Early Warning Model for Acquisition Program Cost and Schedule Growth

15 April 2008

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Agenda

- Background
- Approach
- Results
- Way ahead

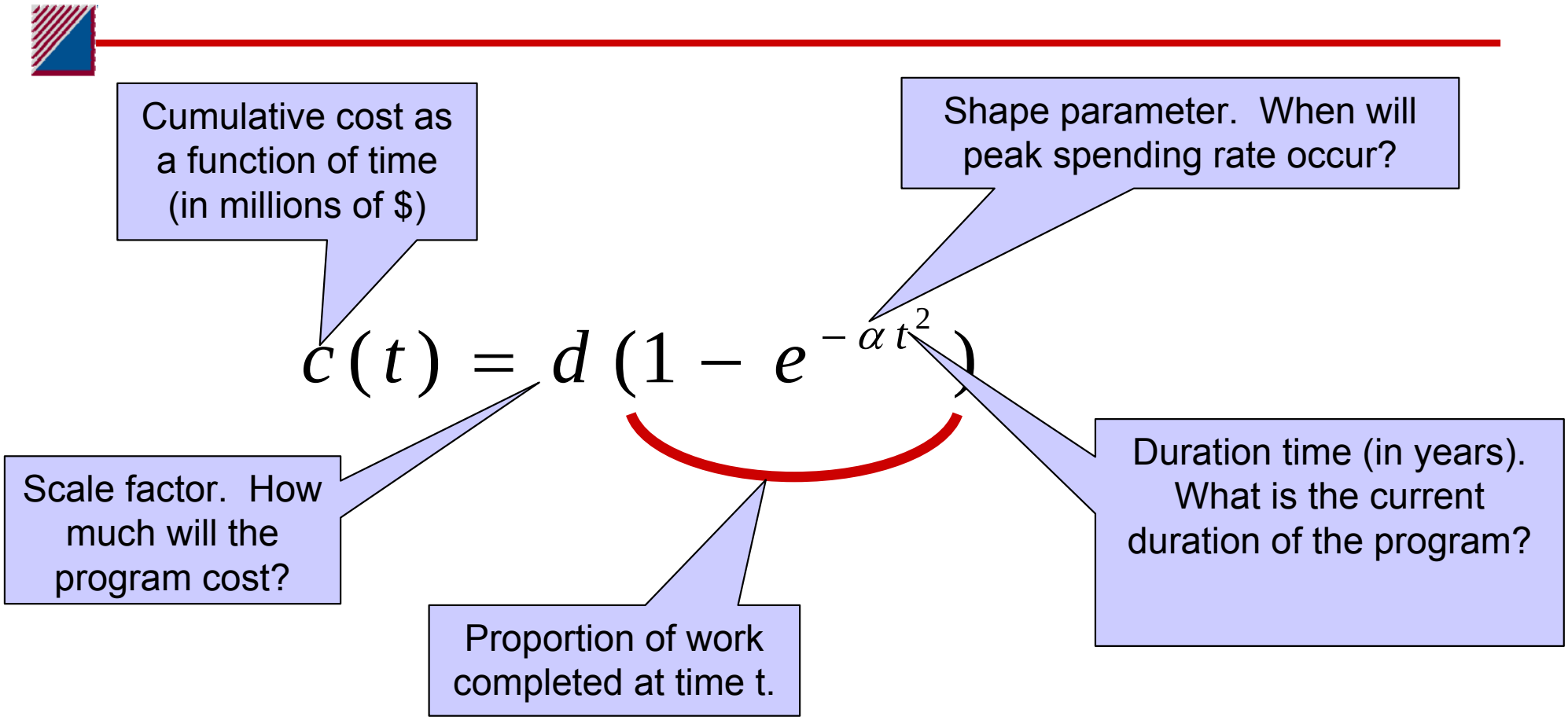
Background

- **Prior related studies**
  - The Rayleigh Analyzer, Theory and Application (Vol. 1)/ AT902C1 (Ducovich, Houser, and Lee)
    - LMI study for OSD
  - The Rayleigh Analyzer, User's Manual (Vol. 2)/AT902C2 (Ducovich, Houser, and Lee)
    - User's guide for Excel Add-on by LMI

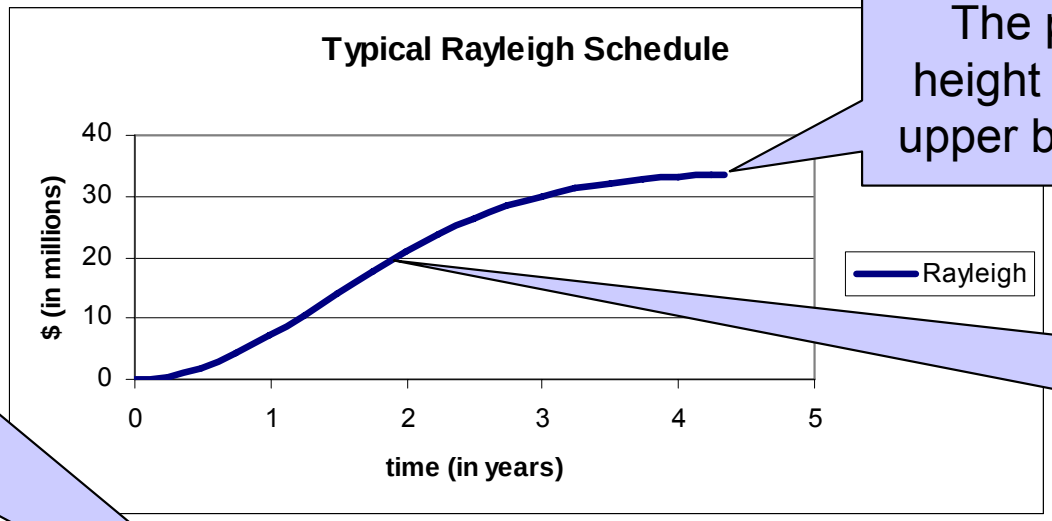
Background, cont'd

- **Prior related studies (cont.)**
  - "Final cost estimates for R&D programs conditioned on realized cost" (MOR, Vol.2, No.2, 1996, Gallagher and Lee)
  - CRM D0015902.A2/Final, May 2007 ("A Stitch in Time Saves Nine: Program Diagnostics Using the Rayleigh Model for Executive Decision-Makers", Dan Davis, Gary Christle, and Wayne Abba)

Early Warning Model



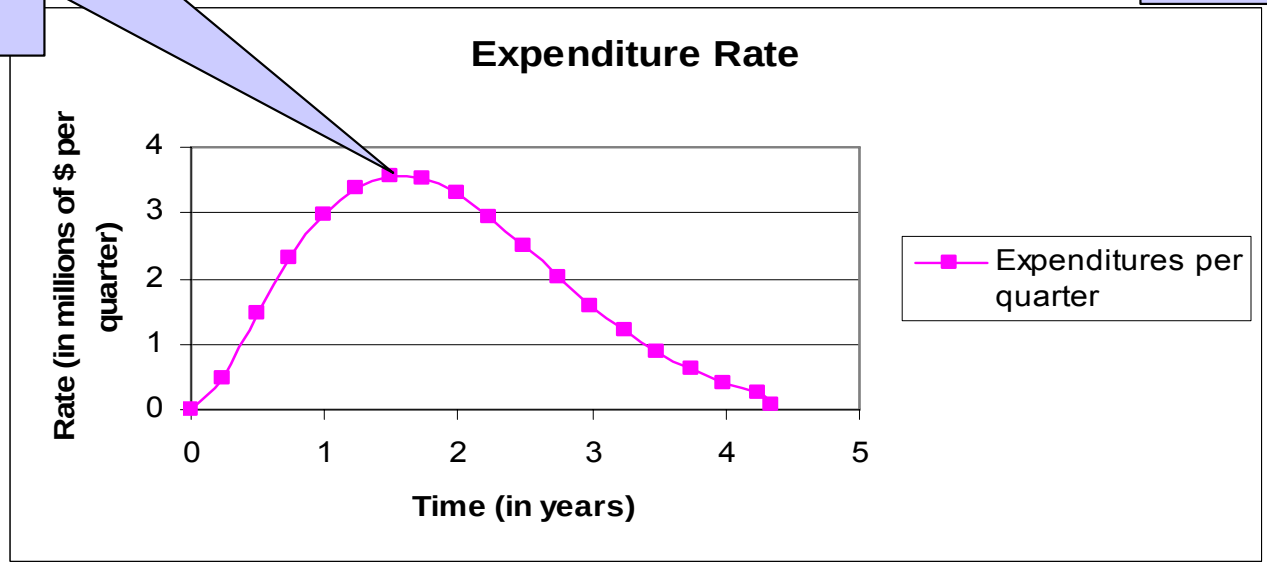
Early Warning Model, cont'd



The parameter d tells us the height of the curve. What is the upper bound on cumulative cost?

This curve inflects when the rate curve below reaches a maximum.

The parameter α tells us the shape of the curve. When does the peak spending rate occur?



Early Warning Model

Reason for Project

- **Previous study (CRM D0015902.A2/final):**
  - **Developed prototype analytical technique**
  - **Validated early warning utility of technique**
  - **Developed prototype executive management tool**
    - **Contract assessment module**
    - **Plan assessment module**
    - **Encorporated preliminary business insights**
  - **Demonstrated practicality of prototype**
  - **Validated for R&D contracts only**
  - **Used information sets that were available only early in the contract life (the 3d, 4th, and 5th submissions)**
  - **Did not calculate standard errors or risk regions**

Early Warning Model

Reason for Project, cont'd

- **Sponsor liked prototype and wanted to add:**
  - **Criteria for when to use Rayleigh model**
  - **Validation using full range of information sets over entire life of contracts**
  - **Improved data loading instructions**
  - **Version 2 algorithms**
  - **Exploration of expanding model to:**
    - **Procurement contracts**
    - **Program level assessments**
  - **Expanded and improved business insight feature**
  - **Improved user interface**

Early Warning Model

Reason for Project, cont'd

- **Study tasks:**
  - **Collect data**
  - **Update optimization algorithm**
  - **Account for the "missing 30 percent" of cost growth**
    - **Calculate confidence region**
    - **Calculate contract cost and schedule risk**
    - **Develop Rayleigh spline option**
      - **Incorporate Over-target Baseline**
  - **Revalidate using information sets over entire life of contract**
  - **Update plan assessment module**
  - **Improve data upload**
  - **Explore use with procurement contracts**
  - **Explore use with program level analysis**
  - **Improve user interface**
  - **Improve and expand business insights**

Early Warning Model

Approach

- Update model algorithm ✓
- Confirm that Non-linear Least Squares with restricted parameters (NRP) is best implementation of model ✓
- Revalidate with information sets over full life of contract ✓
  - Confirm Rayleigh is best fit ✓
  - Confirm Rayleigh predictions are most accurate ✓
  - Confirm use of unadjusted data is better or as good as analysis with inflation-adjusted data ✓
  - Confirm model is still best even as “business practices” evolve ✓
  - Confirm Rayleigh provides reliable early warning ✓
    - Confirm trend of Rayleigh predictions converges ✓
    - Confirm trend of Rayleigh predictions converges the quickest ✓
    - Confirm trend of Rayleigh predictions is stable (non-volatile) ✓
  - Confirm Rayleigh applicability does not depend on service type ✓

Early Warning Model

Approach, cont'd

- Incorporate contract-level cost and schedule risk ✓
  - Calculate approximate standard errors and confidence regions ✓
  - Calculate cost risk ✓
  - Calculate schedule risk ✓
- Investigate use of the model with program level budget data ✓
- Test applicability of model to procurement contracts ✓
- Upgrade user interface
- Develop Rayleigh spline package for tool to account for "missing 30%" ✓
- Upgrade "business insight" prompts in tool ✓
- Explicitly link model to AOP-like management process

Summary of results

- Database consisted of 107 completed contracts
- In 100% of the contracts the NRP method outperformed unrestricted NLLS
  - NRP less volatile (more stable)
  - NRP converged faster
  - NRP gave better predictions

Summary of results, cont'd

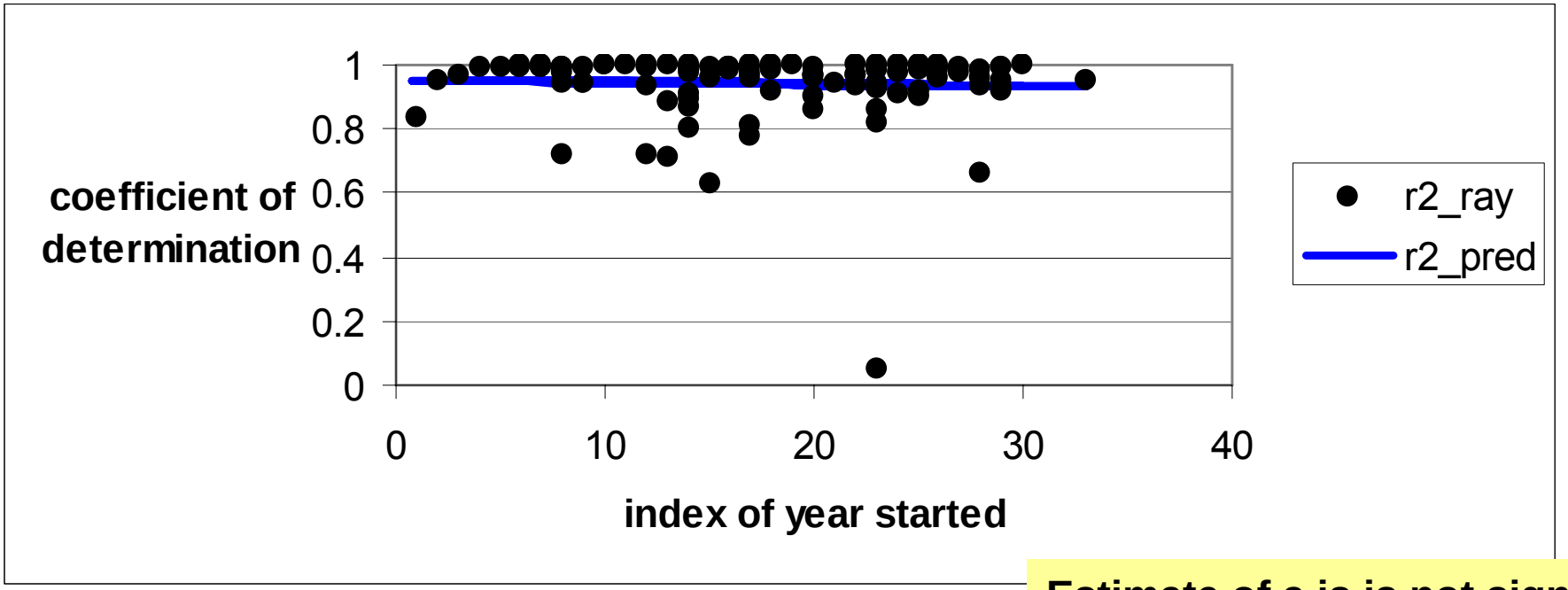
- Rayleigh (NRP) yields an R2:
  - Greater or equal to .9 in 93 contracts (87%)
  - Between .8 and .9 in 9 contracts (8%)
  - Between .7 and .8 in 4 contracts (4%)
  - Less than .6 in 1 contract (1%)

This means that Rayleigh NRP achieves a good fit to the data in all but 1 case out of 107.

Summary of results, cont'd

- Database included 36 Navy, 36 AF, and 35 Army contracts
- Navy average R2=.947
- AF average R2=.951
- Army average R2=.941
- Standard t-test shows that no service average differs significantly from overall average or R2=.947

Summary of results, cont'd



Model: R2= a +b*WSDATEIndex

a_hat	b_hat
0.952	-0.00057
(.0277)	(.001443)

Estimate of a is is not significantly differently for the average R2 and the estimate of the slope term is not significantly different from 0.

Summary of results, cont'd

- 1970s average R2 is .96
- 1980s average R2 is .94
- 1990s average R2 is .93
- 2000s average R2 is .95
- Overall average R2 is .95

Summary of results, cont'd

- Rayleigh (NRP) average R2 is .947
- Rayleigh with nominal data is better or almost as good as Rayleigh with real inflation-adjusted data 102 out of 107 cases (95%)
  - And Rayleigh with nominal data has higher R2 (.947 > .933)

Summary of results, cont'd

- Rayleigh (NRP) is best EAC generator over the life of a contract 70% of the time
  - Rayleigh NRP is best or second best 82% of the time (88 out of 107)
- EAC1 is the best 2% of the time
- EAC2 is the best 4% of the time
- EAC3 is the best 13% of the time
- The contractor is the best 4.5% of the time
- The PM is the best 6.5% of the time

The contractor or the PM estimate profile is the worst 51% of the time

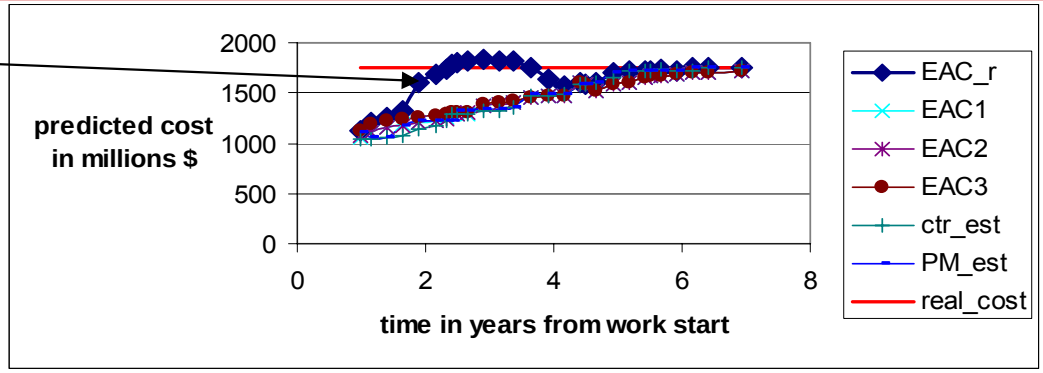
Summary of results, cont'd

- All estimates converge to final realized cost and duration over time
- Rayleigh (NRP) estimate of cost converges fastest 93% of the time
- Rayleigh (NRP) is the unique leading indicator 17% of the time

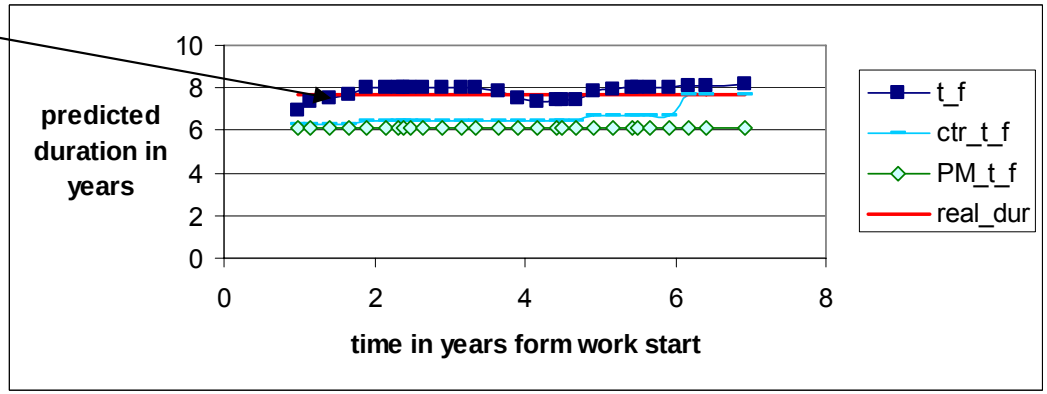
The other EAC calculation methods and the contractor and the PMs estimate trends **never** are the unique leading indicator.

Summary of results, cont'd

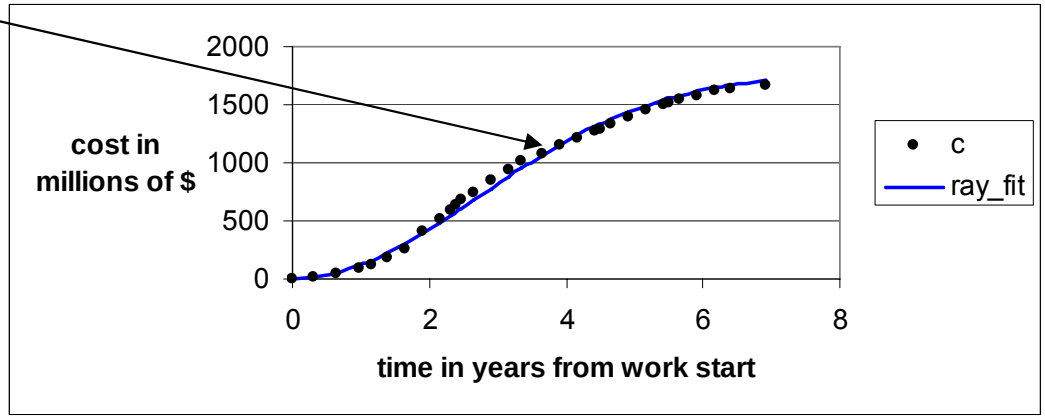
Predictions converge fastest, are stable, and are relatively most accurate.



Prediction of duration is Almost dead on



Fit of Rayleigh (NRP) is almost perfect

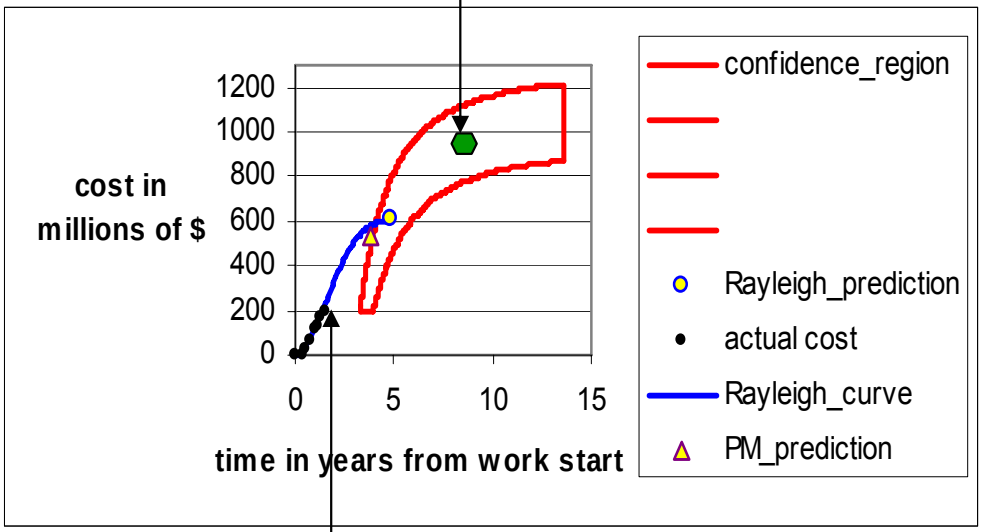


Review Rayleigh fit to data

- Criteria to evaluate
  - Fit score
  - Relative accuracy score
  - Absolute convergence score
  - Relative convergence score
  - Leading indicator score
- Give examples of good cumulative scores
- Review bad scores
  - Explain why Rayleigh doesn't appear to work
  - Develop rules of thumb for application of Rayleigh
  - Develop cautionary comments for use of Rayleigh

Cost and schedule risk (148-8)

Eventual cost will be $960.5 M with a duration of 8.1 years



Time is now 1.56 years after work started

	Cost Risk
Risk that cost will exceed PM's estimate	91%
Risk that cost will exceed PM's estimate by 10%	88%
Risk that cost will exceed PM's estimate by 25%	84%
50/50 Cost = **$910M**	50%

	Schedule risk
Risk that duration will exceed PM's estimate	97%
Risk that duration will exceed PM's estimate by 10%	94%
Risk that duration will exceed PM's estimate by 25%	88%
50/50 duration= **8.5 years**	50%

Rayleigh fit to program RDT&E funding profiles: Summary

- 39 programs
  - 16 Navy programs
  - 9 Army programs
  - 13 Air Force programs
  - 1 DoD program
- Overall average fit: R2 = .979
  - Navy average fit: R2 = .978
  - Army average fit: R2 = .987
  - Air Force average fit: R2 = .976
  - DoD average fit: R2 = .98

Way ahead

- Develop risk region and risk analysis
- Expand business insights
- Explore application to production contracts
- Explore application to program/budget data?

Conclusion

- Questions/comments?

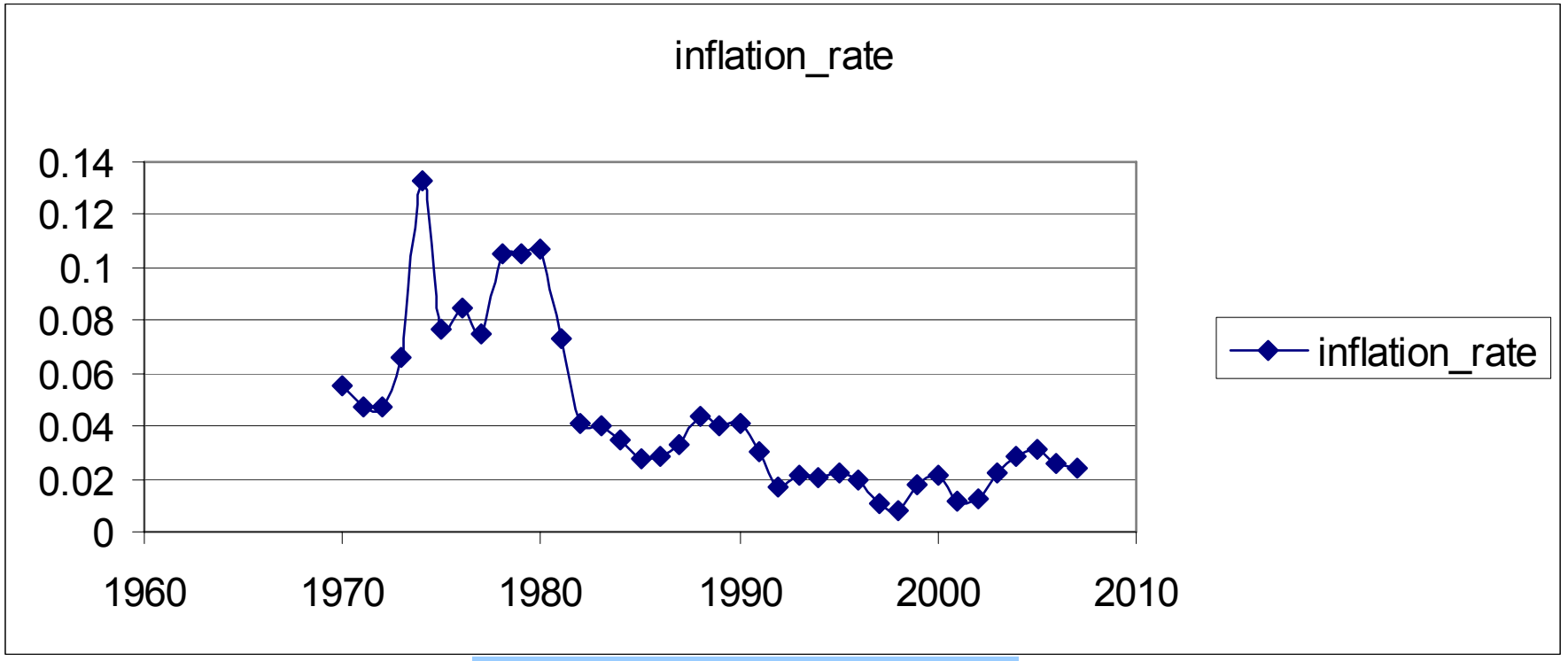
Back-up

- Back-up slides

Early warning model

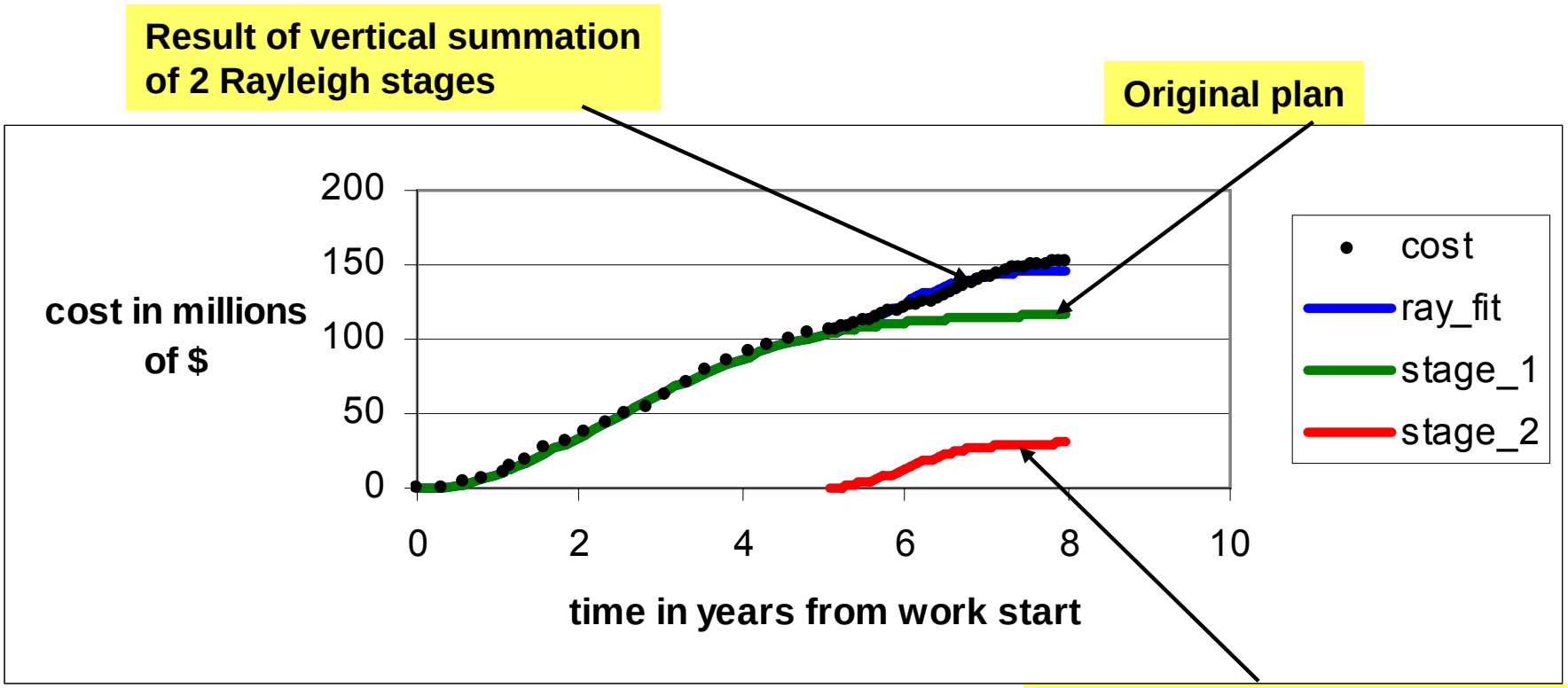
NRP Rayleigh with nominal data gives best fit

Five cases when Rayleigh with real inflation data did noticeably better started work in 1974, 1982, 1983,1984, and 1986. Only one of these occurred during a high inflation period.

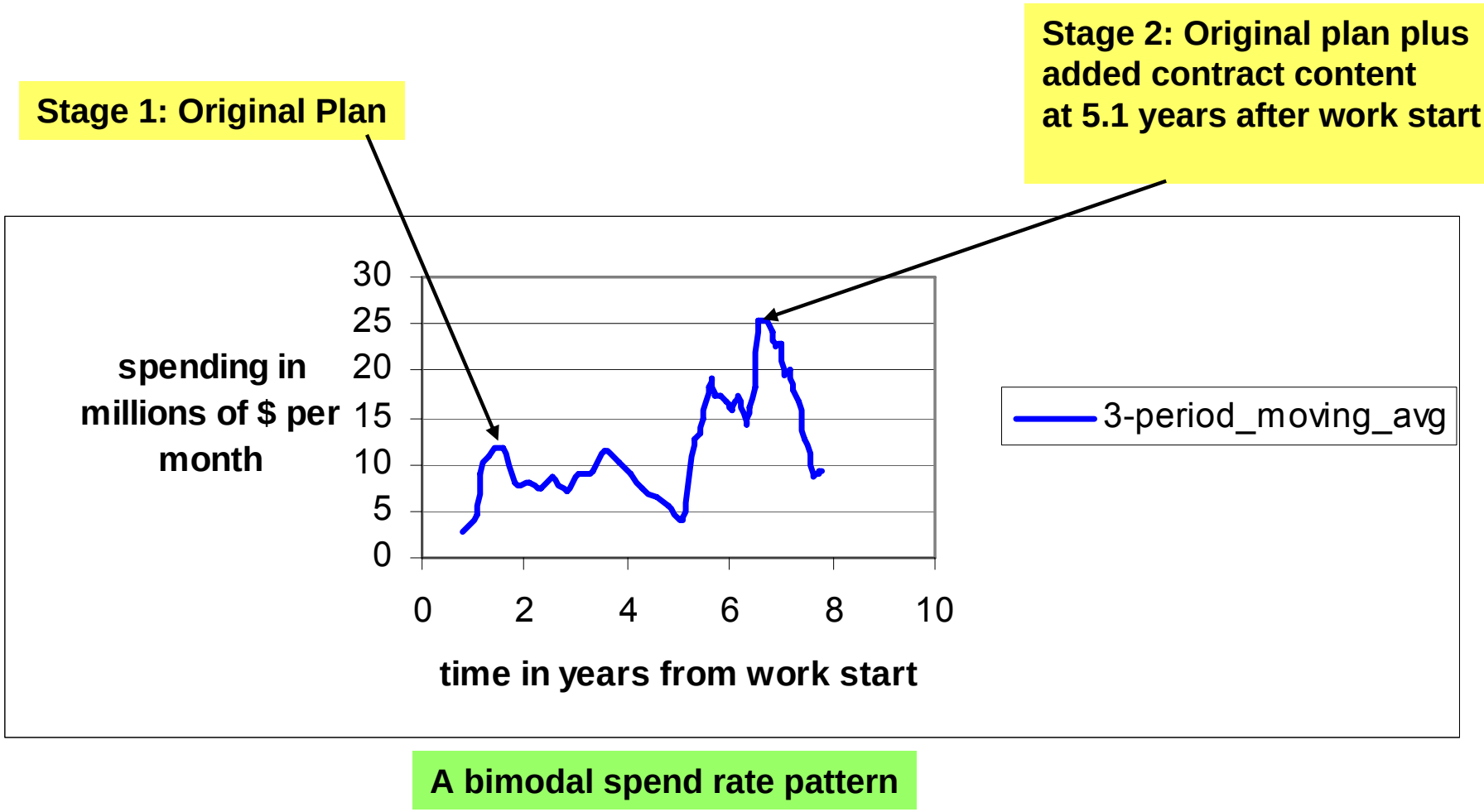


Inflation rates for RDT&E)

2 Rayleigh Spline (148-9)



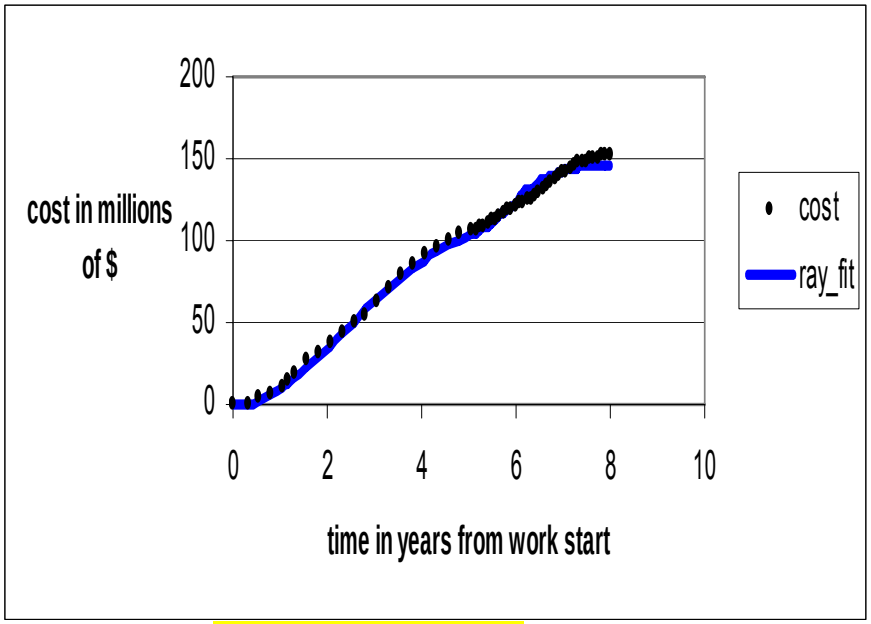
2 Rayleigh Spline (148-9)



A bimodal spend rate pattern

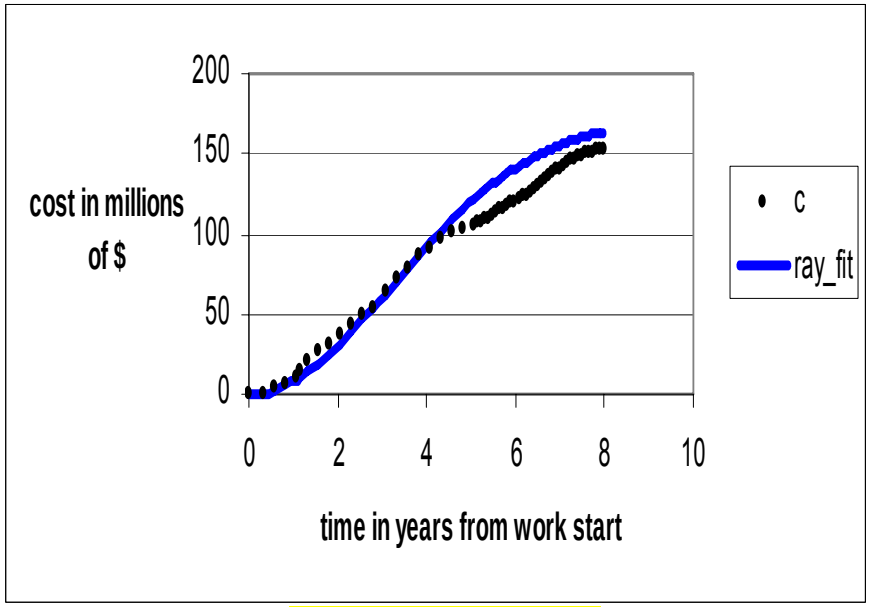
2 Rayleigh Spline and Single Rayleigh comparison (148-9)

2 Rayleigh Spline



R2=.995

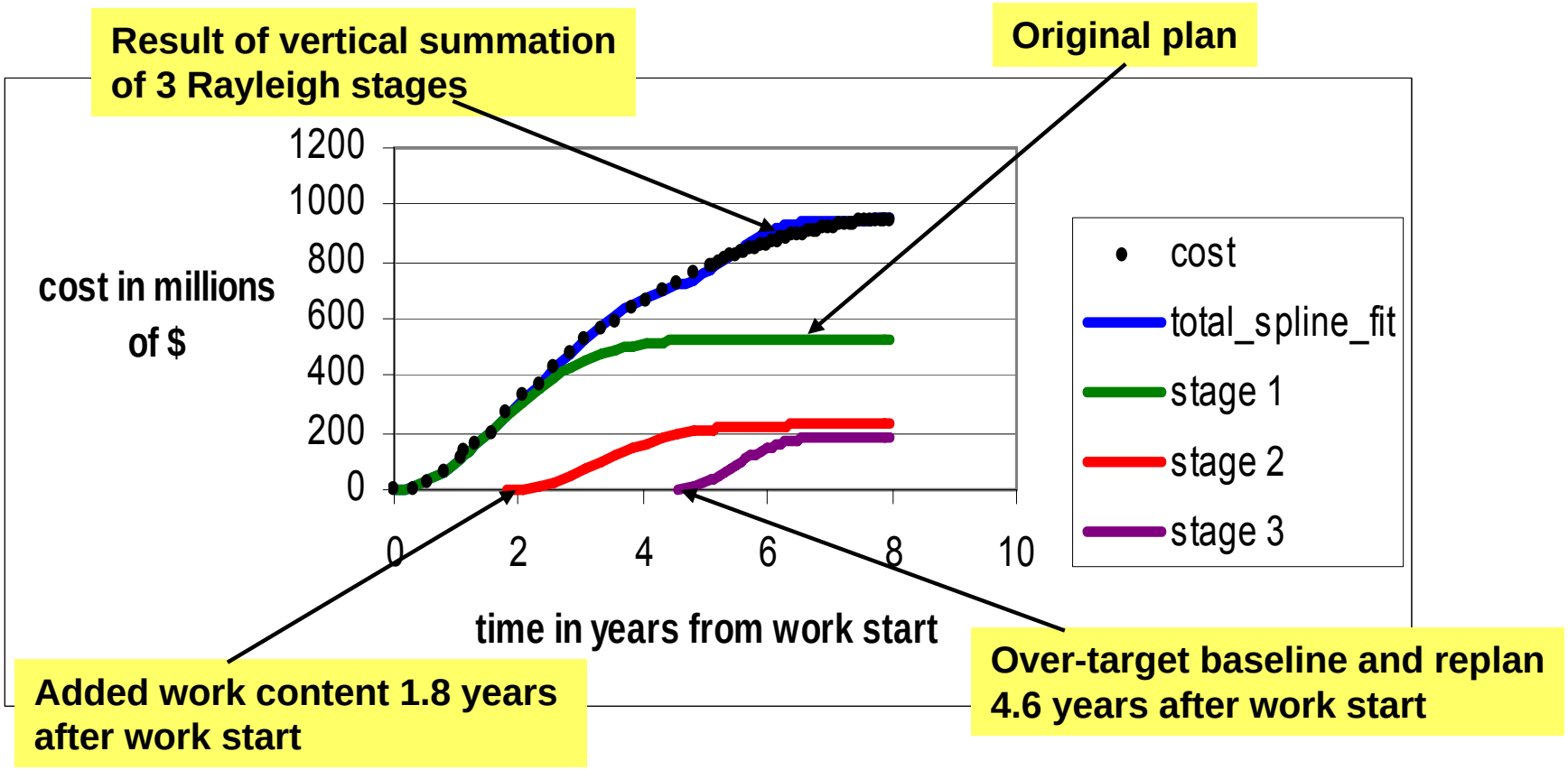
Single Rayleigh



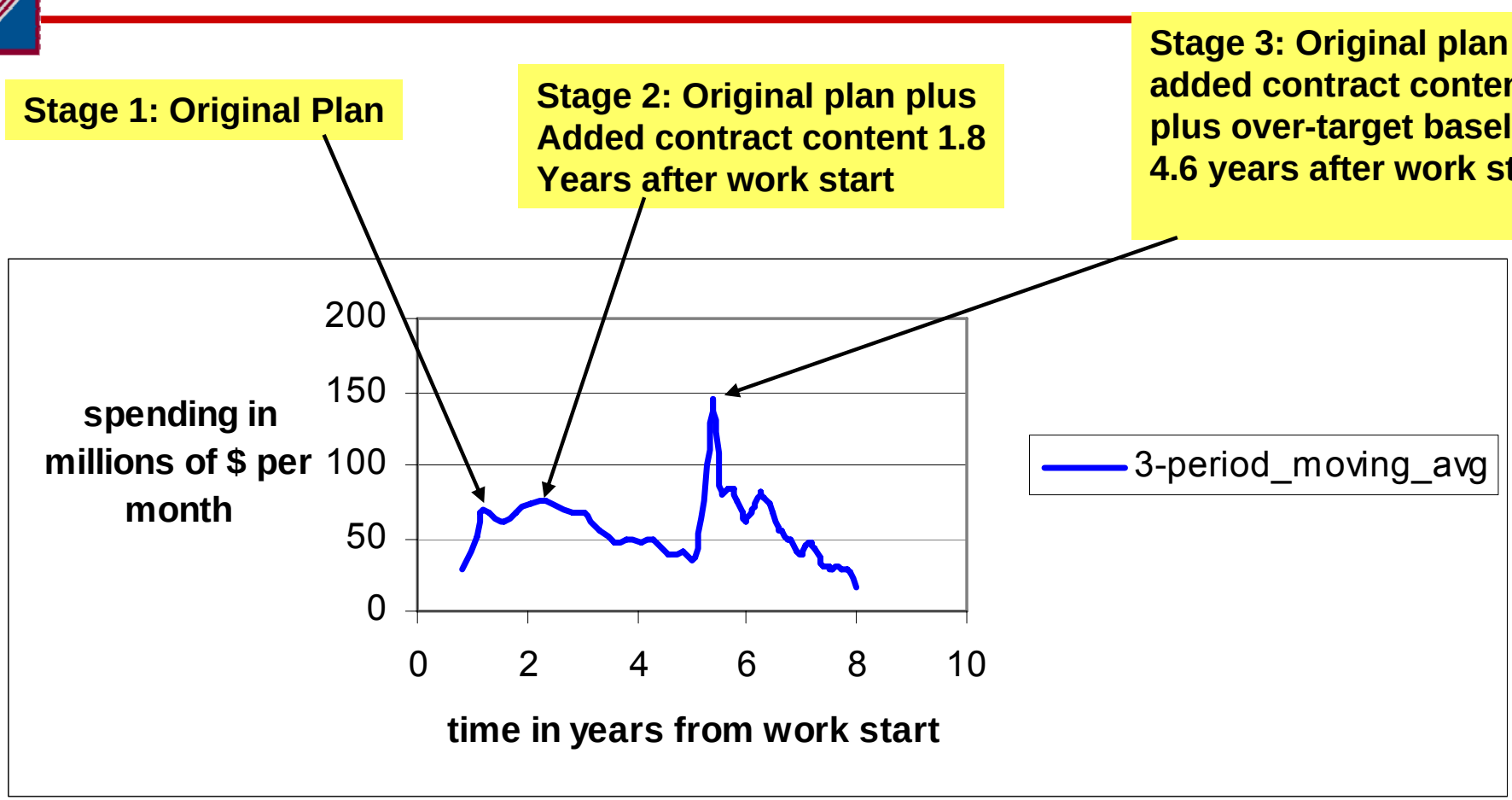
R2=.916

Even the best linear fit only had R2=.991

3 Rayleigh Spline (148-8)



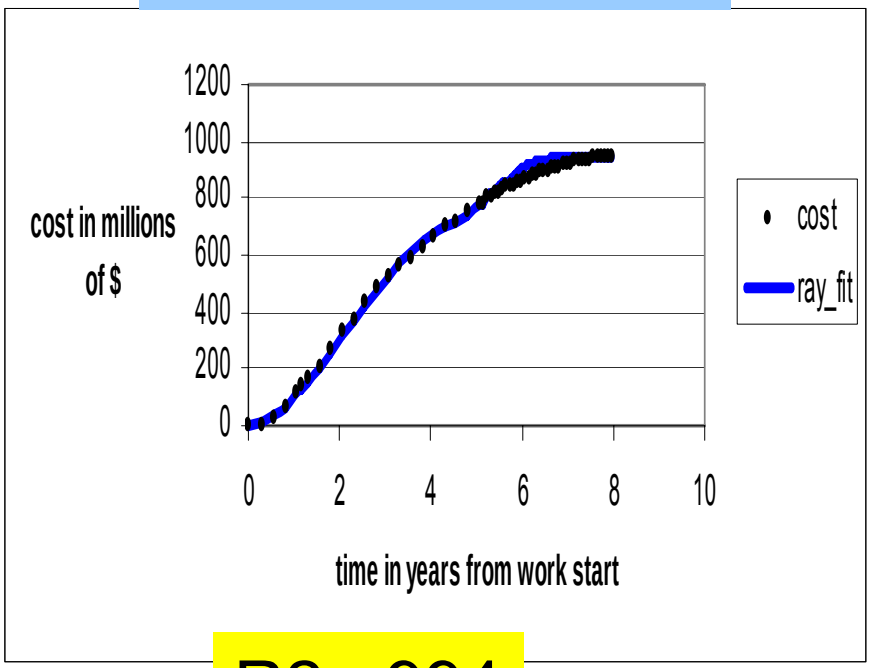
3 Rayleigh Spline (148-8)



A trimodal spend rate pattern

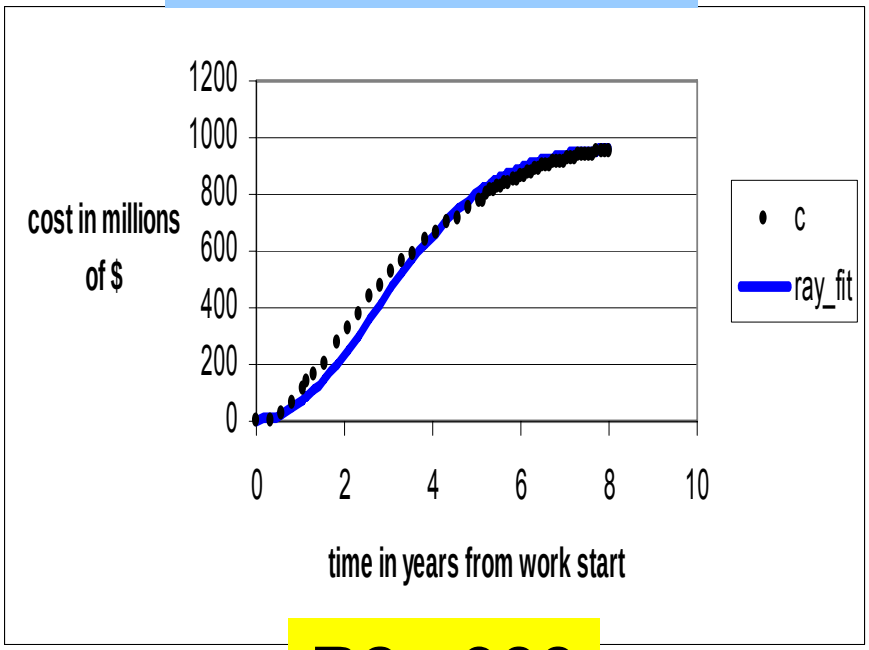
3 Rayleigh Spline and Single Rayleigh comparison (148-8)

3 Rayleigh Spline



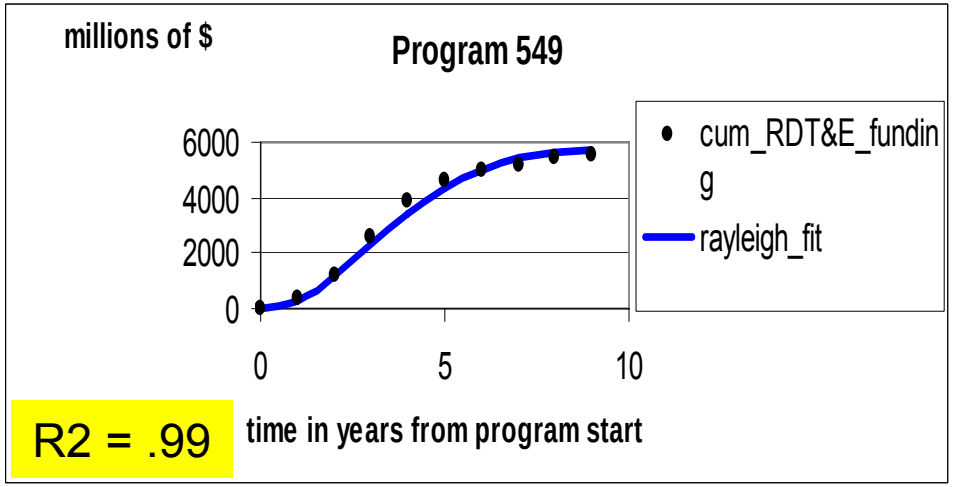
R2=.994

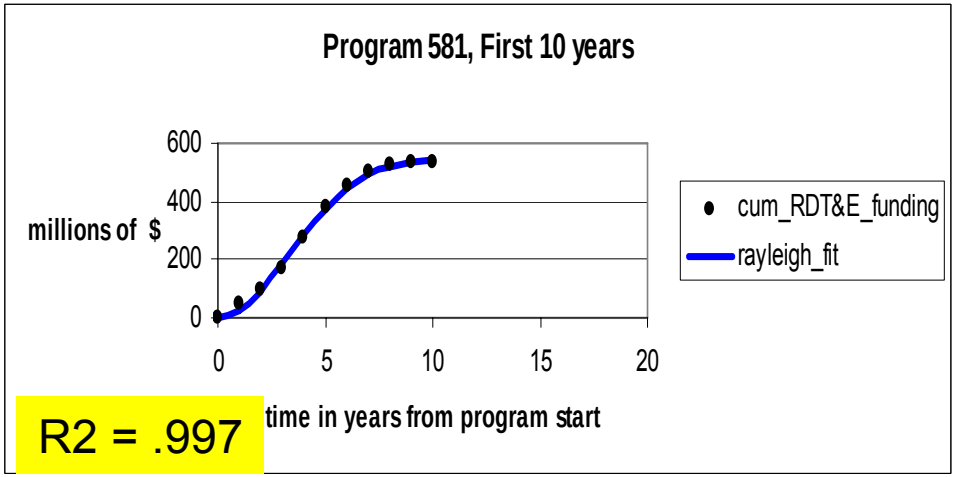
Single Rayleigh

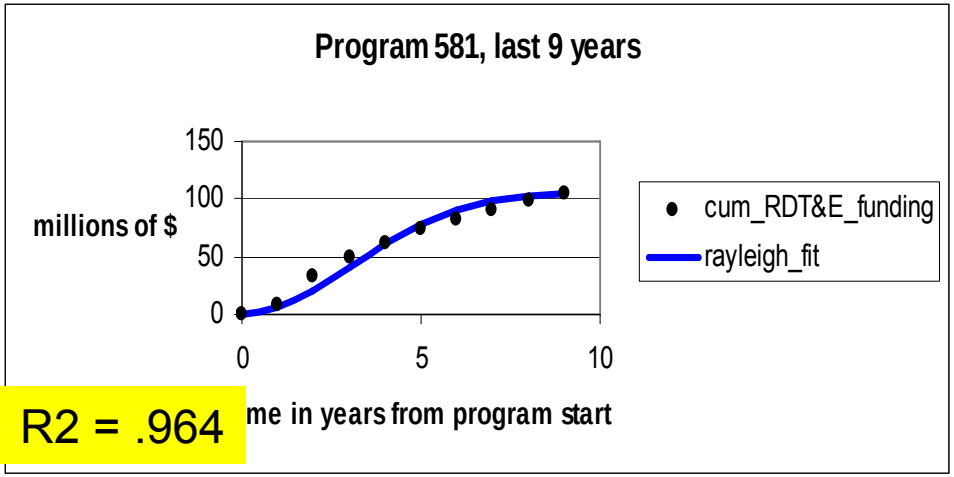


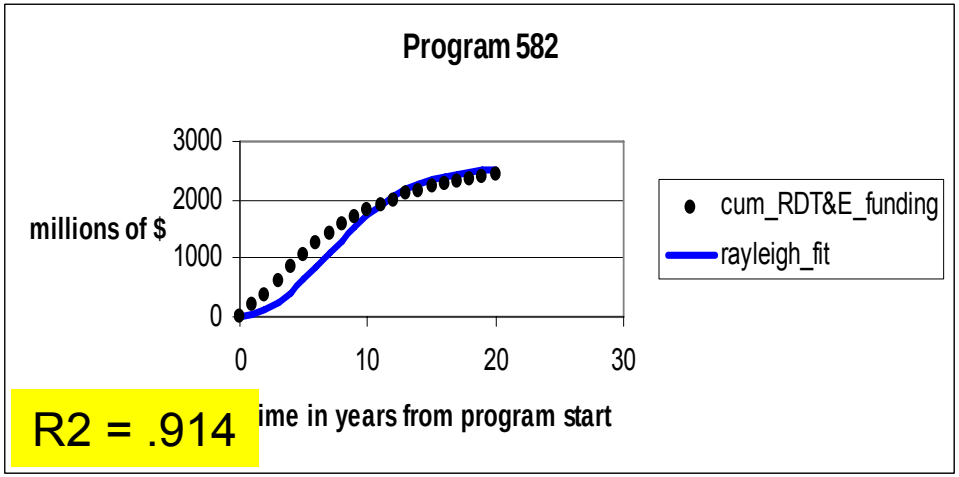
R2=.988

RDT&E funding profiles

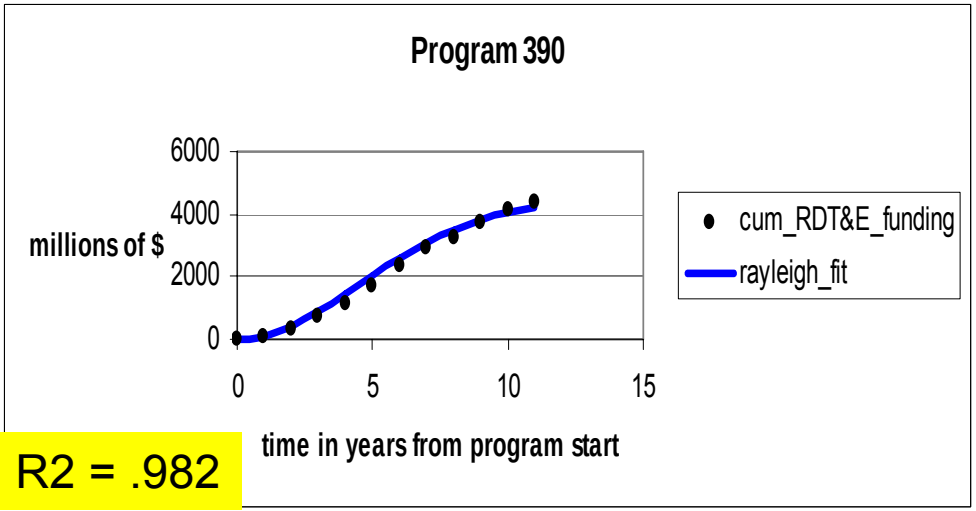




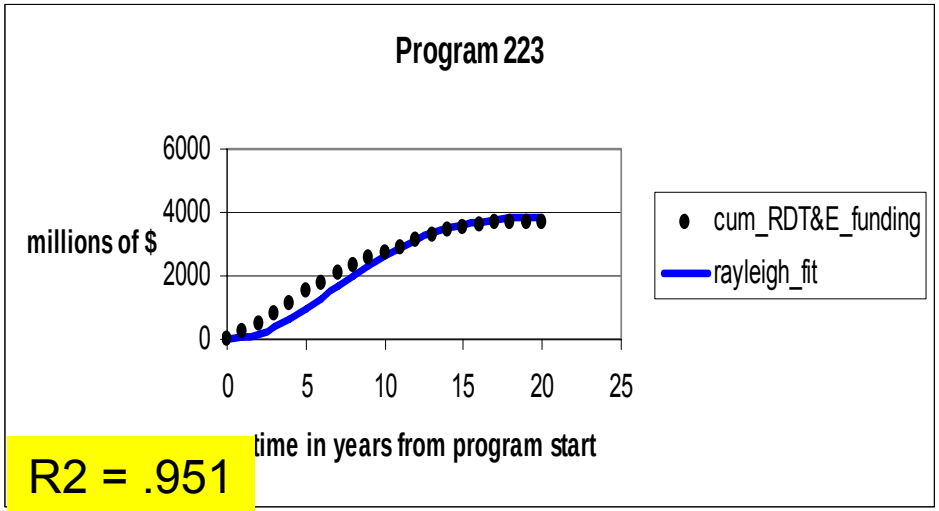




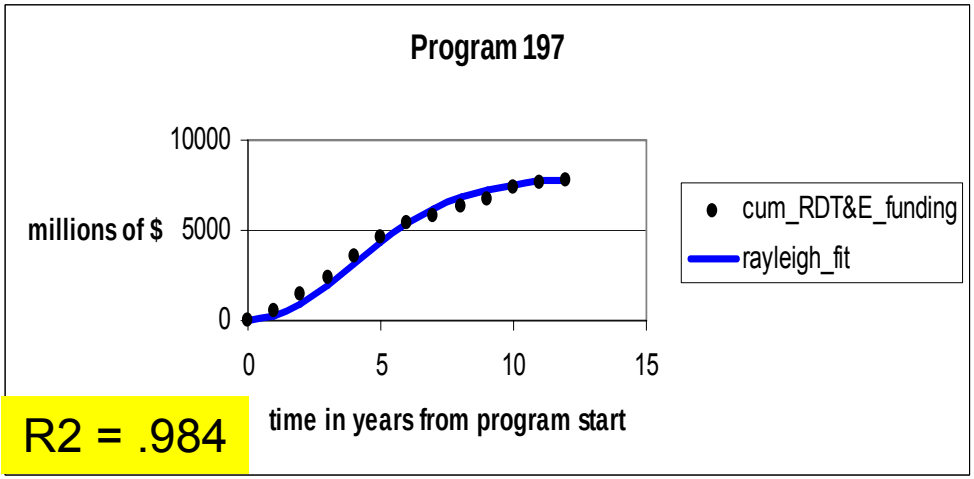
RDT&E funding profiles, cont'd



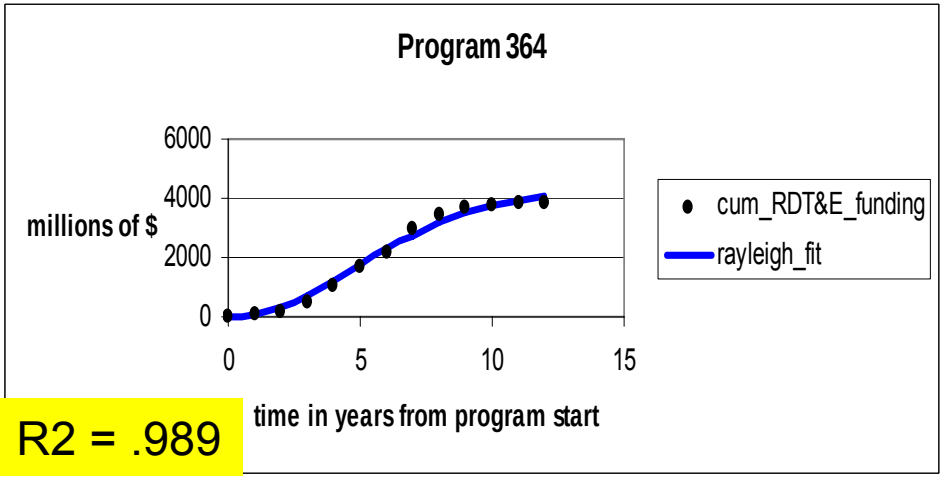
R2 = .982



R2 = .951

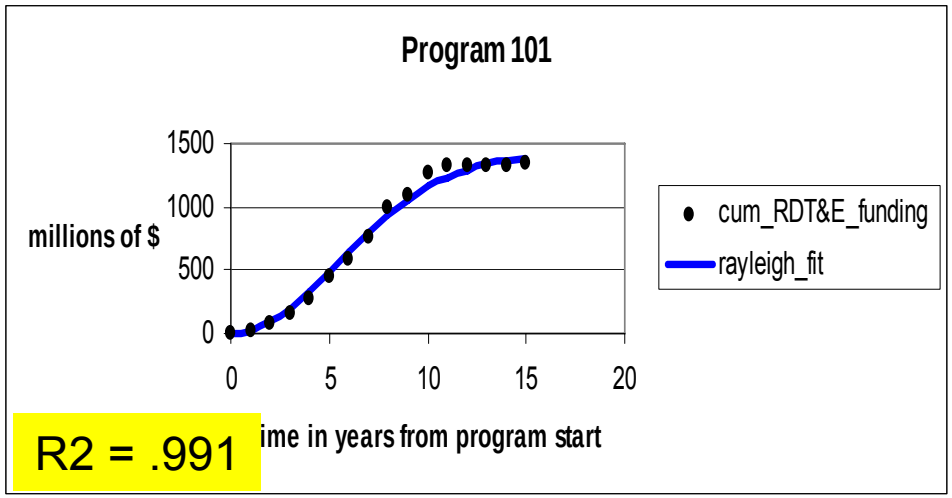


R2 = .984

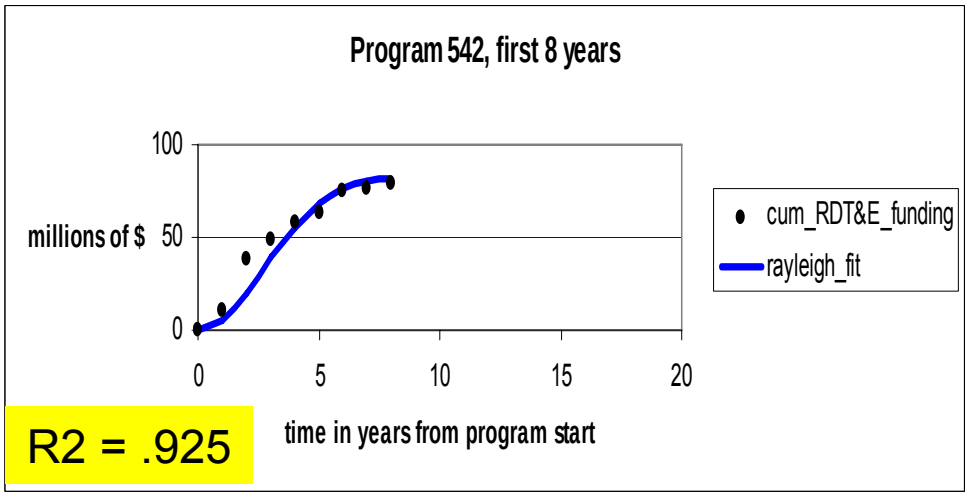


R2 = .989

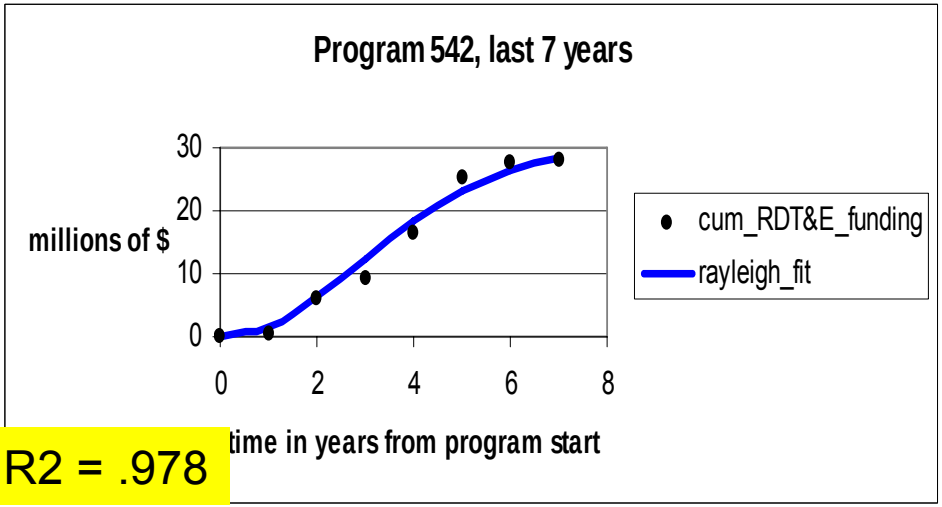
RDT&E funding profiles, cont'd



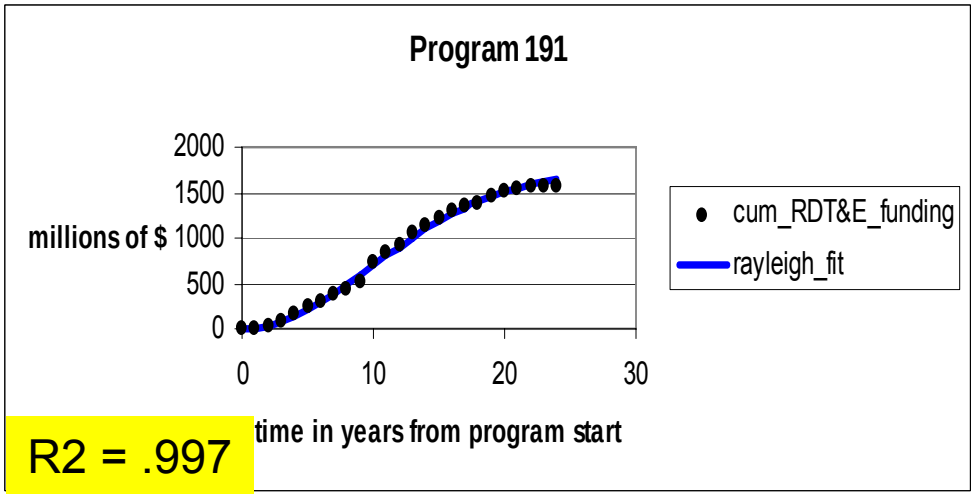
R2 = .991



R2 = .925

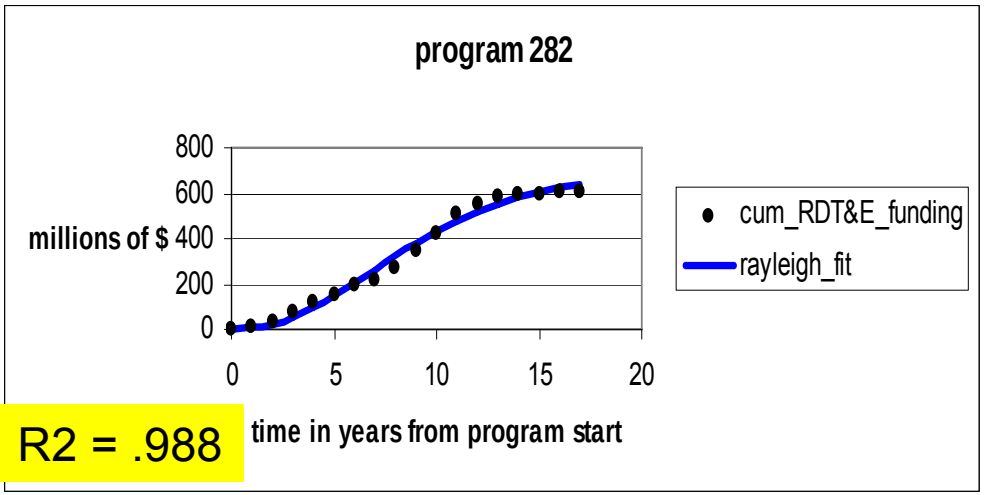


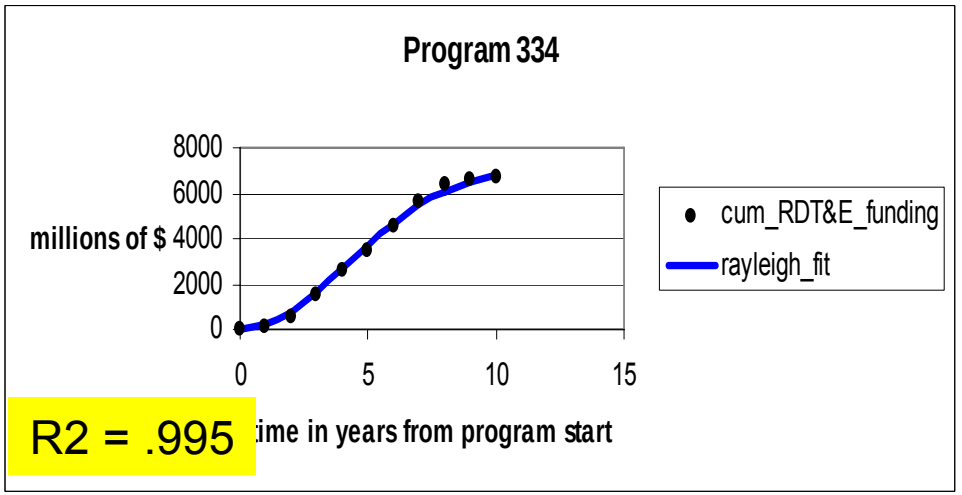
R2 = .978

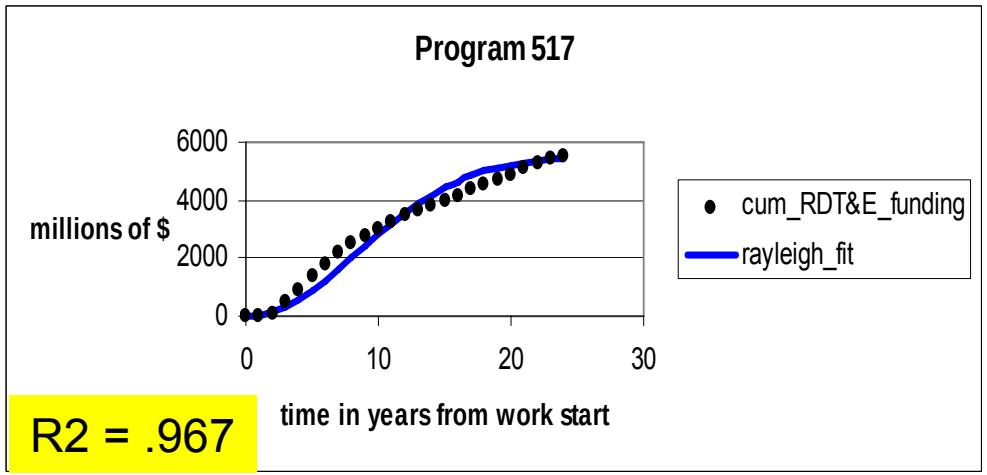


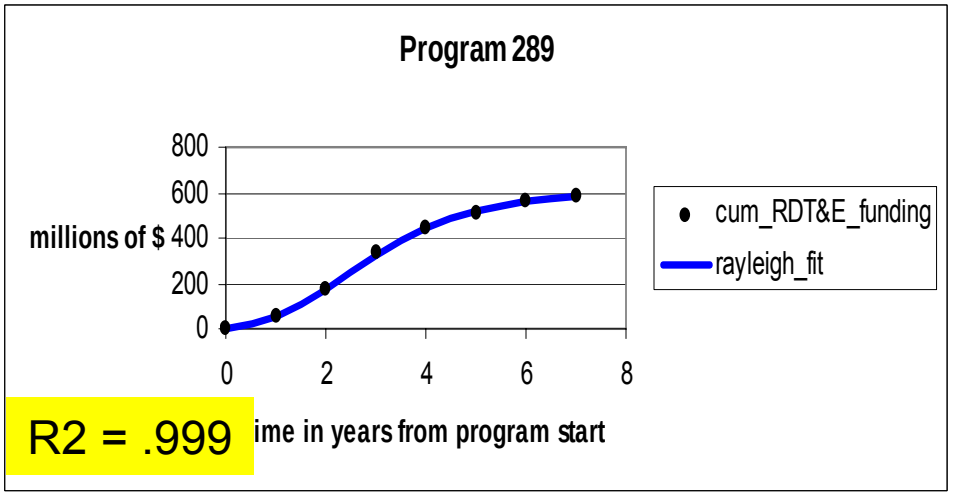
R2 = .997

RDT&E funding profiles, cont'd

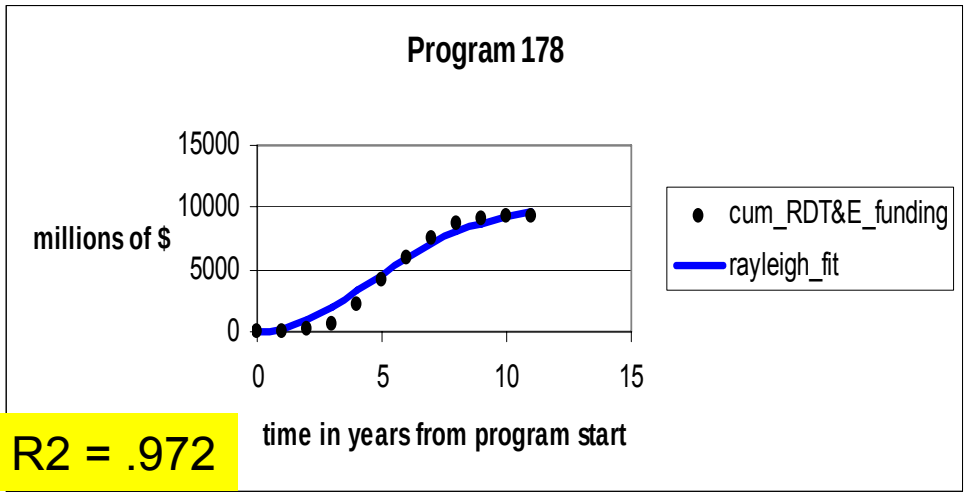




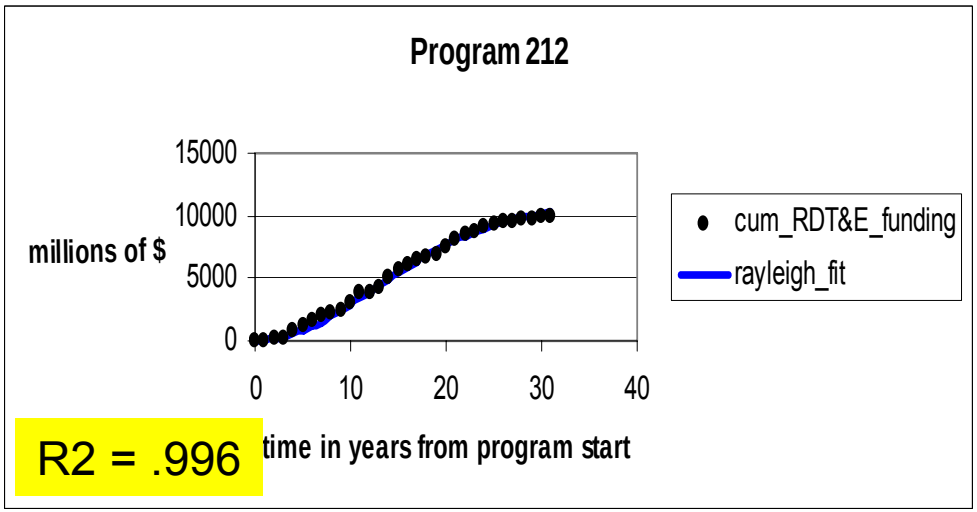




RDT&E funding profiles, cont'd

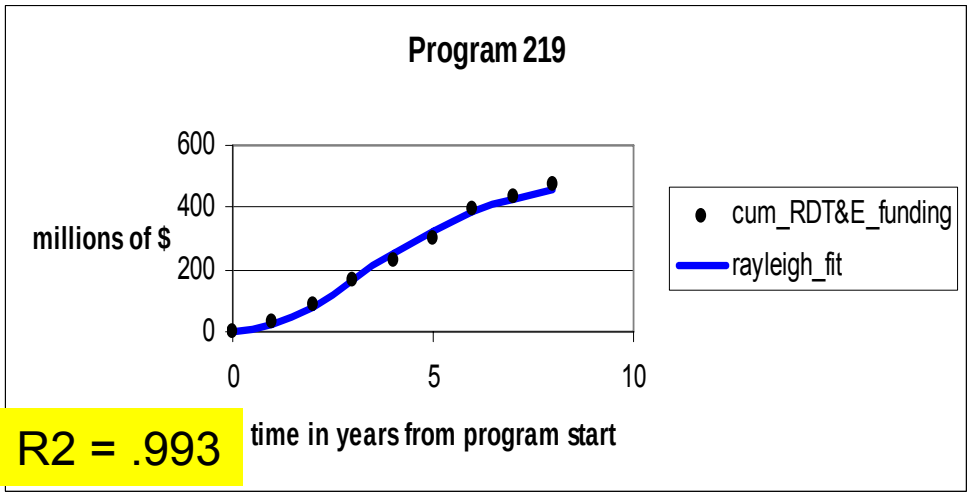


R2 = .972

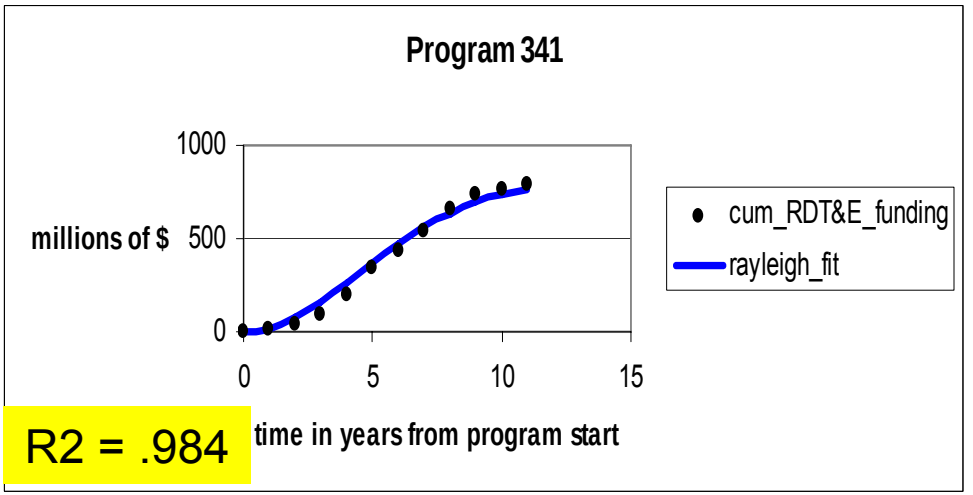


R2 = .996

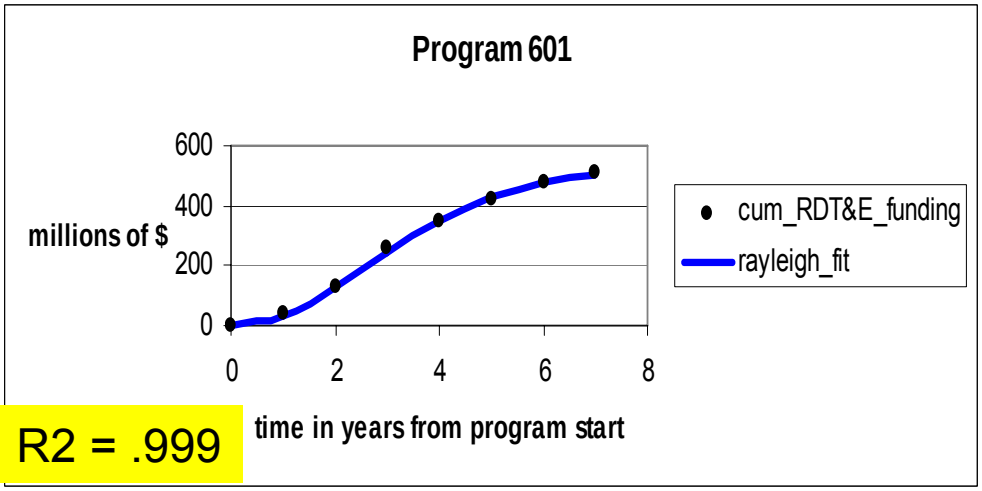
RDT&E funding profiles



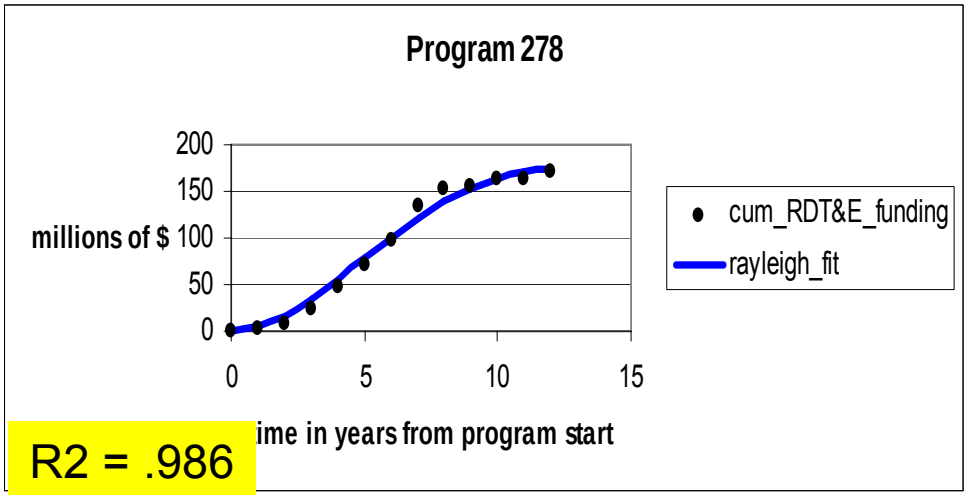
R2 = .993



R2 = .984

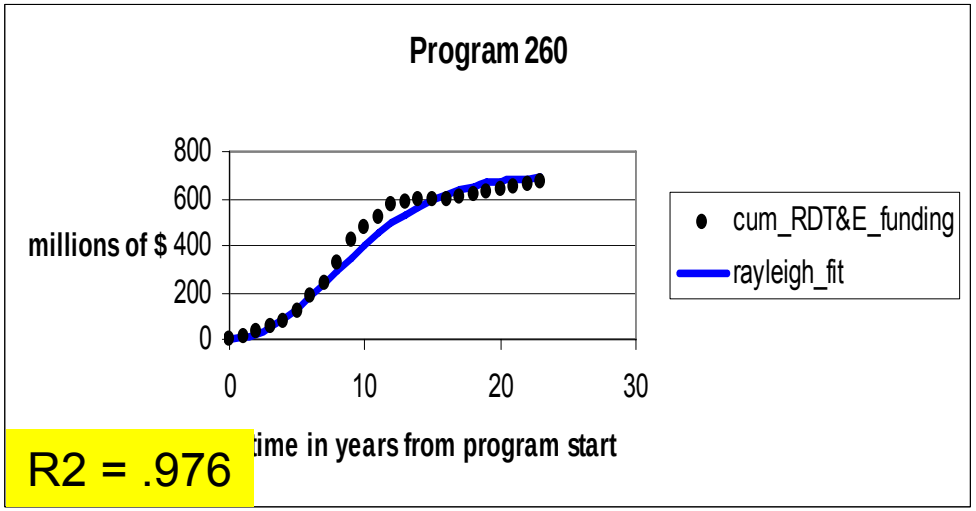


R2 = .999

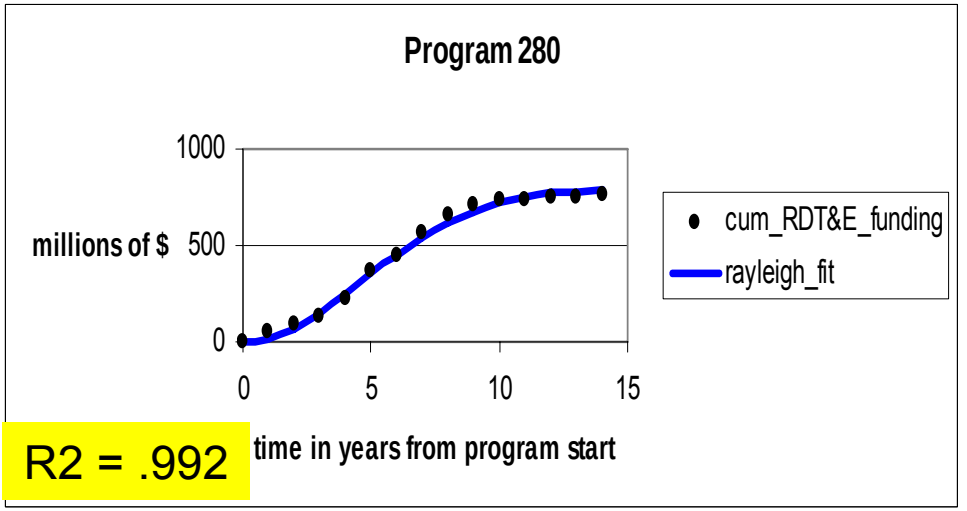


R2 = .986

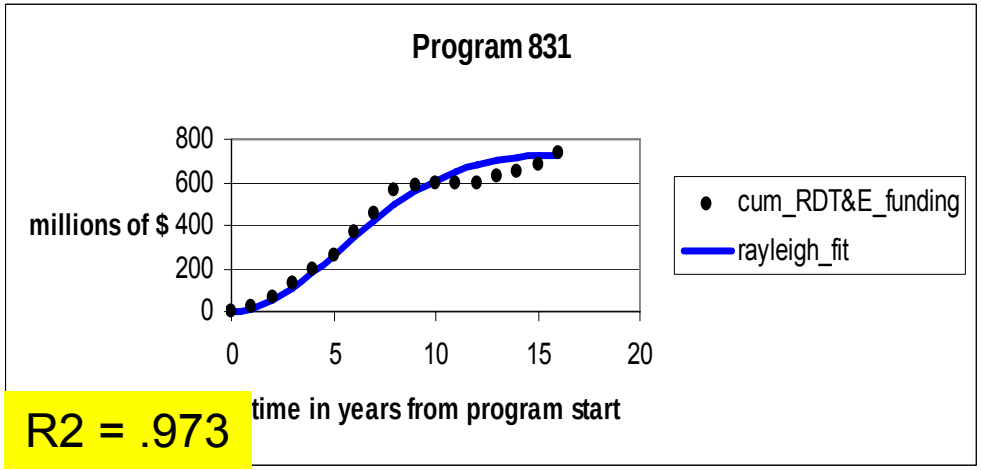
RDT&E funding profiles, cont'd



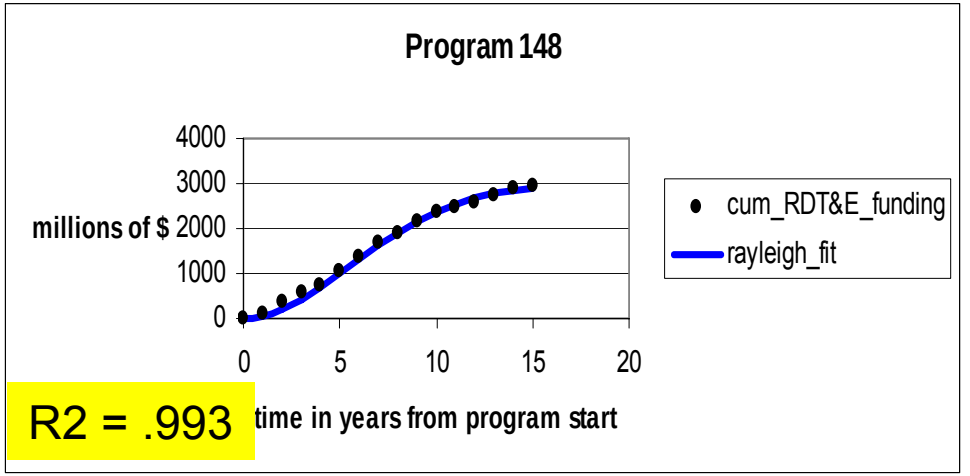
R2 = .976



R2 = .992



R2 = .973



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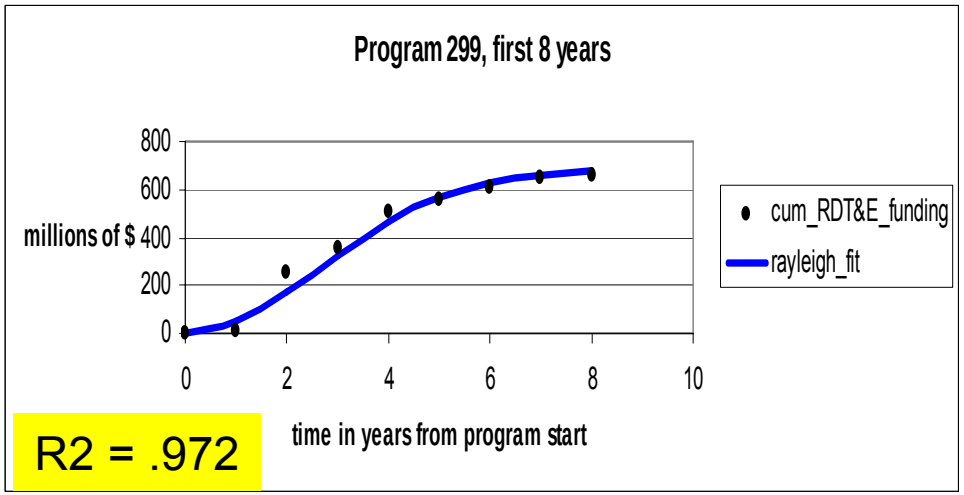
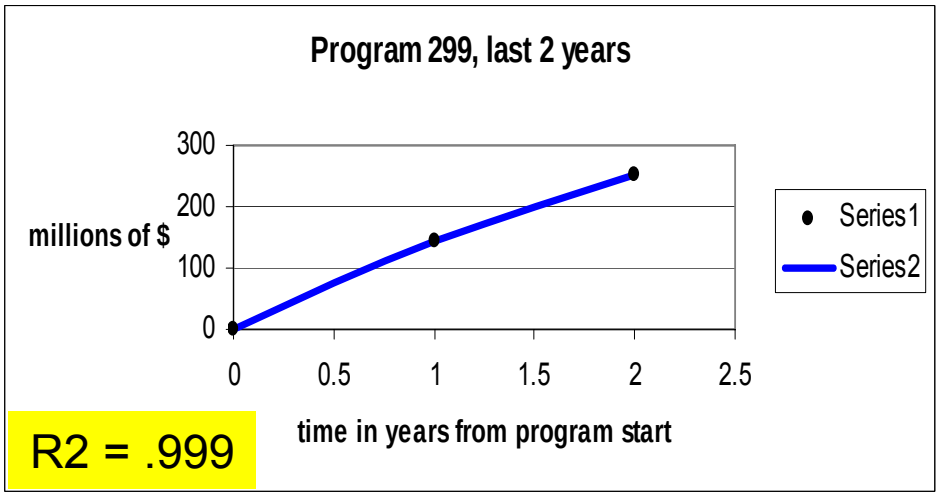
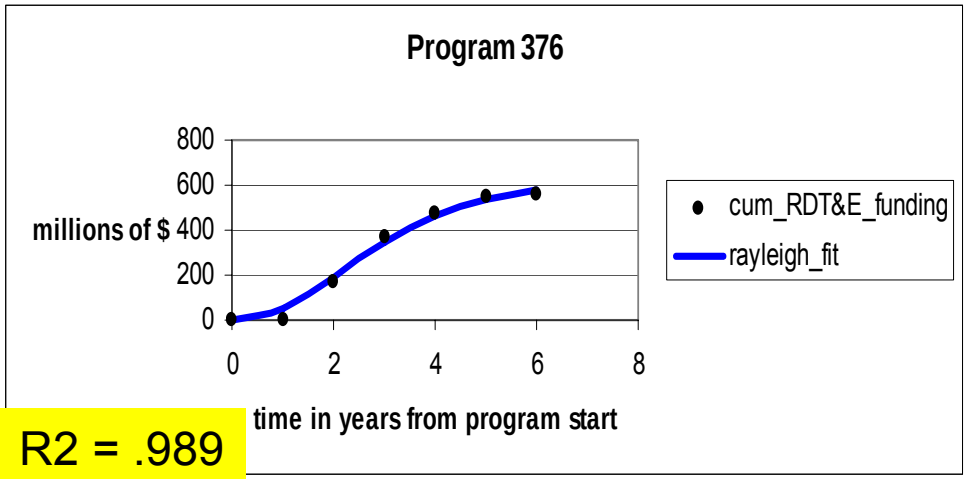
RDT&E funding profiles, cont'd





RDT&E funding profiles



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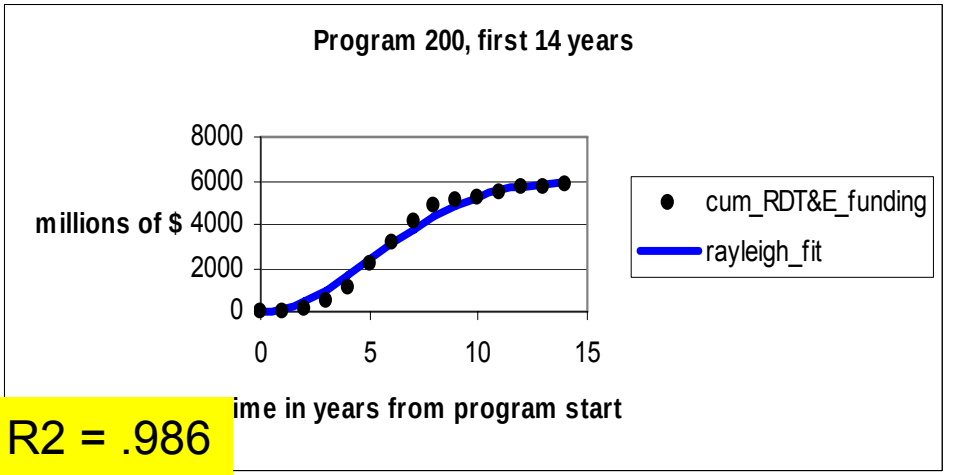

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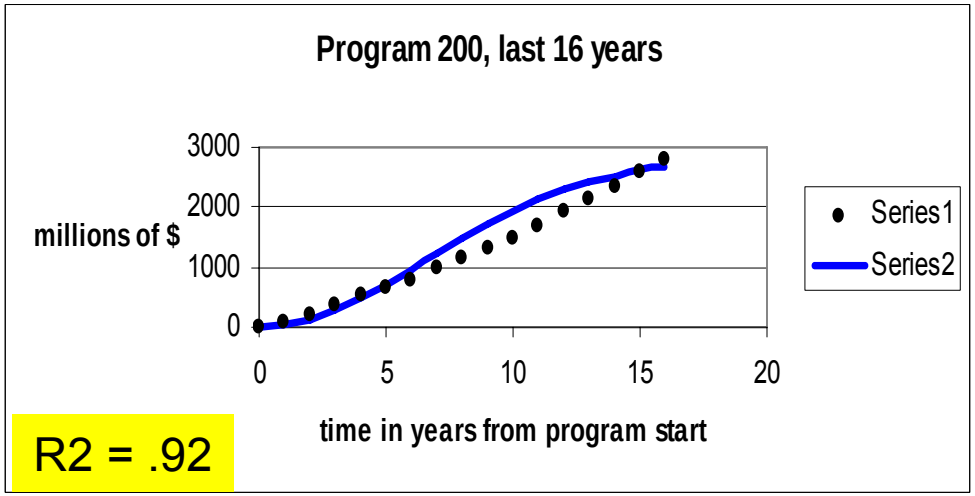

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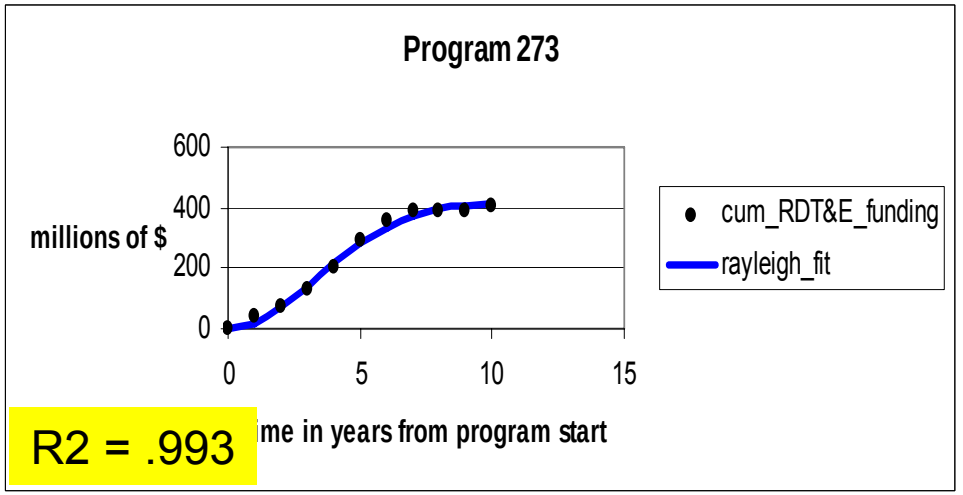
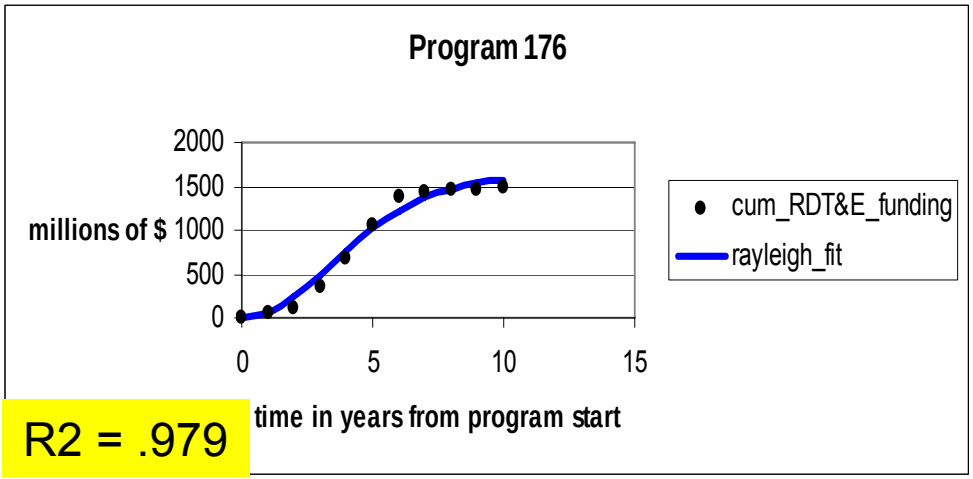


R2 = .993

RDT&E funding profiles, cont'd



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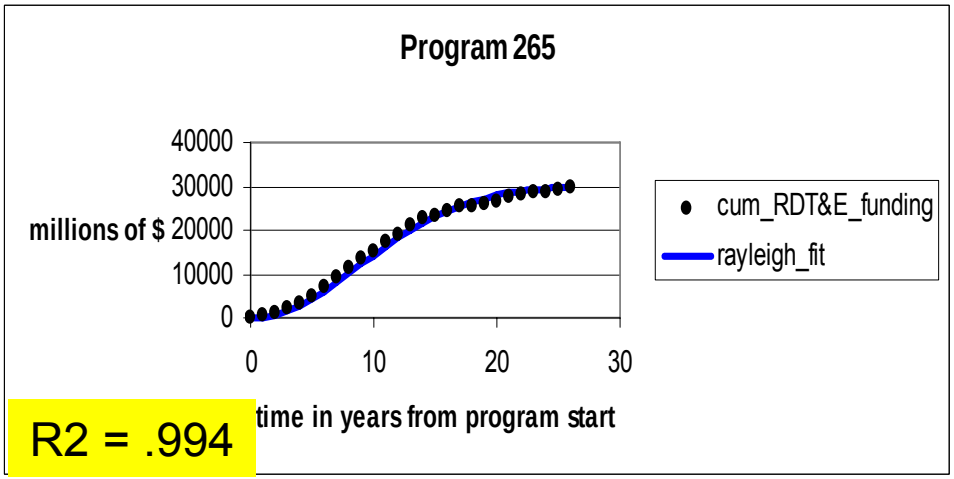

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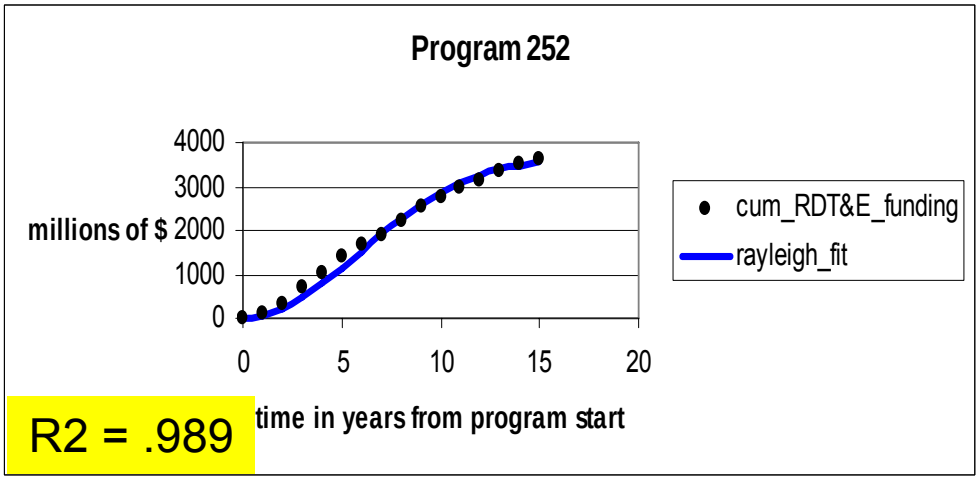
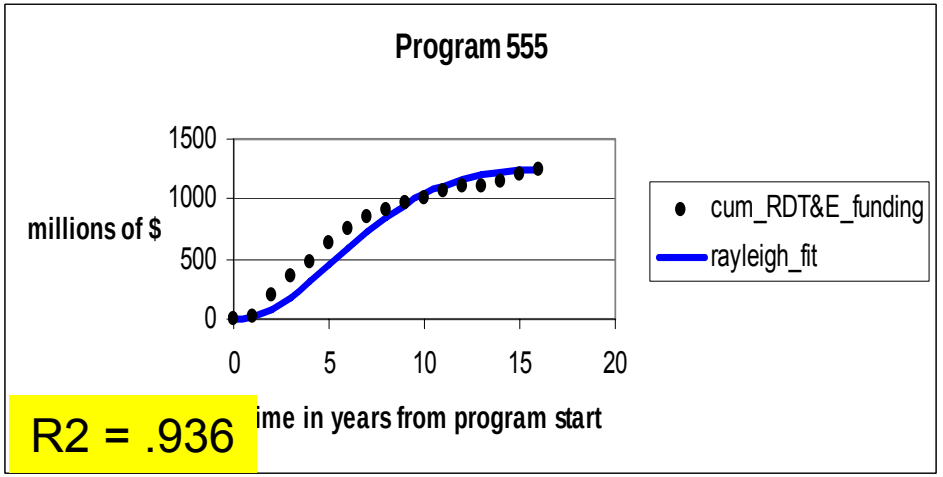


R2 = .989



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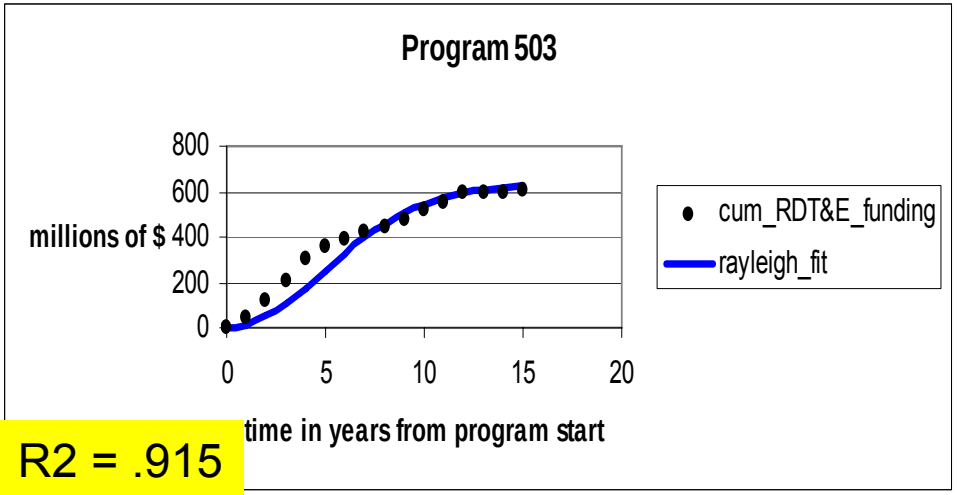

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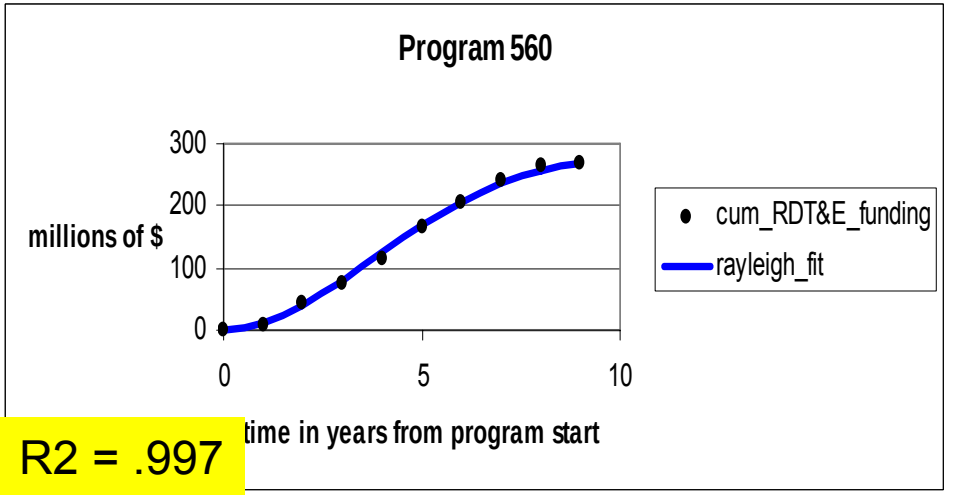

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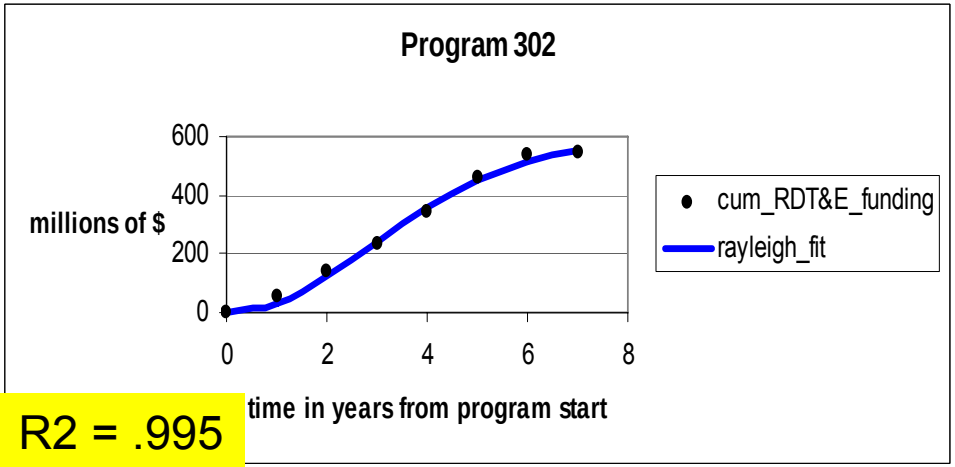

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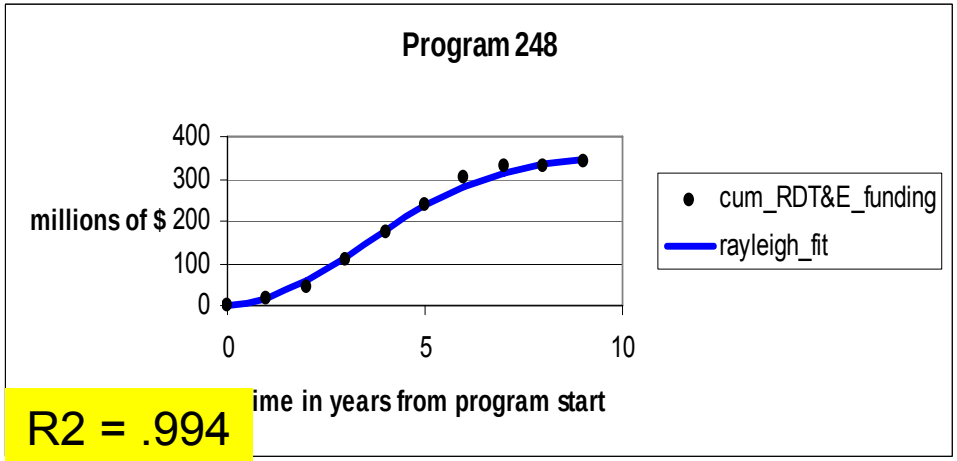
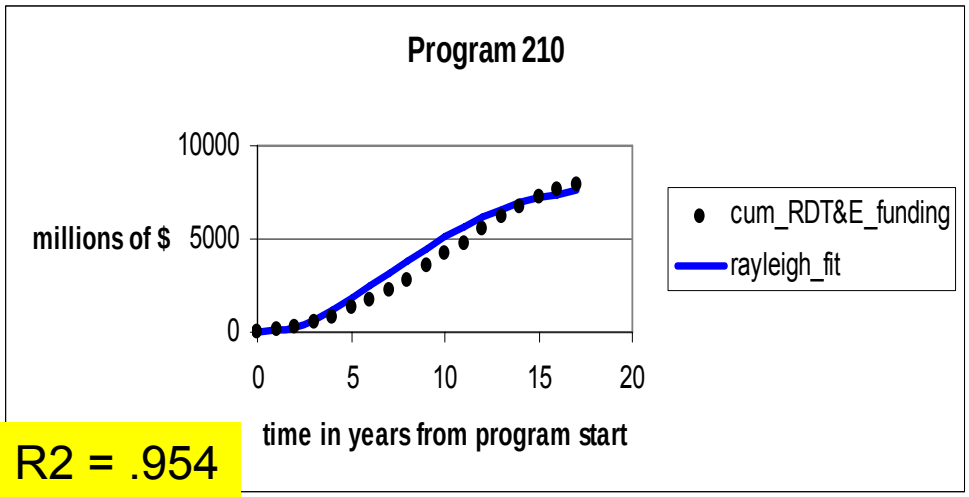


R2 = .994

RDT&E funding profiles, cont'd



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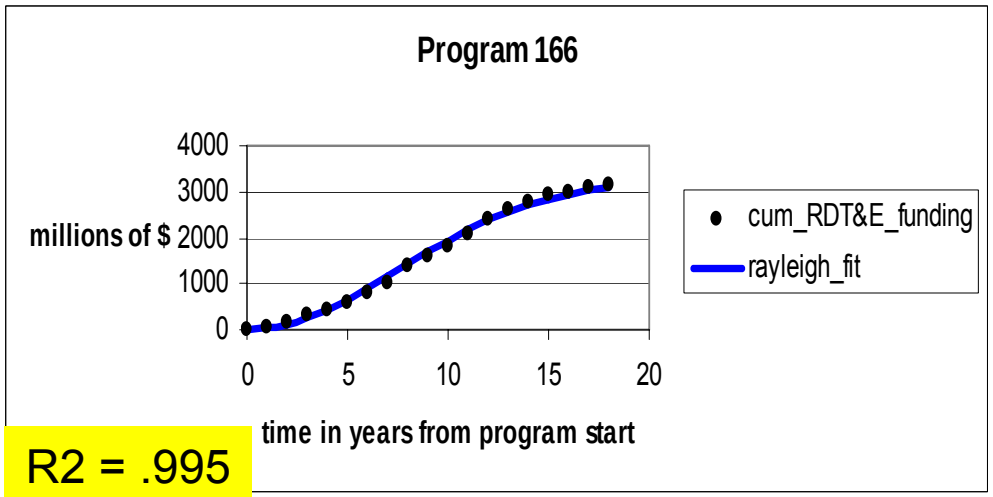
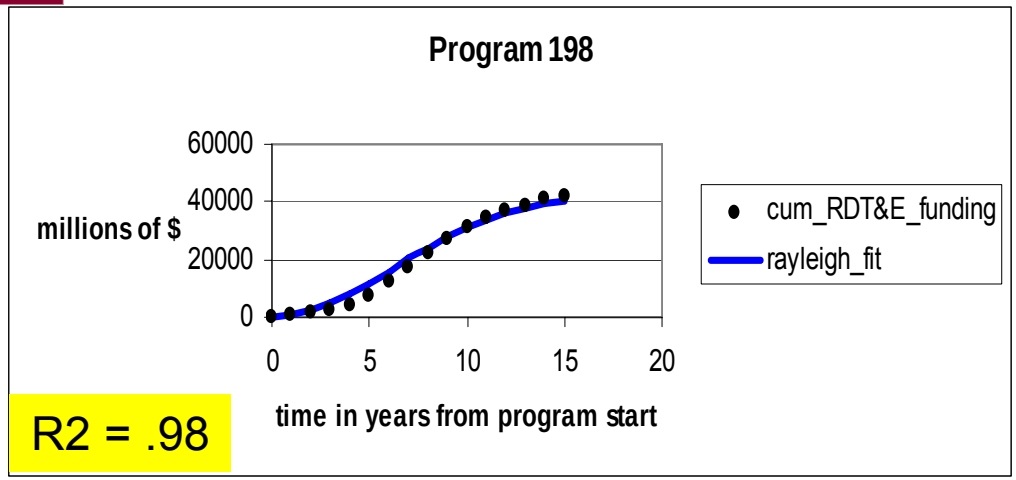


R2 = .995

RDT&E funding profiles



Research Task: Questions to Be Addressed

- How can an executive effectively use questionable EVM data for management decisions?
- Can new tools be developed or “old” tools modified to give earlier warning of impending contract execution problems?

Briefing Agenda

- Summarize Rayleigh model (Version 1)
- Summarize results of validation (Version 1)
- Describe tool
  - One module for “traditional” analysis
  - One module for assessment of an original plan before actual cost data have been collected
- Potential impact of study
- Rayleigh, Version 2
- Recommendations

The Rayleigh Model

Cumulative cost as a function of time (in millions of $)

Shape parameter. When will peak spending rate occur?

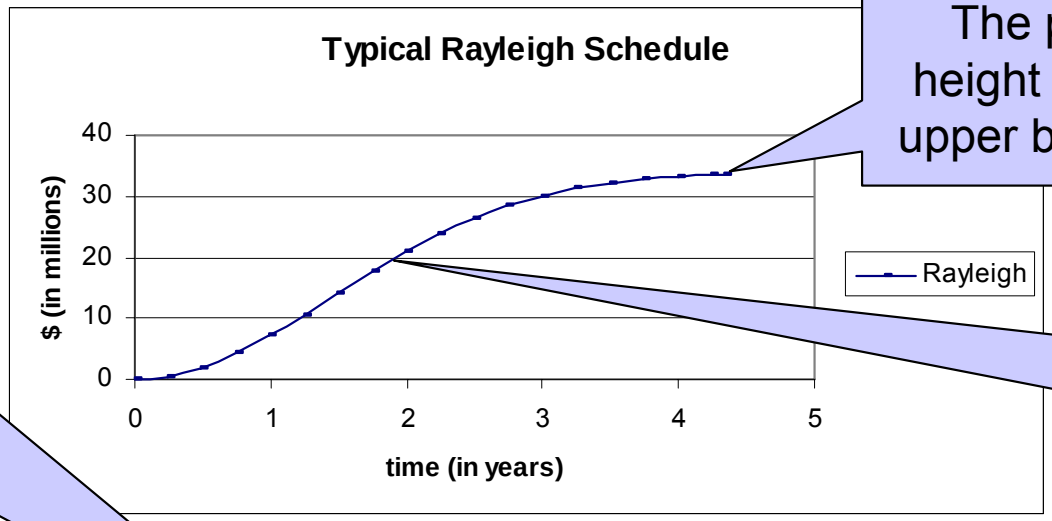
$$c(t) = d\left(1 - e^{-\alpha t^2}\right)$$

Scale factor. How much will the program cost?

Proportion of work completed at time t.

Duration time (in years). What is the current duration of the program?

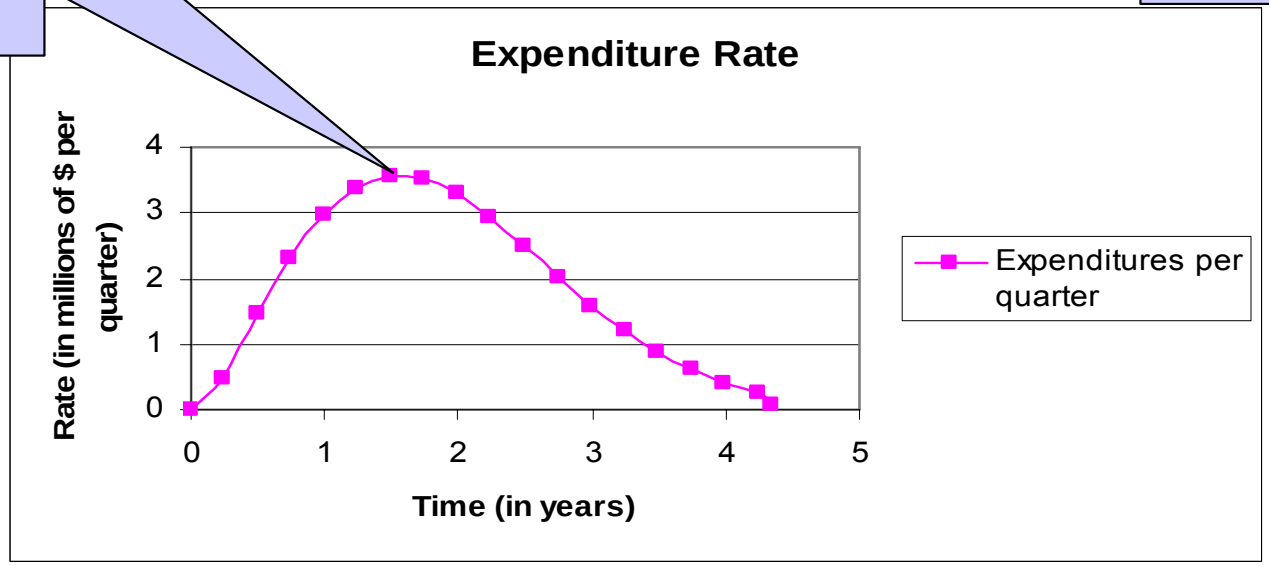
An Example of a Rayleigh Schedule



The parameter d tells us the height of the curve. What is the upper bound on cumulative cost?

The parameter α tells us the shape of the curve. When does the peak spending rate occur?

This curve inflects when the rate curve below reaches a maximum.



Rayleigh Model Advantages

- The model is applied only to R&D contracts
- Rayleigh is a plausible model of cumulative cost accrual over the life of a contract
- The model is based on dollars that have not been adjusted for inflation
- The model depends only on standard currently available EVM data (no new reports)
- The model only requires 3 actual cost submissions and a budget

Rayleigh Model Advantages

- The model does not depend on the reliability of Earned Value (BCWP) submissions
- The model predicts both EAC and completion date
- The model predicts the path of actuals to completion date
- The model is Excel-based using standard Solver add-in

Validation of the Rayleigh model

- Compared accuracy of predictions considering cost at completion and completion time
- Methods compared
  - Rayleigh estimate
  - Contractor estimate
  - PM Estimate

Validation (cont)

- Methods compared (cont)
  - EAC1 (BAC/CPI plus max of contractor and PM time estimate)
  - EAC 2 (Actuals+(BAC-EV)/(.8CPI+.2SPI) plus max of contractor and PM time estimate)
  - EAC 3 (Actuals +(BAC-EV)/(CPI X SPI) plus max of contractor and PM time estimate)
  - Note: EAC1, EAC2, and EAC3 methods do not produce an independent estimate of duration time

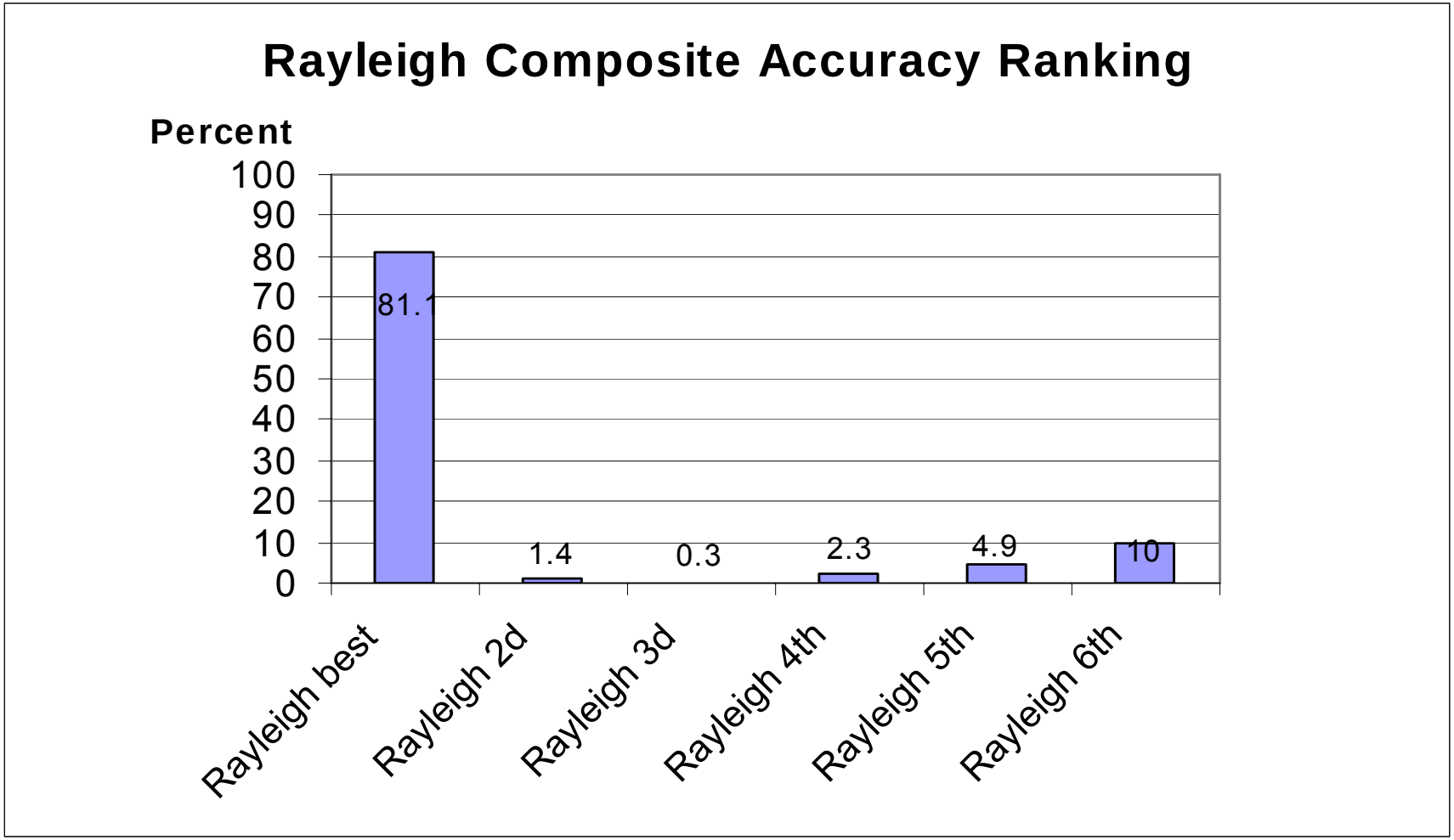
Validation (cont)

- Selected programs for regression analyses
- Selected only R&D programs
- Selected complete programs
  - Eliminated programs less than 90% complete to get valid baselines
  - Eliminated programs with over 2 years between work start and first submission to evaluate early warning utility

Validation (cont)

- Began with entire CAS database
- Selected 74 programs
- Consisting of 115 contracts
- Earliest start date 1/1/1970
- Latest start date 8/1/2002
- All services included

Rayleigh validation results



How much better were Rayleigh predictions? (EAC)

- All estimates underestimate final cost over 78% of the time. When they underestimate cost:
  - Rayleigh underestimates final cost on average by 30%
  - The contractor underestimates on average by 35%
  - The PM underestimates on average by 37%
  - The EAC1 method underestimates on average by 34%
  - The EAC2 method underestimates on average by 34%
  - The EAC3 method underestimates on average by 32%

How much better were Rayleigh predictions? (time)

- All estimates underestimate final contract duration over 73% of the time. When they underestimate duration :
  - Rayleigh underestimates duration on average by 24%
  - The contractor underestimates on average by 35%
  - The PM underestimates on average by 55%

Conclusions from database validation

- Rayleigh yields best estimate of final cost
- Rayleigh yields best estimate of time duration

Conclusions from database validation (cont)

- Rayleigh is still short of final cost on average by 30%
- A basic assumption of all EAC techniques is that we know full scope at the time of prediction and we fit the sparse data with a single Rayleigh curve
- Earlier CNA study (“Program Cost Growth: The Navy’s Experience 1983-2004”)
  - Total cost growth is level from 1978-2004
  - Within the total, the “overrun" component is declining and the “changes” component is increasing
- We think the bulk of the 30% shortfall is attributable to contract changes

Executive Cost and Schedule Assessment (XCaSA) tool

- Executive Plan Assessment Module (XPAM)
  - Allows executive to assess plan realism before any actuals are submitted
- Executive Contract Assessment Module (XCAM)
  - Allows executive to assess contract performance after at least 3 submissions of actuals

XCaSA (cont)

- XCAM (cont)
  - Incorporates Rayleigh estimates
  - Displays “traditional” analysis for comparison
  - Incorporates relevant DCMA tripwires

New metrics (XCAM)

- Cost Overrun Vulnerability Index:

$$COVI = \frac{EAC_{Rayleigh}}{BAC_N}$$

- Schedule Slip Vulnerability Index:

$$SSVI = \frac{\hat{t}_{Rayleigh}}{\hat{t}_{N,PM}}$$

New features (XPAM)

- Plan Validity Index
- “What if” drills

XCaSA advantages

- User friendly
- Interactive
- Provides useful information early in life of contract
- Uses built-in Solver add-in with widely used Excel spreadsheet software
- Provides business insights

Dashboard view of XCAM

Program Name	EFV
Contract Name	SDD
Contract Number	M67854-01-C-0001
As of Date of data	24-Oct-06
Start date of contract	Feb-01
PM estimated completion date	Sep-08
PM contract duration (years)	7.59
Rayleigh estimated completion date	Apr-10
Rayleigh contract duration (years)	9.17
EAC contractor	1142.7
EAC PM	1166.5
EAC Rayleigh	1173.75
EAC 1	1163.99
EAC 3	1173.75
TA Budget	1065.4
CPI	0.92
SPI	0.96
TCPI PM	0.91
TCPI Rayleigh	0.88
Cost Overrun Vulnerability Index	1.1
Schedule Slip Vulnerability Index	1.21
TCPI_PM_Differential	-0.01
TCPI_Rayleigh_Differential	-0.04

Step 1: Select Program

Step 2: Import Data

Step 3: Do calculations

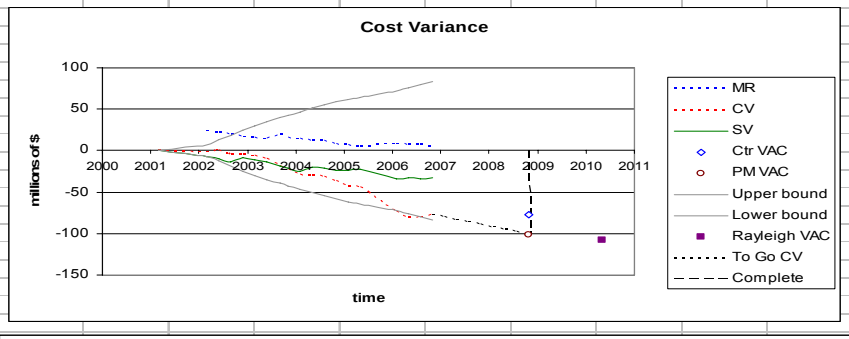
Step 4: Display summary metrics

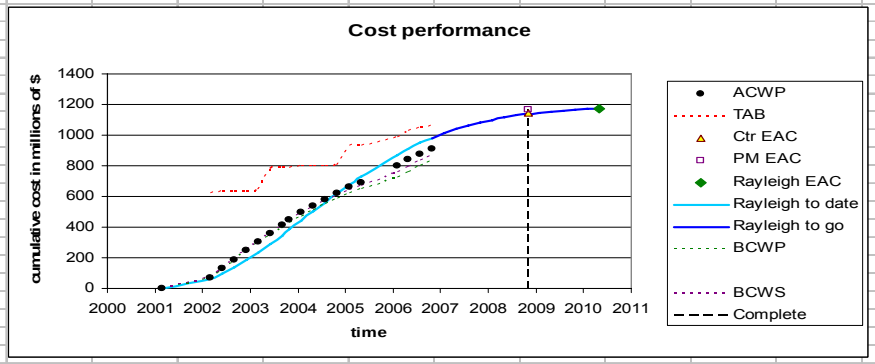
Step 5: Have tool graph variance

Step 6: Have tool graph performance

Step 7: Clear all

	0.1
	0.05
	0.1
	0.05





Cost Status
Comment on Cost Vulnerability Index (Line 20).
Questions:
Are you adequately budgeted?
If not, what are your plans to resolve the budget issue?
Do you have a cost reduction program?
What are Nunn-McCurdy implications?

Schedule Status
Comment on Schedule Slip Vulnerability Index (Line 21).
Questions:
What is the basis for your schedule assessment?
Do you routinely do schedule risk assessments?
What are the implications of slipping the PM's schedule?
What are the most important critical path tasks over the next 12 months?

Future Cost Performance
Comment on TCPI (Line 22).
This is a realistic projection of future overrun.

Cost Variance Graph
If CV has recent flat or positive slope, explain improvement in CV.
If SV has flat or recent positive slope, explain improvement in SV.
Why is PM's cost projection more pessimistic than contractor's?
Is remaining MR sufficient to cover remaining risk?

Cost Performance
If the TAB is increasing, explain the increasing contract scope.
Does your EAC include projected increases in TAB?
When will changes stop?

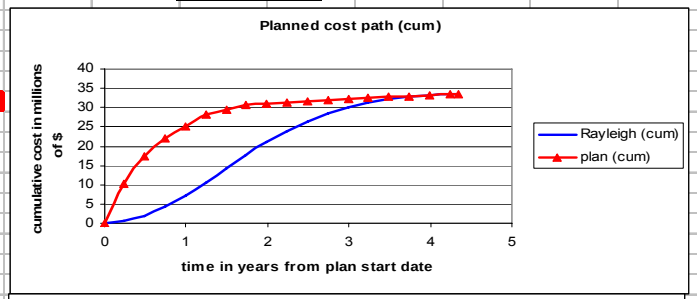
Dashboard view of XPAM

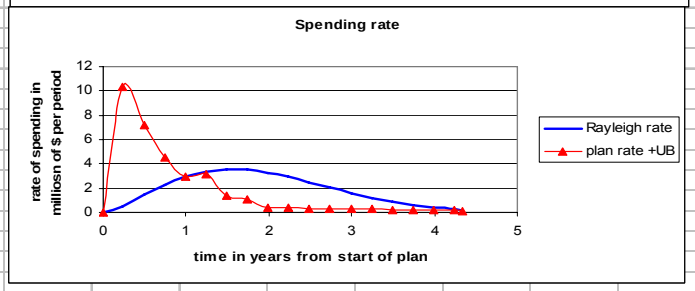
Program Number (PNO)	777
Contract Number (CNO)	3
As of date of plan	28-Feb-06
Start of plan	01-Feb-06
Total Planned Cost (in millions of $)	33.5
Total Planned Duration (in years from start date)	4.34
Amount of Undistributed Budget	0
Number of future periods over which to distribute UB	0
Plan Validity Index	0.397379463
Nature of plan	Frontloaded
"What if" final contract cost (in millions of $)	33.5
"What if" final contract duration (years from start)	1.531463003

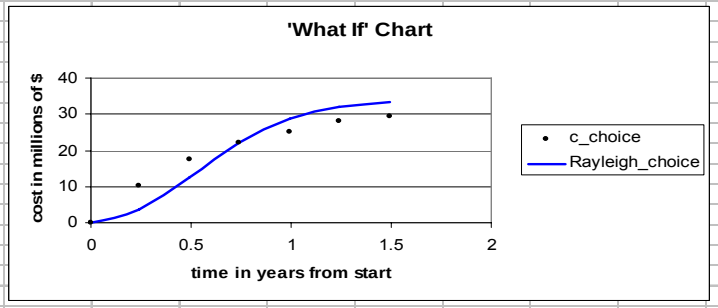
This plan is initially frontloaded.
Explain why the plan has most of the effort in the first half of the program.
Are labor resources in place to support a rapid build-up?
There is low effort in later phases. Is this consistent with the test plan and other work content (for example, production start)?
Is this consistent with risk assessment?

Step 1:Select Program | Step 2: Get data | Step 3: Do Calculations

Step 4: cum chart | Step 5: rate chart | Step 6: "What if" | Step 7: Clear all







XPAM Advantages

- Only XPAM can assess the initial plan
  - Current EVM diagnostics cannot assess the the plan until after submission of some number of full EVM data
    - Often more than a year after contract start

XCaSA Tool Status

- Tested XCAM with multiple current programs
- Tested XPAM with notional initial program management baselines

Potential Impact

- Improve oversight of programs
- Obtain early assessments of plan and contract execution
- Make better informed tradeoff decisions
- Make EVM tool of choice across the government

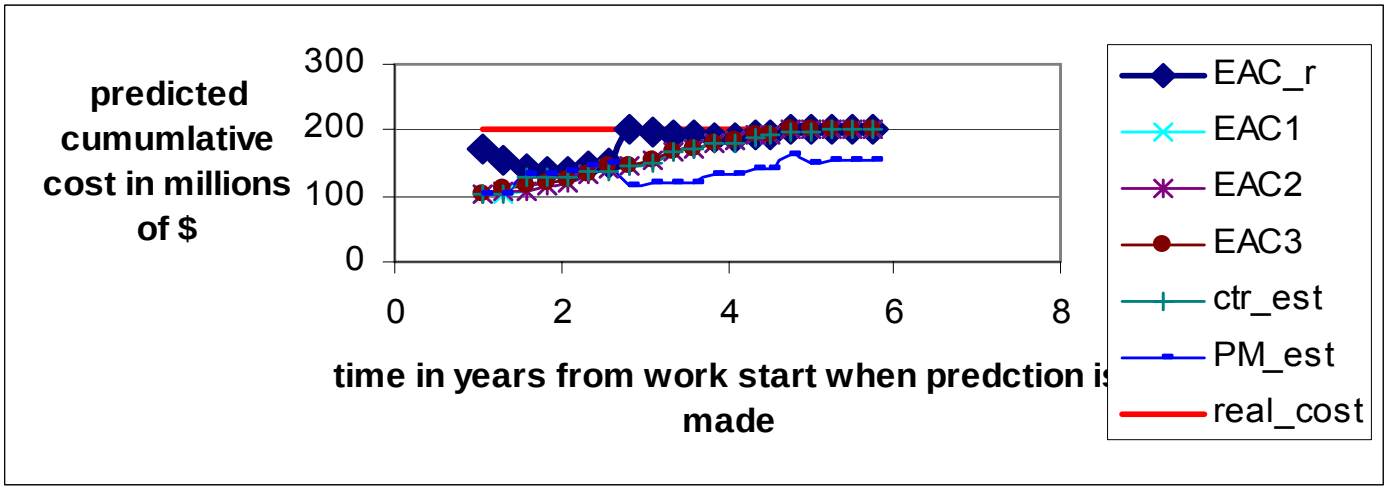
Rayleigh, Version 2

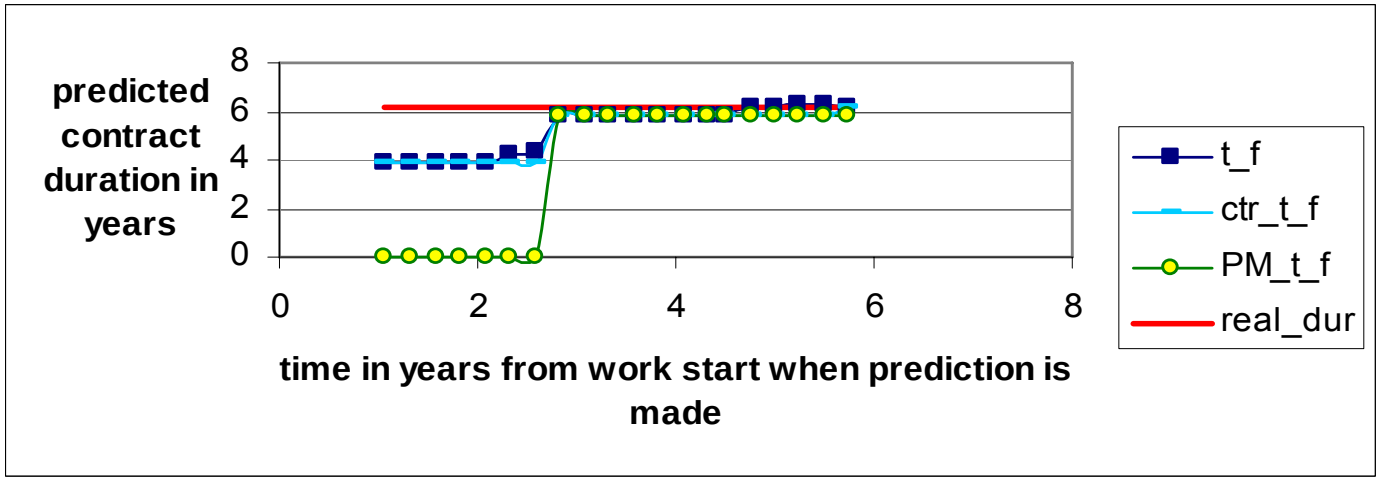
- Update model algorithm and revalidate
- Incorporate contract-level cost and schedule risk
- Investigate use of the model with program level budget data
- Test applicability of model to procurement contracts
- Upgrade user interface
- Determine feasibility of developing Monte Carlo policy simulation package with Rayleigh spline for tool to account for “missing 30%”
- Upgrade “insight” prompts in tool
- Link model to AOP-like management process

Update model algorithm and revalidate

- Re-estimated using non-linear least squares with restricted monotonically transformed parameters (NRMP)
- Improves efficiency of computation
- Enables approximation of risk region
- Revalidated with over 2500 information sets

Update model algorithm and revalidate: results

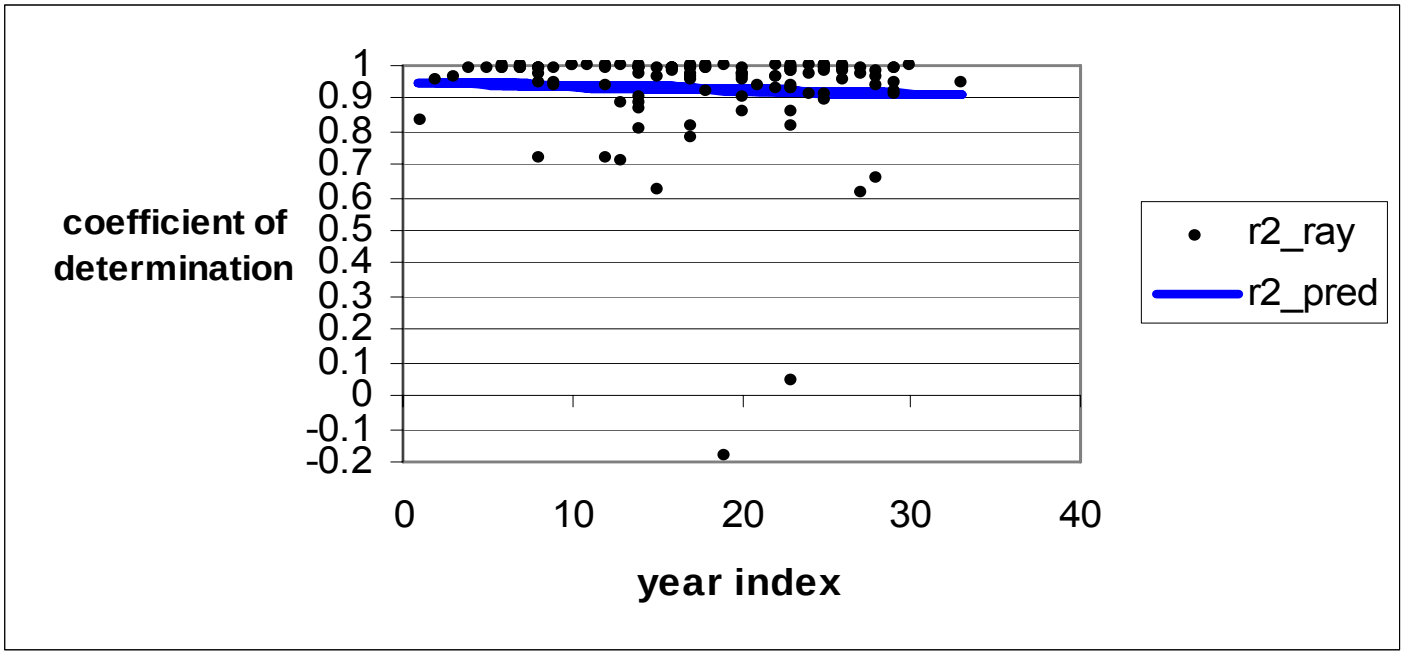




Results of more comprehensive analysis

- Rayleigh estimates final cost with greater than or equal accuracy 67.4% of the time
- Rayleigh estimates final contract duration with greater than or equal accuracy 58.5% of the time
- Rayleigh estimate of final cost converges to within 10% of the final actual cost with greater than or equal speed 92% of the time
- The average speed of convergence for the Rayleigh final cost estimate is .48

Results of more comprehensive analysis



Average R^2=.93

Model: r_2=a + b*WSDATEINDEX

a_hat:
.95
(.038108)

b_hat:
-.00126
(.001978)

Results of more comprehensive analysis

- Compared Rayleigh with “level of effort” model
- Rayleigh a better “fit” 63% of the time
- Rayleigh better or virtually the same “fit” 85% of the time
- Linear model is unambiguously better “fit” 15% of the time

Results of more comprehensive analysis

- Estimated covariance matrix
- Calculated confidence ellipse in parameter space
- Mapped ellipse into “final-cost/final-duration” space
- Graphed confidence region

Results of more comprehensive analysis

Results of more comprehensive analysis