-year budget constraint variables.

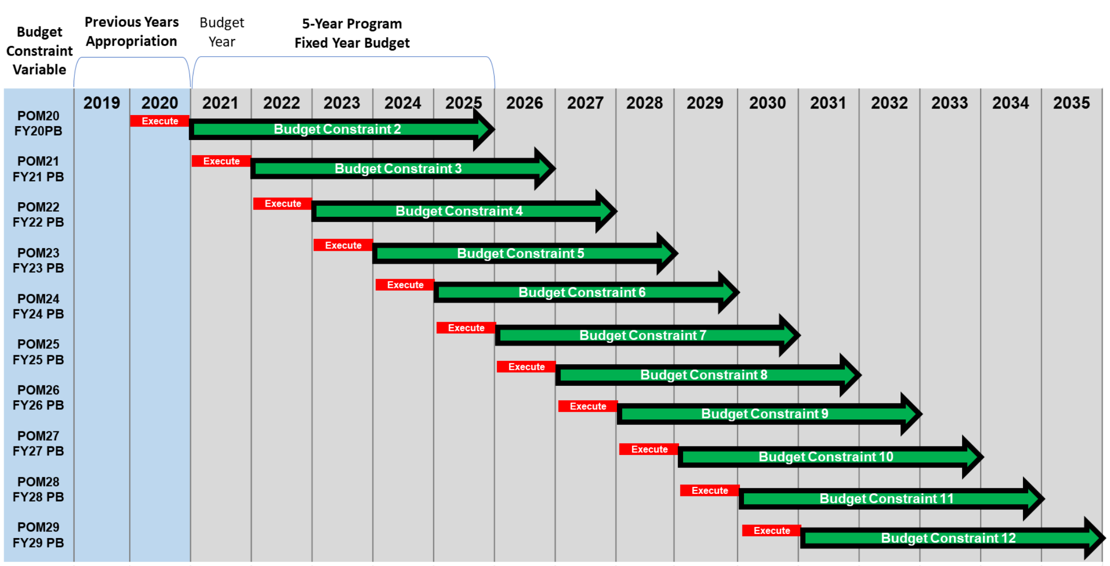

Figure 3.4. Budget Constraint Variable

In the following section, we will provide a basis for our linear programming model and then derive the optimization model to maximize total operational benefit subject to the five-year budget constraint variables and theater funding levels.

3.6 Basis of Linear Programming

The generality of linear programming has been in existence since 1827 when Joseph Fourier introduced a system for solving linear inequalities [24]. The technique of linear programming was introduced in 1939 by a Soviet mathematician and economist, Leonid Kantorovich. During World War II, he developed a model to predict expenditures and returns subject to costs [24]. Initially, this optimization methodology was overlooked by the USSR. However, in 1975, Kantorovich and the Dutch-American, T.C. Koopmans, shared the Nobel prize in economics for their work in classical economic problems using the linear programming methodology known as the Simplex algorithm we use today.

The basis of linear programming is to find maximum or minimum values of a linear function given a number of inequalities subject to specific constraints [25]. Linear programming is widely used in the field of operations research and has led to expanding concepts in other areas utilizing optimization theory such as economics and business management. Linear programming is widely used in the transportation industry as a way of optimizing the shipment of goods while minimizing cost subject to the availability of resources such as fuel.

3.7 Linear Programming Formulation

In order to compute the program mix that maximizes the total operational benefit, we will create a liner programming model that takes into account the following three components.

1. Objective Function
2. Decision Variables
3. Problem Constraints

Next, we will define and compute each component that will make up our optimization model.

3.7.1 Objective Function

The goal of our optimization model is to maximize total operational benefit across two theaters of operation. Total operational benefit is computed by multiplying the funding level by the operational benefit for each theater. Then, we sum the totals across both theaters as shown in Equation (3.6).

$$Total\ Op\ Benefit = Wt_{th_A} * OpBenefit_{th_A} + Wt_{th_B} * OpBenefit_{th_B} \tag{3.6}$$

3.7.2 Decision Variables

There are two types of decision variables: binary variables that determine the percentage of procurement per theater and the cost function variables that compute the total cost of the optimized program mix. The binary decision variable will equal 1 if the program is acquired at level L or 0 if the program is not acquired at level L. Once a program is acquired, the cost will be computed at the specified procurement level.

$$x_{i,0,t} = \begin{cases} 1, & \text{NO system is procured, legacy systems remain in place} \\ 0, & \text{system } i \text{ procured to 50\% or 100\%} \end{cases}$$

$$x_{i,50,t} = \begin{cases} 1, & \text{system } i \text{ procured to 50\%} \\ 0, & \text{system } i \text{ NOT procured to 50\%} \end{cases}$$

$$x_{i,100,t} = \begin{cases} 1, & \text{system } i \text{ procured to 100\%} \\ 0, & \text{system } i \text{ NOT procured to 100\%} \end{cases}$$

Since there are three decision points, 34 programs, and two theaters, our optimization model will include 204 decision variables.

3.7.3 Model Constraints

In this section, we formulate our constraint variables for the linear programming model. First, we analyze the cost function created in AMA's model. We then adopt this cost model into our optimization model to generate the budget constraint variable. Finally, we define the binary variables and the theater procurement constraint.

Budget Constraint

In AMA's model, total program costs are a function of fixed costs and variable costs. The current model does not include operating and support costs or disposal costs. Program costs include two different appropriations or "colors of money": Research Development Testing and Evaluation (RDTE) and Procurement. Since all programs have achieved Milestone B, the fixed portion of RDTE and Procurement is considered a sunk cost and incurs no cost savings if the scope of a program is reduced or if a program is cancelled. The variable portion of program costs will vary based on the quantity of formations procured.

Equation (3.7) displays the current cost estimation model. Since we are analyzing the impact of a budget constraint, we will implement the existing cost model and the estimated program costs for the duration of the acquisition period. As shown in Equation (3.8), the total budget is equivalent to the future projected obligations.

$$Total\ Cost = \sum_i [(RDTE_{i,y} + Procurement_{i,y}) * FormationCost] + Fixed\ Costs \tag{3.7}$$

$$Total\ Budget = \sum_i [TOA_{i,y}] \tag{3.8}$$

i - Priority Modernization Program y - Fiscal Year

When total cost is equal to or less than the total budget of all combined programs, we will acquire 100% of each program for each theater and achieve 100% of operational benefit. Therefore, we set Equation (4.1) equal to (4.2) in order to generate the minimum budget required to maximizing total operational benefit as shown in Equation (3.9) and (3.10), respectively.

$$Total\ Cost = Projected\ Budget \tag{3.9}$$

$$\sum_i [(RDTE_{i,y} + Procurement_{i,y}) * FormationCost] + Fixed\ Costs = \sum_i [TOA_{i,y}] \tag{3.10}$$

Since the fixed costs are stable throughout the acquisition timeline, we only incorporate variable costs in the budget constraint model. Therefore, we subtract fixed costs from both sides of Equation (3.11) to derive our budget constraint, as shown in Equation (3.12).

$$\sum_i [(RDTE_{i,y} + Procurement_{i,y}) * FormationCost] = \sum_i [TOA_{i,y}] - Fixed\ Costs \tag{3.11}$$

$$Budget\ Constraint = \sum_i [TOA_{i,y}] - Fixed\ Costs \tag{3.12}$$

Our annual budget constraint for the optimization model is shown in Equation (3.13).

$$\sum_i [(RDTE_{i,y} + Procurement_{i,y}) * FormationCost] \leq \textbf{Annual Budget Constraint} \tag{3.13}$$

By referencing Figure 3.4, we compute the five-year budget constraint variable by summing five-year increments of the annual budget constraint. Equation 3.14 becomes the final five-year budget constraint we will implement in the optimization model.

$$\sum_{i,5-year} [(RDTE_{i,y} + Procurement_{i,y}) * FormationCost] \leq \textbf{5-yr Budget Constraint} \tag{3.14}$$

Purchase Decision Constraint

Since we will only acquire 0%, 50%, or 100% of a program per theater, we create a binary variable for every program for each theater. Table 3.1 displays the decision constraints for three of the 34 programs.

Table 3.3. Operational Benefit by Theater Constraint

	Theater A									Theater B											
	at 0%			at 50%			at 100%			at 0%			at 50%			at 100%			Constraint		
Program	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	LHS	sign	RHS
1	1	0	0	1	0	0	1	0	0										$\sum x_{1,1}$	$\leq$	1
2	0	1	0	0	1	0	0	1	0										$\sum x_{2,1}$	$\leq$	1
3	0	0	1	0	0	1	0	0	1										$\sum x_{3,1}$	$\leq$	1
1										1	0	0	1	0	0	1	0	0	$\sum x_{1,2}$	$\leq$	1
2										0	1	0	0	1	0	0	1	0	$\sum x_{2,2}$	$\leq$	1
3										0	0	1	0	0	1	0	0	1	$\sum x_{3,2}$	$\leq$	1

With 34 programs, three funding levels, and two theaters of operation, we create 68 binary variables and 80 constraint variables for the optimization model.

3.8 Optimization Model

Equation (3.15) displays the objective function of our model. The model constraints are shown in equations (3.16), (3.17), and (3.18).

Maximize:

$$\textbf{Total Operation Benefit} = \sum TheaterWeight_t \sum_j w_{j,t} * valOpMetScales_{j,t} \tag{3.15}$$

Subject To:

$$x_{i,0,A} + x_{i,50,A} + x_{i,100,A} \leq 1 \tag{3.16}$$

$$x_{i,0,B} + x_{i,50,B} + x_{i,100,B} \leq 1 \tag{3.17}$$

$$\sum_{i,5-year} [(RDTE_{i,y} + Proc_{i,y}) * FormationCost] \leq \textbf{5-yr Budget Constraint} \tag{3.18}$$

3.9 Solving the Linear Programming Model

There is an abundant source of solvers available for solving linear programs. Initially, we created a test model in Excel using the add-in, Solver. The test model consisted of seven programs over two theaters with two decision points (50% or 100%) per theater. The linear programming model consisted of 28 decision variables and 30 constraints. Excel Solver's function worked well for the test program. However, once we integrated the full model, Solver could not compute an optimal solution as we exceeded the maximum number of authorized variables.

We then analyzed linear programming packages implemented in R to maintain consistency with AMA's current model. R has three unique linear programming packages based on the type of variables included in the model. Since our model does not contain mixed integer variables, we will implement the lpSolve and lpSolveAPI packages.

The lpSolveAPI package is the second implementation of the original lpSolve package. It contains multiple functions for solving linear programming models and provides the required output for performing statistical analysis. The R code and output file for the five-year budget constraint is provided in Appendix A and Appendix B, respectively.

3.10 Sensitivity Analysis

Sensitivity analysis (or what-if analysis) is the process of recalculating the optimization model, with varying input parameters, to determine how a change in input values will impact results. In order to determine the possible implications a budget constraint will have on the total operational benefit, we will incrementally reduce the budget constraint by five percent and iterate through the model until we have results comparing a budget threshold from 100% to 50%.

In Chapter 4, we will summarize model results and highlight the projected budget impact on operational benefit by theater, portfolio, and program. Then we will compare the results of the five-year budget constraint versus the annual budget constraint.

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CHAPTER 4:
Results

4.1 Introduction

In this chapter, we will provide the results of the optimization model subject to our five-year budget constraint and examine the impact on operational benefit by theater, portfolio, and program. Then we will compare the results of our five-year budget constraint with an annual budget constraint.

4.2 Five-Year Budget Constraint

When the five-year budget constraint equals total obligations, we acquire all systems at 100%. Therefore, the maximum total operational benefit is 1.0. Figure 4.1 displays the impact a five-year budget constraint will have on the total operational benefit when the budget is decremented from 10% to 50%.

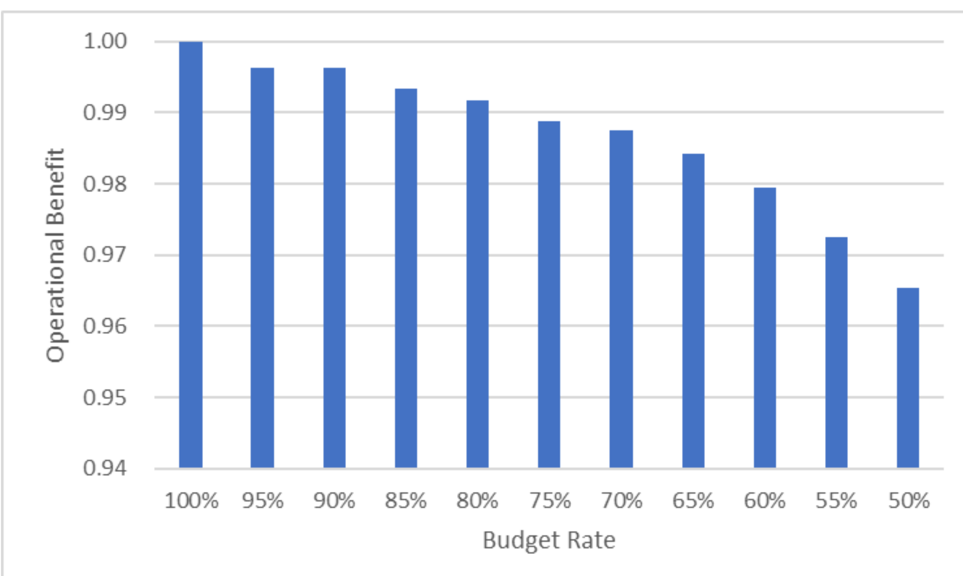


Figure 4.1. Impact of a Five-year Budget Constraint on Operational Benefit

The initial budget constraints have minimal impact on the overall operational benefit. If we experience a 50% decrement in our operating budget, the total operational benefit is reduced by 4%. Next we will analyze the impact a budget constraint will have on the operational benefit by theater, portfolio, and program.

4.2.1 Impact on Operational Benefit by Theater

Figure 4.2 displays the impact on operational benefit for each theater.

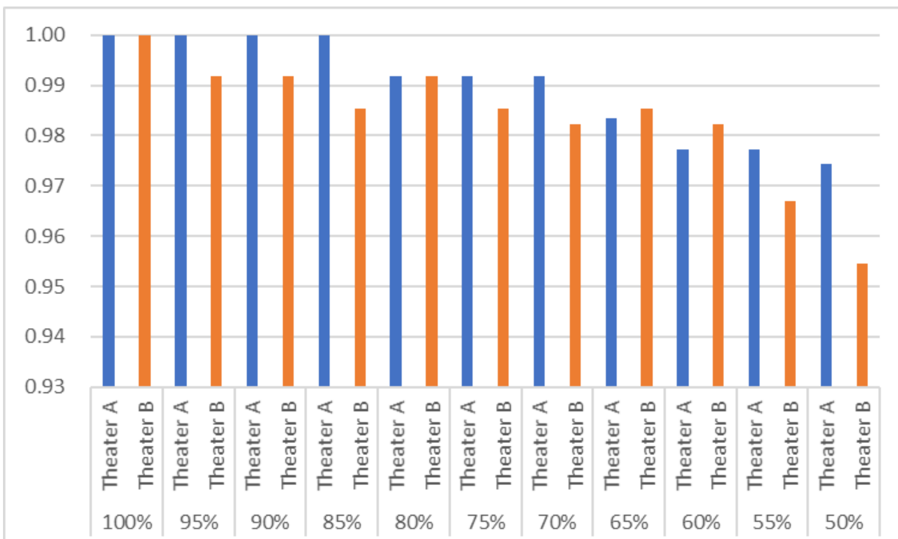


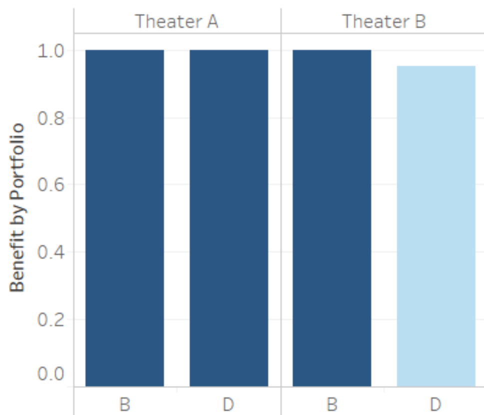
Figure 4.2. Impact of a Five-year Budget Constraint by Theater

The operational impact is evenly spread among the two theaters of operation with no obvious disparity until we reach a decrement of 50%. At this point, a decrement has a greater impact on Theater B. Next, we will compare the impact on operational benefit by portfolio for Theater A and B.

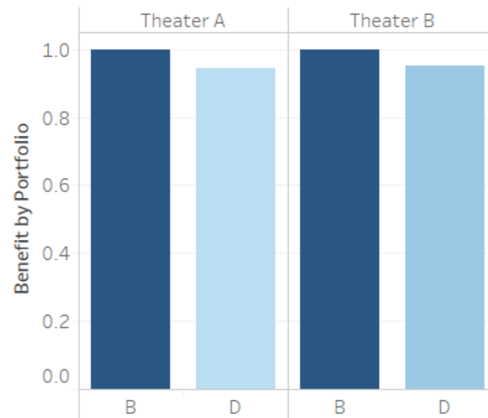
4.2.2 Impact on Operational Benefit by Portfolio

In Figure 4.3, we display the computed operational benefit by portfolio for a budget decrement of 10%, 20%, 30%, and 40%, respectively.

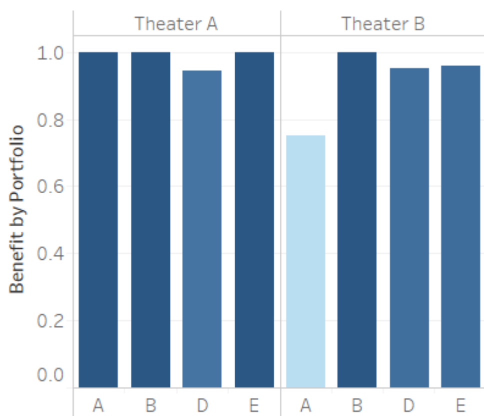
As the data suggests, the initial decrements only impact Portfolio D.



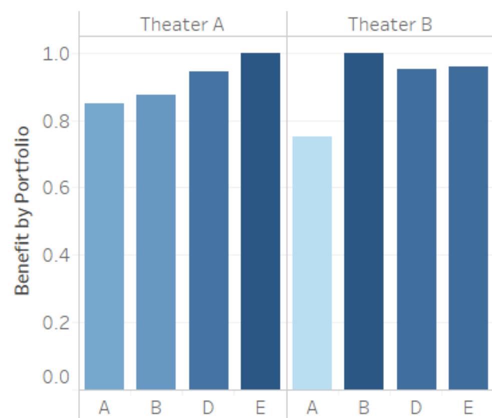
(a) 10% Decrement



(b) 20% Decrement



(c) 30% Decrement



(d) 40% Decrement

Figure 4.3. Impact on Portfolio B and D

Once the budget decrement exceeds 20%, Portfolios A and E are also impacted. Figure 4.4 displays the results of a 50% budget decrement.

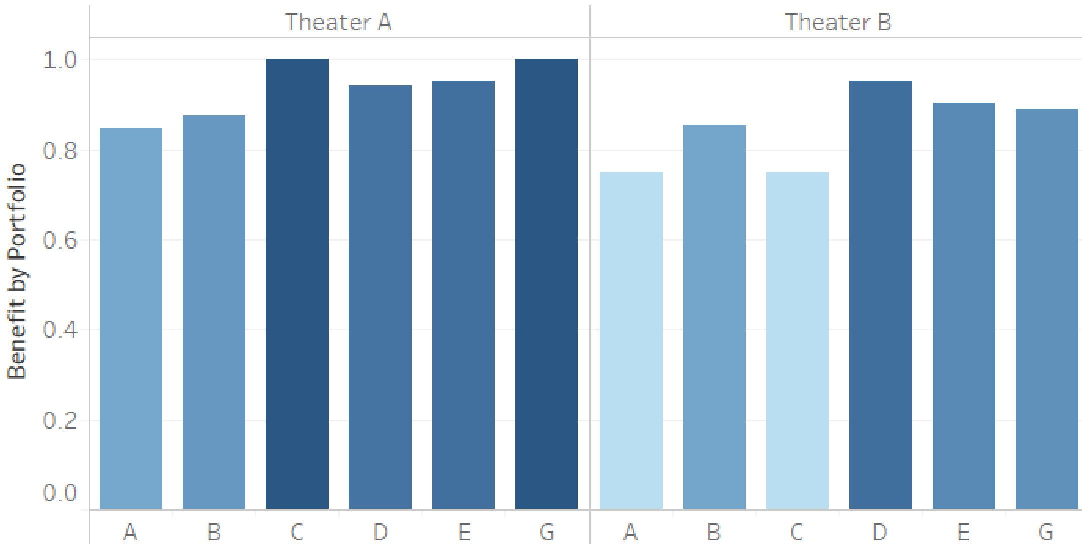


Figure 4.4. 50% Decrement on Portfolios A, B, C, D, E, and G

By decrementing the budget 50%, the funding level of six portfolios are impacted. This result could stem from one of the two following possibilities.

1. The portfolio cost is significantly reduced when the funding level is 50% or 0%. Thus, this limits the impact on the overall model.
2. The legacy equipment currently in operation for each theater provides significant operational benefit to the force.

Portfolio D consists of programs that are significant cost drivers when determining total cost of the model. Therefore, reducing the funding within this portfolio offsets a constrained budget with limited impact on other portfolios.

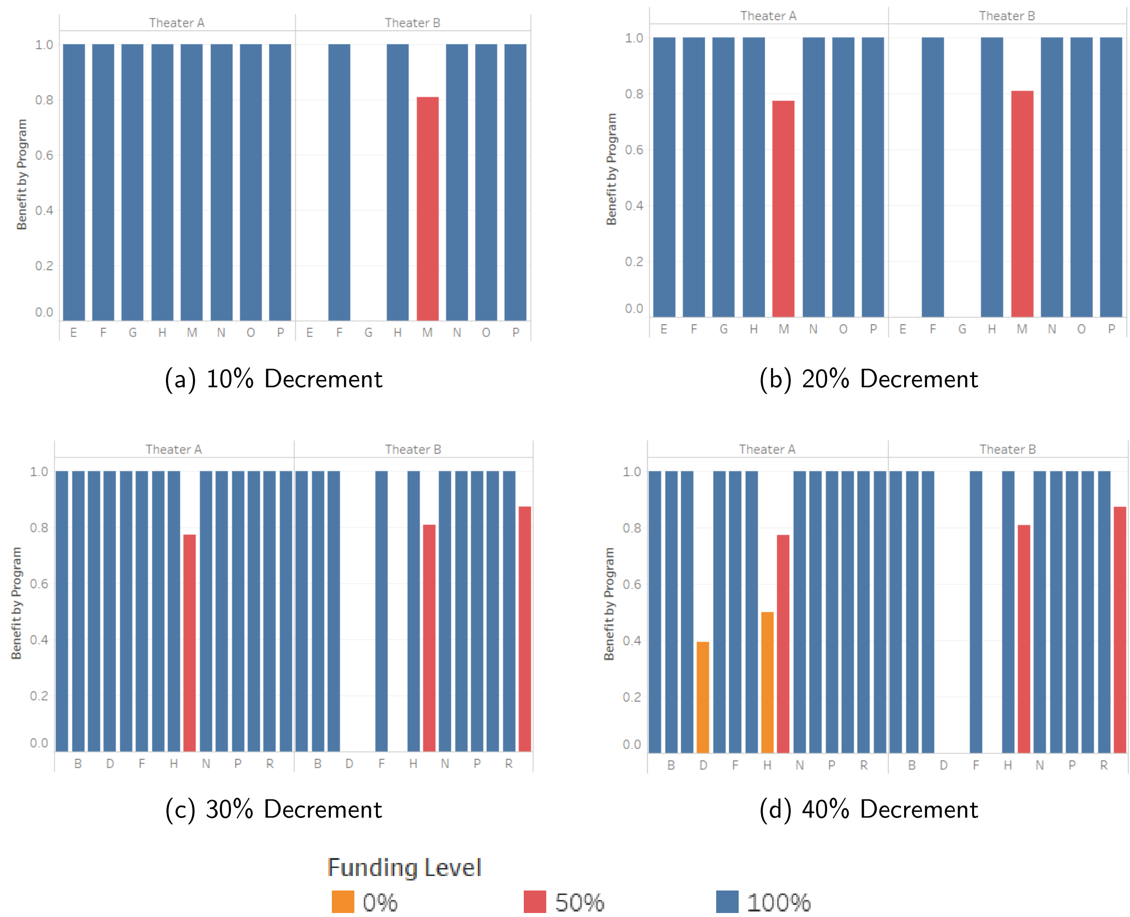
Table 4.1. Operational Benefit Values for Portfolios B and D

	Theater A			Theater B		
	0%	50%	100%	0%	50%	100%
Portfolio B	106	165	204	30	50	65
Portfolio D	150	207	268	150	212	287

As for operational benefit, Table 4.1 displays the operational benefit for Portfolios B and D and that highlights the operational benefit is not significantly impacted as the funding level is reduced. If portfolios B or D is not requisitioned, the legacy equipment will provide over 50% of the operational benefit compared to the modernized program.

4.2.3 Impact on Operational Benefit by Program

This section will focus on the programs within each portfolio discussed in Section 4.2.2. The computed operational benefit by program is shown in Figure 4.5 with a budget decrement of 10%, 20%, 30%, and 40%, respectively. Programs displayed in orange have been reduced to a funding level of 0% while programs displayed in red have been reduced to 50%, whereas Programs E and G have been reduced to a zero funding level and have no operational value for Theater B.



(a) 10% Decrement

(b) 20% Decrement

(c) 30% Decrement

(d) 40% Decrement

Figure 4.5. Impact on Program Operational Benefit

Budget decrements up to 40% will affect Programs D, H, and M in Theater A and Programs D, E, G, M, and S in Theater B. Any decrement over this amount will have a trickle effect on other programs, as shown in Figure 4.6.

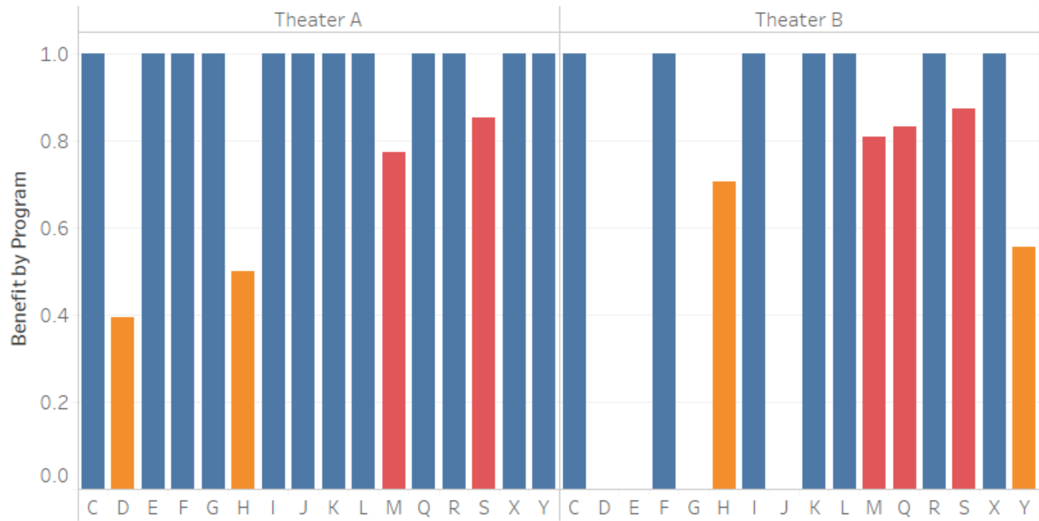


Figure 4.6. 50% Decrement on Portfolios A, B, C, D, E, and G by Program

At a 50% budget decrement, Programs M and S have been reduced to a 50% funding level while all other impacted programs have a funding level of 0%; therefore, they maintain the legacy equipment. Table 4.2 displays the operational benefit values for each program impacted by a 50% decrement.

Table 4.2. Operational Benefit Values for Portfolios A, B, D, and E

		Theater A			Theater B		
		0%	**50%**	**100%**	**0%**	**50%**	**100%**
Portfolio A	Program A	0.0	51.3	65.0	0.0	42.5	57.5
	Program B	23.8	61.3	77.6	17.0	47.5	59.2
	Program C	24.3	48.3	58.1	10.4	25.0	32.9
	Program D	24.3	27.4	30.6	10.4	10.6	10.8
Portfolio B	Program E	33.2	40.4	48.8	0.0	0.0	0.0
	Program F	0.0	35.0	50.0	0.0	15.0	22.5
	Program G	60.0	70.0	80.0	0.0	0.0	0.0
	Program H	12.5	20.0	25.0	30.0	35.0	42.5
Portfolio D	Program M	40.0	56.7	73.3	40.0	56.7	70.0
	Program N	40.0	55.0	73.3	40.0	55.0	73.3
	Program O	35.0	45.0	65.0	35.0	40.0	50.0
	Program P	35.0	55.0	75.0	35.0	55.0	75.0
Portfolio E	Program Q	35.0	50.0	60.0	35.0	50.0	60.0
	Program R	25.0	50.0	70.0	25.0	50.0	70.0
	Program S	21.7	34.2	40.0	21.7	34.2	39.2

The four programs most impacted by a severe budget constraint are Programs D, H, M, and S. Program D provides minimal operational benefit for both theaters while Program H provides minimal benefit to Theater B. Program M is the highest cost driver within the model and, beginning in 2022, the procurement timeline spans the entire acquisition period. Program S has a relatively high cost per formation and is procured in a single year, 2021. Therefore, cutting these two programs will offset our budget constraint for the duration of the program timeline. Reducing funding levels for these four programs will maximize operational benefit if budgets are drastically constrained for the entire length of our procurement timeline.

Fundamentally, this ideology emphasizes the importance of the optimization model in determining the program mix that maximizes operational benefit. By computing the overall trade-off at each funding level, we can provide ASL with a detailed analysis of each modernization program to assist in determining the most feasible allocation of resources to maximize total operational benefit and achieve AFC's priorities.

4.3 Annual Budget Constraint Comparison

Similar to the five-year budget constraint, if the annual budget constraint equals total obligations, the maximum total operational benefit is 1.0. Figure 4.7 displays the impact the annual budget constraint will have on total operational benefit.

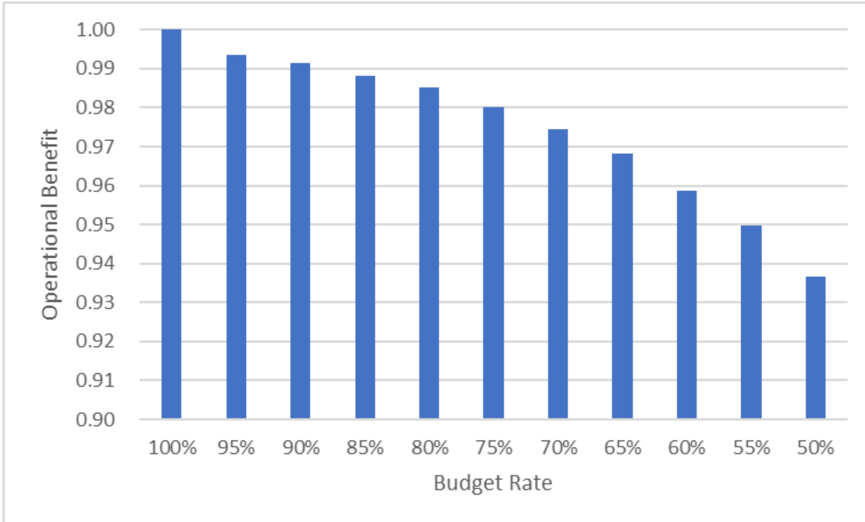
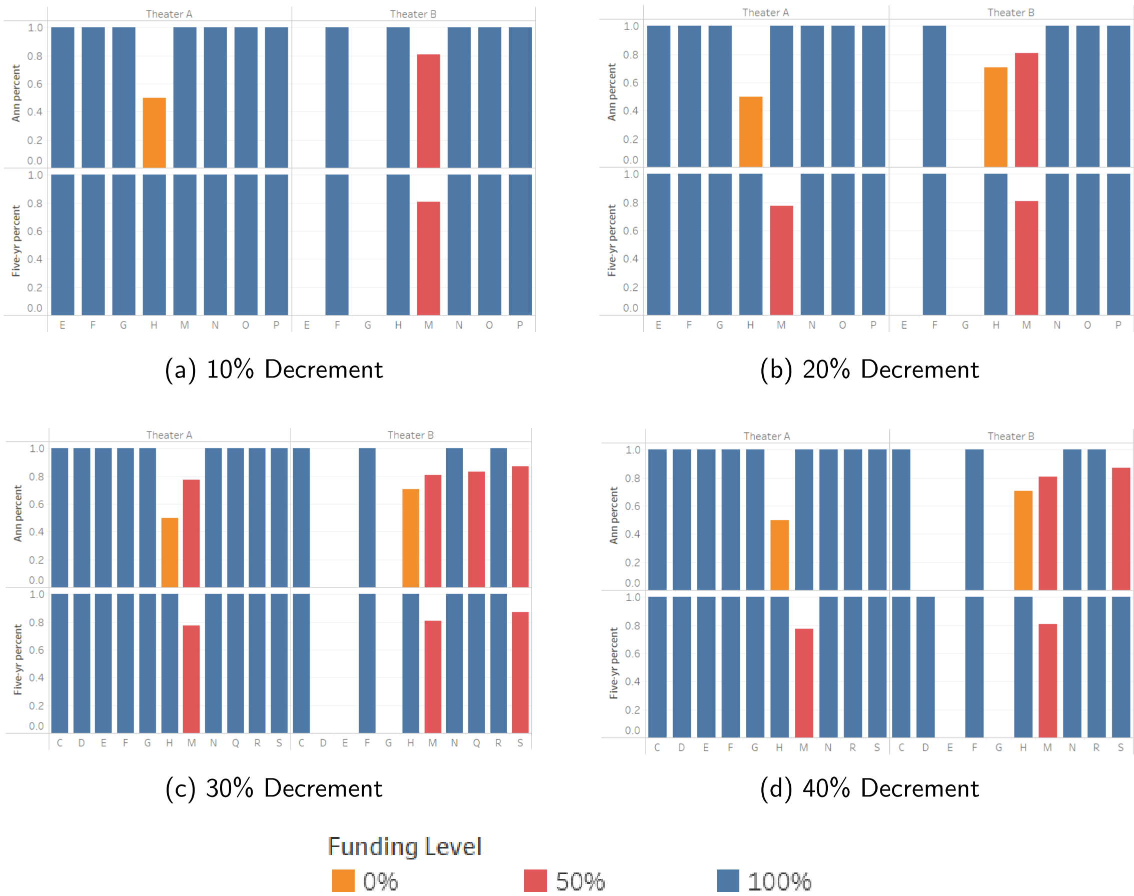


Figure 4.7. Impact of an Annual Budget Constraint on Operational Benefit

The initial impact on operational benefit subject to an annual budget constraint versus a five-year budget constraint does not differ significantly when comparing total benefit by theater or by portfolio. When we compute the operational benefit by program using a 10% annualized budget constraint, Program H is reduced to 50% in Theater A while all other programs remain consistent to the five-year constraint variable. Once the budget decrement exceeds 10%, the impacted programs vary slightly as shown in Figure 4.9.



(a) 10% Decrement

(b) 20% Decrement

(c) 30% Decrement

(d) 40% Decrement

Figure 4.8. Five-year vs. Annual Budget Constraint

When compared to the five-year constraint, the annual constraint will have a greater impact on operational benefit and impact a greater number of programs. Figure 4.9 displays the impact a 50% decrement will have on operational benefit across each theater.

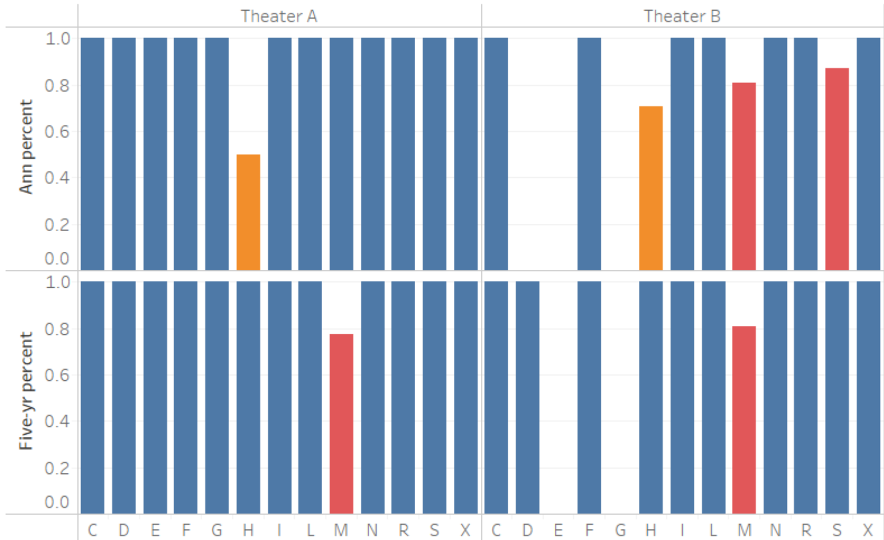


Figure 4.9. 50% Decrement on Portfolios A, B, C, and D

As noted in Section 2.3.3, the CBO expects program obligations to rise over the next 15 years at the same time the current administration is considering constraining budgets to offset the nation's growing debt. As we do not anticipate a substantial budget decrement to impact the Army's modernization efforts, our results provide ASL the recommended mix of programs to maximize operational benefit given a range of decrements.

If we experience a decrement of five percent, funding for Program D should be reduced to zero. This would impact Portfolio B for both theaters. For budget decrements between five and 15%, Programs D and K would not be funded in Theater A but fully funded in Theater B. Thus, this will impact Portfolios B and D.

One note of interest is the funding level for programs impacted by a budget decrement. For all budget decrements we analyzed, the only programs funded at 50% were Program D and Program F when confronted with a 30% and 35% decrement, respectively. All other impacted programs are not funded.

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CHAPTER 5:
Conclusion

5.1 Summary of Results

This thesis provides a new perspective to aid decision makers in determining the optimal mix of acquisition programs that maximizes operational benefit by formulating a five-year budget constraint based off the FYDP process. We reviewed the defense budget formulation process and analyzed the compilation of FYDP in relation to the defense acquisition process. By combining the program cost estimates into five-year rolling estimates, our model presents a more systematic representation of the budget formulation and acquisition process when compared to an annual budget constraint.

We implemented this methodology within an optimization model to compute the total operational benefit subject to our five-year budget constraint. By using sensitivity analysis, we computed the operational benefit with budget constraints varying from a 5% to 50% decrement. For budget decrements less than 30%, we discovered the five-year budget constraint returned a total operational benefit similar to the annual budget constraint. Once the budget decrement increased beyond this 30% threshold, the five-year budget constraint model returned a higher operational benefit and reduced the impact on the overall Army modernization effort.

Table 5.1 highlights the funding level of each program, displays how a five-year budget decrement will impact operational benefit by theater, and the decrement level of each impacted portfolio/program.

Table 5.1. Impact on Program Funding Level

Budget Decrement	Theater Benefit A	Theater Benefit B	Portfolio Impacted A	Portfolio Impacted B	Program Impacted (Funding Level) A	Program Impacted (Funding Level) B
0%	1.0000	1.0000	-	-	-	-
10%	1.0000	0.9940	-	D	-	M = 50%
20%	0.9933	0.9940	D	D	M = 50%	M = 50%
30%	0.9917	0.9822	D	A, B, D, E	M = 50%	D = 0% M = 50% S = 50%
40%	0.9772	0.9822	A, B, D	A, D, E	D = 0% H = 0% M = 50%	D = 0% M = 50% S = 50%
50%	0.9743	0.9546	A, B, D, E	A, B, C, D, E, G	D = 0% H = 0% M = 50% S = 50%	D = 0% H = 0% J = 0% M = 50% Q = 50% S = 50% Y = 0%

As this data represents, due to the operational benefit of legacy equipment within each theater of operation, during times of budgetary constraints, programs that do not offer substantial operational benefit will receive no additional resources. Thus, this maintains the legacy equipment, such as Programs D, E, G, and H. Program M, funded at 50% in each theater, is the high cost driver within the model that spans almost the length of the acquisition timeline. Portfolios B and D are the most impacted portfolios. Portfolio B includes four programs whose legacy equipment provides substantial operational benefit. Portfolio D includes the four highest cost programs, which includes Program M.

The output of our linear programming model is not a substitute for the decision making process. Instead, the real benefit of our model is to provide ASL with the following information to assist in the decision making process.

1. Provide ASL a quantitative analysis to aid in the overall decision making process when determining what program mix, for each theater, will provide the greatest operational benefit under future budgetary constraints.
2. Inform ASL of the impact on program allocation per theater if the budget is decremented during the acquisition process. This will predict possible equipment short-

falls that may result, thus impacting CCMD and their ability to maintain 100% operational readiness.

5.2 Recommendations for Further Research

During our initial research, we questioned the validity of some factors currently used in the cost and budget computation that ultimately impacts the proposed optimization of total operational benefit. In Table 5.2, we propose future updates to the current methodology and then we explain the potential benefit of each proposed methodology change.

Table 5.2. Proposed Methodology for Future Research

	Current Methodology	Proposed Methodology
1.	Point estimates are used for program cost estimates.	Incorporate cost and uncertainty analysis in the model.
2.	Schedule risk is not a determining factor in the model.	Incorporate a schedule risk variance and implement results into the optimization model.
3.	No inflation adjustments in current model.	Normalize data for inflation.
4.	Current model only incorporates RDTE and Procurement costs.	Incorporate program Life Cycle Costs in the model.
5.	No computation to determine program correlation.	Create a correlation matrix to determine if programs have a positive or negative correlation of being acquired.
7.	No dialogue with Program Managers (PM).	Create a dialogue with PM's to determine program status and receive updates to possible cost or schedule performance variances that may impact program deliveries and/or total costs.

5.2.1 Cost Risk and Uncertainty

Current cost data is derived from the cPROBE environment utilized by the Army G8 budget management database. The cPROBE contains budget proposals for the current FYDP. AFC maps directly to the data to incorporate the most up to date cost data. The cost data obtained from cPROBE is a point estimate of the program's cost. A point estimate is a single value estimate produced by an analyst prior to assessing all values. From a mathematical perspective, this point estimate is simply one value among many feasible values and acts like an "anchor" for which other estimates can be derived [26].

Costs can be analyzed using a probability density function. When analyzing cost uncertainty, it is common to see more probability density to the right of a point estimate than to the left [26]. However, a point estimate is one possible outcome and may lie anywhere on the program's probability distribution. The probability density function (PDF) will not be identical for each program and depends on the underlying cost factors and program structure (i.e., a cost estimate for an armored multi-purpose vehicle will not have the same PDF as virtual trainer).

The benefits of incorporating cost uncertainty analysis within the model is to provide AMA with another tool in determining the potential risk cost overruns could have on the acquisition process and possible impacts on the total operational benefit of the modernization effort.

5.2.2 Schedule Risk

When analyzing the schedule risk and uncertainty of a program, we are interested in the probability that a program will not meet current forecasts of delivery and how such a delay could impact operational benefit or CCMD within each theater. Schedule uncertainty arises due to estimating errors or overly optimistic estimates that contractors cannot meet [27].

In order to estimate and account for schedule risk and uncertainty, the duration of a program's critical path should be analyzed to determine specific milestones that, if not met, could lead to significant program delays. Schedule risk should be computed and monitored as a delay in a program will directly impact operational benefit and could be an indicator of a more significant issue within the program.

5.2.3 Normalize Data for Inflation

When working with cost or budget data over multi-year time periods, data should be normalized for inflation. During periods we experience a stagnant or constrained budget, once cost data is adjusted for inflation, our proposed budget will fall short of total obligations.

According to a recent Federal Register, the DOD, General Services Administration (GSA), and NASA have requested an amendment to the Federal Acquisition Regulation (FAR) that requires an adjustment every five years of statutory acquisition-related thresholds for inflation [28].

Each service provides inflationary indices for each appropriation. Normalizing all data according to the Army's applicable inflation indices will assist in preventing unforeseen cost overruns and highlight possible shortfalls during the early stages of the acquisition process.

5.2.4 Program Life Cycle Costs

Current U.S. legislative code requires the development of life cycle cost estimates (LCCE) at major milestones in the defense acquisition process. Under United States Code (USC) Title 10, section 2432, the SECDEF must report a full LCCE for each MDAP [18]. The intent of computing and reporting the LCCE is to understand the total cost of the project from "cradle to grave," also known as "whole life costing," and incorporates the following costs:

1. RDTE,
2. Procurement,
3. Operating and Support, and
4. Disposal.

The importance of incorporating life cycle costs within the initial program cost estimate has become apparent when the Navy received cost estimates of over $1 billion for dismantling and disposing of the ex-USS *Enterprise*. The first USS *Enterprise* (CVN-65) was commissioned in 1961 and served the Navy for 51 years prior to decommissioning. In the Government Accountability Office (GAO) report to congressional committees regarding the disposal costs, the GAO acknowledged the disposal costs were part of the final phase of the program's life cycle. However, the GAO found that no cost, schedule, risk management, or general performance of dismantlement and disposal was incorporated in Navy policy [29].

5.2.5 Program Correlation

As discussed in Section 1.4, AFC has eight priority portfolios consisting of 34 programs. Each portfolio contains three to five programs that support the specific portfolio objective. We suggest incorporating a correlation matrix that would provide guidance as to the probability that if Program A of Portfolio A is acquired, will this have a positive/negative correlation on whether Programs B or C is acquired? Determining inter-correlation among portfolios will provide analysts with a better understanding of how to compute operational benefit for competing programs and provide more accurate recommendations to ASL.

5.2.6 Dialogue with PM

Create a dialogue with the PM to determine a program's status and receive updates regarding possible cost or schedule performance variances that may impact program deliveries and/or total costs. The PM is responsible for ensuring the program meets all thresholds during each phase of the acquisition process.

APPENDIX A:
R Code — Five-Year Budget Constraint

```
library (readxl)
library (scales)
library  (lpSolve)
library  (lpSolveAPI)

# Read Budget and Fixed Cost Data
fixed_years = read_excel(input_file , sheet = 'fixed_year') # Years for costing and purchasing
noncft_costs = read_excel(input_file , sheet = 'nonCFTProgramCosts', range = 'A6:M8')
noncft_costs = data.frame(noncft_costs [,-1], row.names = noncft_costs$APPN)
colnames(noncft_costs) = fixed_years$years

# Read Budget and Fixed Cost Data
five_year_budget = read_excel(input_file , sheet = 'budget', range = 'A9:M10') # Net 5-year fixed budget
five_year_budget = data.frame(five_year_budget[,-1])
five_year_budget = as.numeric(five_year_budget)

# Compute the Budget Constraint Variable
total_fixed_cost = data.frame('nonCFT_RDTE' = as.numeric(noncft_costs['RDTE',]),
                              'nonCFT_Procurement' = as.numeric(noncft_costs['PROC',]),
                              row.names = fixed_years$years)

total_fixed_cost$budget = as.numeric(five_year_budget) # Add the budget column to the end
total_five_year_budget = (five_year_budget-noncft_costs['RDTE',] - noncft_costs['PROC',])

#Read cost data
TheaterA_50 = read_excel(input_file , sheet = 'Model_34_Programs', range = 'W247:AH281')
TheaterA_50 = t(unname(data.frame(TheaterA_50)))
TheaterA_100 = read_excel(input_file , sheet = 'Model_34_Programs', range = 'W284:AH318')
TheaterA_100 = t(unname(data.frame(TheaterA_100)))
TheaterB_50 = read_excel(input_file , sheet = 'Model_34_Programs', range = 'BH247:BS281')
TheaterB_50 = t(unname(data.frame(TheaterB_50)))
TheaterB_100 = read_excel(input_file , sheet = 'Model_34_Programs', range = 'BH284:BS318')
TheaterB_100 = t(unname(data.frame(TheaterB_100)))

# Set Objective Function variables
obj_benefit = read_excel(input_file , sheet = 'portfolio', range = 'V1:AA35')
obj_benefit = as.matrix(obj_benefit)
TheaterA_100_BEN = obj_benefit[,6]
TheaterA_50_BEN = obj_benefit[,5]
TheaterA_0_BEN = obj_benefit[,4]
TheaterB_100_BEN = obj_benefit[,3]
TheaterB_50_BEN = obj_benefit[,2]
TheaterB_0_BEN = obj_benefit[,1]
objfn <- c(TheaterA_100_BEN, TheaterA_50_BEN, TheaterA_0_BEN, TheaterB_100_BEN, TheaterB_50_BEN, TheaterB_0_BEN)
objfn = t(data.frame(objfn))
```

```r
objfn = as.numeric(objfn)

## Sensitivity Analysis Parameters
budget_rate = 1.00
budget_cut = .05
n = 12
i = 1

five_year_Budget_constraint_variables <- matrix(ncol=12, nrow=n)
Max_benefit <- matrix(ncol=1, nrow=n)
Objective_function <- matrix(ncol=204, nrow=n)
Budget_Rate <- matrix(ncol=1, nrow=n)

for(i in 1:n){
  if (i==n+1){
    break
  }else {
    five_year_budget_constraint = total_five_year_budget * budget_rate

  ##### Define Parameters #####

  # Create LPMO with 80 constraints and 204 decision variables and set to Maximize Benefit
  lprec <- make.lp(80, 204)
  lp.control(lprec, sense="max")

  # Set values in first 128 columns as Binary Variables
  set.column(lprec, 1, c(1, TheaterA_100[,1]), indices = c(1, 69:80))
  set.column(lprec, 2, c(1, TheaterA_100[,2]), indices = c(2, 69:80))
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set.column(lprec, 139, c(1, TheaterB_50[,3]), indices = c(37, 69:80))
set.column(lprec, 140, c(1, TheaterB_50[,4]), indices = c(38, 69:80))
set.column(lprec, 141, c(1, TheaterB_50[,5]), indices = c(39, 69:80))
set.column(lprec, 142, c(1, TheaterB_50[,6]), indices = c(40, 69:80))
set.column(lprec, 143, c(1, TheaterB_50[,7]), indices = c(41, 69:80))
set.column(lprec, 144, c(1, TheaterB_50[,8]), indices = c(42, 69:80))
set.column(lprec, 145, c(1, TheaterB_50[,9]), indices = c(43, 69:80))
set.column(lprec, 146, c(1, TheaterB_50[,10]), indices = c(44, 69:80))
set.column(lprec, 147, c(1, TheaterB_50[,11]), indices = c(45, 69:80))
set.column(lprec, 148, c(1, TheaterB_50[,12]), indices = c(46, 69:80))
set.column(lprec, 149, c(1, TheaterB_50[,13]), indices = c(47, 69:80))
set.column(lprec, 150, c(1, TheaterB_50[,14]), indices = c(48, 69:80))
set.column(lprec, 151, c(1, TheaterB_50[,15]), indices = c(49, 69:80))
set.column(lprec, 152, c(1, TheaterB_50[,16]), indices = c(50, 69:80))
set.column(lprec, 153, c(1, TheaterB_50[,17]), indices = c(51, 69:80))
set.column(lprec, 154, c(1, TheaterB_50[,18]), indices = c(52, 69:80))
set.column(lprec, 155, c(1, TheaterB_50[,19]), indices = c(53, 69:80))
set.column(lprec, 156, c(1, TheaterB_50[,20]), indices = c(54, 69:80))
set.column(lprec, 157, c(1, TheaterB_50[,21]), indices = c(55, 69:80))
set.column(lprec, 158, c(1, TheaterB_50[,22]), indices = c(56, 69:80))
set.column(lprec, 159, c(1, TheaterB_50[,23]), indices = c(57, 69:80))
set.column(lprec, 160, c(1, TheaterB_50[,24]), indices = c(58, 69:80))
set.column(lprec, 161, c(1, TheaterB_50[,25]), indices = c(59, 69:80))
set.column(lprec, 162, c(1, TheaterB_50[,26]), indices = c(60, 69:80))
set.column(lprec, 163, c(1, TheaterB_50[,27]), indices = c(61, 69:80))
set.column(lprec, 164, c(1, TheaterB_50[,28]), indices = c(62, 69:80))
set.column(lprec, 165, c(1, TheaterB_50[,29]), indices = c(63, 69:80))
set.column(lprec, 166, c(1, TheaterB_50[,30]), indices = c(64, 69:80))
set.column(lprec, 167, c(1, TheaterB_50[,31]), indices = c(65, 69:80))
set.column(lprec, 168, c(1, TheaterB_50[,32]), indices = c(66, 69:80))
set.column(lprec, 169, c(1, TheaterB_50[,33]), indices = c(67, 69:80))
```

```
set.column(lprec, 170, c(1, TheaterB_50[,34]), indices = c(68, 69:80))

set.column(lprec, 171, 1, indices = 35)
set.column(lprec, 172, 1, indices = 36)
set.column(lprec, 173, 1, indices = 37)
set.column(lprec, 174, 1, indices = 38)
set.column(lprec, 175, 1, indices = 39)
set.column(lprec, 176, 1, indices = 40)
set.column(lprec, 177, 1, indices = 41)
set.column(lprec, 178, 1, indices = 42)
set.column(lprec, 179, 1, indices = 43)
set.column(lprec, 180, 1, indices = 44)
set.column(lprec, 181, 1, indices = 45)
set.column(lprec, 182, 1, indices = 46)
set.column(lprec, 183, 1, indices = 47)
set.column(lprec, 184, 1, indices = 48)
set.column(lprec, 185, 1, indices = 49)
set.column(lprec, 186, 1, indices = 50)
set.column(lprec, 187, 1, indices = 51)
set.column(lprec, 188, 1, indices = 52)
set.column(lprec, 189, 1, indices = 53)
set.column(lprec, 190, 1, indices = 54)
set.column(lprec, 191, 1, indices = 55)
set.column(lprec, 192, 1, indices = 56)
set.column(lprec, 193, 1, indices = 57)
set.column(lprec, 194, 1, indices = 58)
set.column(lprec, 195, 1, indices = 59)
set.column(lprec, 196, 1, indices = 60)
set.column(lprec, 197, 1, indices = 61)
set.column(lprec, 198, 1, indices = 62)
set.column(lprec, 199, 1, indices = 63)
set.column(lprec, 200, 1, indices = 64)
set.column(lprec, 201, 1, indices = 65)
set.column(lprec, 202, 1, indices = 66)
set.column(lprec, 203, 1, indices = 67)
set.column(lprec, 204, 1, indices = 68)

# Set constraint types
const = rep("<=", 80)
set.constr.type(lprec, const)

# Set RHS of constraint variables
binary_variables = rep(1, 68)
rhs <- c(binary_variables, five_year_budget_constraint)
set.rhs(lprec, rhs)

# Set variable type to Binary
set.type(lprec, 1:204, "binary")

# Set Row and Column names for decision variables and constraints
```

```
RowNames <- c("ThA1", "ThA2", "ThA3", "ThA4", "ThA5", "ThA6", "ThA7", "ThA8", "ThA9",
              "ThA10", "ThA11", "ThA12", "ThA13", "ThA14", "ThA15", "ThA16", "ThA17",
              "ThA18", "ThA19", "ThA20", "ThA21", "ThA22", "ThA23", "ThA24", "ThA25",
              "ThA26", "ThA27", "ThA28","ThA29", "ThA30", "ThA31", "ThA32", "ThA33",
              "ThA34", "ThB1", "ThB2", "ThB3", "ThB4", "ThB5", "ThB6", "ThB7", "ThB8",
              "ThB9", "ThB10", "ThB11", "ThB12", "ThB13", "ThB14", "ThB15", "ThB16",
              "ThB17", "ThB18", "ThB19", "ThB20", "ThB21", "ThB22", "ThB23", "ThB24",
              "ThB25", "ThB26", "ThB27", "ThB28","ThB29", "ThB30", "ThB31", "ThB32",
              "ThB33", "ThB34", "20-24", "21-25", "22-26", "23-27", "24-28", "25-29",
              "26-30", "27-31", "28-32", "29-33", "30-34", "31-35")

ColNames <- c("TA1_100", "TA2_100", "TA3_100", "TA4_100", "TA5_100", "TA6_100", "TA7_100",
              "TA8_100", "TA9_100", "TA10_100", "TA11_100", "TA12_100", "TA13_100", "TA14_100",
              "TA15_100", "TA16_100", "TA17_100", "TA18_100", "TA19_100", "TA20_100", "TA21_100",
              "TA22_100", "TA23_100", "TA24_100", "TA25_100", "TA26_100", "TA27_100", "TA28_100",
              "TA29_100", "TA30_100", "TA31_100", "TA32_100", "TA33_100", "TA34_100", "TA1_50",
              "TA2_50", "TA3_50", "TA4_50", "TA5_50", "TA6_50", "TA7_50", "TA8_50", "TA9_50",
              "TA10_50", "TA11_50", "TA12_50", "TA13_50", "TA14_50", "TA15_50", "TA16_50",
              "TA17_50", "TA18_50", "TA19_50", "TA20_50", "TA21_50", "TA22_50", "TA23_50",
              "TA24_50", "TA25_50", "TA26_50", "TA27_50", "TA28_50", "TA29_50", "TA30_50",
              "TA31_50", "TA32_50", "TA33_50", "TA34_50", "TA1_0", "TA2_0", "TA3_0", "TA4_0",
              "TA5_0", "TA6_0", "TA7_0", "TA8_0", "TA9_0", "TA10_0", "TA11_0", "TA12_0", "TA13_0",
              "TA14_0", "TA15_0", "TA16_0", "TA17_0", "TA18_0", "TA19_0", "TA20_0", "TA21_0",
              "TA22_0", "TA23_0", "TA24_0", "TA25_0", "TA26_0", "TA27_0", "TA28_0", "TA29_0",
              "TA30_0", "TA31_0", "TA32_0", "TA33_0", "TA34_0", "TB1_100", "TB2_100", "TB3_100",
              "TB4_100", "TB5_100", "TB6_100", "TB7_100", "TB8_100", "TB9_100", "TB10_100",
              "TB11_100", "TB12_100", "TB13_100", "TB14_100", "TB15_100", "TB16_100", "TB17_100",
              "TB18_100", "TB19_100", "TB20_100", "TB21_100", "TB22_100", "TB23_100", "TB24_100",
              "TB25_100", "TB26_100", "TB27_100", "TB28_100", "TB29_100", "TB30_100", "TB31_100",
              "TB32_100", "TB33_100", "TB34_100", "TB1_50", "TB2_50", "TB3_50", "TB4_50", "TB5_50",
              "TB6_50", "TB7_50", "TB8_50", "TB9_50", "TB10_50", "TB11_50", "TB12_50", "TB13_50",
              "TB14_50", "TB15_50", "TB16_50", "TB17_50", "TB18_50", "TB19_50", "TB20_50",
              "TB21_50", "TB22_50", "TB23_50", "TB24_50", "TB25_50", "TB26_50", "TB27_50",
              "TB28_50", "TB29_50", "TB30_50", "TB31_50", "TB32_50", "TB33_50", "TB34_50", "TB1_0",
              "TB2_0", "TB3_0", "TB4_0", "TB5_0", "TB6_0", "TB7_0", "TB8_0", "TB9_0", "TB10_0",
              "TB11_0", "TB12_0", "TB13_0", "TB14_0", "TB15_0", "TB16_0", "TB17_0", "TB18_0",
              "TB19_0", "TB20_0", "TB21_0", "TB22_0", "TB23_0", "TB24_0", "TB25_0", "TB26_0",
              "TB27_0", "TB28_0", "TB29_0", "TB30_0", "TB31_0", "TB32_0", "TB33_0", "TB34_0")


# Set objective function (T1/100%/50% T2/100%/50%)
set.objfn(lprec, objfn)

##### Solve the Optimization Problem #####
dimnames(lprec) <- list(RowNames, ColNames)
solve(lprec)
get.objective(lprec)
get.variables(lprec)
get.constraints(lprec)
summary(lprec)
```

```
########################################
obj = get.objective(lprec)
variables = get.variables(lprec)

Budget_Rate[i,] <- paste(budget_rate)
Max_benefit[i,] <- paste(as.numeric(obj))
five_year_Budget_constraint_variables[i,] <- paste(five_year_budget_constraint)
Objective_function[i,] <- paste(variables)

budget_rate = budget_rate - budget_cut
}
}
```

APPENDIX B:
lpSolve Output — Five-Year Budget Constraint

```
% \inputRcode[caption={},numbers=left,numberstyle=\tiny]{optimization_full_2.txt}
/* Objective function */
max: +50 TA1_100 +58 TA2_100 +35 TA3_100 +45 TA4_100 +25 TA5_100 +80 TA6_100 +65 TA7_100 +50 TA8_100 +80 TA9_100
 +60 TA10_100 +70 TA11_100 +73 TA12_100 +50 TA13_100 +75 TA14_100 +55 TA15_100 +73 TA16_100 +50 TA17_100
 +68 TA18_100 +46 TA19_100 +68 TA20_100 +73 TA21_100 +30 TA22_100 +30 TA23_100 +90 TA24_100 +90 TA25_100
 +42 TA26_100 +45 TA27_100 +35 TA28_100 +45 TA29_100 +80 TA30_100 +70 TA31_100 +35 TA32_100 +37 TA1_50
 +44 TA2_50 +22 TA3_50 +43 TA4_50 +20 TA5_50 +70 TA6_50 +62 TA7_50 +45 TA8_50 +65 TA9_50 +50 TA10_50
 +57 TA11_50 +55 TA12_50 +40 TA13_50 +55 TA14_50 +45 TA15_50 +55 TA16_50 +47 TA17_50 +55 TA18_50 +35 TA19_50
 +45 TA20_50 +55 TA21_50 +27 TA22_50 +27 TA23_50 +80 TA24_50 +80 TA25_50 +34 TA26_50 +30 TA27_50 +30 TA28_50
 +30 TA29_50 +48 TA30_50 +50 TA31_50 +25 TA32_50 +15 TA2_0 +7 TA3_0 +40 TA4_0 +60 TA6_0 +60 TA7_0 +55 TA9_0
 +15 TA10_0 +40 TA11_0 +40 TA12_0 +35 TA13_0 +35 TA14_0 +33 TA15_0 +23 TA16_0 +28 TA17_0 +20 TA18_0 +11 TA19_0
 +5 TA20_0 +23 TA21_0 +20 TA22_0 +20 TA23_0 +65 TA24_0 +65 TA25_0 +10 TA27_0 +25 TA28_0 +10 TA29_0 +18 TA30_0
 +25 TA31_0 +TA32_0 +57 TB1_100 +73 TB2_100 +64 TB3_100 +44 TB4_100 +40 TB5_100 +80 TB6_100 +40 TB7_100
 +58 TB8_100 +78 TB9_100 +55 TB10_100 +73 TB11_100 +73 TB12_100 +65 TB13_100 +75 TB14_100 +55 TB15_100
 +73 TB16_100 +50 TB17_100 +63 TB18_100 +69 TB19_100 +58 TB20_100 +75 TB21_100 +25 TB22_100 +25 TB23_100
 +80 TB24_100 +80 TB25_100 +42 TB26_100 +70 TB27_100 +60 TB28_100 +70 TB29_100 +80 TB30_100 +70 TB31_100
 +45 TB32_100 +43 TB1_50 +61 TB2_50 +53 TB3_50 +37 TB4_50 +25 TB5_50 +70 TB6_50 +35 TB7_50 +54 TB8_50
 +63 TB9_50 +40 TB10_50 +57 TB11_50 +55 TB12_50 +45 TB13_50 +55 TB14_50 +45 TB15_50 +55 TB16_50 +47 TB17_50
 +45 TB18_50 +49 TB19_50 +37 TB20_50 +55 TB21_50 +21 TB22_50 +21 TB23_50 +72 TB24_50 +72 TB25_50 +34 TB26_50
 +50 TB27_50 +40 TB28_50 +50 TB29_50 +48 TB30_50 +55 TB31_50 +35 TB32_50 +23 TB2_0 +31 TB3_0 +28 TB4_0
 +60 TB6_0 +30 TB7_0 +34 TB8_0 +53 TB9_0 +30 TB10_0 +40 TB11_0 +40 TB12_0 +35 TB13_0 +35 TB14_0 +33 TB15_0
 +23 TB16_0 +28 TB17_0 +15 TB18_0 +8 TB19_0 +10 TB20_0 +30 TB21_0 +15 TB22_0 +15 TB23_0 +60 TB24_0 +60 TB25_0
 +20 TB27_0 +10 TB28_0 +20 TB29_0 +18 TB30_0 +15 TB31_0 +5 TB32_0;

/* Constraints */
ThA1: +TA1_100 +TA1_50 +TA1_0 <= 1;
ThA2: +TA2_100 +TA2_50 +TA2_0 <= 1;
ThA3: +TA3_100 +TA3_50 +TA3_0 <= 1;
ThA4: +TA4_100 +TA4_50 +TA4_0 <= 1;
ThA5: +TA5_100 +TA5_50 +TA5_0 <= 1;
ThA6: +TA6_100 +TA6_50 +TA6_0 <= 1;
ThA7: +TA7_100 +TA7_50 +TA7_0 <= 1;
ThA8: +TA8_100 +TA8_50 +TA8_0 <= 1;
ThA9: +TA9_100 +TA9_50 +TA9_0 <= 1;
ThA10: +TA10_100 +TA10_50 +TA10_0 <= 1;
ThA11: +TA11_100 +TA11_50 +TA11_0 <= 1;
ThA12: +TA12_100 +TA12_50 +TA12_0 <= 1;
ThA13: +TA13_100 +TA13_50 +TA13_0 <= 1;
ThA14: +TA14_100 +TA14_50 +TA14_0 <= 1;
ThA15: +TA15_100 +TA15_50 +TA15_0 <= 1;
ThA16: +TA16_100 +TA16_50 +TA16_0 <= 1;
ThA17: +TA17_100 +TA17_50 +TA17_0 <= 1;
ThA18: +TA18_100 +TA18_50 +TA18_0 <= 1;
ThA19: +TA19_100 +TA19_50 +TA19_0 <= 1;
ThA20: +TA20_100 +TA20_50 +TA20_0 <= 1;
ThA21: +TA21_100 +TA21_50 +TA21_0 <= 1;
```

ThA22: +TA22_100 +TA22_50 +TA22_0 <= 1;
ThA23: +TA23_100 +TA23_50 +TA23_0 <= 1;
ThA24: +TA24_100 +TA24_50 +TA24_0 <= 1;
ThA25: +TA25_100 +TA25_50 +TA25_0 <= 1;
ThA26: +TA26_100 +TA26_50 +TA26_0 <= 1;
ThA27: +TA27_100 +TA27_50 +TA27_0 <= 1;
ThA28: +TA28_100 +TA28_50 +TA28_0 <= 1;
ThA29: +TA29_100 +TA29_50 +TA29_0 <= 1;
ThA30: +TA30_100 +TA30_50 +TA30_0 <= 1;
ThA31: +TA31_100 +TA31_50 +TA31_0 <= 1;
ThA32: +TA32_100 +TA32_50 +TA32_0 <= 1;
ThB1: +TB1_100 +TB1_50 +TB1_0 <= 1;
ThB2: +TB2_100 +TB2_50 +TB2_0 <= 1;
ThB3: +TB3_100 +TB3_50 +TB3_0 <= 1;
ThB4: +TB4_100 +TB4_50 +TB4_0 <= 1;
ThB5: +TB5_100 +TB5_50 +TB5_0 <= 1;
ThB6: +TB6_100 +TB6_50 +TB6_0 <= 1;
ThB7: +TB7_100 +TB7_50 +TB7_0 <= 1;
ThB8: +TB8_100 +TB8_50 +TB8_0 <= 1;
ThB9: +TB9_100 +TB9_50 +TB9_0 <= 1;
ThB10: +TB10_100 +TB10_50 +TB10_0 <= 1;
ThB11: +TB11_100 +TB11_50 +TB11_0 <= 1;
ThB12: +TB12_100 +TB12_50 +TB12_0 <= 1;
ThB13: +TB13_100 +TB13_50 +TB13_0 <= 1;
ThB14: +TB14_100 +TB14_50 +TB14_0 <= 1;
ThB15: +TB15_100 +TB15_50 +TB15_0 <= 1;
ThB16: +TB16_100 +TB16_50 +TB16_0 <= 1;
ThB17: +TB17_100 +TB17_50 +TB17_0 <= 1;
ThB18: +TB18_100 +TB18_50 +TB18_0 <= 1;
ThB19: +TB19_100 +TB19_50 +TB19_0 <= 1;
ThB20: +TB20_100 +TB20_50 +TB20_0 <= 1;
ThB21: +TB21_100 +TB21_50 +TB21_0 <= 1;
ThB22: +TB22_100 +TB22_50 +TB22_0 <= 1;
ThB23: +TB23_100 +TB23_50 +TB23_0 <= 1;
ThB24: +TB24_100 +TB24_50 +TB24_0 <= 1;
ThB25: +TB25_100 +TB25_50 +TB25_0 <= 1;
ThB26: +TB26_100 +TB26_50 +TB26_0 <= 1;
ThB27: +TB27_100 +TB27_50 +TB27_0 <= 1;
ThB28: +TB28_100 +TB28_50 +TB28_0 <= 1;
ThB29: +TB29_100 +TB29_50 +TB29_0 <= 1;
ThB30: +TB30_100 +TB30_50 +TB30_0 <= 1;
ThB31: +TB31_100 +TB31_50 +TB31_0 <= 1;
ThB32: +TB32_100 +TB32_50 +TB32_0 <= 1;
20−24: +3.079664 TA1_100 +1.452537 TA2_100 +1.586927 TA3_100 +1.694649 TA4_100 +0.617051 TA5_100 +0.180424 TA6_100 +1.049449 TA7_100 +2.101583 TA8_100 +0.462025 TA9_100 +1.677088 TA10_100 +9.352426 TA11_100 +0.917156 TA12_100 +0.15625 TA13_100 +0.371328 TA14_100 +0.816958 TA15_100 +0.652577 TA16_100 +0 TA17_100 +0.940691796875 TA18_100 +1.921067 TA19_100 +1.1082155 TA20_100 +1.473806 TA21_100 +0.00421737525 TA22_100 +0.284757522375 TA23_100 +1.318935 TA24_100 +0.7507705 TA25_100 +0.31475 TA26_100 +0 TA27_100 +0 TA28_100 +0 TA29_100 +0.2023 TA30_100 +0 TA31_100 +0.2112 TA32_100 +3.079664 TA1_50 +1.112537 TA2_50 +1.331177 TA3_50 +1.694649 TA4_50 +0.617051 TA5_50 +0.180424 TA6_50 +0.814249 TA7_50 +2.101583 TA8_50 +0.327025 TA9_50 +1.677088 TA10_50 +7.789926

TA11_50 +0.292156 TA12_50 +0 TA13_50 +0.215078 TA14_50 +0.504458 TA15_50 +0.340077 TA16_50 +0 TA17_50 +0.594165 TA18_50 +1.531067 TA19_50 +1.07973425 TA20_50 +1.445306 TA21_50 +0.00191698875 TA22_50 +0.274885055625 TA23_50 +1.1374875 TA24_50 +0.59025925 TA25_50 +0 TA26_50 +0 TA27_50 +0 TA28_50 +0 TA29_50 +0 TA30_50 +0 TA31_50 +0.096 TA32_50 +3.079664 TB1_100 +1.316537 TB2_100 +1.714802 TB3_100 +2.80743 TB4_100 +0.617051 TB5_100 +1.16354069125 TB6_100 +0.696649 TB7_100 +2.101583 TB8_100 +0.372025 TB9_100 +1.677088 TB10_100 +9.352426 TB11_100 +0.917156 TB12_100 +0.15625 TB13_100 +0.371328 TB14_100 +0.816958 TB15_100 +0.652577 TB16_100 +0 TB17_100 +0.940691796875 TB18_100 +1.441067 TB19_100 +1.089228 TB20_100 +1.473806 TB21_100 +0.001533591 TB22_100 +0.2732396445 TB23_100 +0.98628125 TB24_100 +0.456499875 TB25_100 +0.31475 TB26_100 +0 TB27_100 +0 TB28_100 +0 TB29_100 +0.2023 TB30_100 +0 TB31_100 +0.0768 TB32_100 +3.079664 TB1_50 +1.044537 TB2_50 +1.459052 TB3_50 +2.065576 TB4_50 +0.617051 TB5_50 +0.50812956375 TB6_50 +0.637849 TB7_50 +2.101583 TB8_50 +0.282025 TB9_50 +1.677088 TB10_50 +7.789926 TB11_50 +0.292156 TB12_50 +0 TB13_50 +0.215078 TB14_50 +0.504458 TB15_50 +0.340077 TB16_50 +0 TB17_50 +0.594165 TB18_50 +1.291067 TB19_50 +1.0702405 TB20_50 +1.445306 TB21_50 +0.0007667955 TB22_50 +0.26994882225 TB23_50 +0.95604 TB24_50 +0.429748 TB25_50 +0 TB26_50 +0 TB27_50 +0 TB28_50 +0 TB29_50 +0 TB30_50 +0 TB31_50 +0.0384 TB32_50 <= 69.7680645431;

21−25: +3.399907 TA1_100 +1.833535 TA2_100 +1.395507 TA3_100 +1.422552 TA4_100 +0.68037 TA5_100 +0.096594 TA6_100 +0.972934 TA7_100 +2.357018 TA8_100 +0.487641 TA9_100 +2.441142 TA10_100 +9.796389 TA11_100 +0.925357 TA12_100 +0.15625 TA13_100 +0.346612 TA14_100 +0.802454 TA15_100 +0.677255 TA16_100 +0 TA17_100 +0.806989796875 TA18_100 +2.519193 TA19_100 +0.984451 TA20_100 +1.239332 TA21_100 +0.005623167 TA22_100 +0.2331246965 TA23_100 +1.21138 TA24_100 +0.5974025 TA25_100 +0.472125 TA26_100 +0 TA27_100 +0 TA28_100 +0 TA29_100 +0.30345 TA30_100 +0 TA31_100 +0.264 TA32_100 +3.325907 TA1_50 +1.323535 TA2_50 +1.139757 TA3_50 +1.422552 TA4_50 +0.68037 TA5_50 +0.096594 TA6_50 +0.659334 TA7_50 +2.357018 TA8_50 +0.307641 TA9_50 +2.441142 TA10_50 +8.233889 TA11_50 +0.300357 TA12_50 +0 TA13_50 +0.190362 TA14_50 +0.489954 TA15_50 +0.364755 TA16_50 +0 TA17_50 +0.460463 TA18_50 +2.031693 TA19_50 +0.9274885 TA20_50 +1.182332 TA21_50 +0.002555985 TA22_50 +0.2199614075 TA23_50 +1.0299325 TA24_50 +0.43689125 TA25_50 +0 TA26_50 +0 TA27_50 +0 TA28_50 +0 TA29_50 +0 TA30_50 +0 TA31_50 +0.12 TA32_50 +3.399907 TB1_100 +1.629535 TB2_100 +1.523382 TB3_100 +3.0917235 TB4_100 +0.68037 TB5_100 +1.07971069125 TB6_100 +0.502534 TB7_100 +2.357018 TB8_100 +0.367641 TB9_100 +2.441142 TB10_100 +9.796389 TB11_100 +0.925357 TB12_100 +0.15625 TB13_100 +0.346612 TB14_100 +0.802454 TB15_100 +0.677255 TB16_100 +0 TB17_100 +0.806989796875 TB18_100 +1.919193 TB19_100 +0.946476 TB20_100 +1.239332 TB21_100 +0.002044788 TB22_100 +0.217767526 TB23_100 +0.87872625 TB24_100 +0.303131875 TB25_100 +0.472125 TB26_100 +0 TB27_100 +0 TB28_100 +0 TB29_100 +0.30345 TB30_100 +0 TB31_100 +0.096 TB32_100 +3.325907 TB1_50 +1.221535 TB2_50 +1.267632 TB3_50 +1.9789425 TB4_50 +0.68037 TB5_50 +0.42429956375 TB6_50 +0.424134 TB7_50 +2.357018 TB8_50 +0.247641 TB9_50 +2.441142 TB10_50 +8.233889 TB11_50 +0.300357 TB12_50 +0 TB13_50 +0.190362 TB14_50 +0.489954 TB15_50 +0.364755 TB16_50 +0 TB17_50 +0.460463 TB18_50 +1.731693 TB19_50 +0.908501 TB20_50 +1.182332 TB21_50 +0.001022394 TB22_50 +0.213379763 TB23_50 +0.848485 TB24_50 +0.27638 TB25_50 +0 TB26_50 +0 TB27_50 +0 TB28_50 +0 TB29_50 +0 TB30_50 +0 TB31_50 +0.048 TB32_50 <= 73.3911045875;

22−26: +3.328496 TA1_100 +2.250799 TA2_100 +0.955649 TA3_100 +0.99886 TA4_100 +0.708778 TA5_100 +0 TA6_100 +1.046781 TA7_100 +2.503789 TA8_100 +0.524403 TA9_100 +3.187067 TA10_100 +10.266027 TA11_100 +0.925396 TA12_100 +0.15625 TA13_100 +0.288274 TA14_100 +0.60878 TA15_100 +0.592786 TA16_100 +0 TA17_100 +0.688745796875 TA18_100 +2.752591 TA19_100 +0.8194185 TA20_100 +1.00914 TA21_100 +0.00702895875 TA22_100 +0.186798870625 TA23_100 +1.006436 TA24_100 +0.6779585 TA25_100 +0.6295 TA26_100 +0 TA27_100 +0 TA28_100 +0 TA29_100 +0.4046 TA30_100 +0 TA31_100 +0.264 TA32_100 +3.180496 TA1_50 +1.570799 TA2_50 +0.699899 TA3_50 +0.99886 TA4_50 +0.708778 TA5_50 +0 TA6_50 +0.654781 TA7_50 +2.503789 TA8_50 +0.299403 TA9_50 +3.187067 TA10_50 +8.703527 TA11_50 +0.300396 TA12_50 +0 TA13_50 +0.132024 TA14_50 +0.29628 TA15_50 +0.280286 TA16_50 +0 TA17_50 +0.342219 TA18_50 +2.265091 TA19_50 +0.73397475 TA20_50 +0.92364 TA21_50 +0.00319498125 TA22_50 +0.170344759375 TA23_50 +0.8249885 TA24_50 +0.51744725 TA25_50 +0 TA26_50 +0 TA27_50 +0 TA28_50 +0 TA29_50 +0 TA30_50 +0 TA31_50 +0.12 TA32_50 +3.328496 TB1_100 +1.978799 TB2_100 +1.083524 TB3_100 +3.224422 TB4_100 +0.708778 TB5_100 +0.98311669125 TB6_100 +0.458781 TB7_100 +2.503789 TB8_100 +0.374403 TB9_100 +3.187067 TB10_100 +10.266027 TB11_100 +0.925396 TB12_100 +0.15625 TB13_100 +0.288274 TB14_100 +0.60878 TB15_100 +0.592786 TB16_100 +0 TB17_100 +0.688745796875 TB18_100 +2.152591 TB19_100 +0.762456 TB20_100 +1.00914 TB21_100 +0.002555985 TB22_100 +0.1676024075 TB23_100 +0.67378225 TB24_100 +0.383687875 TB25_100 +0.6295 TB26_100 +0 TB27_100 +0 TB28_100 +0 TB29_100 +0.4046 TB30_100

+0 TB31_100 +0.096 TB32_100 +3.180496 TB1_50 +1.434799 TB2_50 +0.827774 TB3_50 +1.740714 TB4_50 +0.708778 TB5_50 +0.32770556375 TB6_50 +0.360781 TB7_50 +2.503789 TB8_50 +0.224403 TB9_50 +3.187067 TB10_50 +8.703527 TB11_50 +0.300396 TB12_50 +0 TB13_50 +0.132024 TB14_50 +0.29628 TB15_50 +0.280286 TB16_50 +0 TB17_50 +0.342219 TB18_50 +1.965091 TB19_50 +0.7054935 TB20_50 +0.92364 TB21_50 +0.0012779925 TB22_50 +0.16211770375 TB23_50 +0.643541 TB24_50 +0.356936 TB25_50 +0 TB26_50 +0 TB27_50 +0 TB28_50 +0 TB29_50 +0 TB30_50 +0 TB31_50 +0.048 TB32_50 <= 74.4277026319;

23−27: +2.949995 TA1_100 +2.411118 TA2_100 +0.616521 TA3_100 +0.99886 TA4_100 +0.712208 TA5_100 +0 TA6_100 +0.923638 TA7_100 +2.70294 TA8_100 +0.474267 TA9_100 +4.937318 TA10_100 +10.450437 TA11_100 +0.921878 TA12_100 +0.15625 TA13_100 +0.235176 TA14_100 +0.469397 TA15_100 +0.521803 TA16_100 +0 TA17_100 +0.700752796875 TA18_100 +2.553379 TA19_100 +0.535304 TA20_100 +0.734133 TA21_100 +0.00702895875 TA22_100 +0.144308870625 TA23_100 +0.752193 TA24_100 +0.6535465 TA25_100 +0.786875 TA26_100 +0 TA27_100 +0 TA28_100 +0 TA29_100 +0.50575 TA30_100 +0 TA31_100 +0.264 TA32_100 +2.727995 TA1_50 +1.561118 TA2_50 +0.360771 TA3_50 +0.99886 TA4_50 +0.712208 TA5_50 +0 TA6_50 +0.531638 TA7_50 +2.61294 TA8_50 +0.249267 TA9_50 +4.308443 TA10_50 +8.887937 TA11_50 +0.296878 TA12_50 +0 TA13_50 +0.078926 TA14_50 +0.156897 TA15_50 +0.209303 TA16_50 +0 TA17_50 +0.354226 TA18_50 +2.065879 TA19_50 +0.421379 TA20_50 +0.620133 TA21_50 +0.00319498125 TA22_50 +0.127854759375 TA23_50 +0.5707455 TA24_50 +0.49303525 TA25_50 +0 TA26_50 +0 TA27_50 +0 TA28_50 +0 TA29_50 +0 TA30_50 +0 TA31_50 +0.12 TA32_50 +2.949995 TB1_100 +2.071118 TB2_100 +0.744396 TB3_100 +3.7808125 TB4_100 +0.712208 TB5_100 +0.98311669125 TB6_100 +0.335638 TB7_100 +2.64294 TB8_100 +0.324267 TB9_100 +4.518068 TB10_100 +10.450437 TB11_100 +0.921878 TB12_100 +0.15625 TB13_100 +0.235176 TB14_100 +0.469397 TB15_100 +0.521803 TB16_100 +0 TB17_100 +0.700752796875 TB18_100 +1.953379 TB19_100 +0.459354 TB20_100 +0.734133 TB21_100 +0.002555985 TB22_100 +0.1251124075 TB23_100 +0.41953925 TB24_100 +0.359275875 TB25_100 +0.786875 TB26_100 +0 TB27_100 +0 TB28_100 +0 TB29_100 +0.50575 TB30_100 +0 TB31_100 +0.096 TB32_100 +2.727995 TB1_50 +1.391118 TB2_50 +0.488646 TB3_50 +1.9261775 TB4_50 +0.712208 TB5_50 +0.32770556375 TB6_50 +0.237638 TB7_50 +2.58294 TB8_50 +0.174267 TB9_50 +4.098818 TB10_50 +8.887937 TB11_50 +0.296878 TB12_50 +0 TB13_50 +0.078926 TB14_50 +0.156897 TB15_50 +0.209303 TB16_50 +0 TB17_50 +0.354226 TB18_50 +1.765879 TB19_50 +0.383404 TB20_50 +0.620133 TB21_50 +0.0012779925 TB22_50 +0.11962770375 TB23_50 +0.389298 TB24_50 +0.332524 TB25_50 +0 TB26_50 +0 TB27_50 +0 TB28_50 +0 TB29_50 +0 TB30_50 +0 TB31_50 +0.048 TB32_50 <= 75.0793046319;

24−28: +2.342701 TA1_100 +2.22735 TA2_100 +0.423706 TA3_100 +1.488352 TA4_100 +0.713637 TA5_100 +0 TA6_100 +0.886435 TA7_100 +2.422442 TA8_100 +0.432845 TA9_100 +6.382362 TA10_100 +10.200898 TA11_100 +0.795462 TA12_100 +0.125 TA13_100 +0.183934 TA14_100 +0.357913 TA15_100 +0.414893 TA16_100 +0 TA17_100 +0.6739704375 TA18_100 +2.179927 TA19_100 +0.4104365 TA20_100 +0.549898 TA21_100 +0.00702895875 TA22_100 +0.103876870625 TA23_100 +0.660659 TA24_100 +0.561146 TA25_100 +0.786875 TA26_100 +0.225 TA27_100 +1.014 TA28_100 +0.243 TA29_100 +0.50575 TA30_100 +0.125 TA31_100 +0.264 TA32_100 +2.046701 TA1_50 +1.37735 TA2_50 +0.219106 TA3_50 +1.488352 TA4_50 +0.713637 TA5_50 +0 TA6_50 +0.494435 TA7_50 +2.242442 TA8_50 +0.207845 TA9_50 +5.124612 TA10_50 +8.950898 TA11_50 +0.295462 TA12_50 +0 TA13_50 +0.058934 TA14_50 +0.107913 TA15_50 +0.164893 TA16_50 +0 TA17_50 +0.396749 TA18_50 +1.692427 TA19_50 +0.26803025 TA20_50 +0.407398 TA21_50 +0.00319498125 TA22_50 +0.087422759375 TA23_50 +0.515501 TA24_50 +0.432737 TA25_50 +0 TA26_50 +0.1125 TA27_50 +0.507 TA28_50 +0.1215 TA29_50 +0 TA30_50 +0 TA31_50 +0.12 TA32_50 +2.342701 TB1_100 +1.88735 TB2_100 +0.526006 TB3_100 +4.2703045 TB4_100 +0.713637 TB5_100 +0.786493353 TB6_100 +0.298435 TB7_100 +2.302442 TB8_100 +0.282845 TB9_100 +5.543862 TB10_100 +10.200898 TB11_100 +0.795462 TB12_100 +0.125 TB13_100 +0.183934 TB14_100 +0.357913 TB15_100 +0.414893 TB16_100 +0 TB17_100 +0.6739704375 TB18_100 +1.579927 TB19_100 +0.315499 TB20_100 +0.549898 TB21_100 +0.002555985 TB22_100 +0.0846804075 TB23_100 +0.394536 TB24_100 +0.3257295 TB25_100 +0.786875 TB26_100 +0.15 TB27_100 +0.39 TB28_100 +0.162 TB29_100 +0.50575 TB30_100 +0.125 TB31_100 +0.096 TB32_100 +2.046701 TB1_50 +1.20735 TB2_50 +0.321406 TB3_50 +2.4156695 TB4_50 +0.713637 TB5_50 +0.262164451 TB6_50 +0.200435 TB7_50 +2.182442 TB8_50 +0.132845 TB9_50 +4.705362 TB10_50 +8.950898 TB11_50 +0.295462 TB12_50 +0 TB13_50 +0.058934 TB14_50 +0.107913 TB15_50 +0.164893 TB16_50 +0 TB17_50 +0.396749 TB18_50 +1.392427 TB19_50 +0.2205615 TB20_50 +0.407398 TB21_50 +0.0012779925 TB22_50 +0.07919570375 TB23_50 +0.370343 TB24_50 +0.304328 TB25_50 +0 TB26_50 +0.075 TB27_50 +0.195 TB28_50 +0.081 TB29_50 +0 TB30_50 +0 TB31_50 +0.048 TB32_50 <= 74.8830949499;

25−29: +1.750249 TA1_100 +1.995677 TA2_100 +0.298509 TA3_100 +2.000026 TA4_100 +0.829642171875 TA5_100 +0 TA6_100 +0.829556 TA7_100 +2.424279 TA8_100 +0.394081 TA9_100 +7.537463 TA10_100 +9.809109 TA11_100 +0.671557 TA12_100

+0.09375 TA13_100 +0.142783 TA14_100 +0.280675 TA15_100 +0.311878 TA16_100 +0 TA17_100 +0.585592078125 TA18_100 +1.676512 TA19_100 +0.3122265 TA20_100 +0.462479 TA21_100 +0.00702895875 TA22_100 +0.076092870625 TA23_100 +0.252235 TA24_100 +0.4128595 TA25_100 +0.786875 TA26_100 +0.45 TA27_100 +2.028 TA28_100 +0.486 TA29_100 +0.50575 TA30_100 +0.25 TA31_100 +0.2112 TA32_100 +1.454249 TA1_50 +1.145677 TA2_50 +0.145059 TA3_50 +2.000026 TA4_50 +0.767146078125 TA5_50 +0 TA6_50 +0.437556 TA7_50 +2.154279 TA8_50 +0.169081 TA9_50 +5.650838 TA10_50 +8.871609 TA11_50 +0.296557 TA12_50 +0 TA13_50 +0.049033 TA14_50 +0.093175 TA15_50 +0.124378 TA16_50 +0 TA17_50 +0.377676 TA18_50 +1.286512 TA19_50 +0.16982025 TA20_50 +0.319979 TA21_50 +0.00319498125 TA22_50 +0.059638759375 TA23_50 +0.1433665 TA24_50 +0.31655275 TA25_50 +0 TA26_50 +0.225 TA27_50 +1.014 TA28_50 +0.243 TA29_50 +0 TA30_50 +0 TA31_50 +0.096 TA32_50 +1.750249 TB1_100 +1.655677 TB2_100 +0.375234 TB3_100 +4.7819785 TB4_100 +0.7567300625 TB5_100 +0.58987001475 TB6_100 +0.241556 TB7_100 +2.244279 TB8_100 +0.244081 TB9_100 +6.279713 TB10_100 +9.809109 TB11_100 +0.671557 TB12_100 +0.09375 TB13_100 +0.142783 TB14_100 +0.280675 TB15_100 +0.311878 TB16_100 +0 TB17_100 +0.585592078125 TB18_100 +1.196512 TB19_100 +0.217289 TB20_100 +0.462479 TB21_100 +0.002555985 TB22_100 +0.0568964075 TB23_100 +0.05264275 TB24_100 +0.236297125 TB25_100 +0.786875 TB26_100 +0.3 TB27_100 +0.78 TB28_100 +0.324 TB29_100 +0.50575 TB30_100 +0.25 TB31_100 +0.0768 TB32_100 +1.454249 TB1_50 +0.975677 TB2_50 +0.221784 TB3_50 +2.9273435 TB4_50 +0.73589803125 TB5_50 +0.19662333825 TB6_50 +0.143556 TB7_50 +2.064279 TB8_50 +0.094081 TB9_50 +5.021963 TB10_50 +8.871609 TB11_50 +0.296557 TB12_50 +0 TB13_50 +0.049033 TB14_50 +0.093175 TB15_50 +0.124378 TB16_50 +0 TB17_50 +0.377676 TB18_50 +1.046512 TB19_50 +0.1223515 TB20_50 +0.319979 TB21_50 +0.0012779925 TB22_50 +0.05141170375 TB23_50 +0.034498 TB24_50 +0.220246 TB25_50 +0 TB26_50 +0.15 TB27_50 +0.39 TB28_50 +0.162 TB29_50 +0 TB30_50 +0 TB31_50 +0.0384 TB32_50 <= 73.9348940022;

26–30: +1.026006 TA1_100 +1.763997 TA2_100 +0.187787 TA3_100 +2.536847 TA4_100 +0.94563734375 TA5_100 +0 TA6_100 +0.620935 TA7_100 +1.920544 TA8_100 +0.309588 TA9_100 +8.594305 TA10_100 +9.51421 TA11_100 +0.547145 TA12_100 +0.0625 TA13_100 +0.11163 TA14_100 +0.21836 TA15_100 +0.249625 TA16_100 +0.0625 TA17_100 +0.51703571875 TA18_100 +1.035486 TA19_100 +0.2985875 TA20_100 +0.374181 TA21_100 +0.005623167 TA22_100 +0.0472106965 TA23_100 +0.162493 TA24_100 +0.23908 TA25_100 +0.786875 TA26_100 +0.675 TA27_100 +3.042 TA28_100 +0.729 TA29_100 +0.50575 TA30_100 +0.375 TA31_100 +0.1584 TA32_100 +0.804006 TA1_50 +0.913997 TA2_50 +0.085487 TA3_50 +2.536847 TA4_50 +0.82064515625 TA5_50 +0 TA6_50 +0.307335 TA7_50 +1.560544 TA8_50 +0.129588 TA9_50 +6.078805 TA10_50 +8.88921 TA11_50 +0.297145 TA12_50 +0 TA13_50 +0.04913 TA14_50 +0.09336 TA15_50 +0.124625 TA16_50 +0 TA17_50 +0.378425 TA18_50 +0.742986 TA19_50 +0.15618125 TA20_50 +0.231681 TA21_50 +0.002555985 TA22_50 +0.0340474075 TA23_50 +0.089914 TA24_50 +0.1748755 TA25_50 +0 TA26_50 +0.3375 TA27_50 +1.521 TA28_50 +0.3645 TA29_50 +0 TA30_50 +0 TA31_50 +0.072 TA32_50 +1.026006 TB1_100 +1.423997 TB2_100 +0.238937 TB3_100 +5.3187995 TB4_100 +0.799813125 TB5_100 +0.3932466765 TB6_100 +0.150535 TB7_100 +1.680544 TB8_100 +0.189588 TB9_100 +6.917305 TB10_100 +9.51421 TB11_100 +0.547145 TB12_100 +0.0625 TB13_100 +0.11163 TB14_100 +0.21836 TB15_100 +0.249625 TB16_100 +0.0625 TB17_100 +0.51703571875 TB18_100 +0.675486 TB19_100 +0.20365 TB20_100 +0.374181 TB21_100 +0.002044788 TB22_100 +0.031853526 TB23_100 +0.0294315 TB24_100 +0.12137175 TB25_100 +0.786875 TB26_100 +0.45 TB27_100 +1.17 TB28_100 +0.486 TB29_100 +0.50575 TB30_100 +0.375 TB31_100 +0.0576 TB32_100 +0.804006 TB1_50 +0.743997 TB2_50 +0.136637 TB3_50 +3.4641645 TB4_50 +0.7581490625 TB5_50 +0.1310822255 TB6_50 +0.072135 TB7_50 +1.440544 TB8_50 +0.069588 TB9_50 +5.240305 TB10_50 +8.88921 TB11_50 +0.297145 TB12_50 +0 TB13_50 +0.04913 TB14_50 +0.09336 TB15_50 +0.124625 TB16_50 +0 TB17_50 +0.378425 TB18_50 +0.562986 TB19_50 +0.1087125 TB20_50 +0.231681 TB21_50 +0.001022394 TB22_50 +0.027465763 TB23_50 +0.017335 TB24_50 +0.110671 TB25_50 +0 TB26_50 +0.225 TB27_50 +0.585 TB28_50 +0.243 TB29_50 +0 TB30_50 +0 TB31_50 +0.0288 TB32_50 <= 72.3143590102;

27–31: +0.296 TA1_100 +1.224 TA2_100 +0.076725 TA3_100 +3.07289 TA4_100 +1.06021351563 TA5_100 +0 TA6_100 +0.4116 TA7_100 +1.410272 TA8_100 +0.225 TA9_100 +9.64243 TA10_100 +9.20171 TA11_100 +0.422145 TA12_100 +0.03125 TA13_100 +0.08038 TA14_100 +0.15586 TA15_100 +0.187125 TA16_100 +0.125 TA17_100 +0.447730359375 TA18_100 +0.39 TA19_100 +0.2848125 TA20_100 +0.285 TA21_100 +0.00421737525 TA22_100 +0.018099522375 TA23_100 +0.072579 TA24_100 +0.0642045 TA25_100 +0.6295 TA26_100 +0.9 TA27_100 +4.056 TA28_100 +0.972 TA29_100 +0.4046 TA30_100 +0.5 TA31_100 +0.1056 TA32_100 +0.148 TA1_50 +0.544 TA2_50 +0.025575 TA3_50 +3.07289 TA4_50 +0.872725234375 TA5_50 +0 TA6_50 +0.1764 TA7_50 +0.960272 TA8_50 +0.09 TA9_50 +6.498055 TA10_50 +8.88921 TA11_50 +0.297145 TA12_50 +0 TA13_50 +0.04913 TA14_50 +0.09336 TA15_50 +0.124625 TA16_50 +0 TA17_50 +0.378425 TA18_50 +0.195

TA19_50 +0.14240625 TA20_50 +0.1425 TA21_50 +0.00191698875 TA22_50 +0.008227055625 TA23_50 +0.0362895 TA24_50 +0.03210225 TA25_50 +0 TA26_50 +0.45 TA27_50 +2.028 TA28_50 +0.486 TA29_50 +0 TA30_50 +0 TA31_50 +0.048 TA32_50 +0.296 TB1_100 +0.952 TB2_100 +0.1023 TB3_100 +5.298452 TB4_100 +0.8414771875 TB5_100 +0.19662333825 TB6_100 +0.0588 TB7_100 +1.110272 TB8_100 +0.135 TB9_100 +7.54618 TB10_100 +9.20171 TB11_100 +0.422145 TB12_100 +0.03125 TB13_100 +0.08038 TB14_100 +0.15586 TB15_100 +0.187125 TB16_100 +0.125 TB17_100 +0.447730359375 TB18_100 +0.15 TB19_100 +0.189875 TB20_100 +0.285 TB21_100 +0.001533591 TB22_100 +0.0065816445 TB23_100 +0.00604825 TB24_100 +0.005350375 TB25_100 +0.6295 TB26_100 +0.6 TB27_100 +1.56 TB28_100 +0.648 TB29_100 +0.4046 TB30_100 +0.5 TB31_100 +0.0384 TB32_100 +0.148 TB1_50 +0.408 TB2_50 +0.05115 TB3_50 +3.814744 TB4_50 +0.77898109375 TB5_50 +0.06554111275 TB6_50 +0 TB7_50 +0.810272 TB8_50 +0.045 TB9_50 +5.44993 TB10_50 +8.88921 TB11_50 +0.297145 TB12_50 +0 TB13_50 +0.04913 TB14_50 +0.09336 TB15_50 +0.124625 TB16_50 +0 TB17_50 +0.378425 TB18_50 +0.075 TB19_50 +0.0949375 TB20_50 +0.1425 TB21_50 +0.0007667955 TB22_50 +0.00329082225 TB23_50 +0 TB24_50 +0 TB25_50 +0 TB26_50 +0.3 TB27_50 +0.78 TB28_50 +0.324 TB29_50 +0 TB30_50 +0 TB31_50 +0.0192 TB32_50 <= 68.9701375182;

28−32: +0.148 TA1_100 +0.918 TA2_100 +0 TA3_100 +3.07289 TA4_100 +1.1747896875 TA5_100 +0 TA6_100 +0.2744 TA7_100 +0.75 TA8_100 +0.15 TA9_100 +8.762069 TA10_100 +8.88921 TA11_100 +0.297145 TA12_100 +0 TA13_100 +0.04913 TA14_100 +0.09336 TA15_100 +0.124625 TA16_100 +0.1875 TA17_100 +0.378425 TA18_100 +0.195 TA19_100 +0.22785 TA20_100 +0.228 TA21_100 +0.0028115835 TA22_100 +0.01206634825 TA23_100 +0 TA24_100 +0 TA25_100 +0.472125 TA26_100 +1.125 TA27_100 +5.07 TA28_100 +1.215 TA29_100 +0.30345 TA30_100 +0.625 TA31_100 +0.0528 TA32_100 +0.074 TA1_50 +0.408 TA2_50 +0 TA3_50 +3.07289 TA4_50 +0.9248053125 TA5_50 +0 TA6_50 +0.1176 TA7_50 +0.3 TA8_50 +0.06 TA9_50 +5.617694 TA10_50 +8.88921 TA11_50 +0.297145 TA12_50 +0 TA13_50 +0.04913 TA14_50 +0.09336 TA15_50 +0.124625 TA16_50 +0 TA17_50 +0.378425 TA18_50 +0.0975 TA19_50 +0.113925 TA20_50 +0.114 TA21_50 +0.0012779925 TA22_50 +0.00548470375 TA23_50 +0 TA24_50 +0 TA25_50 +0 TA26_50 +0.5625 TA27_50 +2.535 TA28_50 +0.6075 TA29_50 +0 TA30_50 +0 TA31_50 +0.024 TA32_50 +0.148 TB1_100 +0.714 TB2_100 +0 TB3_100 +4.7420615 TB4_100 +0.88314125 TB5_100 +0 TB6_100 +0.0392 TB7_100 +0.45 TB8_100 +0.09 TB9_100 +6.665819 TB10_100 +8.88921 TB11_100 +0.297145 TB12_100 +0 TB13_100 +0.04913 TB14_100 +0.09336 TB15_100 +0.124625 TB16_100 +0.1875 TB17_100 +0.378425 TB18_100 +0.075 TB19_100 +0.1519 TB20_100 +0.228 TB21_100 +0.001022394 TB22_100 +0.004387763 TB23_100 +0 TB24_100 +0 TB25_100 +0.472125 TB26_100 +0.75 TB27_100 +1.95 TB28_100 +0.81 TB29_100 +0.30345 TB30_100 +0.625 TB31_100 +0.0192 TB32_100 +0.074 TB1_50 +0.306 TB2_50 +0 TB3_50 +3.6292805 TB4_50 +0.799813125 TB5_50 +0 TB6_50 +0 TB7_50 +0.15 TB8_50 +0.03 TB9_50 +4.569569 TB10_50 +8.88921 TB11_50 +0.297145 TB12_50 +0 TB13_50 +0.04913 TB14_50 +0.09336 TB15_50 +0.124625 TB16_50 +0 TB17_50 +0.378425 TB18_50 +0.0375 TB19_50 +0.07595 TB20_50 +0.114 TB21_50 +0.000511197 TB22_50 +0.0021938815 TB23_50 +0 TB24_50 +0 TB25_50 +0 TB26_50 +0.375 TB27_50 +0.975 TB28_50 +0.405 TB29_50 +0 TB30_50 +0 TB31_50 +0.0096 TB32_50 <= 63.9403485263;

29−33: +0 TA1_100 +0.612 TA2_100 +0 TA3_100 +3.07289 TA4_100 +1.28936585938 TA5_100 +0 TA6_100 +0.1372 TA7_100 +0.75 TA8_100 +0.075 TA9_100 +7.881708 TA10_100 +8.88921 TA11_100 +0.297145 TA12_100 +0 TA13_100 +0.04913 TA14_100 +0.09336 TA15_100 +0.124625 TA16_100 +0.25 TA17_100 +0.378425 TA18_100 +0 TA19_100 +0.1708875 TA20_100 +0.171 TA21_100 +0.00140579175 TA22_100 +0.006033174125 TA23_100 +0 TA24_100 +0 TA25_100 +0.31475 TA26_100 +1.125 TA27_100 +5.07 TA28_100 +1.215 TA29_100 +0.2023 TA30_100 +0.625 TA31_100 +0 TA32_100 +0 TA1_50 +0.272 TA2_50 +0 TA3_50 +3.07289 TA4_50 +0.976885390625 TA5_50 +0 TA6_50 +0.0588 TA7_50 +0.3 TA8_50 +0.03 TA9_50 +4.737333 TA10_50 +8.88921 TA11_50 +0.297145 TA12_50 +0 TA13_50 +0.04913 TA14_50 +0.09336 TA15_50 +0.124625 TA16_50 +0 TA17_50 +0.378425 TA18_50 +0 TA19_50 +0.08544375 TA20_50 +0.0855 TA21_50 +0.00063899625 TA22_50 +0.002742351875 TA23_50 +0 TA24_50 +0 TA25_50 +0 TA26_50 +0.5625 TA27_50 +2.535 TA28_50 +0.6075 TA29_50 +0 TA30_50 +0 TA31_50 +0 TA32_50 +0 TB1_100 +0.476 TB2_100 +0 TB3_100 +4.185671 TB4_100 +0.9248053125 TB5_100 +0 TB6_100 +0.0196 TB7_100 +0.45 TB8_100 +0.045 TB9_100 +5.785458 TB10_100 +8.88921 TB11_100 +0.297145 TB12_100 +0 TB13_100 +0.04913 TB14_100 +0.09336 TB15_100 +0.124625 TB16_100 +0.25 TB17_100 +0.378425 TB18_100 +0 TB19_100 +0.113925 TB20_100 +0.171 TB21_100 +0.000511197 TB22_100 +0.0021938815 TB23_100 +0 TB24_100 +0 TB25_100 +0.31475 TB26_100 +0.75 TB27_100 +1.95 TB28_100 +0.81 TB29_100 +0.2023 TB30_100 +0.625 TB31_100 +0 TB32_100 +0 TB1_50 +0.204 TB2_50 +0 TB3_50 +3.443817 TB4_50 +0.82064515625 TB5_50 +0 TB6_50 +0 TB7_50 +0.15 TB8_50 +0.015 TB9_50 +3.689208 TB10_50 +8.88921 TB11_50 +0.297145 TB12_50 +0 TB13_50 +0.04913 TB14_50 +0.09336 TB15_50 +0.124625 TB16_50 +0 TB17_50 +0.378425 TB18_50 +0 TB19_50 +0.0569625 TB20_50 +0.0855 TB21_50 +0.0002555985 TB22_50 +0.00109694075 TB23_50 +0 TB24_50 +0 TB25_50 +0 TB26_50 +0.375 TB27_50 +0.975 TB28_50

+0.405 TB29_50 +0 TB30_50 +0 TB31_50 +0 TB32_50 <= 59.7095447163;

30–34: +0 TA1_100 +0.306 TA2_100 +0 TA3_100 +2.458312 TA4_100 +1.28936585938 TA5_100 +0 TA6_100 +0 TA7_100 +0.75 TA8_100 +0 TA9_100 +7.001347 TA10_100 +8.88921 TA11_100 +0.297145 TA12_100 +0 TA13_100 +0.04913 TA14_100 +0.09336 TA15_100 +0.124625 TA16_100 +0.3125 TA17_100 +0.378425 TA18_100 +0 TA19_100 +0.113925 TA20_100 +0.114 TA21_100 +0 TA22_100 +0 TA23_100 +0 TA24_100 +0 TA25_100 +0.157375 TA26_100 +1.125 TA27_100 +5.07 TA28_100 +1.215 TA29_100 +0.10115 TA30_100 +0.625 TA31_100 +0 TA32_100 +0 TA1_50 +0.136 TA2_50 +0 TA3_50 +2.458312 TA4_50 +0.976885390625 TA5_50 +0 TA6_50 +0 TA7_50 +0.3 TA8_50 +0 TA9_50 +3.856972 TA10_50 +8.88921 TA11_50 +0.297145 TA12_50 +0 TA13_50 +0.04913 TA14_50 +0.09336 TA15_50 +0.124625 TA16_50 +0 TA17_50 +0.378425 TA18_50 +0 TA19_50 +0.0569625 TA20_50 +0.057 TA21_50 +0 TA22_50 +0 TA23_50 +0 TA24_50 +0 TA25_50 +0 TA26_50 +0.5625 TA27_50 +2.535 TA28_50 +0.6075 TA29_50 +0 TA30_50 +0 TA31_50 +0 TA32_50 +0 TB1_100 +0.238 TB2_100 +0 TB3_100 +3.0147025 TB4_100 +0.9248053125 TB5_100 +0 TB6_100 +0 TB7_100 +0.45 TB8_100 +0 TB9_100 +4.905097 TB10_100 +8.88921 TB11_100 +0.297145 TB12_100 +0 TB13_100 +0.04913 TB14_100 +0.09336 TB15_100 +0.124625 TB16_100 +0.3125 TB17_100 +0.378425 TB18_100 +0 TB19_100 +0.07595 TB20_100 +0.114 TB21_100 +0 TB22_100 +0 TB23_100 +0 TB24_100 +0 TB25_100 +0.157375 TB26_100 +0.75 TB27_100 +1.95 TB28_100 +0.81 TB29_100 +0.10115 TB30_100 +0.625 TB31_100 +0 TB32_100 +0 TB1_50 +0.102 TB2_50 +0 TB3_50 +2.6437755 TB4_50 +0.82064515625 TB5_50 +0 TB6_50 +0 TB7_50 +0.15 TB8_50 +0 TB9_50 +2.808847 TB10_50 +8.88921 TB11_50 +0.297145 TB12_50 +0 TB13_50 +0.04913 TB14_50 +0.09336 TB15_50 +0.124625 TB16_50 +0 TB17_50 +0.378425 TB18_50 +0 TB19_50 +0.037975 TB20_50 +0.057 TB21_50 +0 TB22_50 +0 TB23_50 +0 TB24_50 +0 TB25_50 +0 TB26_50 +0.375 TB27_50 +0.975 TB28_50 +0.405 TB29_50 +0 TB30_50 +0 TB31_50 +0 TB32_50 <= 54.7313446719;

31–35: +0 TA1_100 +0 TA2_100 +0 TA3_100 +1.843734 TA4_100 +1.28936585938 TA5_100 +0 TA6_100 +0 TA7_100 +0.75 TA8_100 +0 TA9_100 +5.072861 TA10_100 +8.88921 TA11_100 +0.297145 TA12_100 +0 TA13_100 +0.04913 TA14_100 0.09336 TA15_100 +0.124625 TA16_100 +0.3125 TA17_100 +0.30274 TA18_100 +0 TA19_100 +0.0569625 TA20_100 +0.057 TA21_100 +0 TA22_100 +0 TA23_100 +0 TA24_100 +0 TA25_100 +0 TA26_100 +1.125 TA27_100 +5.07 TA28_100 +1.215 TA29_100 +0 TA30_100 +0.625 TA31_100 +0 TA32_100 +0 TA1_50 +0 TA2_50 +0 TA3_50 +1.843734 TA4_50 +0.976885390625 TA5_50 +0 TA6_50 +0 TA7_50 +0.3 TA8_50 +0 TA9_50 +2.557361 TA10_50 +8.88921 TA11_50 +0.297145 TA12_50 +0 TA13_50 +0.04913 TA14_50 +0.09336 TA15_50 +0.124625 TA16_50 +0 TA17_50 +0.30274 TA18_50 +0 TA19_50 +0.02848125 TA20_50 +0.0285 TA21_50 +0 TA22_50 +0 TA23_50 +0 TA24_50 +0 TA25_50 +0 TA26_50 +0.5625 TA27_50 +2.535 TA28_50 +0.6075 TA29_50 +0 TA30_50 +0 TA31_50 +0 TA32_50 +0 TB1_100 +0 TB2_100 +0 TB3_100 +1.843734 TB4_100 +0.9248053125 TB5_100 +0 TB6_100 +0 TB7_100 +0.45 TB8_100 +0 TB9_100 +3.395861 TB10_100 +8.88921 TB11_100 +0.297145 TB12_100 +0 TB13_100 +0.04913 TB14_100 +0.09336 TB15_100 +0.124625 TB16_100 +0.3125 TB17_100 +0.30274 TB18_100 +0 TB19_100 +0.037975 TB20_100 +0.057 TB21_100 +0 TB22_100 +0 TB23_100 +0 TB24_100 +0 TB25_100 +0 TB26_100 +0.75 TB27_100 +1.95 TB28_100 +0.81 TB29_100 +0 TB30_100 +0.625 TB31_100 +0 TB32_100 +0 TB1_50 +0 TB2_50 +0 TB3_50 +1.843734 TB4_50 +0.82064515625 TB5_50 +0 TB6_50 +0 TB7_50 +0.15 TB8_50 +0 TB9_50 +1.718861 TB10_50 +8.88921 TB11_50 +0.297145 TB12_50 +0 TB13_50 +0.04913 TB14_50 +0.09336 TB15_50 +0.124625 TB16_50 +0 TB17_50 +0.30274 TB18_50 +0 TB19_50 +0.0189875 TB20_50 +0.0285 TB21_50 +0 TB22_50 +0 TB23_50 +0 TB24_50 +0 TB25_50 +0 TB26_50 +0.375 TB27_50 +0.975 TB28_50 +0.405 TB29_50 +0 TB30_50 +0 TB31_50 +0 TB32_50 <= 48.0867186719;

/* Variable bounds */
TA1_100 <= 1;
TA2_100 <= 1;
TA3_100 <= 1;
TA4_100 <= 1;
TA5_100 <= 1;
TA6_100 <= 1;
TA7_100 <= 1;
TA8_100 <= 1;
TA9_100 <= 1;
TA10_100 <= 1;
TA11_100 <= 1;

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TA12_100 <= 1;
TA13_100 <= 1;
TA14_100 <= 1;
TA15_100 <= 1;
TA16_100 <= 1;
TA17_100 <= 1;
TA18_100 <= 1;
TA19_100 <= 1;
TA20_100 <= 1;
TA21_100 <= 1;
TA22_100 <= 1;
TA23_100 <= 1;
TA24_100 <= 1;
TA25_100 <= 1;
TA26_100 <= 1;
TA27_100 <= 1;
TA28_100 <= 1;
TA29_100 <= 1;
TA30_100 <= 1;
TA31_100 <= 1;
TA32_100 <= 1;
TA1_50 <= 1;
TA2_50 <= 1;
TA3_50 <= 1;
TA4_50 <= 1;
TA5_50 <= 1;
TA6_50 <= 1;
TA7_50 <= 1;
TA8_50 <= 1;
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TA10_50 <= 1;
TA11_50 <= 1;
TA12_50 <= 1;
TA13_50 <= 1;
TA14_50 <= 1;
TA15_50 <= 1;
TA16_50 <= 1;
TA17_50 <= 1;
TA18_50 <= 1;
TA19_50 <= 1;
TA20_50 <= 1;
TA21_50 <= 1;
TA22_50 <= 1;
TA23_50 <= 1;
TA24_50 <= 1;
TA25_50 <= 1;
TA26_50 <= 1;
TA27_50 <= 1;
TA28_50 <= 1;
TA29_50 <= 1;
```

TA30_50 <= 1;
TA31_50 <= 1;
TA32_50 <= 1;
TA1_0 <= 1;
TA2_0 <= 1;
TA3_0 <= 1;
TA4_0 <= 1;
TA5_0 <= 1;
TA6_0 <= 1;
TA7_0 <= 1;
TA8_0 <= 1;
TA9_0 <= 1;
TA10_0 <= 1;
TA11_0 <= 1;
TA12_0 <= 1;
TA13_0 <= 1;
TA14_0 <= 1;
TA15_0 <= 1;
TA16_0 <= 1;
TA17_0 <= 1;
TA18_0 <= 1;
TA19_0 <= 1;
TA20_0 <= 1;
TA21_0 <= 1;
TA22_0 <= 1;
TA23_0 <= 1;
TA24_0 <= 1;
TA25_0 <= 1;
TA26_0 <= 1;
TA27_0 <= 1;
TA28_0 <= 1;
TA29_0 <= 1;
TA30_0 <= 1;
TA31_0 <= 1;
TA32_0 <= 1;
TB1_100 <= 1;
TB2_100 <= 1;
TB3_100 <= 1;
TB4_100 <= 1;
TB5_100 <= 1;
TB6_100 <= 1;
TB7_100 <= 1;
TB8_100 <= 1;
TB9_100 <= 1;
TB10_100 <= 1;
TB11_100 <= 1;
TB12_100 <= 1;
TB13_100 <= 1;
TB14_100 <= 1;
TB15_100 <= 1;

TB16_100 <= 1;
TB17_100 <= 1;
TB18_100 <= 1;
TB19_100 <= 1;
TB20_100 <= 1;
TB21_100 <= 1;
TB22_100 <= 1;
TB23_100 <= 1;
TB24_100 <= 1;
TB25_100 <= 1;
TB26_100 <= 1;
TB27_100 <= 1;
TB28_100 <= 1;
TB29_100 <= 1;
TB30_100 <= 1;
TB31_100 <= 1;
TB32_100 <= 1;
TB1_50 <= 1;
TB2_50 <= 1;
TB3_50 <= 1;
TB4_50 <= 1;
TB5_50 <= 1;
TB6_50 <= 1;
TB7_50 <= 1;
TB8_50 <= 1;
TB9_50 <= 1;
TB10_50 <= 1;
TB11_50 <= 1;
TB12_50 <= 1;
TB13_50 <= 1;
TB14_50 <= 1;
TB15_50 <= 1;
TB16_50 <= 1;
TB17_50 <= 1;
TB18_50 <= 1;
TB19_50 <= 1;
TB20_50 <= 1;
TB21_50 <= 1;
TB22_50 <= 1;
TB23_50 <= 1;
TB24_50 <= 1;
TB25_50 <= 1;
TB26_50 <= 1;
TB27_50 <= 1;
TB28_50 <= 1;
TB29_50 <= 1;
TB30_50 <= 1;
TB31_50 <= 1;
TB32_50 <= 1;
TB1_0 <= 1;

```
TB2_0 <= 1;
TB3_0 <= 1;
TB4_0 <= 1;
TB5_0 <= 1;
TB6_0 <= 1;
TB7_0 <= 1;
TB8_0 <= 1;
TB9_0 <= 1;
TB10_0 <= 1;
TB11_0 <= 1;
TB12_0 <= 1;
TB13_0 <= 1;
TB14_0 <= 1;
TB15_0 <= 1;
TB16_0 <= 1;
TB17_0 <= 1;
TB18_0 <= 1;
TB19_0 <= 1;
TB20_0 <= 1;
TB21_0 <= 1;
TB22_0 <= 1;
TB23_0 <= 1;
TB24_0 <= 1;
TB25_0 <= 1;
TB26_0 <= 1;
TB27_0 <= 1;
TB28_0 <= 1;
TB29_0 <= 1;
TB30_0 <= 1;
TB31_0 <= 1;
TB32_0 <= 1;

/* Integer definitions */
int TA1_100,TA2_100,TA3_100,TA4_100,TA5_100,TA6_100,TA7_100,TA8_100,TA9_100,TA10_100,TA11_100,TA12_100,
TA13_100,TA14_100,TA15_100,TA16_100,TA17_100,TA18_100,TA19_100,TA20_100,TA21_100,TA22_100,TA23_100,
TA24_100,TA25_100,TA26_100,TA27_100,TA28_100,TA29_100,TA30_100,TA31_100,TA32_100,TA1_50,TA2_50,TA3_50,
TA4_50,TA5_50,TA6_50,TA7_50,TA8_50,TA9_50,TA10_50,TA11_50,TA12_50,TA13_50,TA14_50,TA15_50,TA16_50,TA17_50,
TA18_50,TA19_50,TA20_50,TA21_50,TA22_50,TA23_50,TA24_50,TA25_50,TA26_50,TA27_50,TA28_50,TA29_50,TA30_50,
TA31_50,TA32_50,TA1_0,TA2_0,TA3_0,TA4_0,TA5_0,TA6_0,TA7_0,TA8_0,TA9_0,TA10_0,TA11_0,TA12_0,TA13_0,TA14_0,
TA15_0,TA16_0,TA17_0,TA18_0,TA19_0,TA20_0,TA21_0,TA22_0,TA23_0,TA24_0,TA25_0,TA26_0,TA27_0,TA28_0,TA29_0,
TA30_0,TA31_0,TA32_0,TB1_100,TB2_100,TB3_100,TB4_100,TB5_100,TB6_100,TB7_100,TB8_100,TB9_100,TB10_100,
TB11_100,TB12_100,TB13_100,TB14_100,TB15_100,TB16_100,TB17_100,TB18_100,TB19_100,TB20_100,TB21_100,
TB22_100,TB23_100,TB24_100,TB25_100,TB26_100,TB27_100,TB28_100,TB29_100,TB30_100,TB31_100,TB32_100,
TB1_50,TB2_50,TB3_50,TB4_50,TB5_50,TB6_50,TB7_50,TB8_50,TB9_50,TB10_50,TB11_50,TB12_50,TB13_50,TB14_50,
TB15_50,TB16_50,TB17_50,TB18_50,TB19_50,TB20_50,TB21_50,TB22_50,TB23_50,TB24_50,TB25_50,TB26_50,TB27_50,
TB28_50,TB29_50,TB30_50,TB31_50,TB32_50,TB1_0,TB2_0,TB3_0,TB4_0,TB5_0,TB6_0,TB7_0,TB8_0,TB9_0,TB10_0,
TB11_0,TB12_0,TB13_0,TB14_0,TB15_0,TB16_0,TB17_0,TB18_0,TB19_0,TB20_0,TB21_0,TB22_0,TB23_0,TB24_0,TB25_0,
TB26_0,TB27_0,TB28_0,TB29_0,TB30_0,TB31_0,TB32_0;
```

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