Optimizing Military Capital Planning*

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*Brown, G.G., Dell, R.F., and Newman, A.M., "Optimizing Military Capital Planning," *Interfaces*, 34 (6) , 2004 , pp. 415-425.

Why Optimize?

- “A nation’s military establishment, in wartime or in peace, is a complex of economic and military activities requiring almost unbelievably careful coordination in the implementation of plans produced in its many departments.”

  George Dantzig on early military LP use

military capital planning has always occupied our leadership

- USS Constitution

- One of six frigates requested by G. Washington 1794, and approved by Congress, each to be built by a different shipyard

- Revolutionary technology
- Nationwide resources

- 2.9 Billion (2001 $)

Today, US materiel investment is

- larger than the rest of the world combined
- a substantial influence on domestic technology and production

Materiel investment plans complicated by

- sheer scale and the attention that this attracts
- conflicted objectives
- concerns regarding interoperability and maintainability

Tutorial goals

- introduce these capital planning problems
- discuss need for optimization models
- present ways to render these (and other) optimization models more useful for real-world decision support

ARMY Example

- Helicopter fleet modernization (CAA)
- PHOENIX (1988) $50 Billion plan
- Later models for tactical wheeled vehicles, etc.

Air Force Example

- Space Command

  Space systems and launchers

  (2000) $310 Billion plan

Navy Example

- Capital Investment Planning Aide (CIPA)

  Ship and aircraft procurement

  (2002) $1 Trillion plan

Taxonomy

- Military capital planning problems share many similarities
- Preface:
  - these are hard planning problems

Investment

- Military capital plans require significant national investment of:
  - scarce resources,
  - valuable technology, and/or
  - money

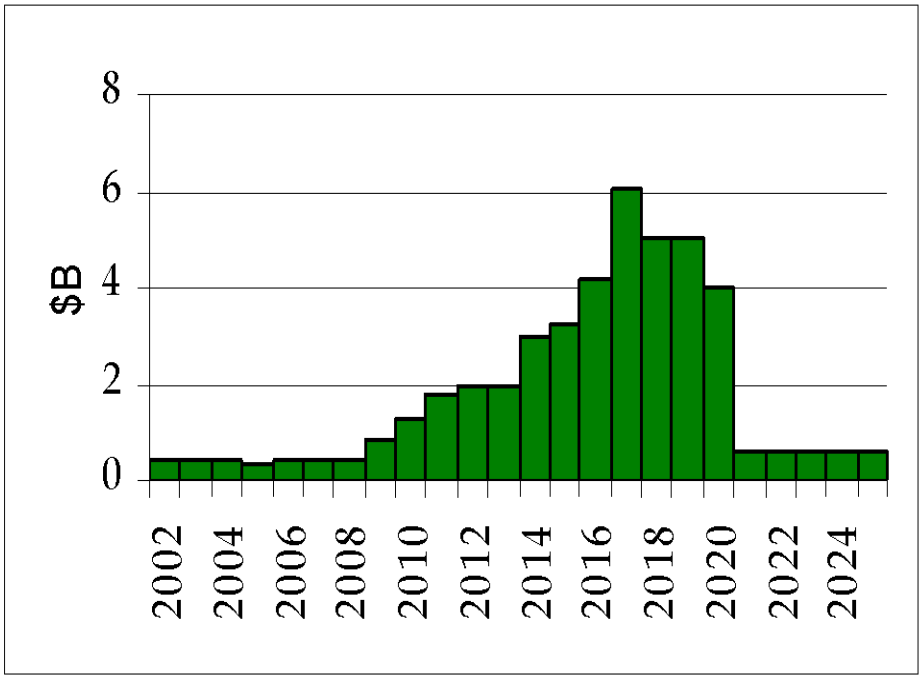
Time Fidelity and Horizon

- Time fidelity is annual
- Planning horizon (25 Years)
  - Years 1-3 “frozen”
  - Years 4-6 “directive”
  - Years 7-20 “informational”
  - Years 21-25 “end effects”
- Program Objective Memorandum (6 year)

Cost Profiles

- Huge research, development, test and evaluation costs may far precede first delivery and follow last
- Economies of scale and learning effects influence per-unit costs

Cost Profiles

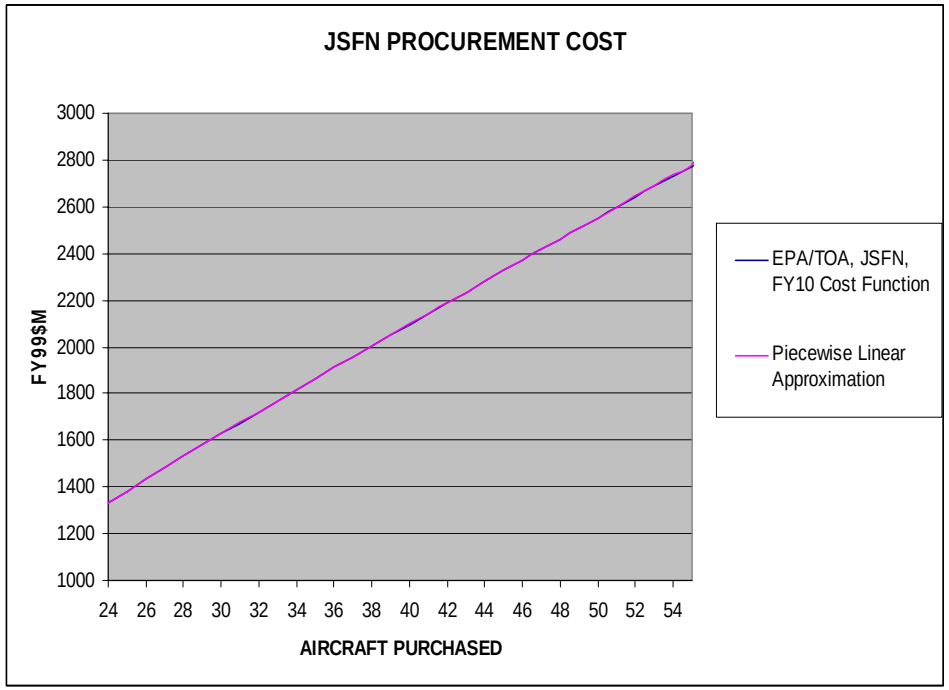


- Most of $44 Billion cost of this space system will be spent before initial operational capability in 2017, nearly all before full operational capability in 2020.

Economies of Scale

$$cost_{JSFN} = qty \left(t \; x^{\log a} \; qty^{\log b} \right)$$

Economies of Scale



- Actual total aircraft cost of JSFN
- Concave,
  but nearly linear

Colors of Money

- Money comes in several “colors”
- Capital is scheduled as annual allocations, but
  - Multi-year programs may shift funding later or earlier
  - Flexibility increases with lead time

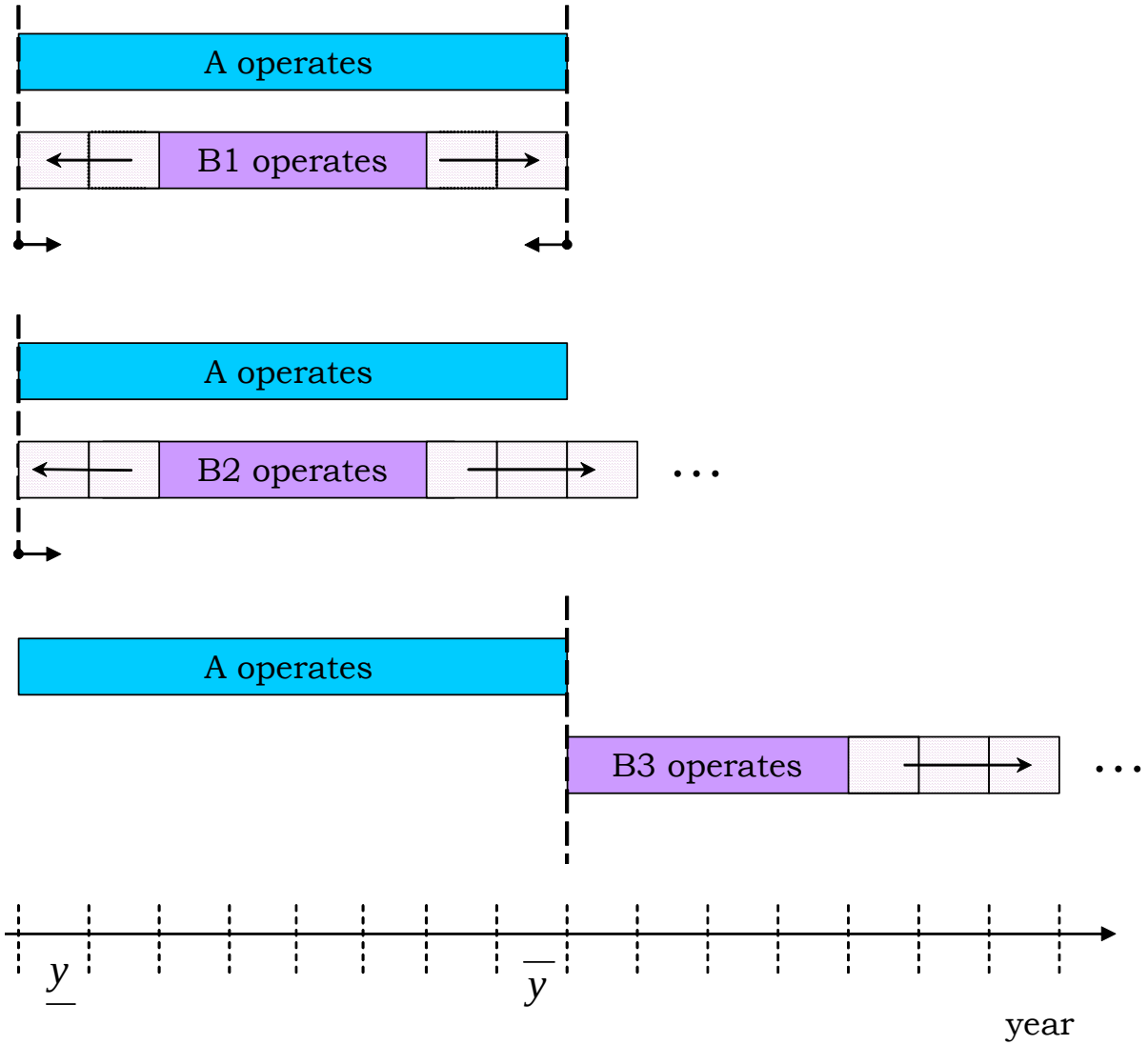
Measure of effectiveness

- The hardest detail
  - Multiple, conflicting criteria
- Clear goals
  - Multiple threat scenarios

Synchrony

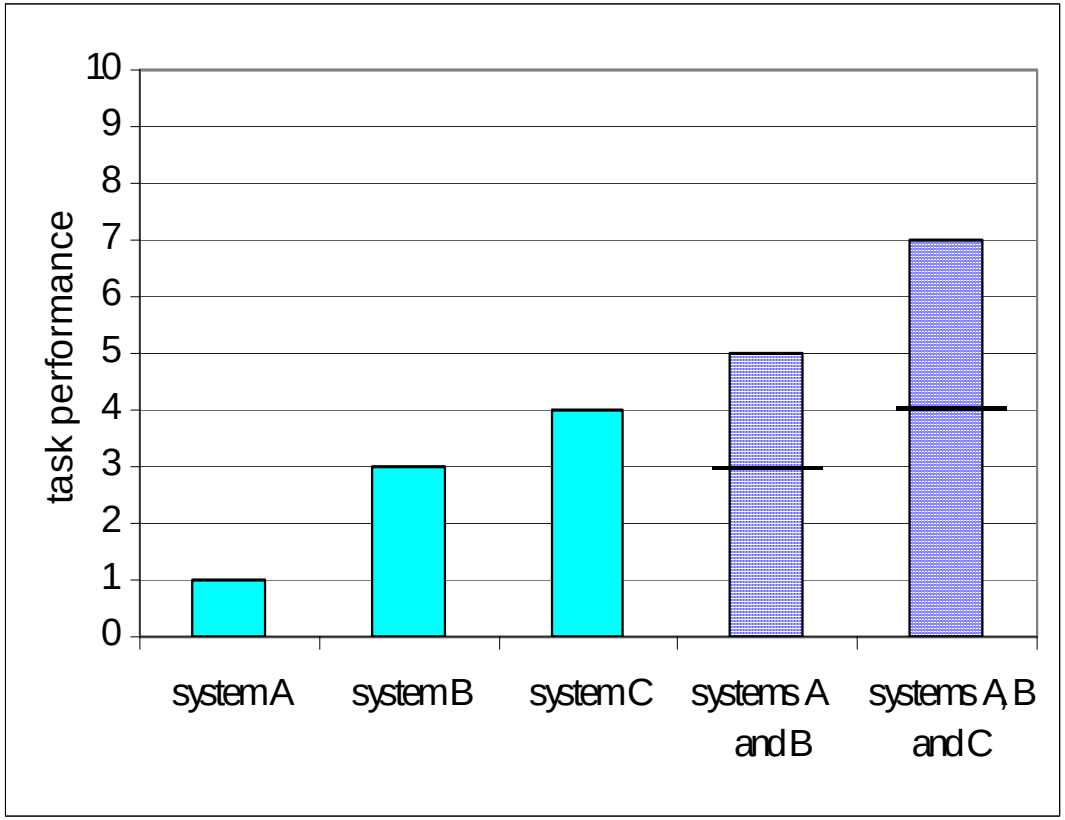
- Major weapons systems
  - share production capacity
  - require support from other systems
  - need to be fielded synchronously

Synchrony



- Concurrent
- Prerequisite
- Contiguous

Synergy



- Some systems work better cooperatively than they do independently

Compassionate Planning

- We hold a monopoly
- Must maintain defense production base
- Must attend to workforce changes
- Must support technology innovation

Compassionate Planning

- Newport News

- Sole US shipyard for CVN's
- No civilian or commercial counterpart
- Foreign sources forbidden

Political Insulation

- Legislative guidance is always a concern for planning
- Meta-theorem:
  - restricting a plan will not save money

Political Insulation

- B1B Lancer
- Rockwell used components from all 50 States

ARMY Example

- Helicopter fleet modernization (CAA)
- PHOENIX (1988) $50 Billion plan
- Later models for tactical wheeled vehicles, etc.

ARMY Example

PHOENIX (1990)

25-year horizon

Constrained by

- Maximum fleet age
- Requirement for new technology
- Complex options to rebuild (SLEP), or build new
- Synchronize production line use of suppliers

Air Force Example

- Space Command

  Space systems and launchers

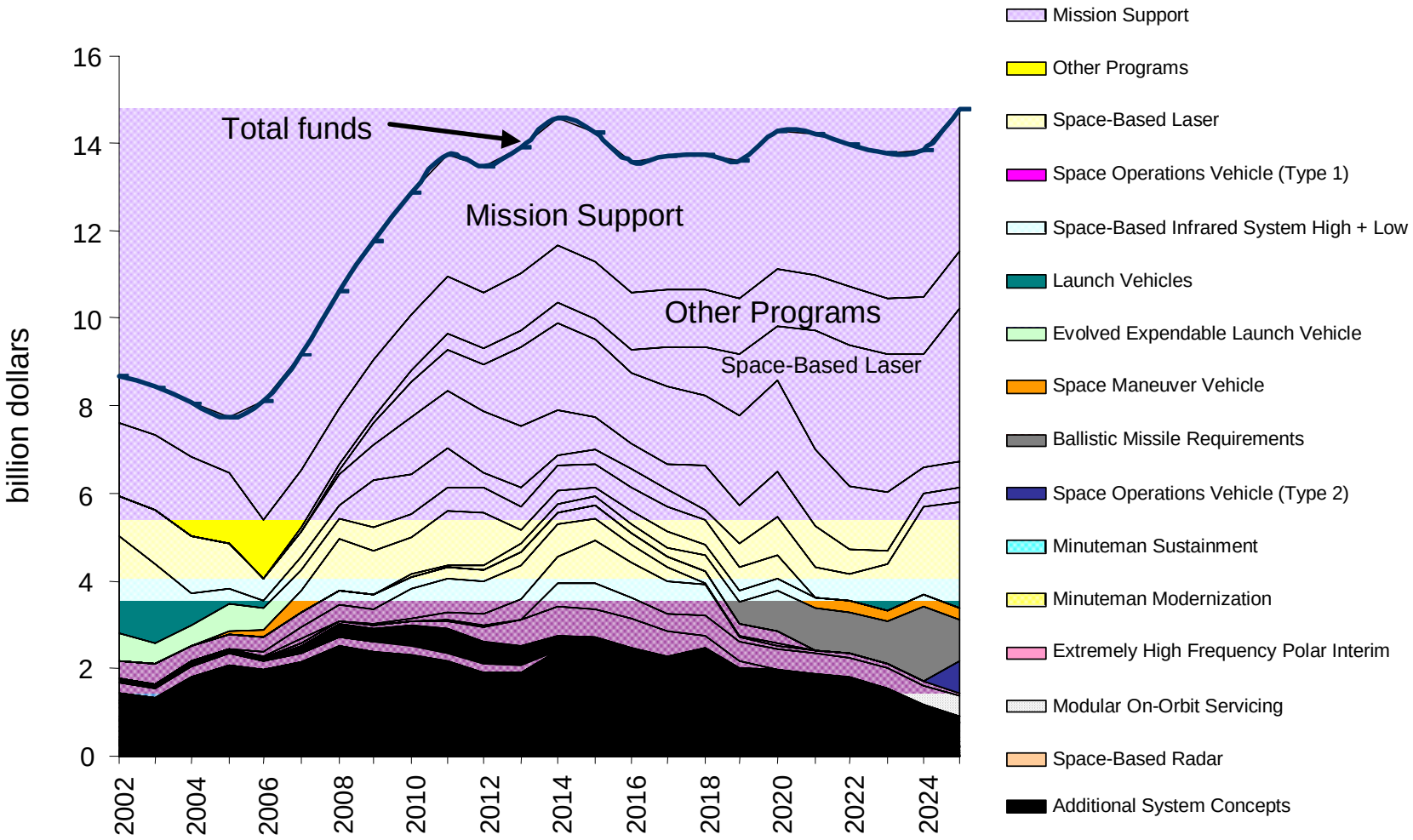
  (2000) $310 Billion plan

USAF Space Command

- Space systems and launchers

- 25-year horizon
- Multiple colors of money
- Many side constraints
- Synchrony and synergy

USAF Space Command



Navy Example

- Capital Investment Planning Aide (CIPA)

  Ship and aircraft procurement

  (2002) $1 Trillion plan




Procurement

FY02

MISSIONS

FY30

Time

Retirement

Logistic, Combat, Support,

Transport, Training, ...


Why Optimize?

- Finding just one feasible plan by hand can take a long time and can be error prone
- Leverage comes with knowing how to make each discrete program decision
  - to fit its multi-year, multi-color costs within budgets, and
  - to synchronize its consequences with other discrete decisions over time

Why Optimize?

- Descriptive models (e.g., spreadsheets) require that you manually prepare a complete, feasible solution to evaluate

- Descriptive models (e.g., simulation) have trouble finding feasible plans, or telling you when no such plan exists

Why Optimize?

- Prescriptive optimization uses a statement of the constraints that apply to all solutions,
- And then finds a good solution

These are Large Models

- Indexes:
  - Years (25)
  - colors of money (3-6)
  - system types (30-75)
  - purchase options (00's)
  - …
- Leads to thousands of constraints and tens of thousands of variables

These are Large, Mixed Integer Models

- Yes-No decisions, each worth billions

The Saving Grace

- Mixed integer programs like these can now be solved on a PC
- Nothing beats a qualitative assessment of solution quality (lower bound) when comparing competing plans

Real-World Decision Support

- Present value
- Elastic constraints
- Persistence
- End-effects
- Relaxation and aggregation

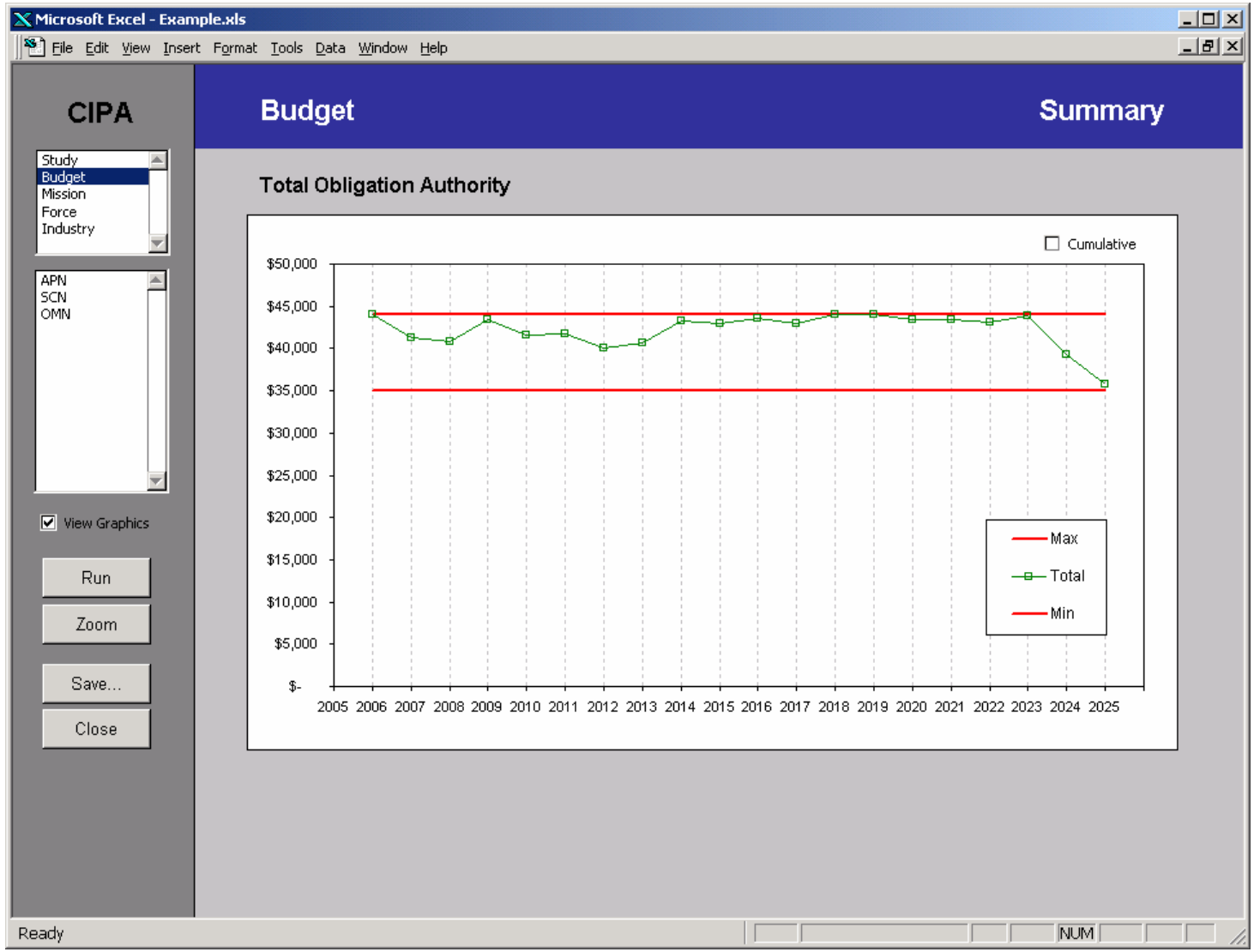
Present Value

- There are two types of present value:
  - Constant dollar conversion
  - “fog of planning” discount
    (“far-future mischief is better than immediate mischief”)

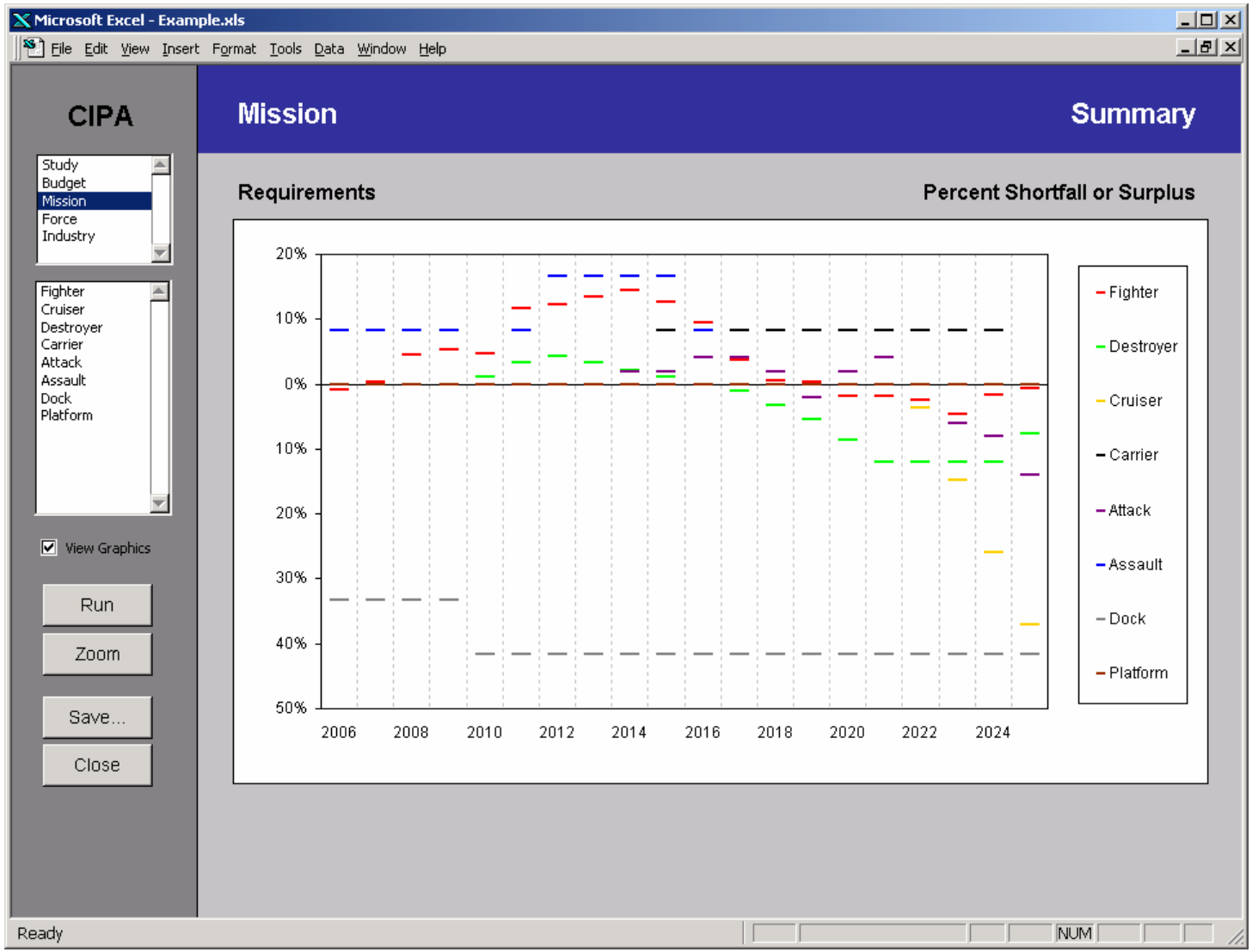
“fog of planning” discount

- A few difficult SCOUT instances:
  - without discount, at least 5,000 seconds
  - with 2.5% discount factor, 400 to 3,500 seconds to obtain a similar solution

A CIPA budget satisfied



Result of satisfied CIPA budget

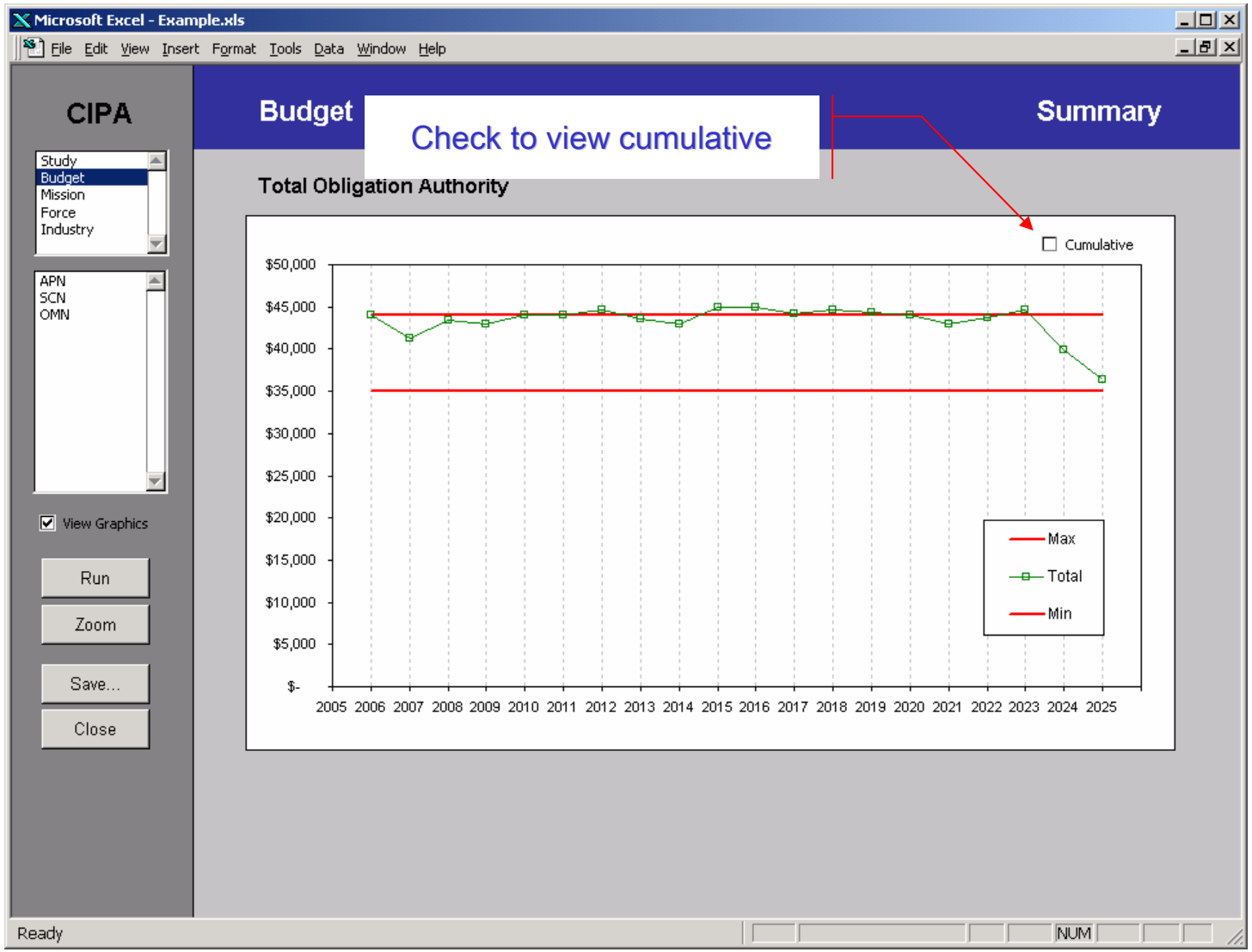


Elastic Constraints

Are additional funds needed to meet CIPA mission requirements or just flexibility in when funds are spent?

Let’s try a little flexibility.

Cumulative budget must be satisfied but deviation from yearly budgets penalized.


Microsoft Excel - Example.xls
File Edit View Insert Format Tools Data Window Help
CIPA
Study
Budget
Mission
Force
Industry
APN
SCN
OMN
View Graphics
Run
Zoom
Save...
Close
Budget
Summary
Check to view cumulative
Total Obligation Authority
Cumulative
$50,000
$45,000
$40,000
$35,000
$30,000
$25,000
$20,000
$15,000
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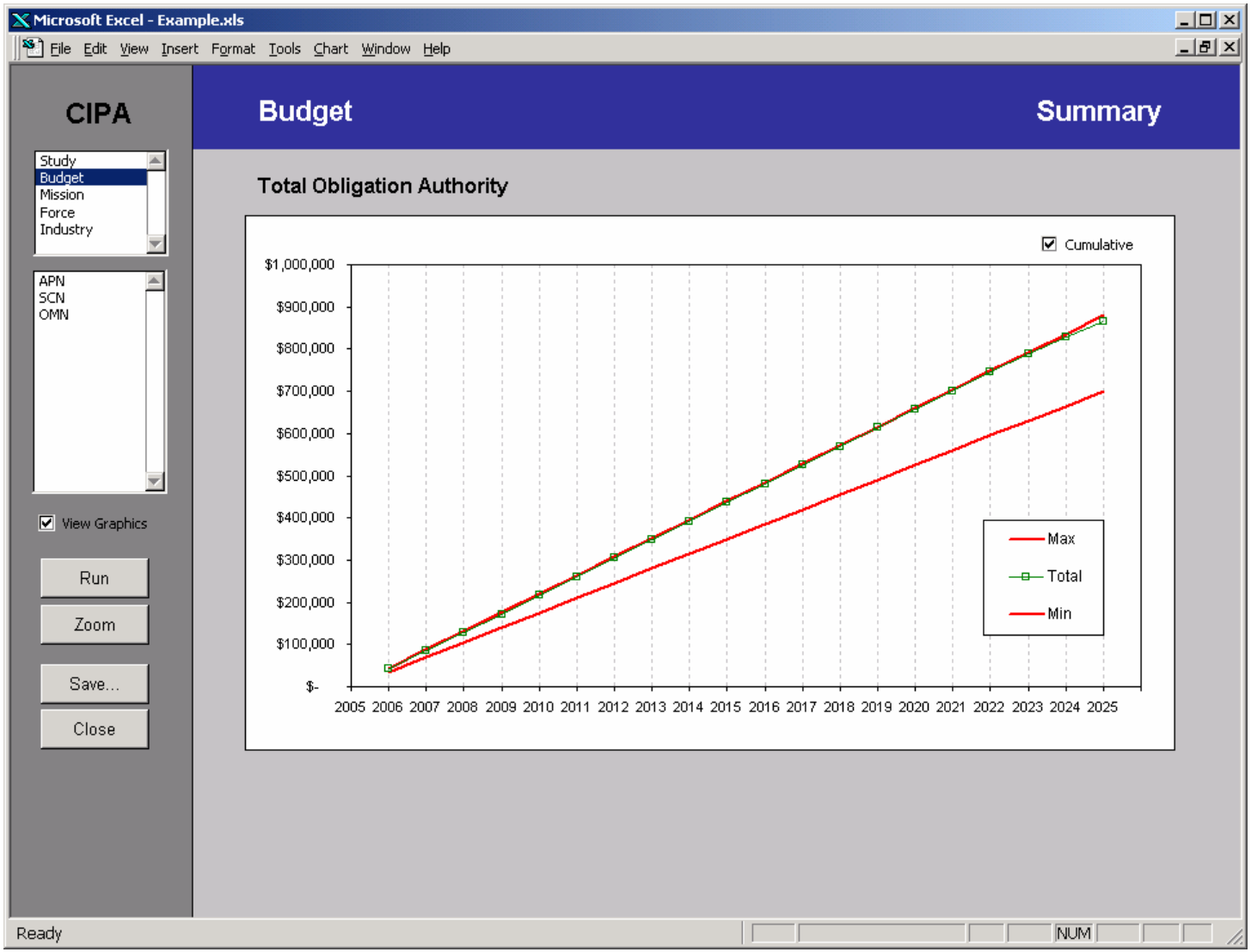
2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025
Max
Total
Min
Ready
NUM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CIPA
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Zoom
Save...
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Budget
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Total Obligation Authority
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$700,000
$600,000
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Max
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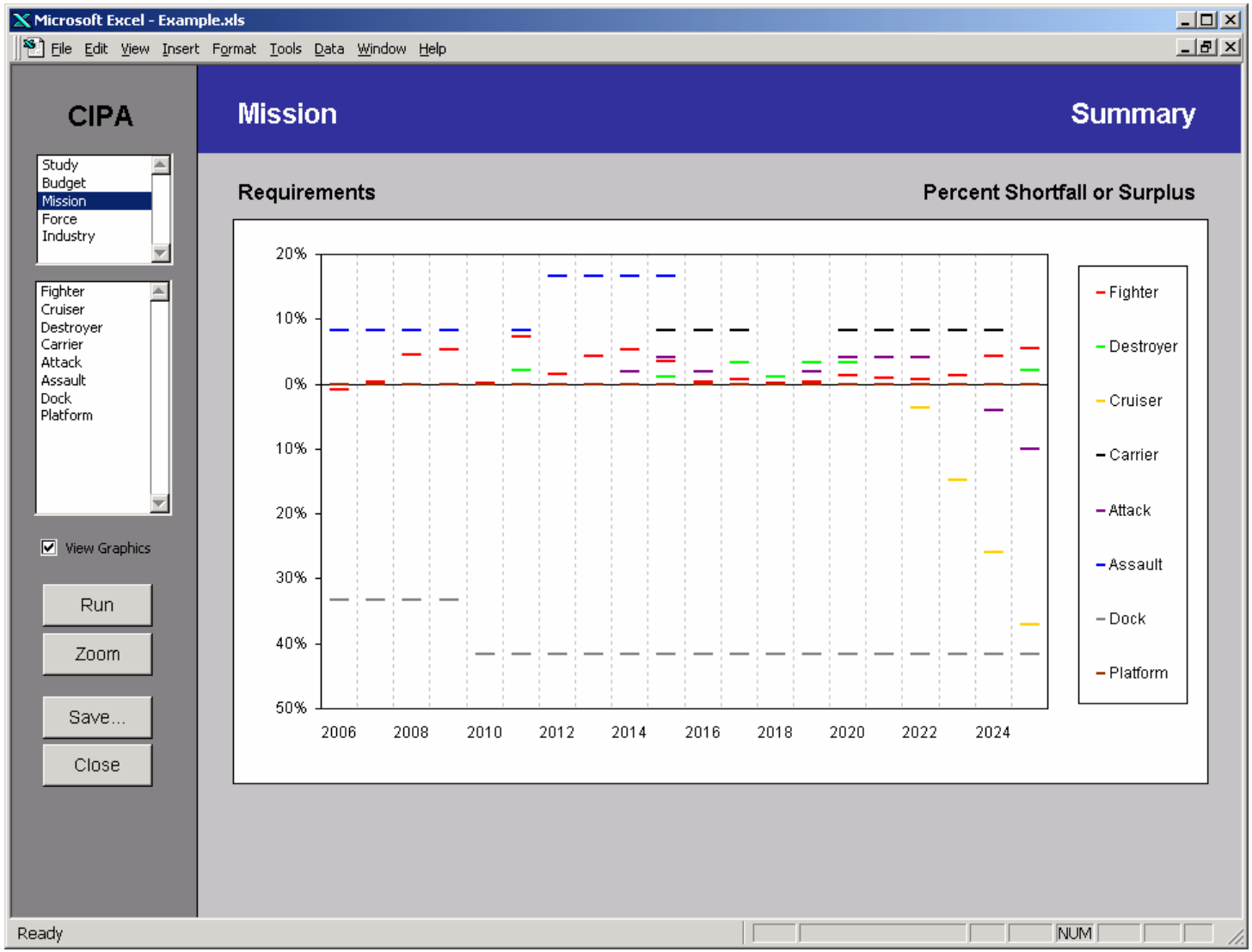
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CIPA
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Fighter
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Destroyer
Carrier
Attack
Assault
Dock
Platform
View Graphics
Run
Zoom
Save...
Close
Mission
Summary
Requirements
Percent Shortfall or Surplus
20%
10%
0%
10%
20%
30%
40%
50%
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
Fighter
Destroyer
Cruiser
Carrier
Attack
Assault
Dock
Platform
Ready
NUM

Question:

Are additional funds needed to meet CIPA mission requirements or just flexibility in when funds are spent?

Answer:

No additional funds are needed.

By knowing when and by how much to shift funds, mission requirements are met for all cases where meeting requirements is possible.

Optimization does this!

Persistence

- Once a plan is published,
- It’s a good idea to avoid frivolous changes
- Sometimes, even when the changes are significant

Persistence

Persist:

"1. to continue steadily or firmly in some state, purpose, course of action, or the like, esp. in spite of opposition, remonstrance, etc.: *to persist in a belief; to persist in one's folly*." Webster's 1989

Persistence and Optimization

A model is naive to recommend a solution
ignorant of its own prior advice

How can solutions differ so drastically?

- often many essentially indistinguishable optimal solutions
- optimization amplifies small input changes into wholesale revision
- optimization doesn’t just use data, it exploits it

Modeling Persistence

- Practical considerations
  - How is existing base solution expressed?
  - How are differences gauged?
  - How are aspirations expressed?

Motivating example

- DERO decides a six-year depot-level maintenance plan exceeding $450 million
- Optimizes available war-ready US Marine Corps tactical ground equipment
  - Directly influences our ability to fight

- Solve DERO for FY2002-2006
- Publish its solution
- One month later, the FY2002 budget is reduced from $105.6M to $104.1M (a 1.4% reduction in only the first of six fiscal years)
- Solve DERO again and compare

Change

- Major Change - complete cancellation/start-up of a program between solutions

- Minor Change - small changes to a program within a FY between solutions

	2002	2003	2004	2005	2006	2007
A0010						
A0043		-3	-3			
A0966						
A1260	-1		1			
A1440						
A1500						
A1503						
A1530						
A2306						
A2635	-1					
A7005	-1					
A7025						
A7035						
A7037						
A7052						
A7055	-4					
A7058						
A7072						
A7500						
A7590						
B0001						
B0114	-1					1
B0395						
B0443						
B0589			1	-0.9		

	2002	2003	2004	2005	2006	2007
B0635		-2				2
B0730	-3	-36			0.3	38.7
B1082						
B1226						
B1298		-1				
B1315			-2		2	
B1580	-1					
B2464						
B2482						
B2685		-4				
C2032		-17				
D0080						
D0105						
D0209						
D0860	2			-1.9		
D0876						
D0877						
D0878						
D0879						
D0880	-82			54.2	27.8	
D1072						
D1134		1		-1		
D1212						
E0180			-11	11		

	2002	2003	2004	2005	2006	2007
E0726						
E0727			1			
E0942						
E0946						
E0947						
E0948						
E0949						
E0950						
E0960	-8	-128	1	135		
E0961	-4					
E0980			-37	21.8	15.2	
E0998		-1	-20	21		
E1037						
E1251	-12		-2		14	
E1313						
E1441	-1	3	2	-4		
E1460						
E1475						
E1836						
E1888	-1	1		-0.93	-0.58	-0.69
E3196						
A0000						
E0000						
E0001						

<u>56</u> changes (20 major and 36 minor)

Persistent Formulation

Minimize:

Changes to old schedule

Subject to:

aspiration level on original objective

original constraints

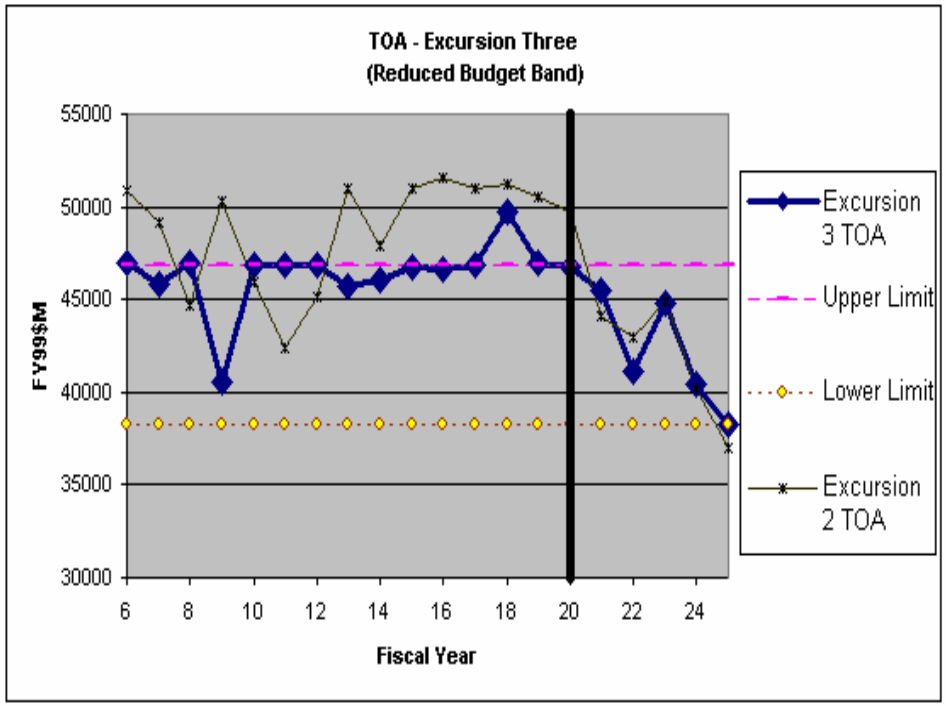
	2002	2003	2004	2005	2006	2007
A0010						
A0043						
A0966						
A1260						
A1440						
A1500	-3			1	2	
A1503						
A1530						
A2306						
A2635						
A7005						
A7025						
A7035						
A7037	-1			1		
A7052						
A7055						
A7058						
A7072						
A7500						
A7590						
B0001						
B0114						
B0395						
B0443						
B0589						

	2002	2003	2004	2005	2006	2007
B0635						
B0730						
B1082						
B1226						
B1298						
B1315						
B1580						
B2464						
B2482						
B2685						
C2032						
D0080						
D0105						
D0209						
D0860						
D0876						
D0877						
D0878						
D0879						
D0880						
D1072						
D1134						
D1212						
E0180						

	2002	2003	2004	2005	2006	2007
E0726						
E0727						
E0942						
E0946						
E0947						
E0948						
E0949						
E0950						
E0960	-1			1		
E0961						
E0980						
E0998						
E1037	-1			1		
E1251						
E1313						
E1441						
E1460						
E1475						
E1836						
E1888				-1.1	-1.5	
E3196	-2			2		
A0000						
E0000						
E0001						

an optimal solution with only 13 changes (1 major)

End Effects



- USN Total Obligated Authority 25-year Budget Band
- It can take many years from payment to delivery of a ship
- Steady decrease in spending during the last five years

Usually sufficient to extend the planning horizon beyond years actually reported

Relaxation and Aggregation

- Even though variables should more realistically have only integer values
  - can keep the restriction in the near term and relaxing it in the far term
- Even though decisions should more realistically be for each year
  - can keep them yearly in the near term and aggregating them in the far term

For more

See *Optimizing Military Capital Planning* by G.G. Brown, R.F. Dell, and A.M. Newman for addition details and over 50 references