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DEFINING THE FUTURE

Software Estimation Through the Use of Earned Value Data

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The Society of Cost Estimating and Analysis

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Introduction

- Generally cost performance report (CPR) data has been tracked by using the estimate at complete (EAC) or latest revised estimate (LRE)
    - If the LRE was an accurate estimate for the final cost of a development effort then the LRE should be fairly stable from the start of a development effort to the end. This was not the case; instability was observed for the LRE over time
- Another study[1] derived an EAC predictor after examining cumulative labor by percent of progress. In that study, it was found that the EAC could be predicted within about 2% - 5% after about the 20% reported physical progress point on two production programs
- Software estimation using milestones is very difficult due to the fluidity of the software development process
    - SW development does contain phases (e.g. requirements review, development, testing). However, with many SW development efforts, these phases may overlap

1. *Ending the EAC Tail Chase: An Unbiased EAC Predictor using Progress Metrics*. Druker, Eric; Coleman, Richard; Cullis, Bethia; Jaekle, Jeff; and Boyadjis, Elizabeth. SCEA, June 2007.

Introduction (cont'd)

- Rather than examining cumulative labor for progress milestones this study examined percent of final cost for a software release over percent of schedule
- This analysis devised an initial EV tracking tool, as a cross check to the LRE in order to more accurately predict a final cost of a SW release based on the percent of schedule rather than a milestone achievement
- An S-curve distribution has been derived in order to distribute the total expenditures of a SW release more accurately
- The S shape distribution is based on the ramping up and down of a SW development effort
  - A derivation of the inflection point was performed to find the point in a release schedule where expenditures begin to ramp down
- Different families of curves were tested to fit the data set and compared with the traditional Rayleigh curve which is used to distribute software development costs

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Data Preparation

- Used March 2006 Cost Performance Report CPR data
- Compiled software data across 7 programs
- Analyzed releases that were in progress (start to finish) over the span of the data
  - Assumed the start date to be the first month costs were reported to a related release (cross-checked with the IRR)
  - Assumed the end date to be the last month where the Actual Cost of Work Performed Current (ACWPcur) went to 0$
    - This was determined to be the end point due to accounting adjustments that followed the end of development
- Rolled up functionality requirements by month in order to obtain a total cost for each release
  - E.g. Import, Export, Integration, Testing, etc.
- Added release-specific costs
  - E.g. Systems Engineering, FAT DR workoff
- Adjusted each months ACWPCur to CY06$

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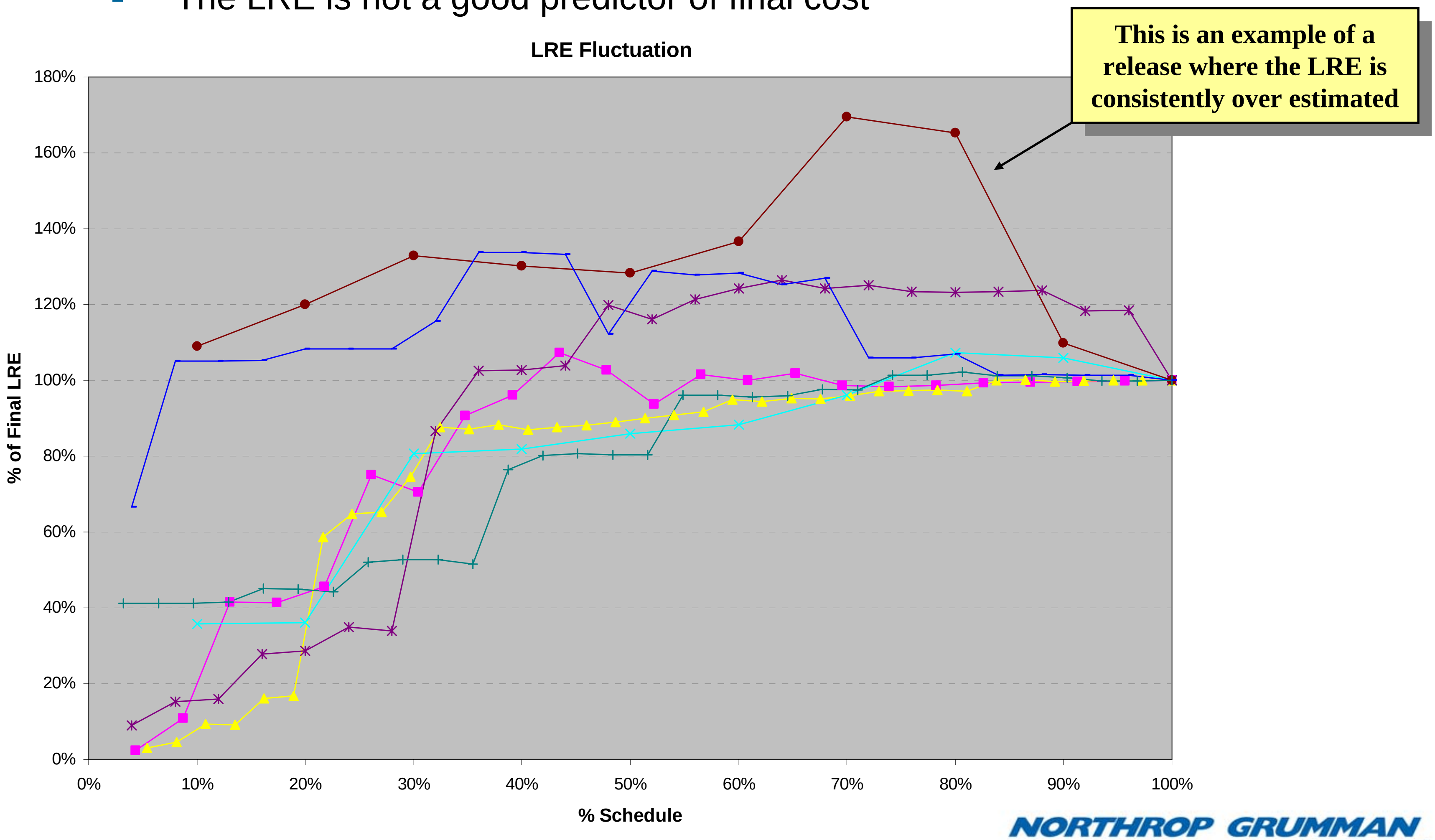
LRE over Schedule

- Looked for a pattern of the LRE over time for all of the releases
  - Found the LRE to be too volatile a measure of final cost for a release
  - The LRE is not a good predictor of final cost



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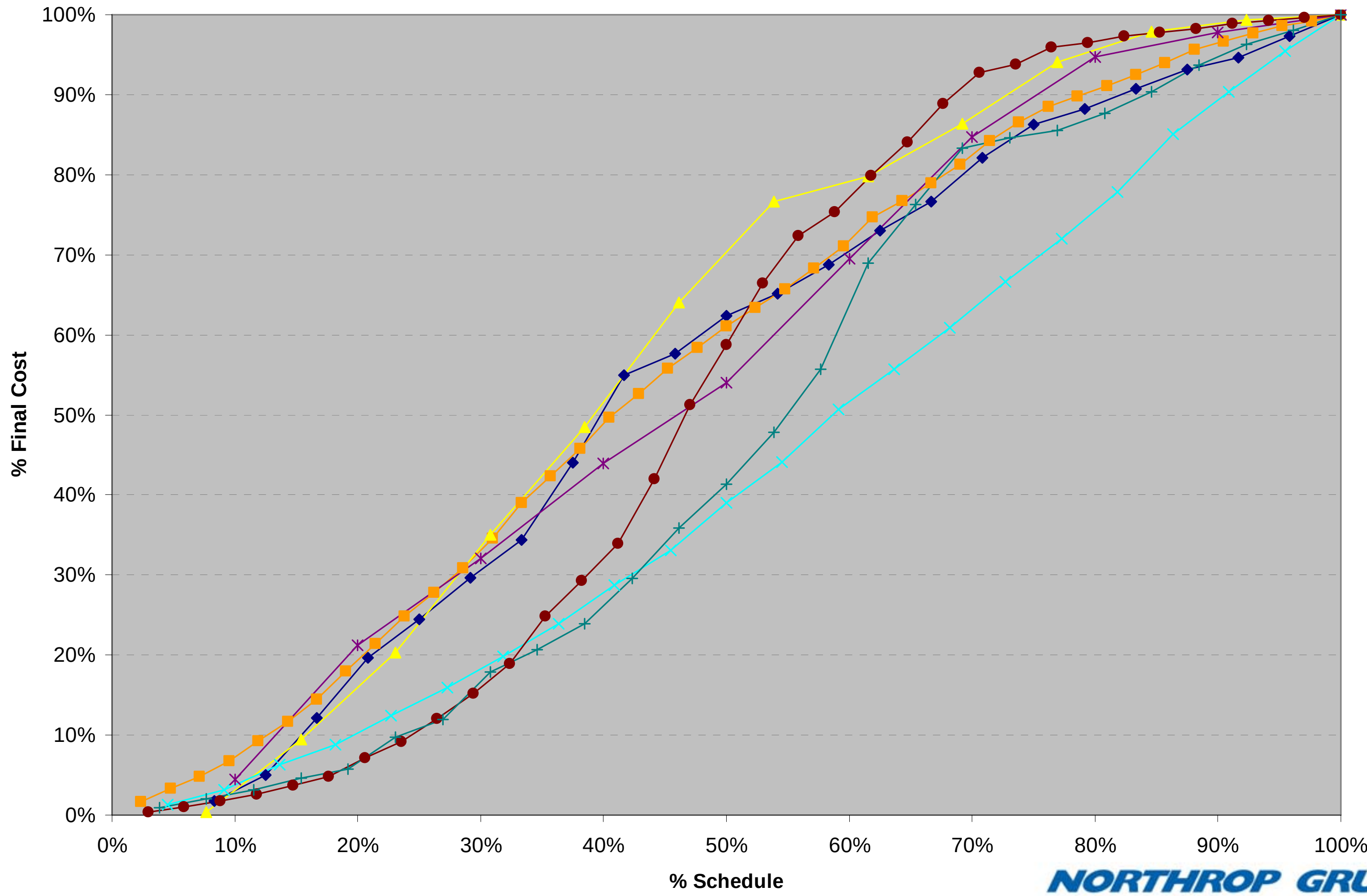
% Cost vs. % Schedule

- Next step was to examine the % of final cost vs. the % of schedule
- Found that the cost of a release tends to follow an S-curve distribution over time, which is expected



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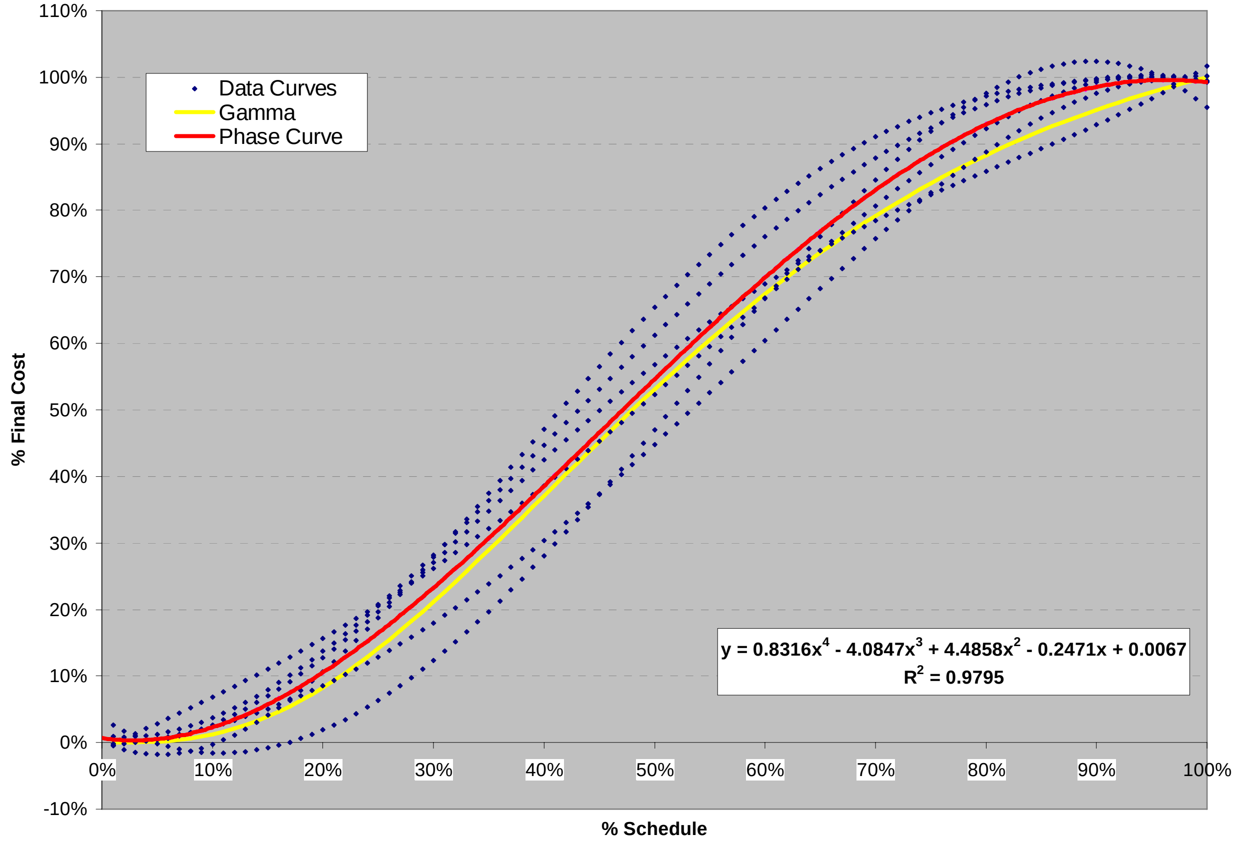
Polynomial and Gamma Curve



- The first attempt to fit a curve to the data was to extrapolate a fourth-order polynomial for each of the releases and then find the average polynomial curve
- There is no justification to use a polynomial because there is no way to determine the order of magnitude. If the data had precise bends in the curve based on significant milestones during the development effort then a polynomial may be justifiable
- The extrapolated polynomials and the gamma curve went above 100% complete towards the end of the development effort which is where it is expected to be the most accurate. Therefore this approach was not used.

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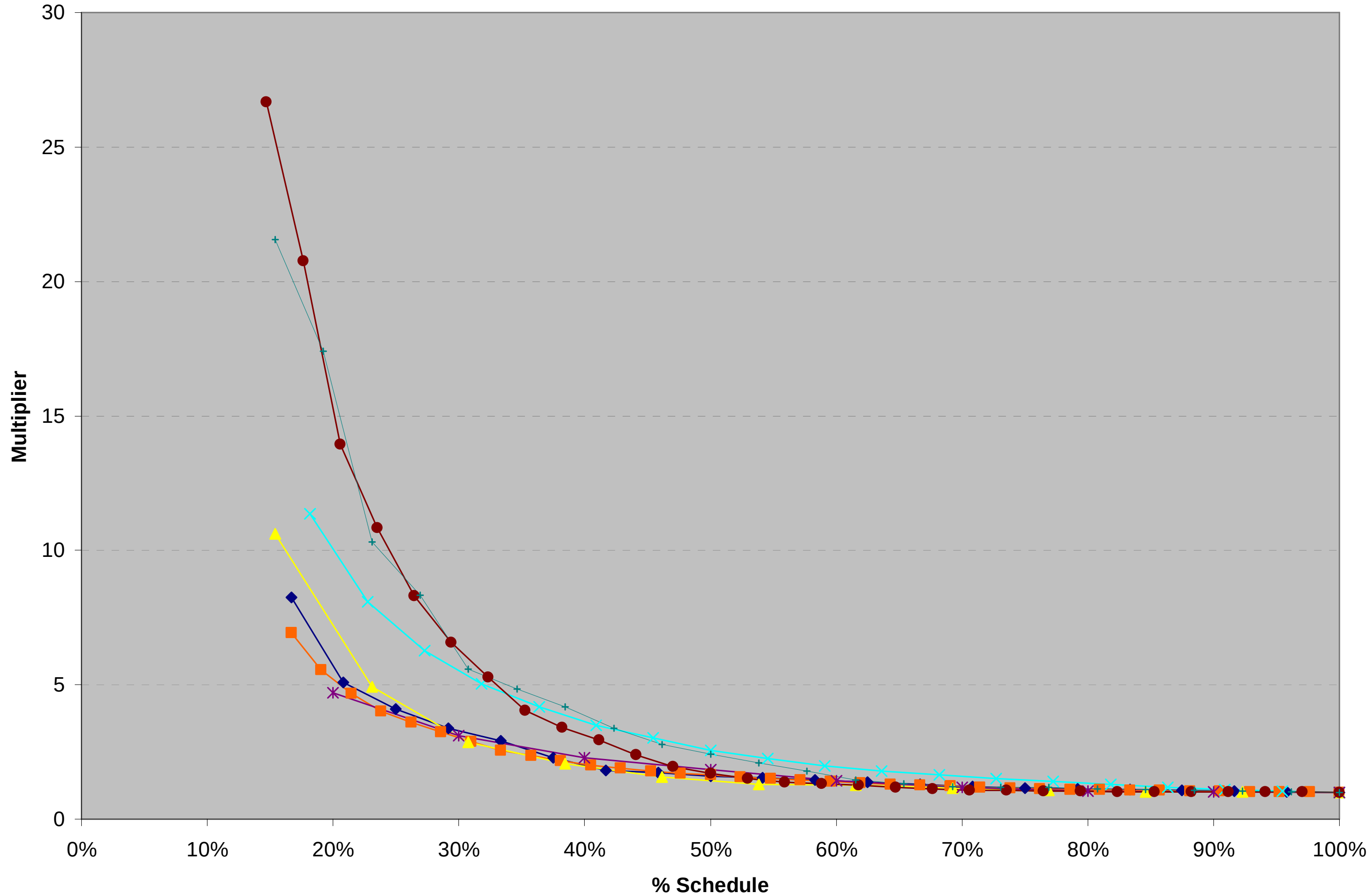
Power Curves – 1/%ACWP



- It is important to take the inverse of the S-curve to look for a different way to derive a curve that fit the data well. The inverse (1/%ACWP) was examined and the data analyzed as multipliers to final cost
- At every % schedule these curves express what you would have to multiply the current cumulative cost by to obtain the final cost of the release

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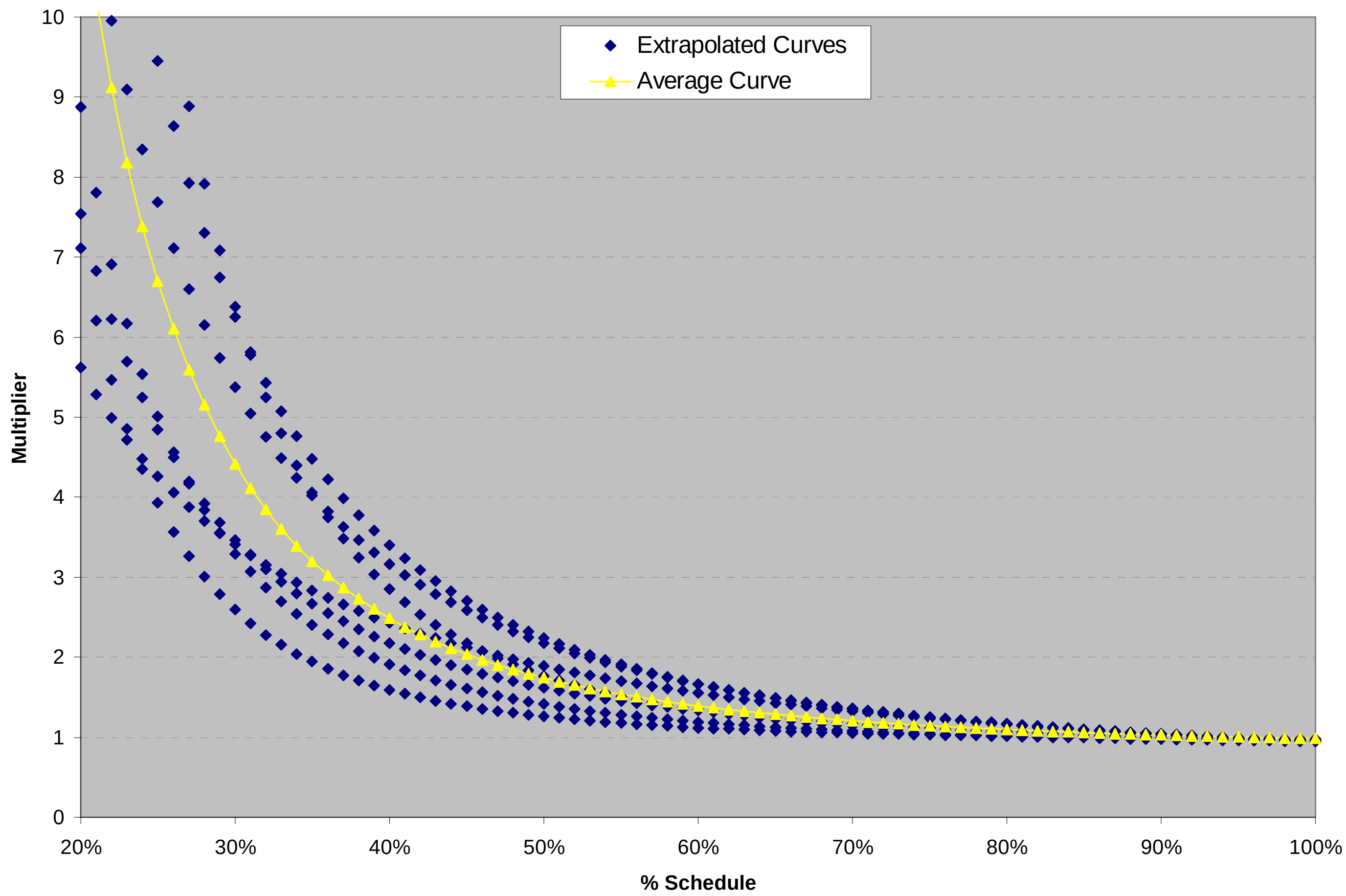
Extrapolated Power Curves



- Power curves for every release were extrapolated using a least squares method. An average power curve was then calculated from the seven extrapolated curves.
- This method could not be used because the error was too high compared to the actual data points

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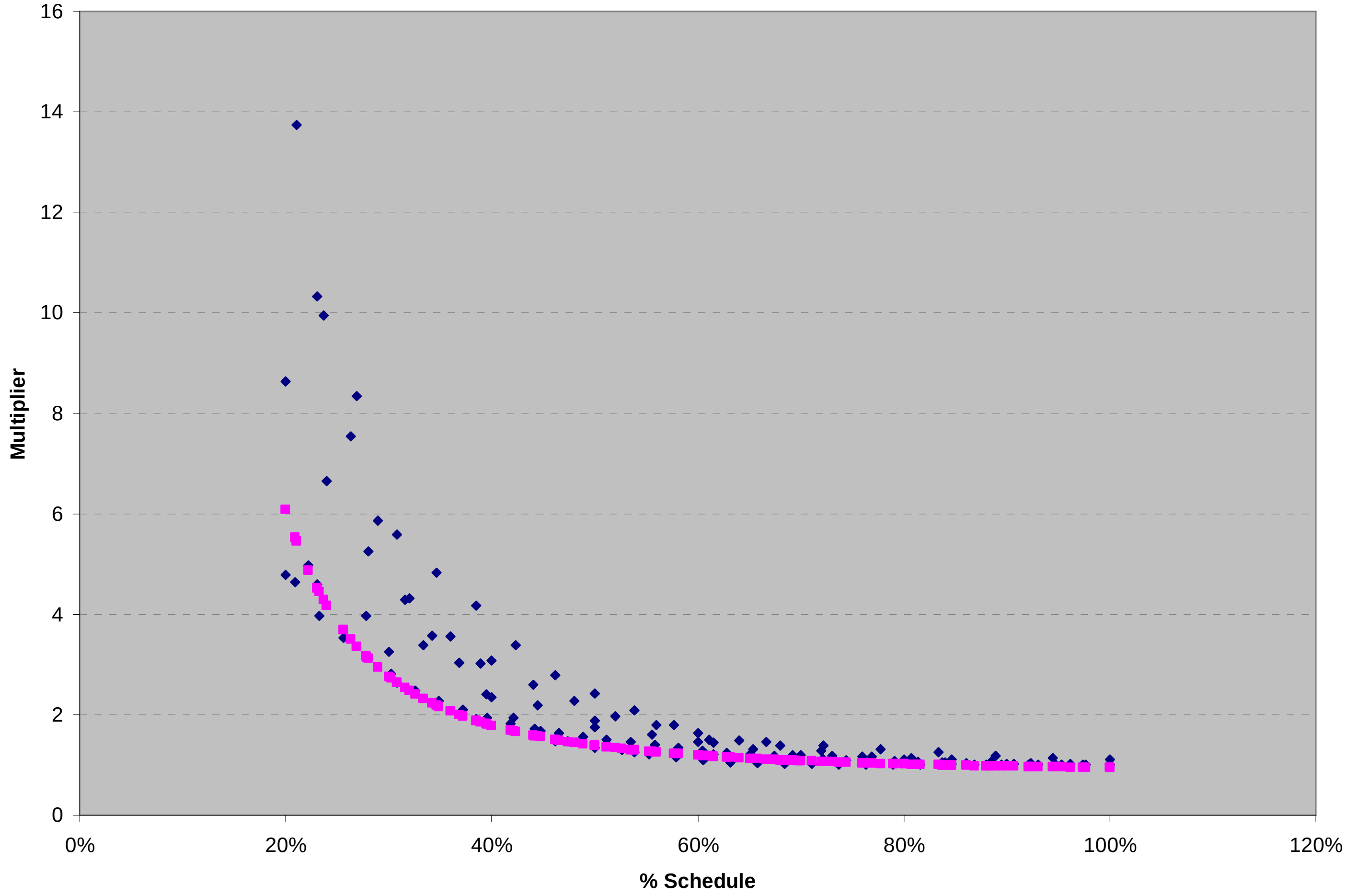
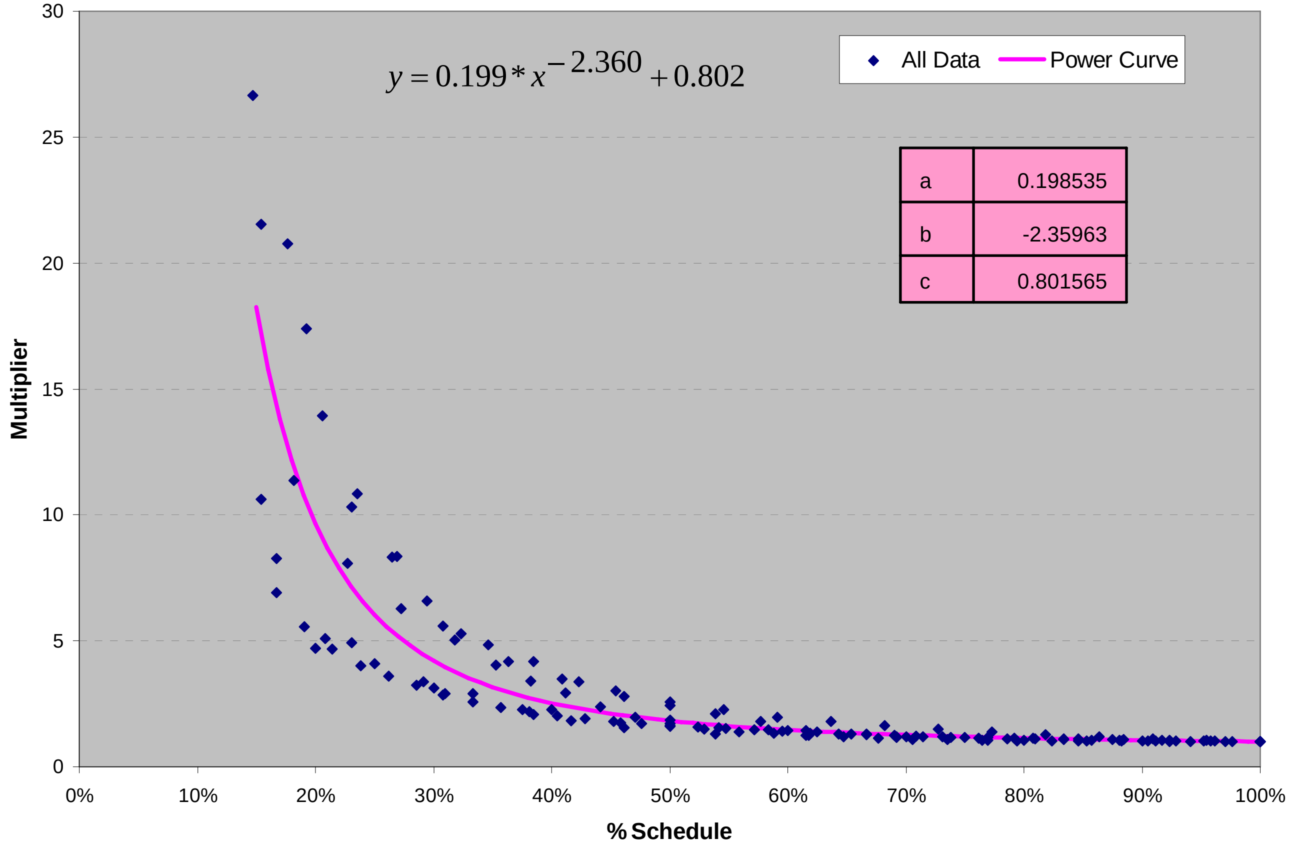
Sum of Squared Errors (SSE) for ACWP



- In order to try and minimize the error from the extrapolated curves a least squares method was used to minimize the error of the predicted final cost. This skewed the power curve towards the most expensive release and therefore it consistently underestimates the other releases.

Release-Specific Power Curves



a	0.198535
b	-2.35963
c	0.801565

- Finally, least squares was used to minimize the sum of squared errors for the multiplier for all the releases
  - A least squares method was used outside the Excel engine in order to derive a y-intercept
- The power curves were derived from 15% on because of the extreme instability in the multiplier early on in the SW development
- This is the curve used for further analysis since it had a low error compared to the other families of curves and this method did not skew the curve towards the cost of a release

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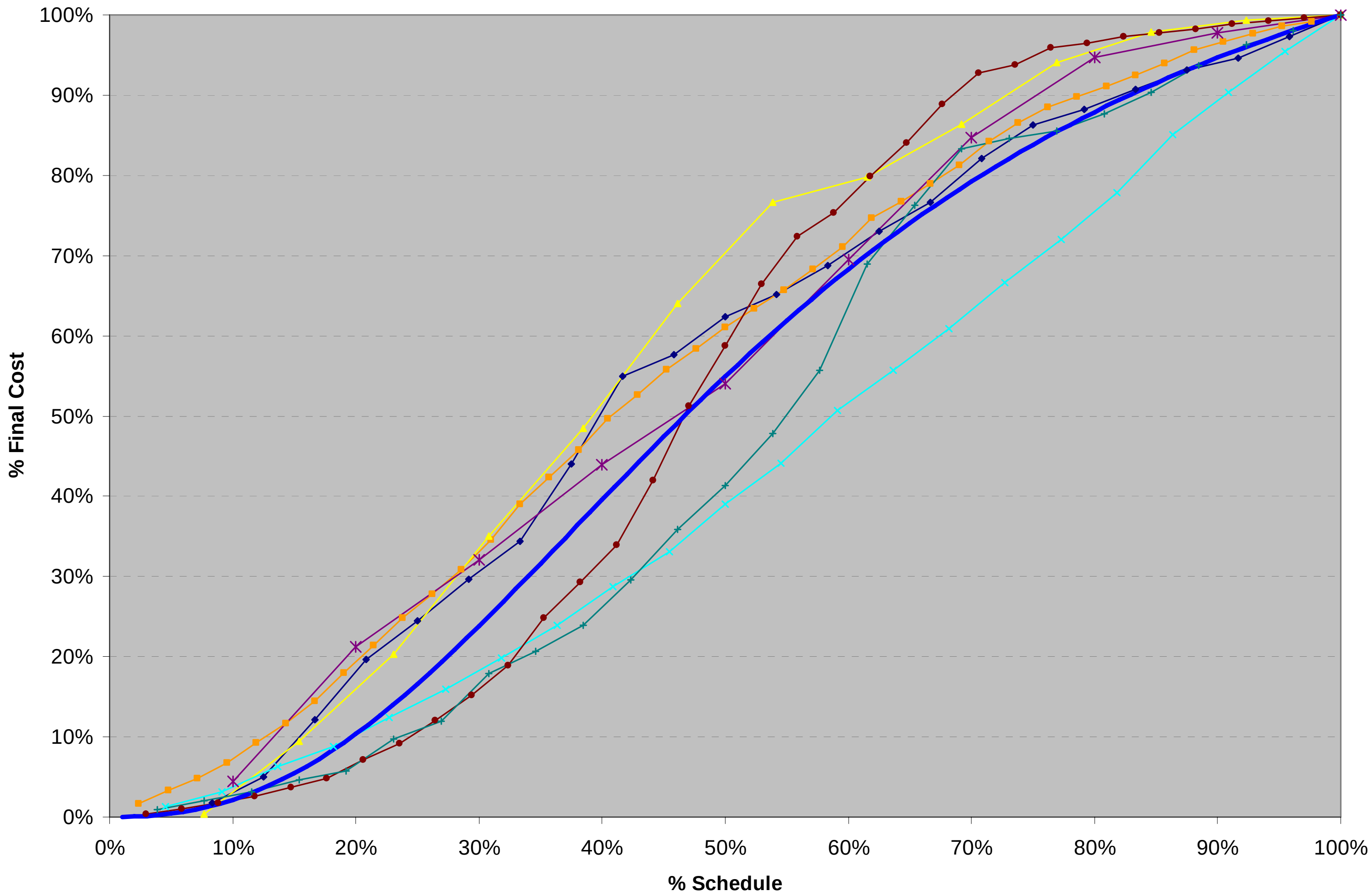
S-Curve Phasing



- The inverse of the power curve derived can be used to distribute total SW expenditures to match the S-curve that SW development generally follows.

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S-Curve Phasing (cont'd)

- If the total SW development costs have already been estimated (perhaps by a dollars per ELOC or hours per ELOC * $ per hour method) and the total projected length of the release is known then this curve can distribute the costs over the length of the release.

$$M = 0.198 * x^{-2.360} + 0.802$$

$$D = 1/M$$

X : % Schedule

M : Multiplier

D : Distribution

- This curve distributes the expenditures of releases while accurately modeling the ramping up and down over time due to the different phases of a software development effort

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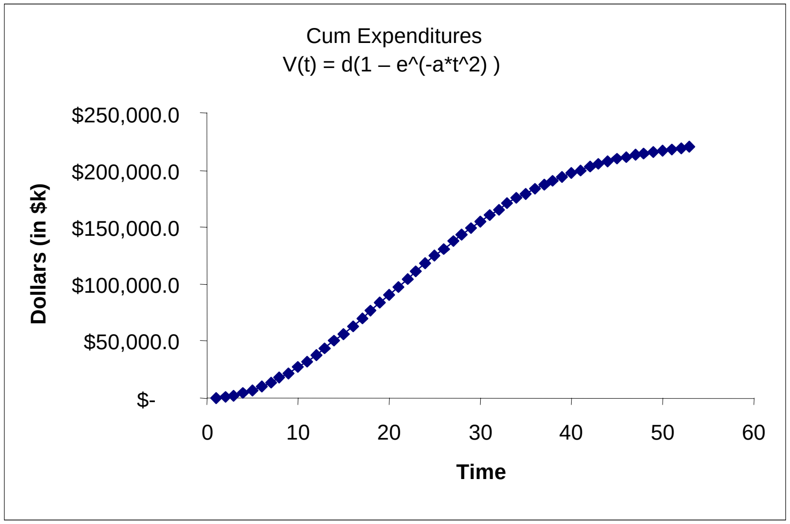
Rayleigh Curve

- A previous study[2] found that "the cumulative costs of R&D projects, derived from earned value systems, typically follow the Rayleigh distribution quite closely."

$$V(t) = d(1-e^{-at^2})$$

a : Shape Parameter d : Scale Factor
t : Time V : Total Effort

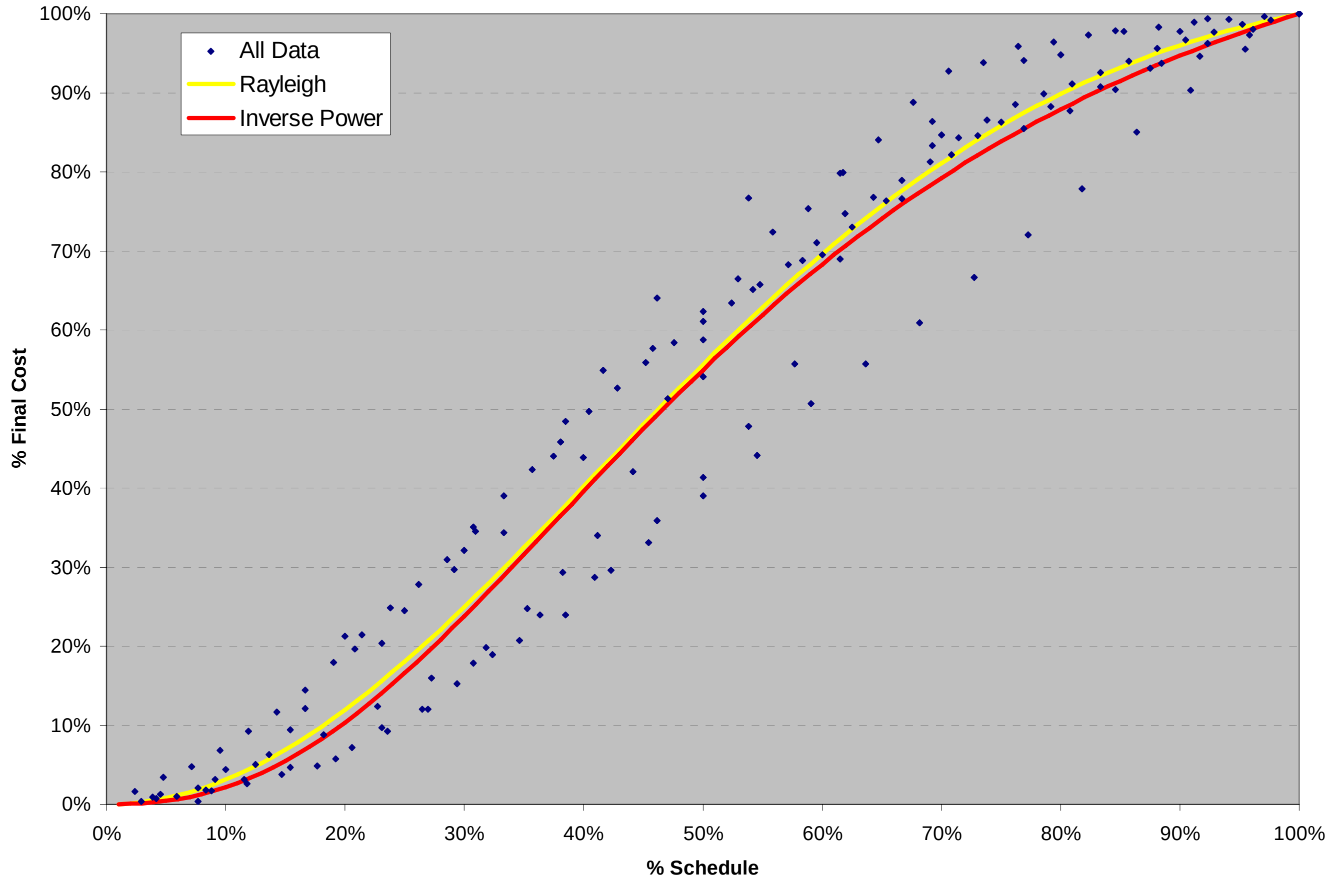
- A past study[3] concluded that "the Rayleigh curve offers tests for the reasonableness of a project's planned earned value phasing."
- Because the Rayleigh curve is an industry accepted distribution, it is important to compare the derived power curve to this standard



2. *Norden-Rayleigh Analysis: A Useful Tool for EVM in Development Projects*, David Lee, Logistics Management Institute, The Measurable News, March 2002

3. *Rayleigh Curves – A Tutorial.* Chelson, Heather; Coleman, Richard; Summerville, Jessica; and Van-Drew, Stephen. SCEA 2004, Manhattan Beach, CA. June 2004.

Rayleigh Curve Comparison



- *a* and *d* were derived by using a least squares method to minimize the error from the seven releases for the fitted Rayleigh curve
- The power and Rayleigh curves both fit the data well and the Rayleigh Curve did not have any lower error than our power curve; therefore, there is no reason to choose the Rayleigh curve over the derived power curve

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Derivation of the Inflection Point

- The inflection point represents the point in time in a release's schedule where expenditures begin to ramp down
- By taking the second derivative of the S-Curve, we are able to find the point of inflection
- The inflection point occurs at 38% of the schedule. This means that on average for the seven releases we examined, expenditures will start ramping down after 38% of the schedule is complete.
  - If the point of inflection is known and the expenditures have not begun to ramp down then it is highly probable that the schedule will not be met

$$M = ax^{b} + c$$

$$D = 1/(ax^{b} + c)$$

$$D' = -1/(ax^{b} + c)^{2} * ax^{b} * b/x$$

$$D'' = 2/(ax^{b} + c)^{3} * a^{2} * (x^{b})^{2} * b^{2}/x^{2} - 1/(ax^{b} + c)^{2} * ax^{b} * b^{2}/x^{2} + 1/(ax^{b} + c)^{2} * ax^{b} * b/x^{2}$$

$$D'' = 0 = a * b * (ax^{(2*b-2)} * b - x^{(b-2)} * b * c + x^{(2*b-2)} * a + x^{(b-2)} * c)/(ax^{b} + c)^{3}$$

$$x = \exp(\ln(c * (b - 1)/a/(b + 1))/b)$$

$$x = \exp(\ln(.802 * (-2.36 - 1)/0.198/(-2.36 + 1))/ - 2.36)$$

$$x = 0.38$$

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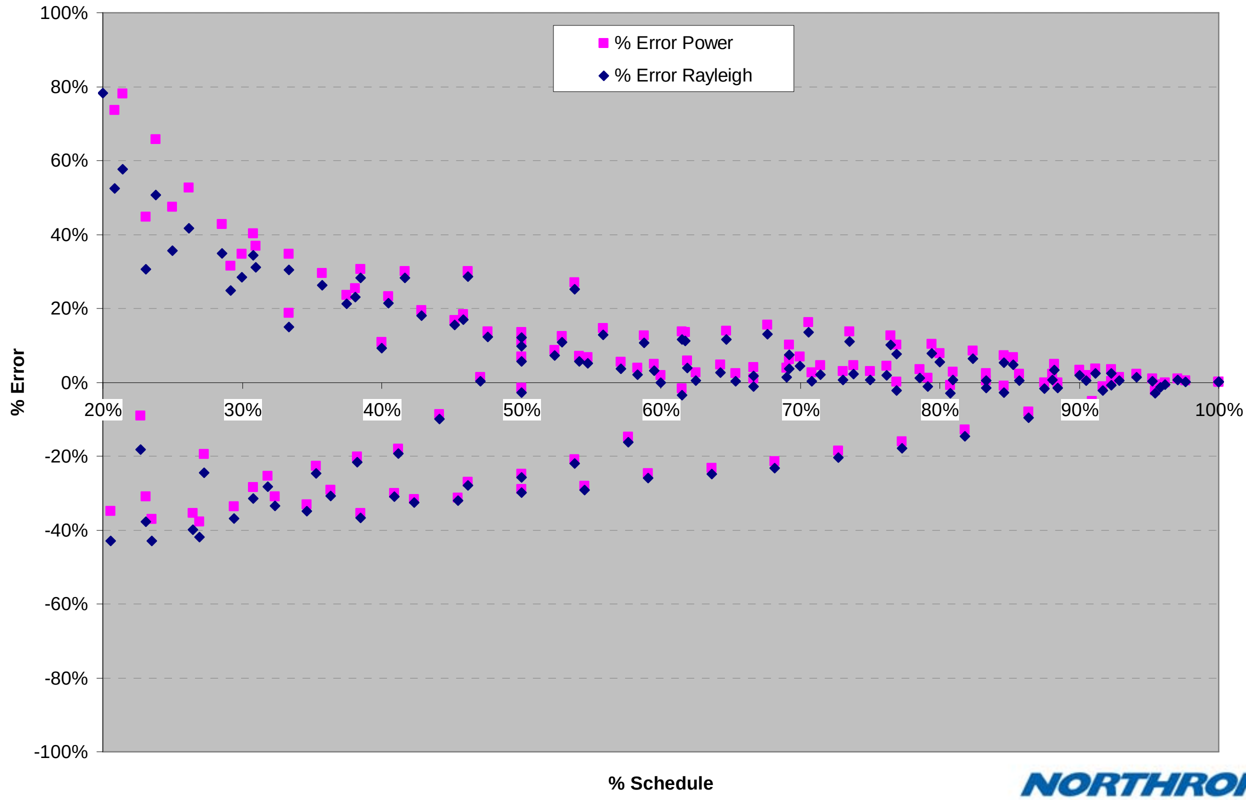
Error Check

- The first error check was for the Rayleigh curve and the power curve
- The two curves were used as predictors for the seven releases and the error was calculated based on the prediction and what the actual cost was
- The % of error is very high at the start then decreases the further along in the schedule for the release
  - This shows what would be expected; the further along in a release the better the estimate would be
- The two sets of errors are roughly the same. The Rayleigh curve has a slightly lower positive error but a higher negative error compared to the power curve



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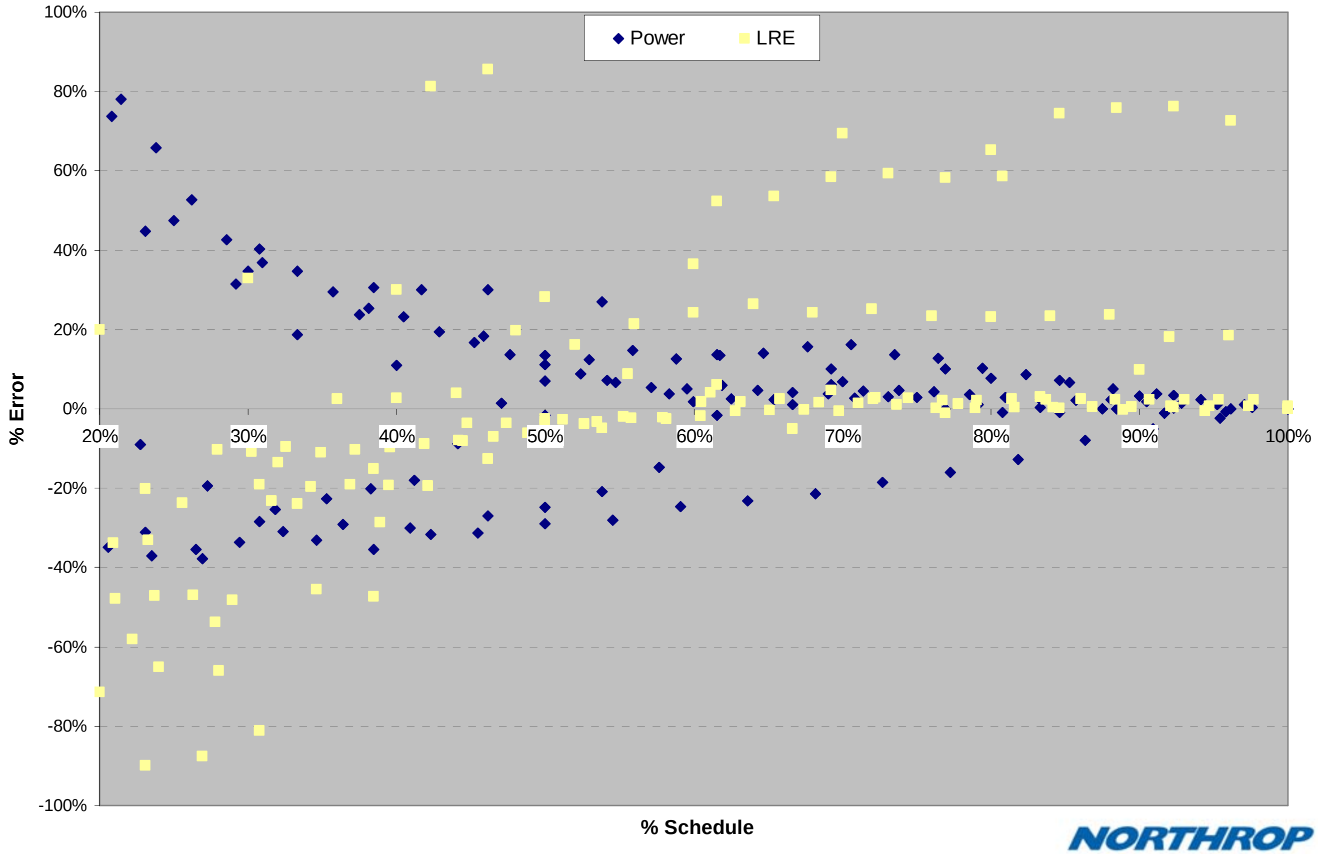
Error Check LRE

- The next error check performed was for the inverse power and the LRE
- The error for the LRE was taken as the actual final cost versus the LRE for each point in time and each release
- This check showed that the LRE was very inconsistent and generally very far off in predicting the final estimate for each release cost compared to the power curve



SW Tracking Tool

- As a tracking method for the LRE the derived power curve can be used to obtain a cross check
  - If there is EV data for an in-progress software release this methodology may be applicable
- Using the projected schedule for the release and the expenditures to date, an independent LRE can be determined

Total Length of the Release in Months
15

INPUTS					
Month	AcwpCum Release	AcwpCum Specific #1	AcwpCum Specific #2	AcwpCum Specific #3	AcwpCum Specific #4
1	$ 5.100				
2	$ 32.600				
3	$ 54.120				

OUTPUT				
%Schedule	Release Specific Cost	Non-Specific Cost	G&A, COM, & Fee	FINAL ESTIMATE
6.7%	$ 607.405	$ 258.729	$ 190.549	**$ 1,056.683**
13.3%	$ 777.535	$ 331.198	$ 243.921	**$ 1,352.654**
20.0%	$ 522.566	$ 222.592	$ 163.935	**$ 909.093**

Using the power equation and the % schedule, a multiplying factor can be obtained

Applying the multiplier to the ACWPcum obtains the independent LRE

The G&A, COM, & Fee are fixed percentages that can be changed by program

Note: The costs and percentages are not actuals but created for example purposes only

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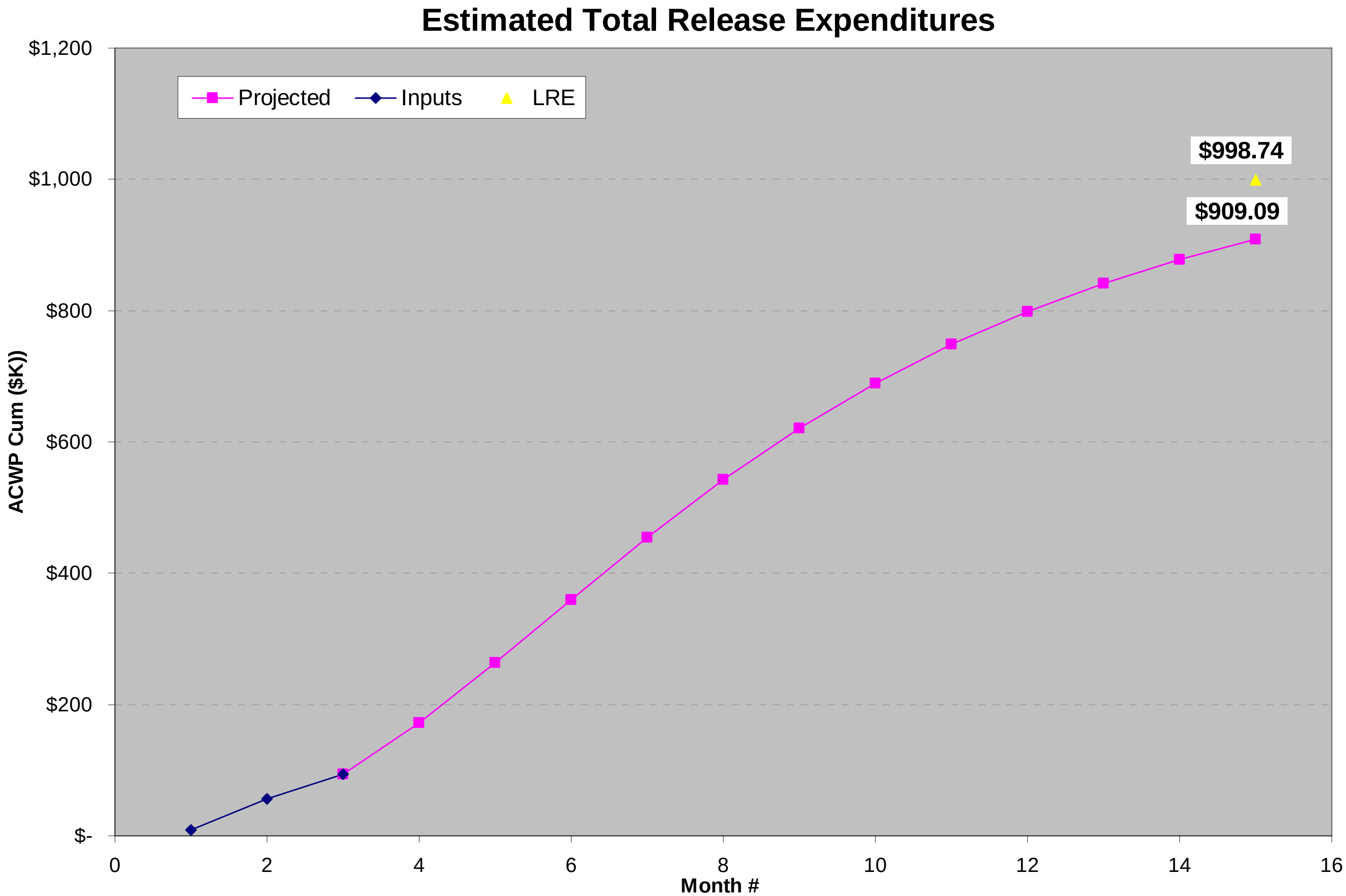
SW Tracking Tool (cont'd)



- An expenditure profile can be deduced from stemming the S-Curve back from the independent LRE to the reported EV data

Note: The costs and LRE are not actuals but created for example purposes only

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Conclusions

- The S-shape distribution of expenditures over time is the result of the ramping up and down of a SW development effort
  - Costs ramp up during the requirements review to the start of the coding phase and ramp down during the end of the coding stages to the testing phase
  - The point of inflection occurs at 38% of the schedule which is where it is expected that expenditures would begin to ramp down
- This study also explained the multiple derivations for curves to fit the data points
  - It was found that an inverse power curve using a least squares method to minimize the sum of squared errors for the multiplier was the curve that best fit our data
- The inverse power curve was compared to a Rayleigh distribution and there was found to be no significant difference between the two curves
- This study has concluded that an inverse power curve can be used as a means to distribute total software costs over the life of the development and that this curve can be used as a tracking tool to cross check the LRE in earned value data sets for software efforts

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Future Research

- Using this methodology, different power curves can be derived for different industries based upon a program's past performance
- This study is dependent on knowing the length of a software release
  - Through combining this study with the predicted schedule from a schedule realism tool[4], a final cost range can be obtained
  - Use past research on code growth to find a statistically significant relationship between code growth, schedule changes, and final expenditures

4. *Schedule Realism Prediction Band Tool.* Converse, Allison, Jaekle, Jeffrey, and Druker, Eric; SCEA, June 2007.

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References

- *Ending the EAC Tail Chase: An Unbiased EAC Predictor using Progress Metrics*. Druker, Eric; Coleman, Richard; Cullis, Bethia; Jaekle, Jeff; and Boyadjis, Elizabeth.. SCEA, June 2007.
- *Norden-Rayleigh Analysis: A Useful Tool for EVM in Development Projects*, David Lee, Logistics Management Institute, The Measurable News, March 2002.
- *Rayleigh Curves – A Tutorial.* Chelson, Heather; Coleman, Richard; Summerville, Jessica; and Van-Drew, Stephen. SCEA 2004, Manhattan Beach, CA. June 2004.
- *Schedule Realism Prediction Band Tool*. Converse, Allison, Jaekle, Jeffrey, and Druker, Eric; SCEA, June 2007.

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