The Society of Cost Estimating and Analysis

Trying To Do Too Much With Too Little: How Poor Portfolio Management Can Lead To Schedule Delays And Cost Overruns

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Presented at the 2011 ISPA/SCEA Conference

Introduction

- **Portfolio management is critical, but sometimes overlooked**
  - **Projects are often started without consideration of the long-term implications**
- **A result of this lack of forethought is trying to accomplish too much with too few resources**
- **Lack of consideration of portfolio management can lead to schedule delays and cost overruns**
- **This presentation discusses the results of cost constraints and schedule delays on cost, which is a consequence of poor portfolio management**
- **An example is used to illustrate the positive impact that portfolio management can have on project and program success**

Cost and Schedule Correlation

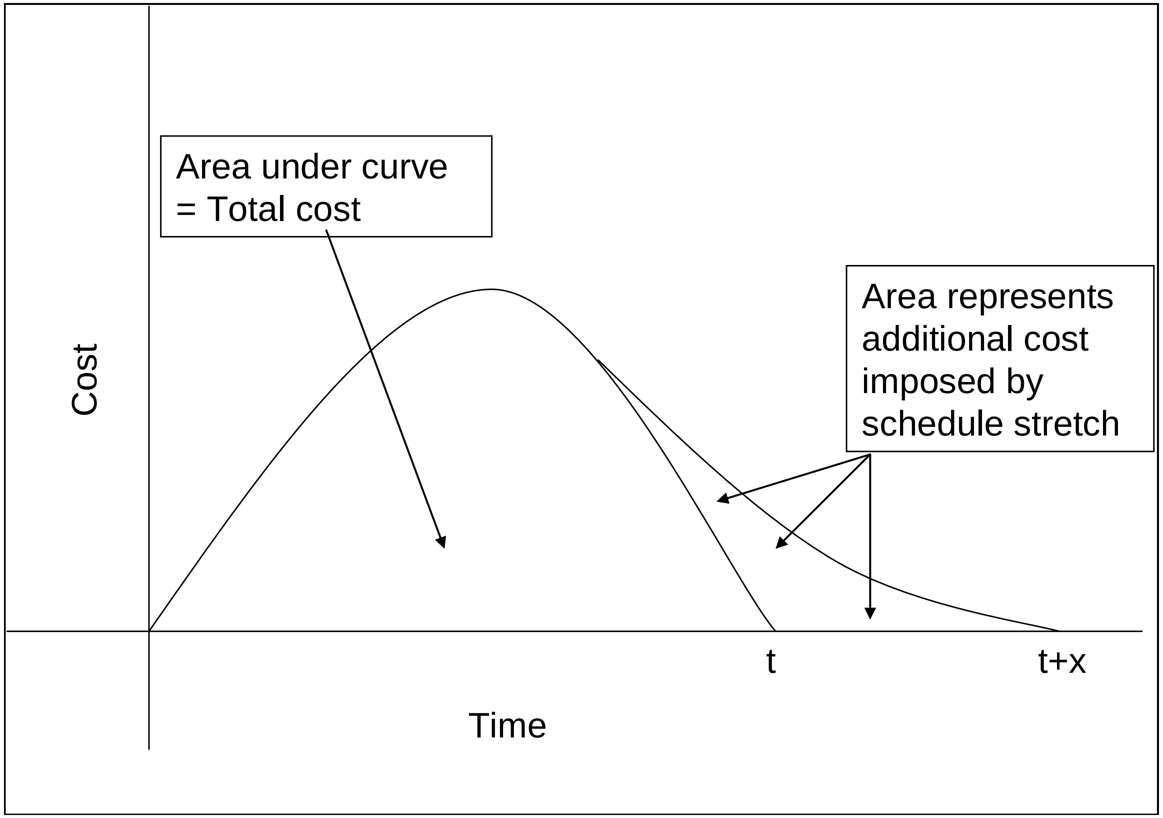
- **Cost and schedule are highly correlated**
  - **If the schedule slips, i.e., the project takes longer than anticipated to complete, then its cost will increase**
    - **Burn rate**
    - **Standing army must be paid**
- **Cost and schedule are mathematically correlated**
  - **A program with a longer schedule generally has higher cost**
  - **A program with a short schedule generally has lower cost**
    - **Unless a program has a compressed schedule**
- **Many models are not currently well-equipped to handle cost and schedule jointly**
  - **Cost and schedule are often analyzed independently of one another**

The Importance of Considering Cost and Schedule Interactions

- Because cost and schedule are interrelated, and changes in schedule have a significant impact on cost, there is a need to model these phenomena
- Government projects are notorious for cost growth
  - In a study of 289 NASA and Department of Defense projects Smart (2011) showed that:
    - 82% of projects experience cost growth
    - Mean cost growth is 52%
    - Half of all projects grow by more than 30%
- Also, most projects incur schedule overruns
  - In a study on schedule growth for 98 spacecraft missions, Smart (2009) showed that 91% of missions analyzed had schedule overruns
    - Mean schedule growth was 38%
    - Half of all schedules grow by more than 25%

Cost Penalties/Benefits Due to Changes in Schedule

- **When the length of the schedule increases, cost increases due to a stretching of the funding profile**



Beta Distributions for Cost Phasing

- The beta distribution is often used for the phasing of cost
- The two-parameter beta distribution is defined by

$$f(x;\alpha,\beta) = \frac{x^{\alpha-1}(1-x)^{\beta-1}}{\int_0^1 u^{\alpha-1}(1-u)^{\beta-1}\,du}$$

- The denominator is the beta function

$$B(\alpha,\beta) = \int_0^1 u^{\alpha-1}(1-u)^{\beta-1}\,du$$

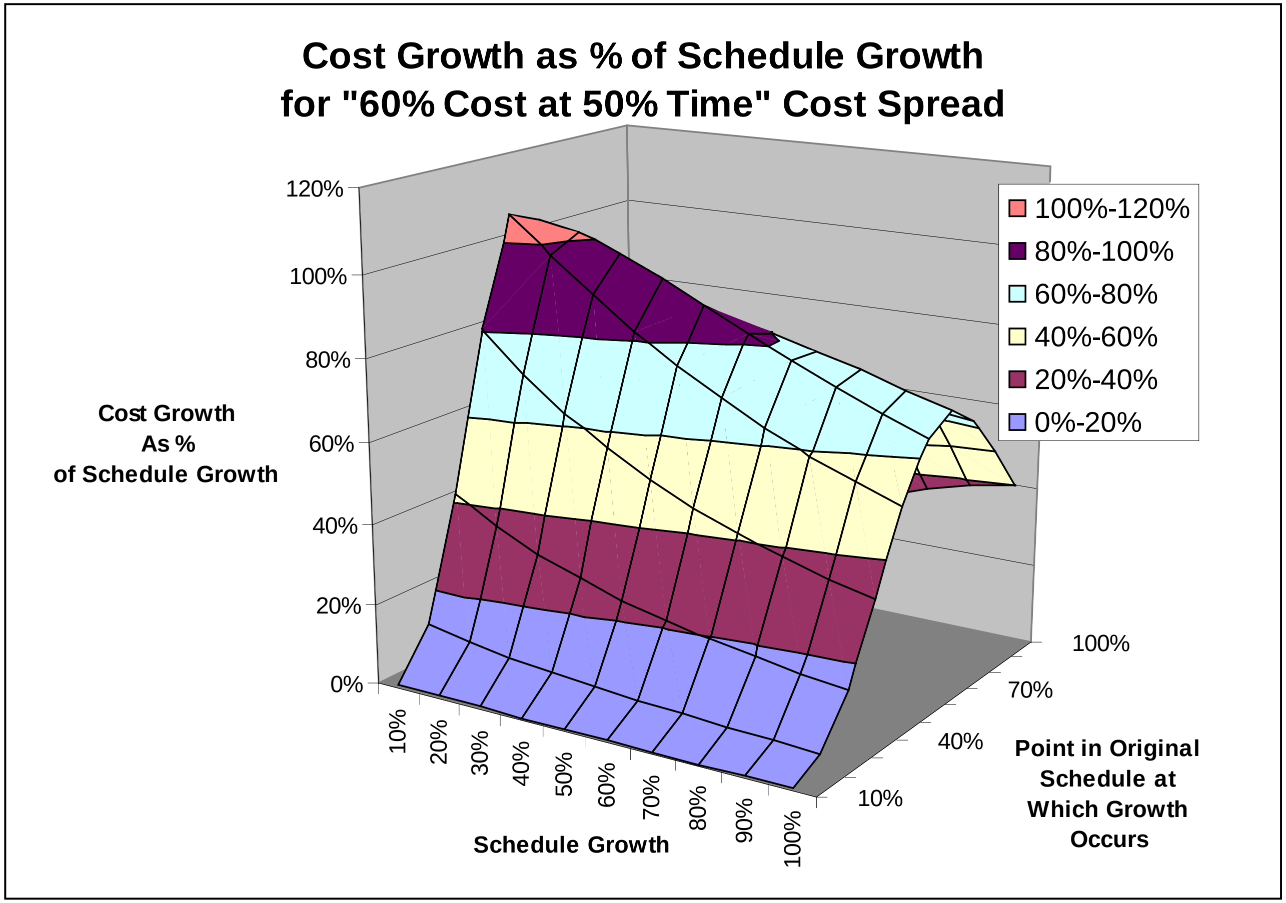
Cost Penalties/Benefits Due to Changes in Schedule (2)

- For example, if a beta distribution is used for time-phasing, a 10% schedule increase that occurs at time *z* will increase the total cost by the amount in the equation below

$$\int_0^z \frac{x^{p-1}(1-x)^{q-1}}{B(p,q)}dx + \int_z^{1.1} \frac{x^{p-1}(1.1-x)^{q-1}}{B(p,q)1.1^{p+q-1}}dx$$

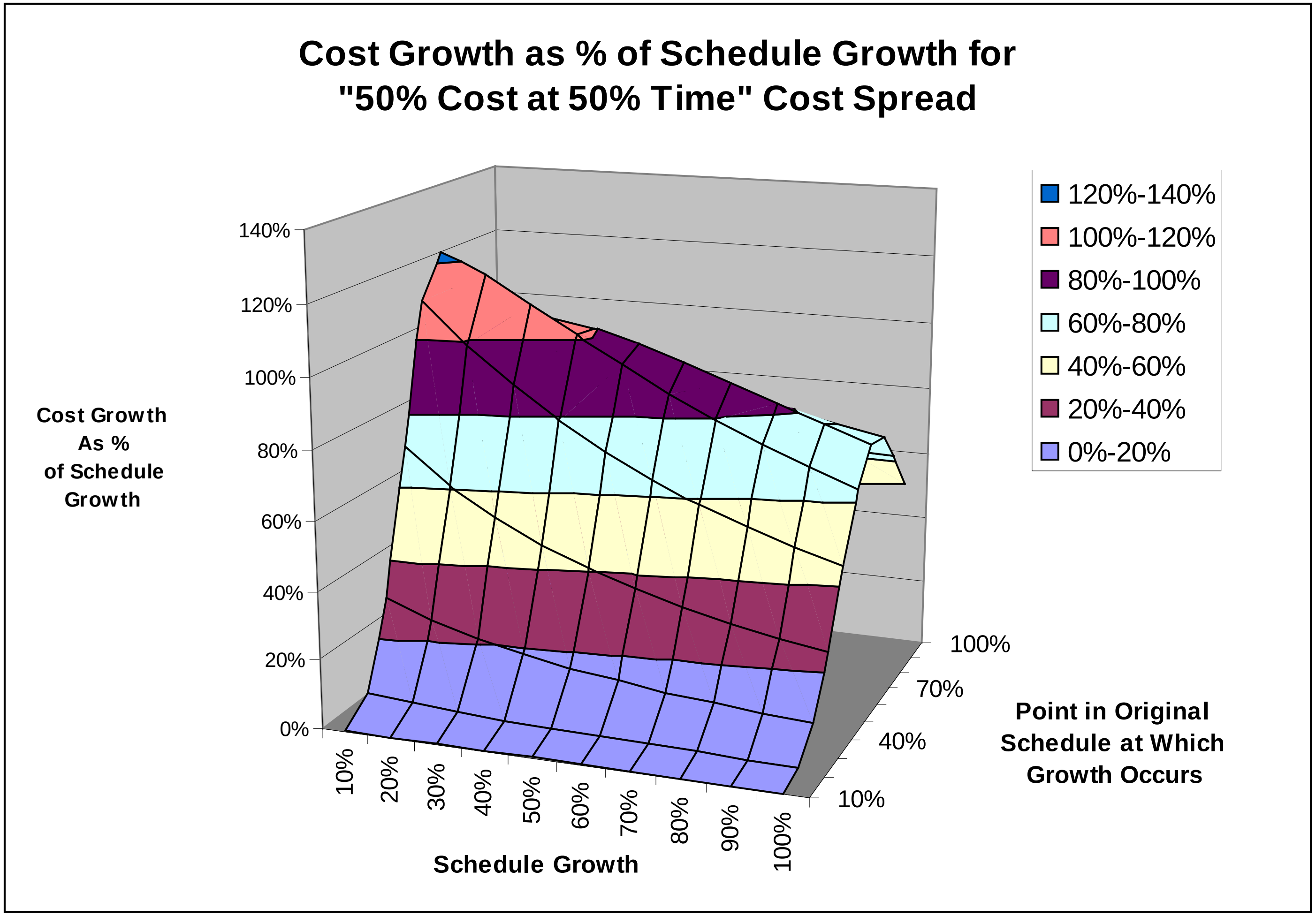
Cost Penalties/Benefits Due to Changes in Schedule

- **Response Surface for Front-Loaded Phasing**



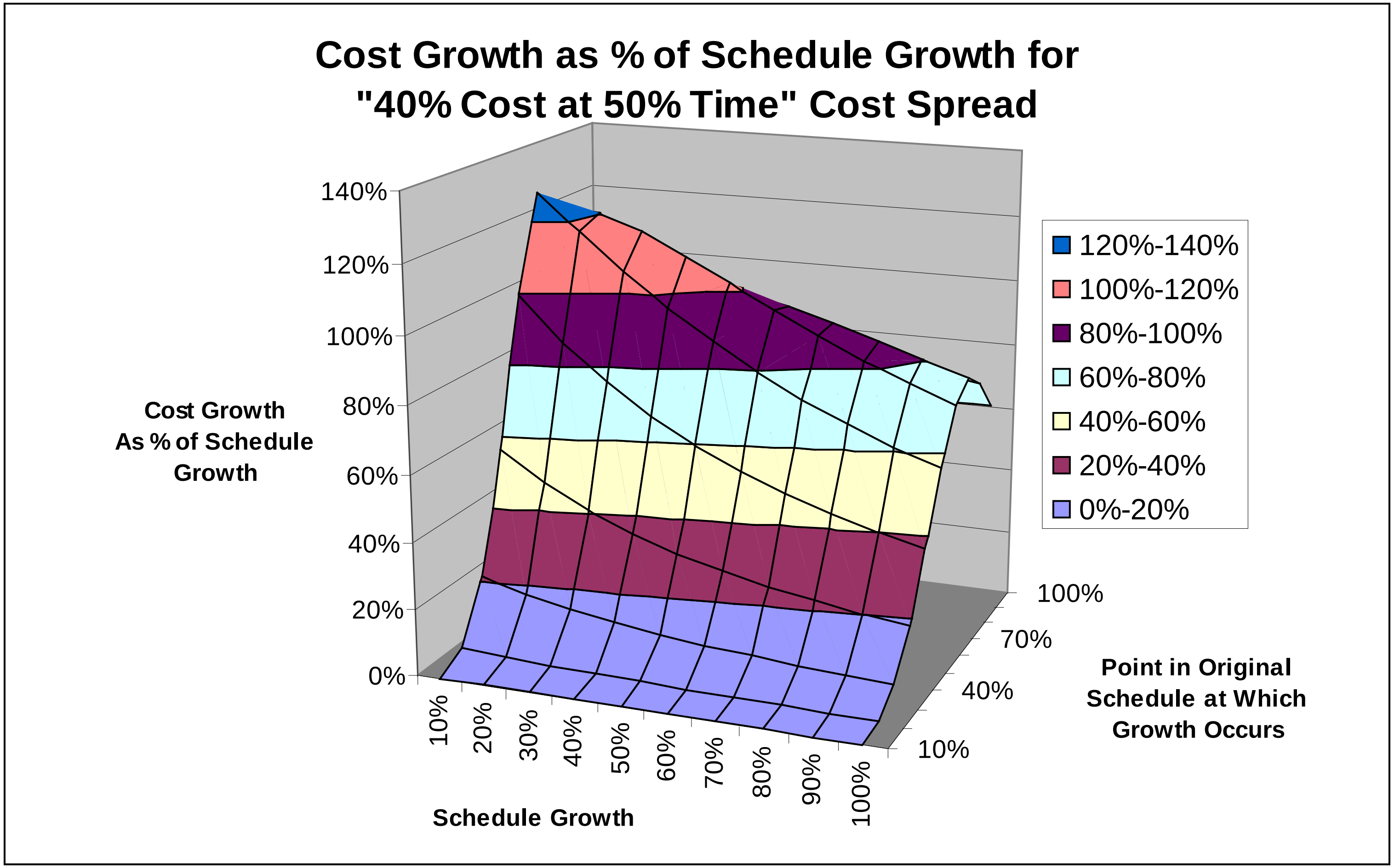
Cost Penalties/Benefits Due to Changes in Schedule

- **Response Surface for Balanced Phasing**



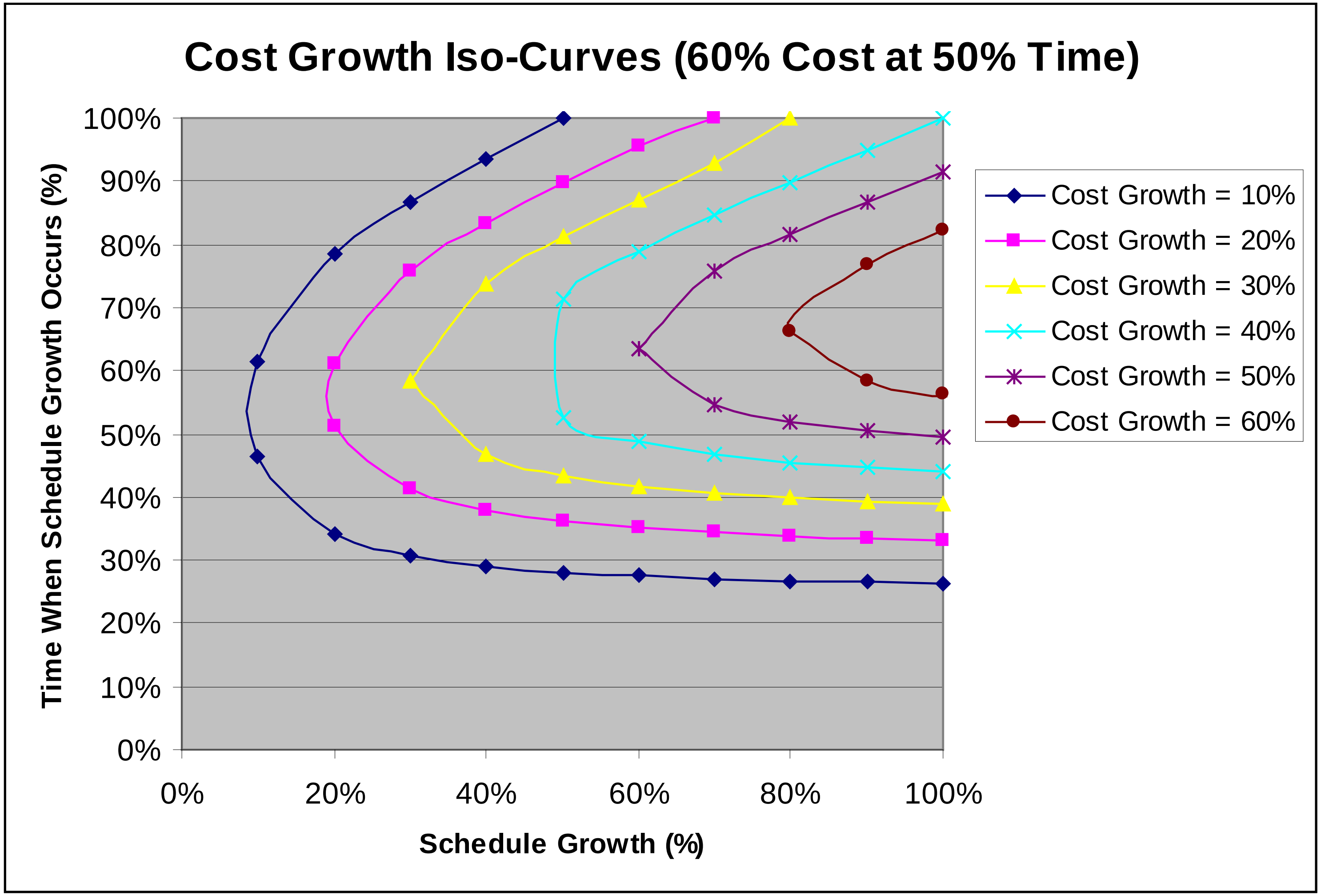
Cost Penalties/Benefits Due to Changes in Schedule

- **Response Surface for Back-Loaded Phasing**



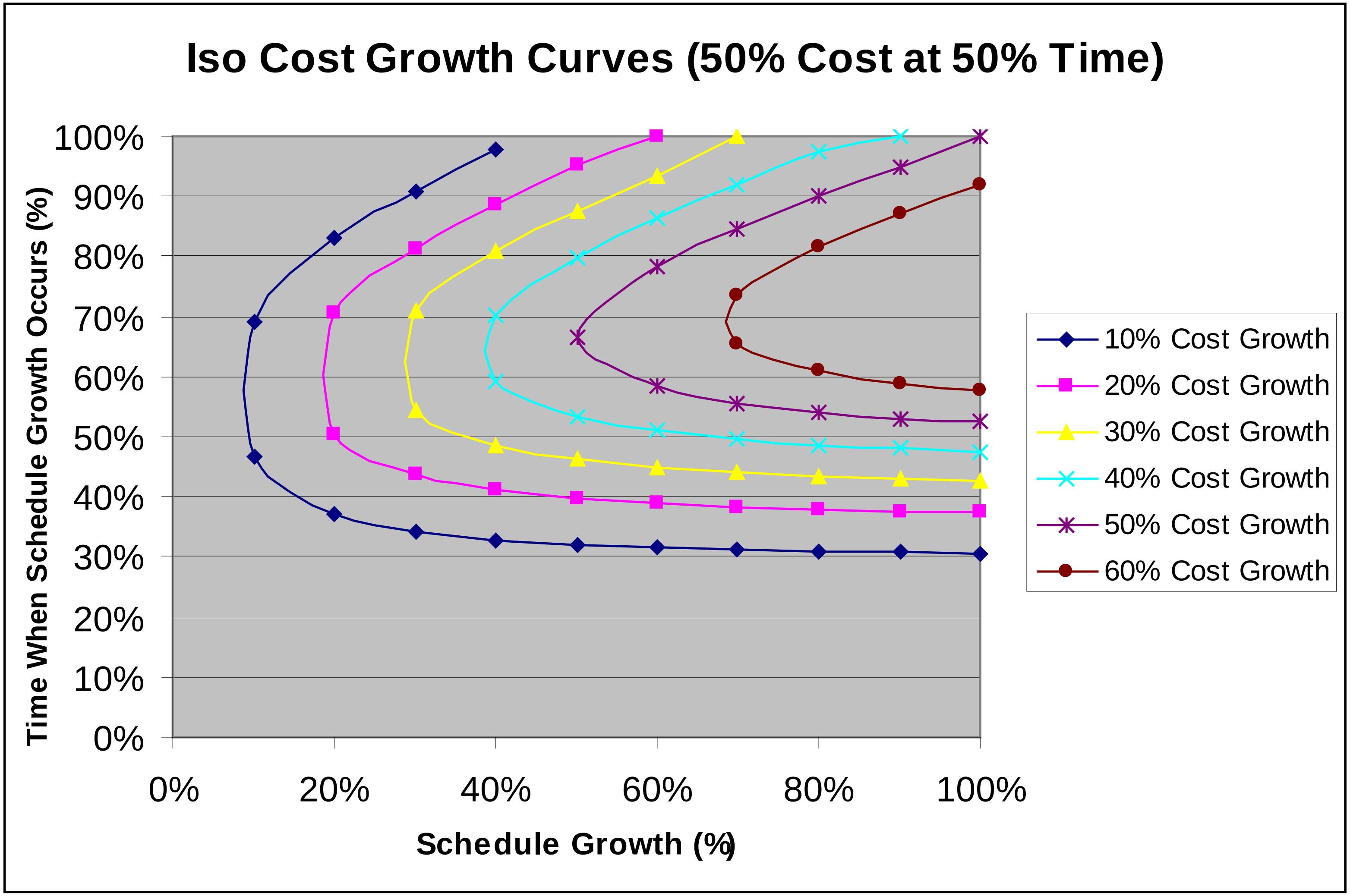
Cost Penalties/Benefits Due to Schedule Increases in 2-D

- **Iso-curves for a front-loaded beta distribution**



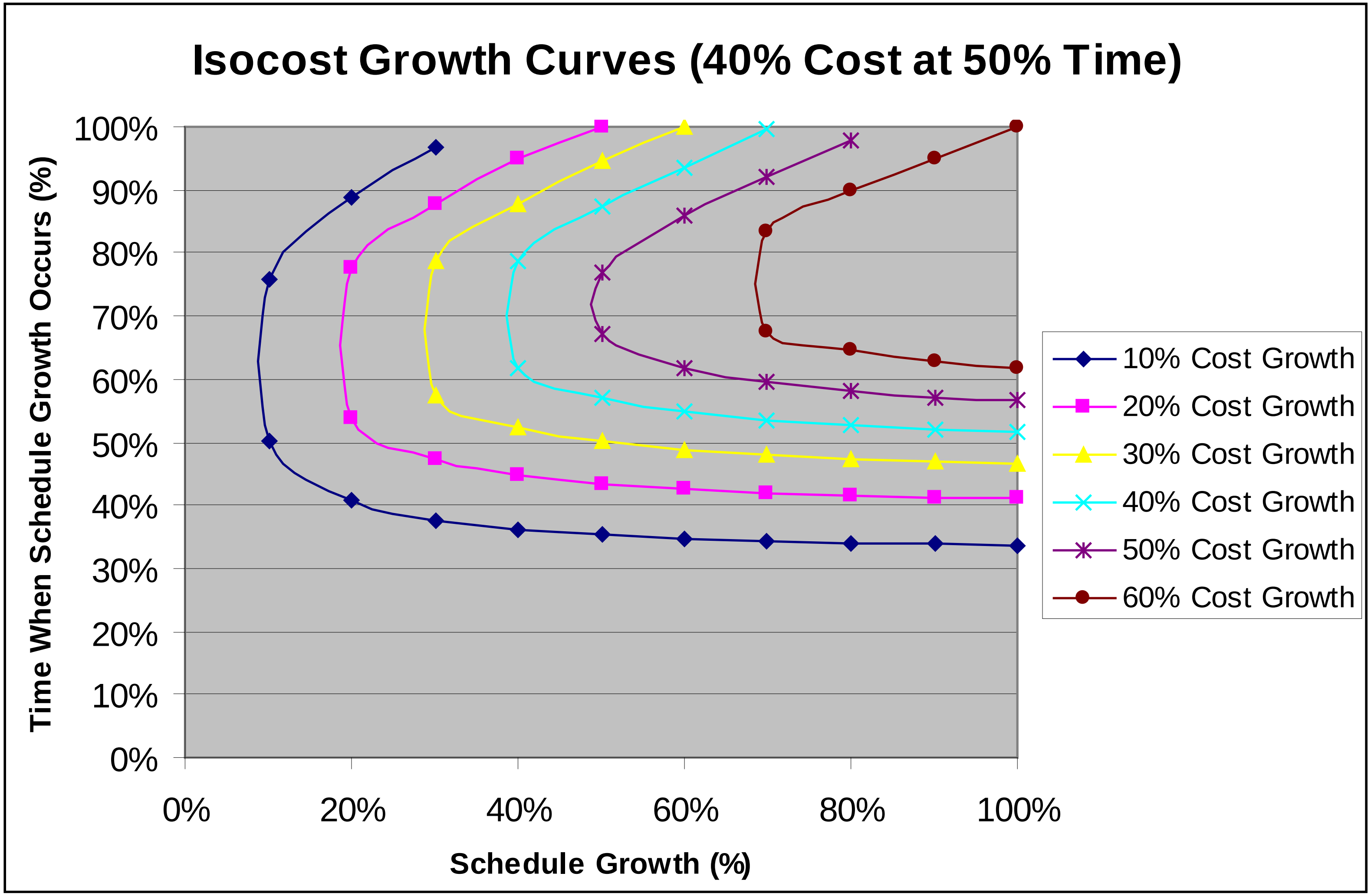
Cost Penalties/Benefits Due to Schedule Increases in 2-D

- **Iso-curves for an even loaded beta distribution**



Cost Penalties/Benefits Due to Schedule Increases in 2-D

- **Iso-curves for a back-loaded beta distribution**



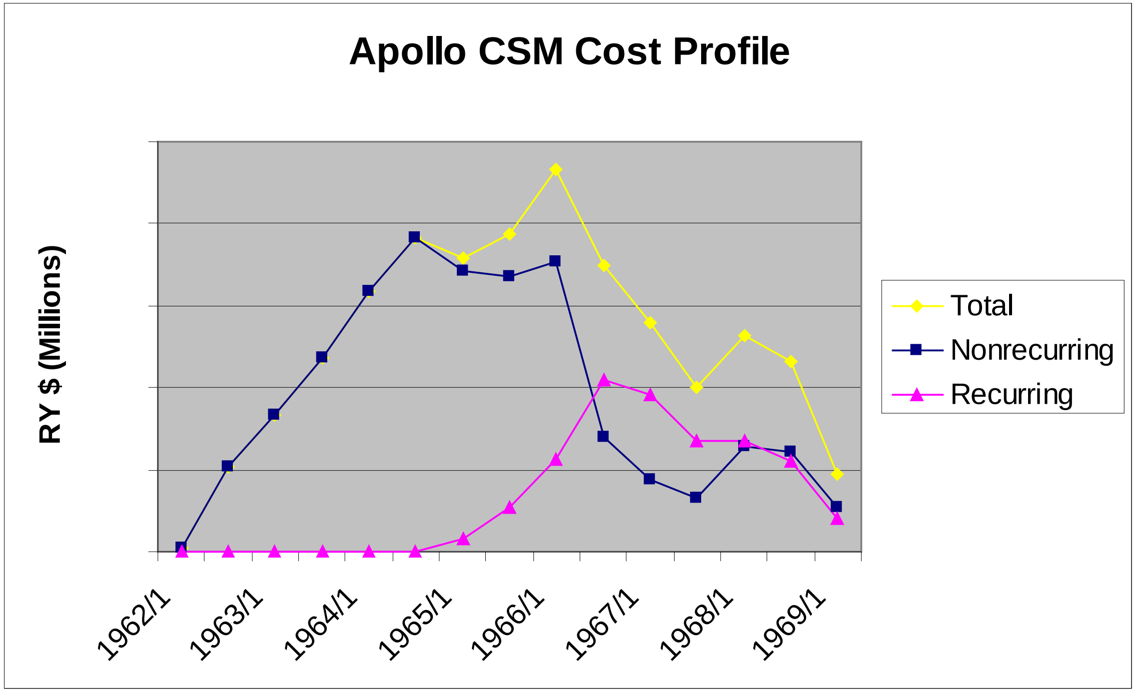
Cost Penalties/Benefits Due to Changes in Schedule - Conclusions

- **Conclusions from theoretical research**
  - **Cost growth is most sensitive to schedule growth (as a % of schedule growth) when**
    - **Schedule growth is small**
    - **Schedule growth occurs in the middle of the schedule (at peak funding)**
      - Validates hypotheses made (but unverified) by previous research
    - **Cost profile is back-loaded (peak occurs in out years)**

Cost Profiles and Smoothness

Cost Estimating

- **Changes in schedule will likely result in jagged, non-smooth changes in cost profiles, unlike the beta distribution**
- **Example**



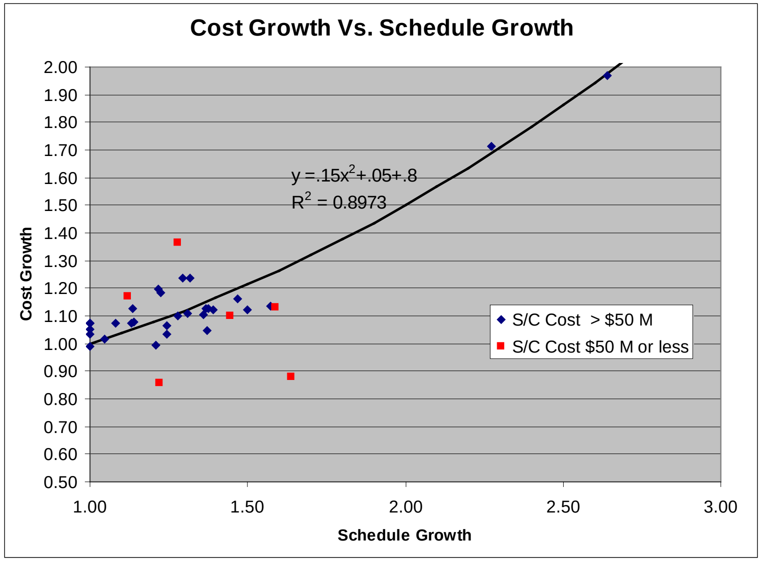
Cost Penalties/Benefits Due to Changes in Schedule - Empirical

- **Collected cost and schedule growth information for over 40 NASA missions**

ACE
ACTS
AE-3
AMPTE-CCE
Aqua
Aura
C GRO
CONTOUR
Dawn
Deep Impact
DMSP-5D
EO-1
FAST
FUSE
GALEX
Galileo
Genesis
GRACE
HEAO-1
Hessi
HETE-II
HST
ICESAT
IMAGE
Landsat-1
Landsat-7
Lunar Orbiter
Lunar Prospector
Magellan
MAP
Mars Exploration Rovers
Mars Observer
Mars Odyssey
Messenger
OSO-8
Saturn V
Shuttle Orbiter
SORCE
Spitzer Space Telescope
Stardust
SWAS
Swift
TDRS-H
Terra
TIMED
TIROS-M
TIROS-N
TRACE
TRIANA
VCL
Viking Orbiter

Cost Penalties/Benefits Due to Changes in Schedule - Best Fit

- Relationship of cost growth to schedule growth is nonlinear
  - Ratio varies from 30 – 50%
- Removed small missions (less than $50 million) from the analysis
  - No clear relationship between cost and schedule for these missions
  - In such cases it may be possible to “buy back” schedule by adding funding



Cost Penalties/Benefits Due to Changes in Schedule - Crosscheck

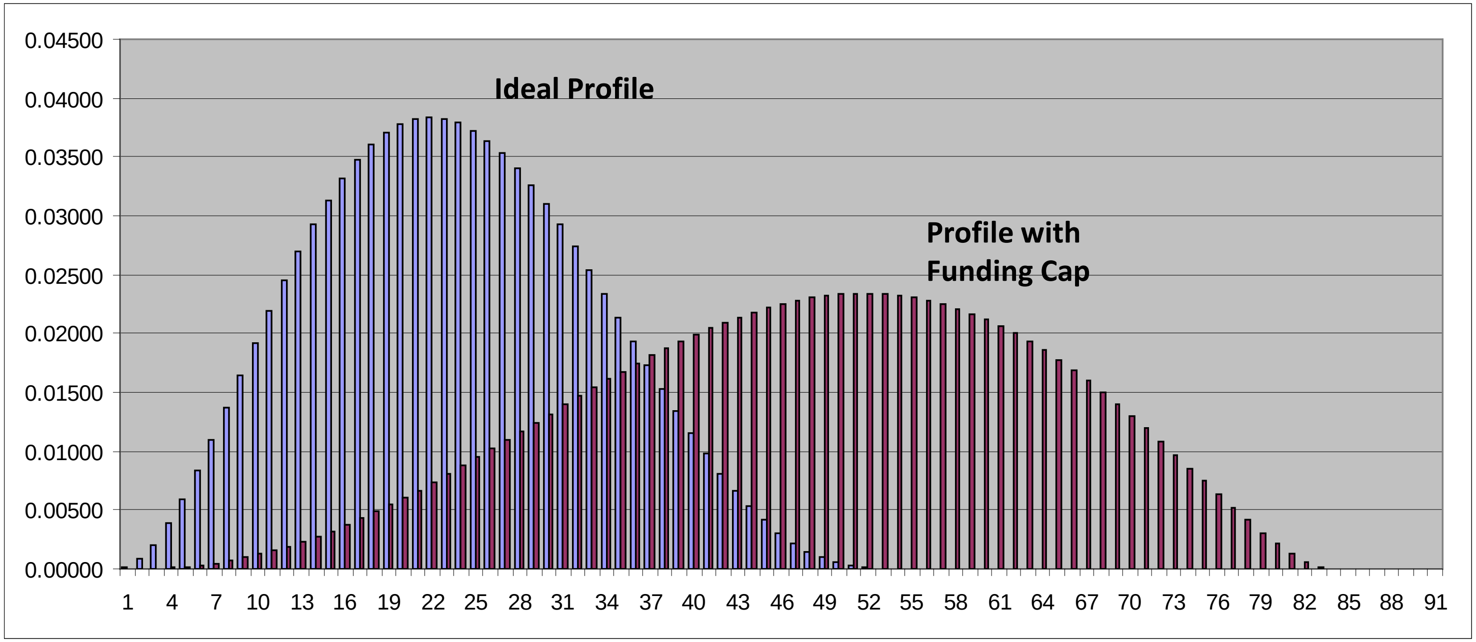
- **The theoretical results may not match real-world data, since changes in schedule can result in discontinuous changes**
  - **Means change in the funding profile may not equal that implied by theory**
- **Compared theoretical results to empirical data based on a case-by-case analysis of cost and schedule growth data by milestone (ATP, PDR, CDR, Delivery, and Launch)**
  - **Relative results of the theory are confirmed by the data, but the assumption that schedule changes are continuous results in consistent underestimation of the effects of schedule increases on cost by about 50%**
- **Conclusion**
  - **Use theoretical analysis for schedule analysis, but apply a continuity adjustment factor equal to 2**

Funding Peak Constraints and Schedule Growth

- **For each project, there is an ideal funding schedule, one that ramps up as the design work gets underway, and then ramps down as fabrication and assembly nears completion and testing ensues**
- **For large programs, the ideal funding peak may exceed the budget for an entire directorate, which requires funding caps that constrain expenditures**
  - **This constraint is non-optimal, leading to delays in activities**
  - **The funding profile peak will be delayed and may shift the profile from being front-loaded to back-loaded**
    - **Results in schedule and cost increases**

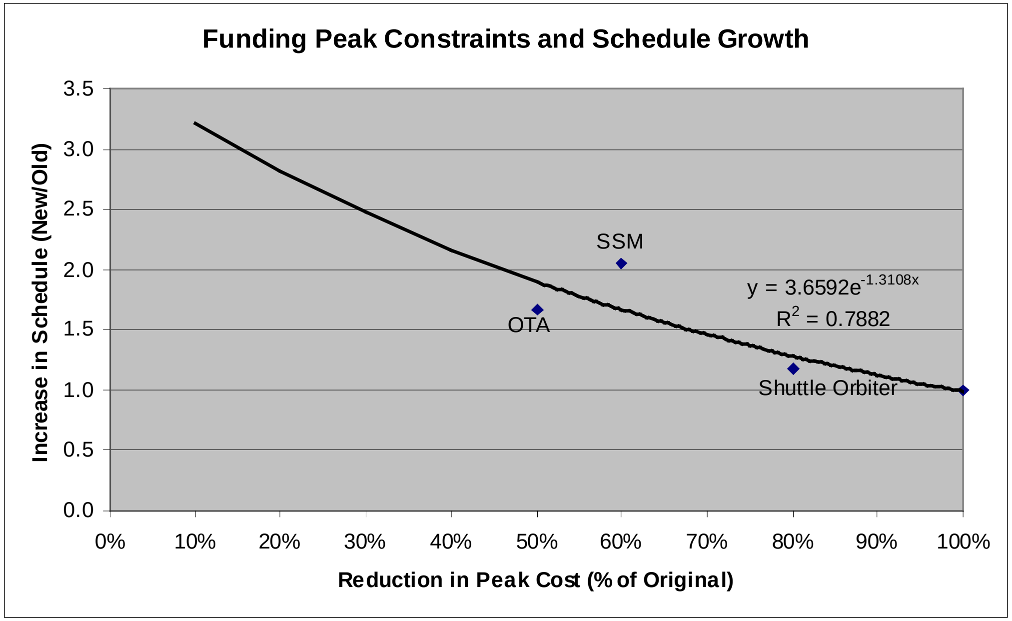
Funding Peak Constraints and Schedule Growth Example

- **Funding Profiles Before and After Cap Is Applied**



Funding Peak Constraints and Schedule Growth Algorithm

- Two prominent missions that experienced significant schedule growth due to funding constraints were Shuttle Orbiter and the Hubble Space Telescope (Emhart PRC, 1988)
  - Both elements of HST, SSM and OTA experienced large schedule increases due to funding constraints

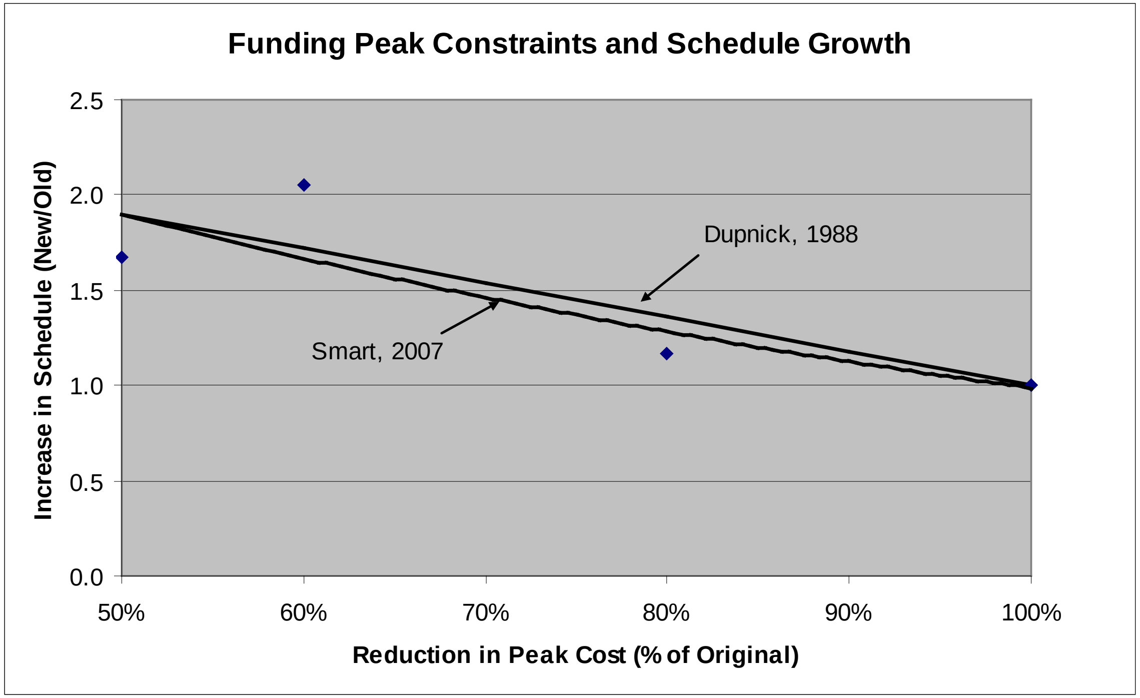


Funding Peak Constraints and Schedule Growth Algorithm

$$Schedule\ Growth\,(\%) = 3.6592\ e^{\left(-1.3108 * \left(1 - \%Reduction\ in\ Peak\ Funding\right)\right)} - 1$$

- **For example, if the reduction in peak funding is 30%, the predicted increase in schedule is 46%**
- **While based on a small data set, funding constraints for major programs are not an everyday occurrence**
- **Despite this small data set, this equation closely agrees with an equation developed by Edwin Dupnick, (Dupnick, 1988)**
  - **Dupnick's equation was based on his experience with "modest-sized" NASA programs at JSC**

Funding Peak Constraints and Schedule Growth Comparison



QTIPS, a NASA Model

- **The preceding research results have been incorporated in a model for NASA called QTIPS**
  - **QTIPS = Quantitative Techniques for Incorporating Phasing and Schedule**
  - **Available from NASA for free (point of contact is Charles Hunt)**
- **QTIPS is used to assess the impacts of funding constraints and schedule delays on cost for the example on portfolio management**

Funding Profiles with Cost Caps

- QTIPS is capable of modeling this impact
- Based on Beta distribution
  - Includes ability to set beta distribution parameters and number of periods
  - Also includes
    - Ability to set annual spending caps
    - Ability to set when first month begins during a fiscal year
    - Ability to constrain cap-imposed profile to peak either before or after the unconstrained profile
    - If cap is too small (annual cap times the number of years in the phasing is less than 120% of the total cost), user is presented with a dialog box informing them of this situation
  - In addition, the user can change specific schedule times for preliminary design, detailed design, fabrication and assembly, and testing, and re-calculate the funding profile and compare with the original funding profile, and determine the effect on overall cost and schedule
    - Determine the impact of schedule changes on cost using the algorithms described in this presentation

Doing Less with More

- **Portfolio optimization involves multiple years**
- **Beginning new projects in order to spend all available funds involves portfolio management year-by-year**
  - **Leads to sub-optimal results**
  - **This is because the first year of a project is the least expensive**
  - **Following years can lead to not having enough funds to execute the entire portfolio efficiently**
    - **Leads to too many projects to be able to fit within the portfolio's budget, further leading to:**
      - **Funding cuts for other projects in the portfolio**
      - **Significant schedule delays, which result in cost overruns**

Traffic Congestion Analogy

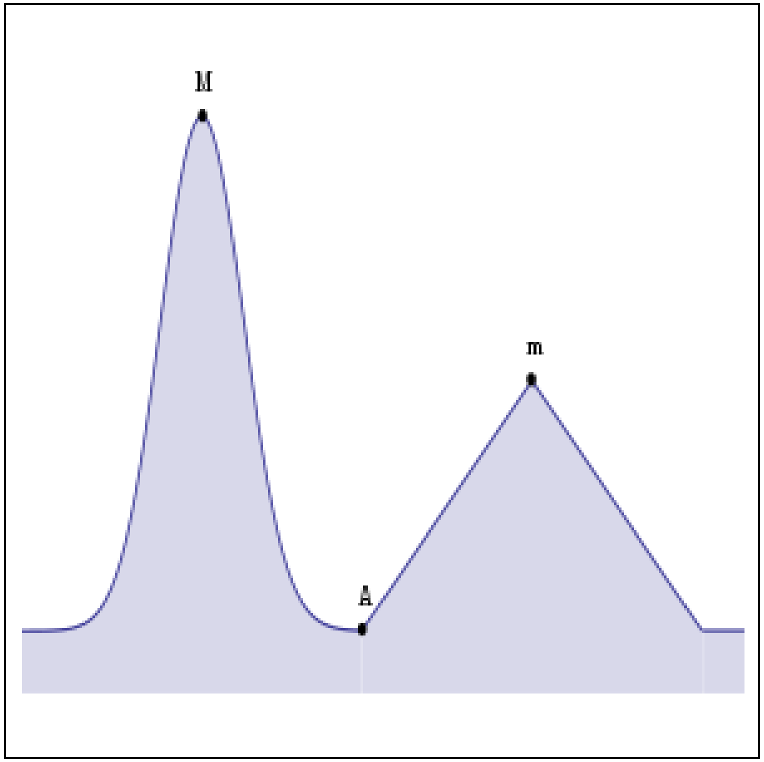
- **Trying to juggle too many projects leads to congestion, slowing down the completion of all projects**

Greedy Algorithms

- The process of looking only one year head is an example of what is termed in optimization as a greedy algorithm
- A greedy algorithm is an algorithm that follows the problem solving heuristic of making the locally optimal choice at each stage with the hope of finding a global optimum
- On some problems, a greedy strategy need not produce an optimal solution
- Greedy algorithms can be characterized as being 'short sighted' or myopic

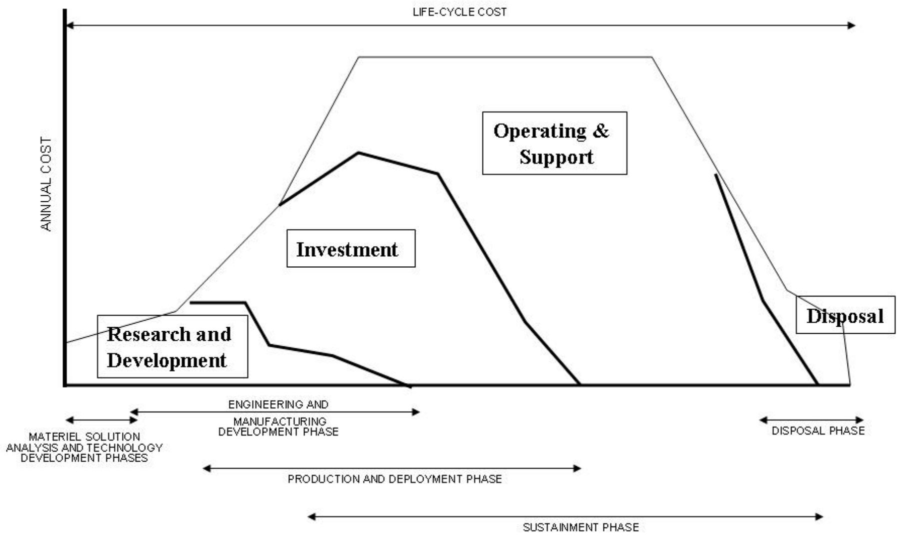
Local Optimality Vs. Global Optimality

- A greedy algorithm may lead to a locally optimal solution that is far from the global optimum
- For example in the graph below the greedy algorithm may result in achieving the value ‘m’ which is significantly below the global maximum ‘M’



The Tip of the Iceberg

- Research and development is often relatively small compared to the costs of producing, operating and disposing of the system
  - Thus the first year is just the tip of the iceberg



Program Life Cycle (Illustrative)

Source: CAPE 2012

Budget Wedges

- The greedy algorithm is encountered in portfolio management when budget wedges are established
  - Whether for one year, or multiple years, little consideration of the full cost impacts of new projects on the overall portfolio may be given when putting into the budget an amount of money that helps get a project started without the full implications for life-cycle cost

Example

- **As an example, consider a series of projects, all of which cost $500 million, as long as there are no schedule delays**
- **For the sake of simplicity ignore the effects of inflation in this example**
- **Assumptions:**
  - **Annual budget for the entire portfolio is $1 billion**
  - **The cost phasing follows a front-loaded beta distribution with α = 2.45 and β = 3.00**

Project Cost Phasing for Example

- **Each project's cost is phased by year according to the follow table:**

Year	Cost ($ Millions)
1	$55.0
2	$156.5
3	$168.5
4	$100.0
5	$20.0

Greedy Approach to Portfolio Management for Example

- Assume program manager takes years one and two into consideration, and starts six projects in year one
  - Affordable in year one

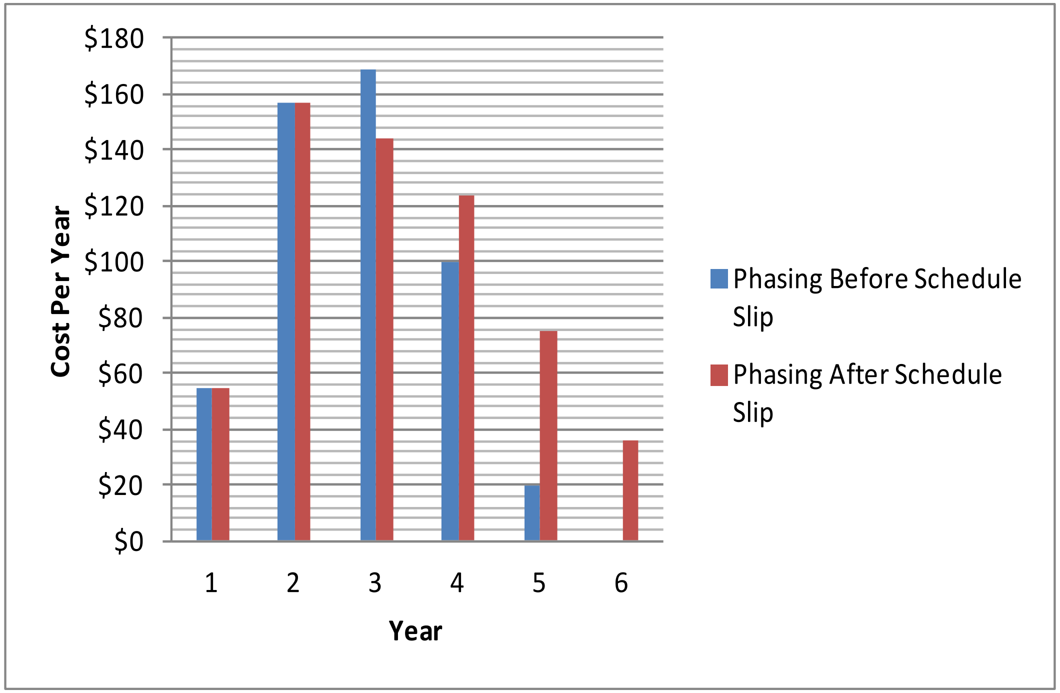
    6*\$55 million = \$330 million < \$1 billion
  - Affordable in year two

    6*\$156.5 million = \$939 million < \$1 billion
  - \$1 billion - \$939 million = \$61 million, so a 7th project is started in year two
  - Not affordable in year three

    6*\$168.5+\$156.5 = \$1,167.5 million
  - Funding cut in year three
    - Assume spread equally among all seven projects

Greedy Approach to Portfolio Management for Example (2)

- The funding cut in year three is not significant
  - Only about 14% for each project in that year
  - It is assumed that the schedule slips only one year as a result
- Applying the QTIPS model, this 20% schedule slip results in an 18% cost growth for the program
  - The total cost for each of the seven programs is $591 million



Greedy Approach to Portfolio Management for Example (3)

- **In year four, there is not enough money to fund project 7 to its full funding**
  - **A funding cut of $17.5 million is applied, leading to another year of schedule delay, and a total cost of $699 million (QTIPS)**

- **Phasing for first seven projects impacted by funding constraints in year four:**

Year	1	2	3	4	5	6	7	8
Project 1	$55.0	$156.5	$144.5	$145.5	$76.5	$13.0		
Project 2	$55.0	$156.5	$144.5	$145.5	$76.5	$13.0		
Project 3	$55.0	$156.5	$144.5	$145.5	$76.5	$13.0		
Project 4	$55.0	$156.5	$144.5	$145.5	$76.5	$13.0		
Project 5	$55.0	$156.5	$144.5	$145.5	$76.5	$13.0		
Project 6	$55.0	$156.5	$144.5	$145.5	$76.5	$13.0		
Project 7		$55.0	$133.0	$127.0	$185.0	$127.0	$61.4	$10.7

Greedy Approach to Portfolio Management for Example (4)

- **The final result of continuing this myopic process for twenty years results in the completion of 26 projects**

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Project 1	$55.0	$156.5	$144.5	$145.5	$76.5	$13.0														
Project 2	$55.0	$156.5	$144.5	$145.5	$76.5	$13.0														
Project 3	$55.0	$156.5	$144.5	$145.5	$76.5	$13.0														
Project 4	$55.0	$156.5	$144.5	$145.5	$76.5	$13.0														
Project 5	$55.0	$156.5	$144.5	$145.5	$76.5	$13.0														
Project 6	$55.0	$156.5	$144.5	$145.5	$76.5	$13.0														
Project 7		$55.0	$133.0	$127.0	$185.0	$127.0	$61.4	$10.7												
Project 8					$55.0	$132.4	$156.4	$164.8	$124.9	$58.4	$7.9									
Project 9					$55.0	$132.4	$156.4	$164.8	$124.9	$58.4	$7.9									
Project 10					$55.0	$132.4	$156.4	$164.8	$124.9	$58.4	$7.9									
Project 11					$55.0	$132.4	$156.4	$164.8	$124.9	$58.4	$7.9									
Project 12					$55.0	$132.4	$156.4	$164.8	$124.9	$58.4	$7.9									
Project 13					$55.0	$132.4	$156.4	$164.8	$124.9	$58.4	$7.9									
Project 14									$55.0	$156.5	$168.5	$100.0	$20.0							
Project 15									$55.0	$156.5	$168.5	$100.0	$20.0							
Project 16									$55.0	$156.5	$168.5	$100.0	$20.0							
Project 17									$55.0	$156.5	$168.5	$100.0	$20.0							
Project 18											$55.0	$119.8	$176.0	$147.2	$78.0	$15.0				
Project 19											$55.0	$119.8	$176.0	$147.2	$78.0	$15.0				
Project 20											$55.0	$119.8	$176.0	$147.2	$78.0	$15.0				
Project 21											$55.0	$119.8	$176.0	$147.2	$78.0	$15.0				
Project 22											$55.0	$119.8	$176.0	$147.2	$78.0	$15.0				
Project 23														$55.0	$156.5	$168.5	$100.0	$20.0		
Project 24														$55.0	$156.5	$168.5	$100.0	$20.0		
Project 25														$55.0	$156.5	$168.5	$100.0	$20.0		
Project 26														$55.0	$156.5	$168.5	$100.0	$20.0		

Greedy Approach to Portfolio Management for Example (5)

- **Total cost of these 26 projects is $15,394 million**
- **The initial cost of these 26 projects was $500 million, which equates to $13,000 million total**
- **Thus poor portfolio management was responsible for over $2 billion in cost growth!**

Greedy Approach to Portfolio Management for Example (5)

- **Over 70% of the projects in the example experienced both cost and schedule delays**
- **The average project experienced 18% cost growth and the average schedule growth is approximately 19%**
  - **Compare to (Smart 2011), average annual cost growth for a large database of NASA and Department of Defense missions equals 50%, with over 80% of missions experiencing cost growth**
- **While the cost growth exhibited for this example represents only one source of cost growth, it demonstrates that *poor portfolio management may be one of the most significant causes of cost growth***
- **As cartoonist Walt Kelley wrote on a poster for Earth Day in 1970, "We have met the enemy and he is us!"**

“We Have Met the Enemy…”

Source: Walt Kelly, Earth Day Poster, 1970

A Better Alternative

- At this point the reader may counter that while the greedy algorithm may result in cost growth and schedule delays, this may lead to more projects being completed than with other strategies
- However, consider the strategy of starting two new projects each year
- While this may not make full use of the $1 billion annual budget until year 5, at years 5 and out, the entire budget is utilized, no schedules are delayed, and thus, under the assumptions of this example, there is no cost growth due to portfolio management issues, nor is there any schedule growth

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A Better Alternative (2)

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Project 1	$55.0	$156.5	$168.5	$100.0	$20.0															
Project 2	$55.0	$156.5	$168.5	$100.0	$20.0															
Project 3		$55.0	$156.5	$168.5	$100.0	$20.0														
Project 4		$55.0	$156.5	$168.5	$100.0	$20.0														
Project 5			$55.0	$156.5	$168.5	$100.0	$20.0													
Project 6			$55.0	$156.5	$168.5	$100.0	$20.0													
Project 7				$55.0	$156.5	$168.5	$100.0	$20.0												
Project 8				$55.0	$156.5	$168.5	$100.0	$20.0												
Project 9					$55.0	$156.5	$168.5	$100.0	$20.0											
Project 10					$55.0	$156.5	$168.5	$100.0	$20.0											
Project 11						$55.0	$156.5	$168.5	$100.0	$20.0										
Project 12						$55.0	$156.5	$168.5	$100.0	$20.0										
Project 13							$55.0	$156.5	$168.5	$100.0	$20.0									
Project 14							$55.0	$156.5	$168.5	$100.0	$20.0									
Project 15								$55.0	$156.5	$168.5	$100.0	$20.0								
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Project 26													$55.0	$156.5	$168.5	$100.0	$20.0			
Project 27														$55.0	$156.5	$168.5	$100.0	$20.0		
Project 28														$55.0	$156.5	$168.5	$100.0	$20.0		
Project 29															$55.0	$156.5	$168.5	$100.0	$20.0	
Project 30															$55.0	$156.5	$168.5	$100.0	$20.0	
Project 31																$55.0	$156.5	$168.5	$100.0	$20.0
Project 32																$55.0	$156.5	$168.5	$100.0	$20.0

$20.0
$20.0
$100.0
$100.0
$168.5
$168.5
$156.5
$156.5
$55.0
$55.0
$1,000

- **Starting with year 5 the sum of each column is $1 billion**

A Better Alternative (3)

- Under this strategy, 32 projects are completed, six more than with the myopic strategy
  - This is 23% more than with the greedy approach to portfolio management
- Thus the greedy algorithm to portfolio inclusion can be extremely inefficient
- It is worth spending time and energy, and even dedicated staff, to portfolio management

Ramifications of the Example

- The ramifications of this example are significant
  - Not only does trying to start projects prematurely result in schedule delays and cost growth for individual projects, it also results in getting less done at the overall portfolio level
  - Lack of portfolio management is an impediment to meeting organizational goals

How to Address this Issue

- The way to fix this issue is to do in-depth analysis at the portfolio level
  - The same methods and techniques used by cost estimators for individual projects can also be effectively utilized in portfolio level analysis
  - This includes risk analysis
- Also it is imperative to develop life-cycle cost estimates before programming funds for these projects
- This means developing credible life-cycle cost estimates before any programming of funds occurs

A Second Issue Impacting Portfolio Management

- Risk is measured on a project-by-project basis
  - Current policy requires only that risk be reported at this level
- This provide no information about risk at the portfolio level
  - Conventional wisdom is that this will be handled by a magical “portfolio effect” that will reduce risk at the total level
- It has been suggested that due to diversification across a suite of missions it is possible to achieve a high level of confidence in the overall budget while setting budgets for individual missions at a lower level
  - For example, when there are numerous projects in a portfolio, it may be possible to achieve an 80% probability of no cost overruns for the entire portfolio while only budgeting individual projects are budgeted so that there is only a 60% probability of no cost overruns
- However, the author (Smart 2008, 2009, 2010) has thoroughly debunked the notion of a portfolio effect
- Bottom line is that risk should be measured at the portfolio level, there are no shortcuts for effectively doing this

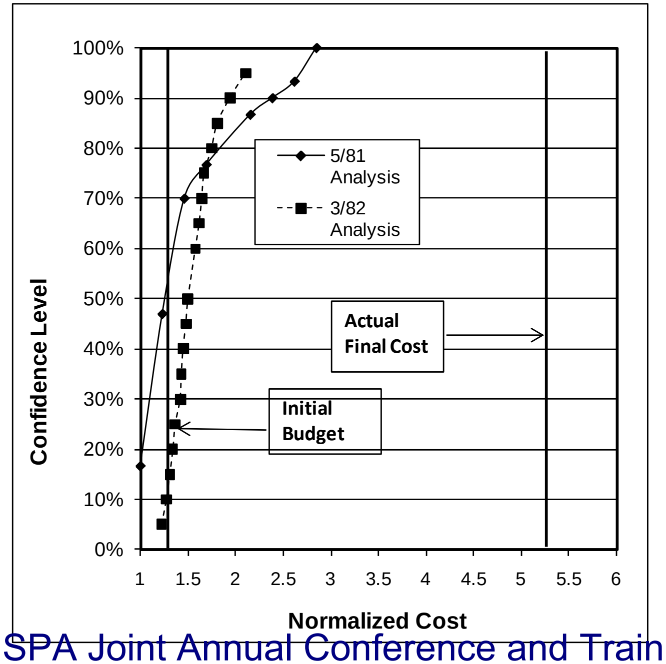
Dilbert on the Portfolio Effect

A Third Issue Impacting Portfolio Management

- **It is difficult to effectively manage at the portfolio level if risk is systematically understated**
  - **Yet this is all too common**
- **As demonstrated by the author (Smart 2011), there is a severe disconnect between cost risk analysis and the final cost**

Cost Risk Compared to Final Actual Cost – Tethered Satellite

- Tethered Satellite System was a joint project between NASA and the Italian Space Agency
- Two separate cost risk analyses were conducted
  - May, 1981 and March, 1982
- Final actual cost was more than double the 90th percentile of the March, 1982 S-curve



Summary

- **Cost, schedule, and the phasing of cost over schedule are intrinsically linked**
  - **Changes in schedule for an established program result in cost growth**
  - **Reduction in annual funding also leads to schedule growth, which in turn leads to cost growth**
  - **There is empirical evidence to support both these facts**
- **Portfolio management is key to overseeing the interactions among cost, schedule, and phasing for multiple projects within a portfolio**
  - **Not managing effectively at the portfolio level results in trying to do too much with too little**
    - **Leads to cost growth, schedule growth, and significant inefficiencies**
    - **Result is inefficiencies, and getting less done**

Summary (2)

- **Other issues at the portfolio management level are a lack of risk analysis at the portfolio level**
    - **Relying upon a mythical portfolio effect is not a substitute for calculating risk at the portfolio level**
- **Also, incorporating sufficient risk is critical for project realism**
    - **Not doing this leads management to believe more than can be done with the available resources than is actually achievable**
- **Addressing these portfolio management issues will go a long way towards addressing endemic cost growth in government projects and programs, which will result in accomplishing more**

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