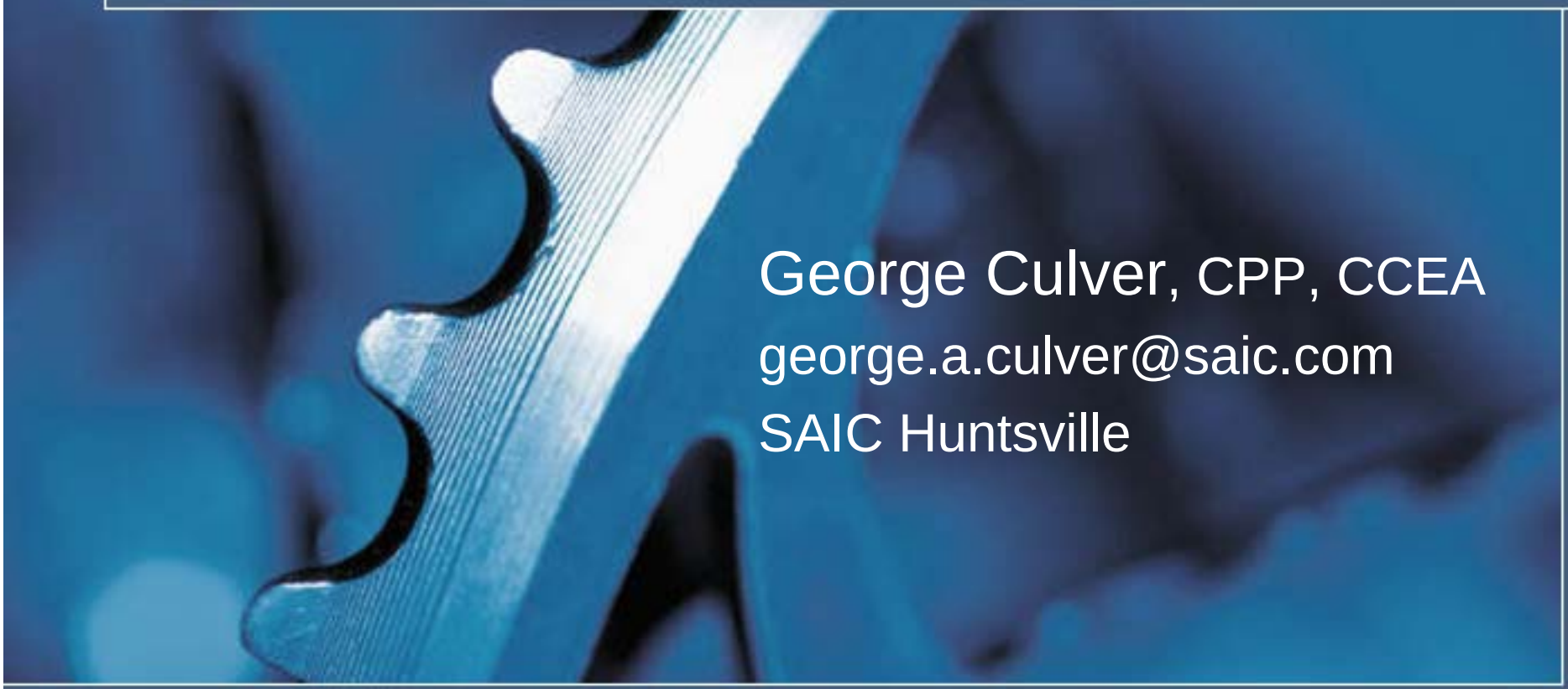
Parametric Schedule Estimation for Launch Vehicles



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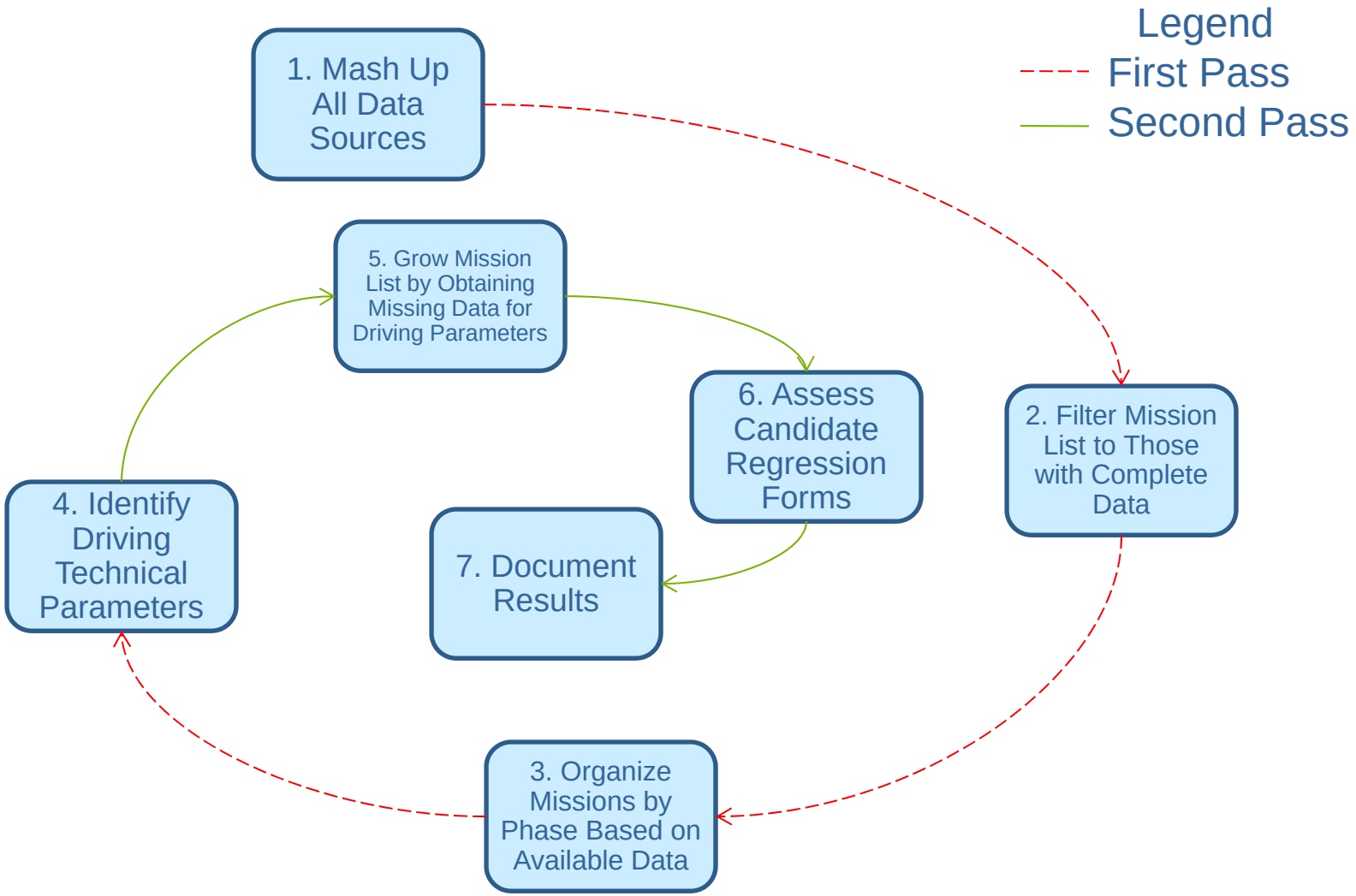
Rationale and Process Followed

- This investigation analyzes historical data to identify schedule drivers.
- Goal is to derive schedule estimating relationships (SERs) at the phase level.
  - Phase is defined as the duration between major project milestones.
- This investigation uses a 2-pass approach.

2-Pass Approach

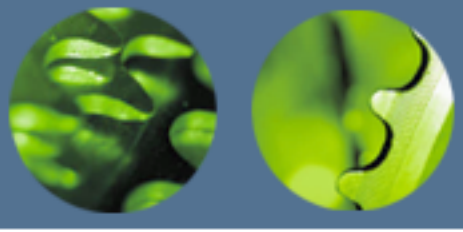


Data Sources

- Technical and schedule data used in this study came primarily from three sources:
  1. Rutkowski schedule database
  2. QuickCost database
  3. NAFCOM 2008 database

- Additional data obtained from the REDSTAR library to fill-in missing values.

https://redstar.saic.com



Missions Assessed

AE-3	HAWKEYE	SWAS	S-IVB	Magellan
AEM-HCMM	HEAO-1	TDRS-A	Skylab Airlock	Mariner-6
ALEXIS	HEAO-2	TOMSEP	Skylab OWS	Mariner-10
AMPTE-CCE	HEAO-3	TOPEX	Spacelab	MCO
ATS-6	HST OTA	UARS	SRB	MGS
Chandra	HST SSM	Apollo CSM & LM	SRM	Mars Odyssey
COBE	LANDSAT-1	Centaur-D	SSME	Mars Pathfinder
CRRESS	LANDSAT-4	Centaur-G’	X-33	MPL
DART	LANDSAT-7	External Tank	X-38 DPS	NEAR
DE-1	MAGSAT	Gemini	Cassini	Pioneer Venus
DE-2	MSTI 1	IUS	CONTOUR	Stardust
DSCS-II	NATO III	Lunar Rover	Deep Impact	Viking
ERBS	OSO-8	OMV	Galileo	Voyager 2
FAST	SAMPEX	Shuttle Orbiter	Genesis	
GRO	SCATHA	S-II	Lunar Prospector	

■ Earth Orbiting □ Launch Vehicle/Manned ■ Planetary

SER Generation Results (1 of 2)

- SERs generated with full mission set for 4 schedule durations

Phase	Approach	Number of Points	F-Test p-value	Pearson's R-Sq	SEE
Start-PDR	Multiplicative (Mission Class Avg)	87	0.036	0.274	0.88
	Multiplicative (Mission Class Trim Mean)	87	0.0437	0.267	0.881
	Additive	87	0.0289	0.281	1.22
PDR-CDR	Multiplicative (Mission Class Avg)	82	0.0121	0.325	0.635
	Multiplicative (Mission Class Trim Mean)	82	0.0141	0.32	0.636
	Additive	82	0.0543	0.275	1.091
Start-CDR	Multiplicative (Mission Class Avg)	87	0.0279	0.282	0.58
	Multiplicative (Mission Class Trim Mean)	87	0.0102	0.312	0.623
	Additive	87	0.006	0.327	1.31
CDR-Delivery	Multiplicative (Mission Class Avg)	61	<0.0001	0.628	0.42
	Multiplicative (Mission Class Trim Mean)	61	<0.0001	0.605	0.435
	Additive	61	0.0132	0.422	1.27

- In these runs, not much difference between multiplicative approaches
- Additive approach as good or worse than multiplicative
- No appreciable difference with PDR as a milestone
- No acceptable SERs up to CDR milestone using all missions

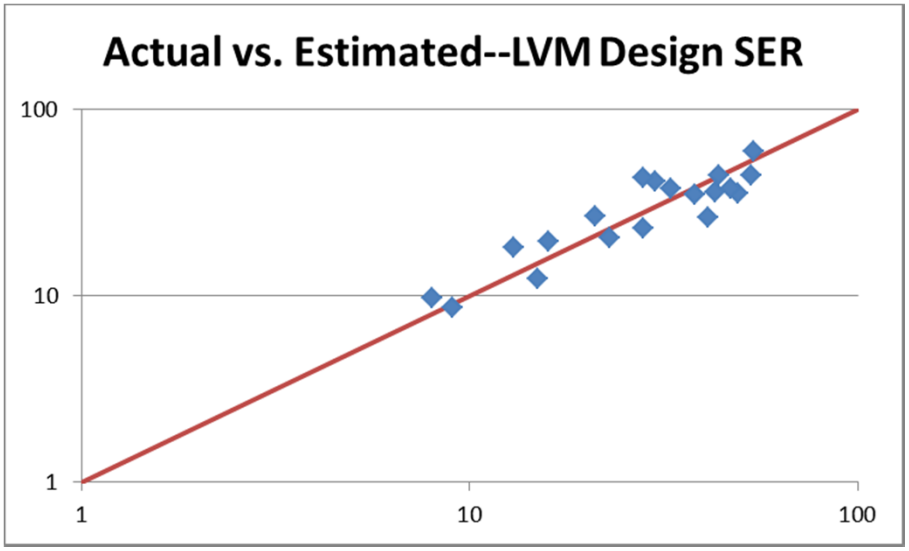
SER Generation Results (2 of 2)

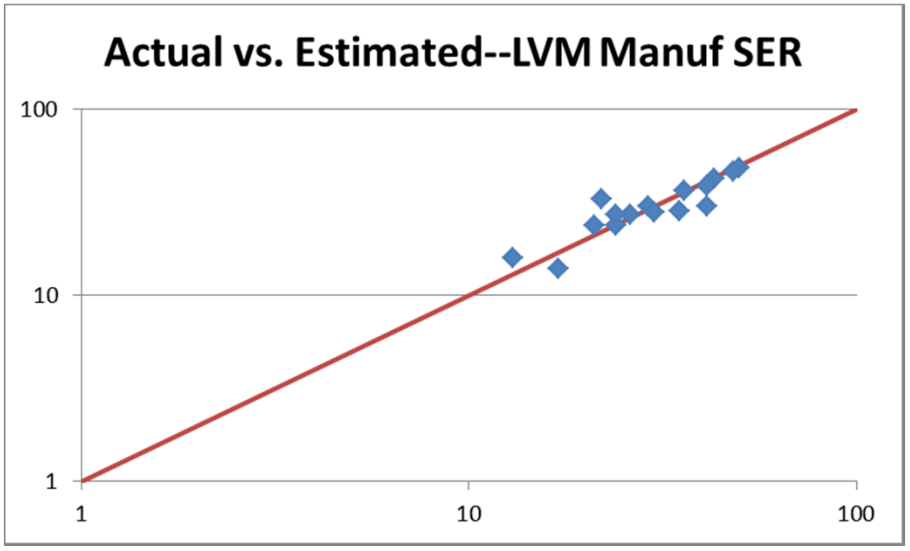
- Therefore, next step was to investigate Mission Class-specific SERs
  - Earth Orbiting (EO)
  - Launch Vehicle/Manned (LV/M)
  - Planetary (PL)
- This yielded more significant results

Phase	Mission Class	Number of Points	F-Test p-value	Pearson's R-Sq	SEE
Start-CDR (Design)	Earth Orbiting	35	<0.001	0.826	0.329
	Launch Vehicle / Manned	19	0.005	0.727	0.327
	Planetary	25	<0.001	0.804	0.227
CDR-Delivery (Manufacturing)	Earth Orbiting	22	<0.001	0.856	0.306
	Launch Vehicle / Manned	16	0.008	0.821	0.219
	Planetary	22	<0.001	0.751	0.301

Launch Vehicle/Manned SER Regression

$Start\_CDR\_Dur = 377.877\, FundAvail^{-0.779}\, ManufMethods^{-0.089}$ $StartYr^{0.124}\, StreamEM^{-0.432}\, \mathrm{Re}usable^{0.393}\, Crewed^{0.925}$ $PostApollo\, \mathrm{Re}qts^{0.366}\, Parallel^{-0.508}$	F Test p-value = 0.005 Pearson R^2 = 0.727 Est Std Error = 0.327
$CDR\_Delivery\_Dur = 13.768\, EngrMgmt^{0.177}\, PowerGen^{0.084}$ $StartYr^{-0.163}\, Crewed^{0.310}\, PostApollo\, \mathrm{Re}qts^{0.730}\, Parallel^{-0.968}$	F Test p-value = 0.008 Pearson R^2 = 0.821 Est Std Error = 0.219





Independent Variable Details

- Mix of indicator and numeric variables
- Heritage to NAFCOM Management Factor definitions
- Complexity Variable is sum of normalized Dry Weight, Maximum Data Rate, and Number of Instruments
  - Aggregated these variables to alleviate autocorrelation effects
  - Normalized to avoid effects of scale

	Indicator?	Units
CommSat	Yes	
Complexity - Dry Wt - MaxData - Num Instruments		pounds kbps
Crewed	Yes	
Design Life		Months
DoD-Owned	Yes	
Engr Mgt		
Funding Avail		
Great Obs Class	Yes	
Manuf Methods		
Off-the-Shelf Bus	Yes	
Parallelization	Yes	
Post-Apollo Man-Rated Requirements	Yes	
Power Generated		LEO Equiv Watts
Reusable	Yes	
RTG-Powered	Yes	
Start Year		Yr-1960
Streamlined Engr Mgmt	Yes	
Test Approach		

Regression Factor Trends

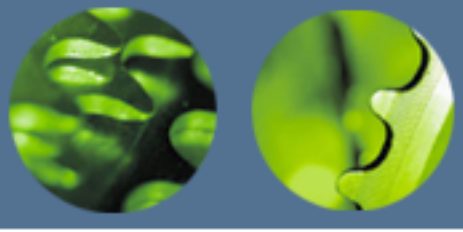
Are there any meaningful trends for SER regression factors?

- Project start year is the most common factor
- Engineering Mgmt significant in some capacity for all SERs
- Many class-specific factors significant

	Start-CDR			CDR-Delivery			Total
	EO	LV/M	PL	EO	LV/M	PL	
Start Year	X	X	X	X	X	X	6
Streamlined Engr Mgmt	X	X	X			X	4
Design Life	X		X	X			3
CommSat	X			X			2
Complexity	X					X	2
Crewed		X			X		2
DoD-Owned	X			X			2
Engr Mgt				X	X		2
Funding Avail		X	X				2
Great Obs Class	X			X			2
Manuf Methods	X	X					2
Parallelization		X			X		2
Post-Apollo Man-Rated Requirements		X			X		2
RTG-Powered			X			X	2
Off-the-Shelf Bus				X			1
Power Generated					X		1
Reusable		X					1
Test Approach	X						1

Legend

- X — Significant to SER
- Not significant
- Excluded from Analysis

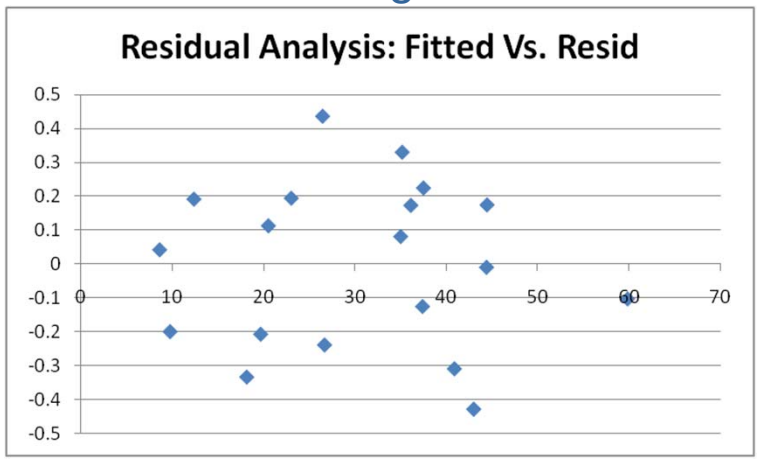


Regression Validation

- As a means of validation, the same data was used to generate SERs with a different regression method
  - Minimum Unbiased Percent Error (MUPE) selected
- Results obtained were nearly identical to log-transformed ordinary least squares (LOLS) regressions
  - Magnitude of coefficients changed very little—coefficients differed by less than 12%
  - Statistical significance very similar
  - Adds credibility to LOLS results
- Addition verification performed to test fundamental assumptions of LOLS regression

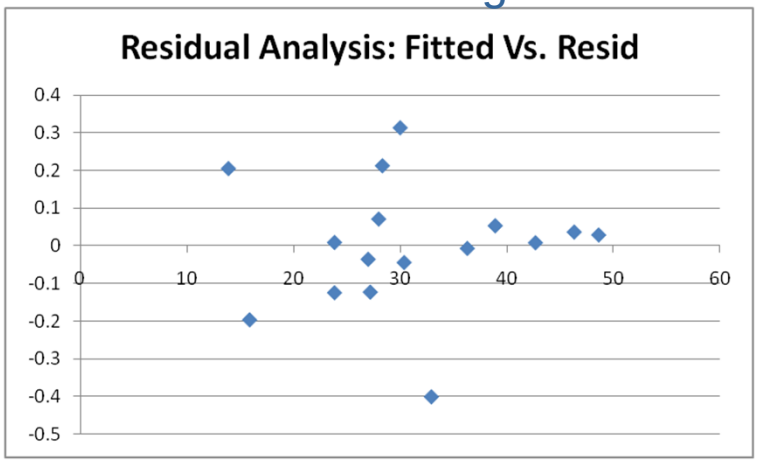
LVM SER Residual Analysis—Acceptable

LVM Design SER



Equal Variance Assumption: No significant trend evident, assumption valid.

LVM Manufacturing SER



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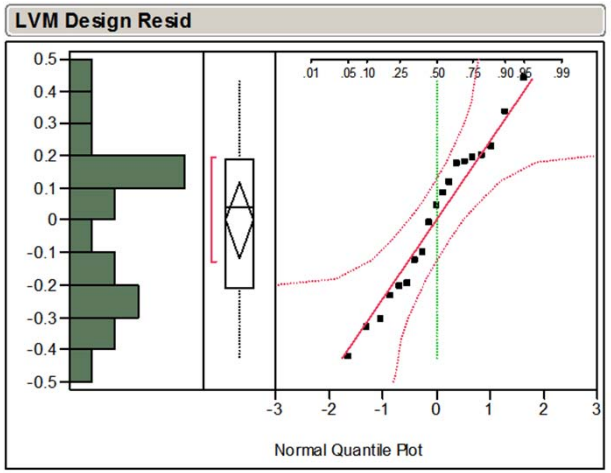
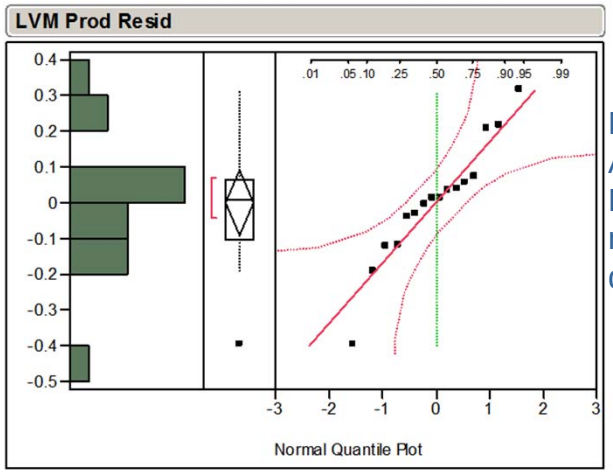


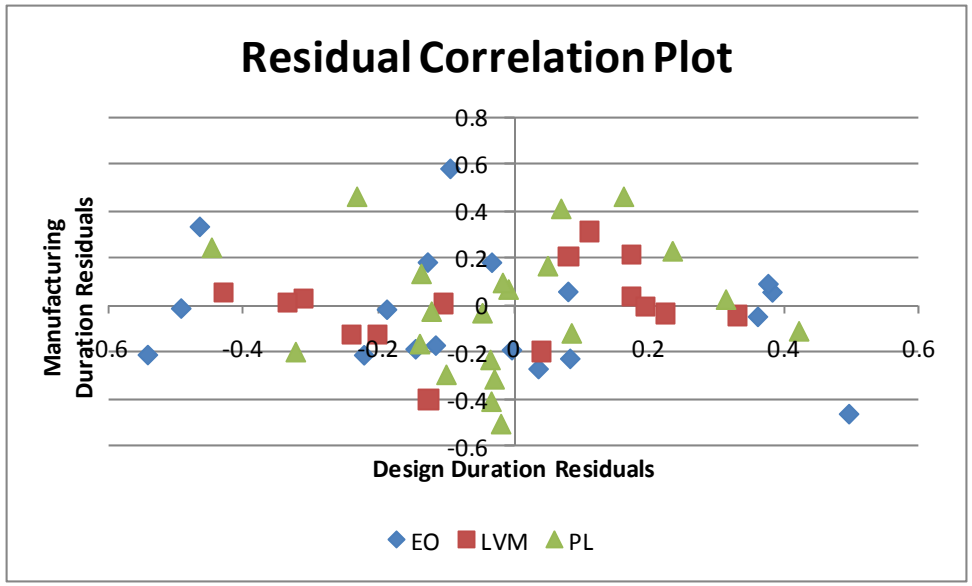
Normality Assumption: Log residuals normally distributed.



Normality Assumption: Log residuals normally distributed.

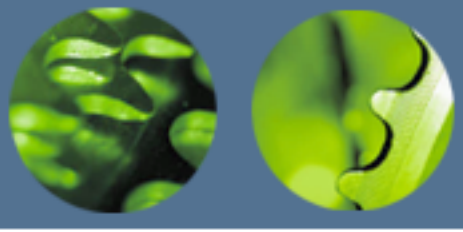
Design & Manufacturing Correlation

- Desirable to combine estimated design & manufacturing durations.
  - Means sum together
  - Garvey shows that variances sum with covariance factor
- Analysis shows there is no correlation between the design and manufacturing residuals.
  - Pearson's R^2 correlation of 0.0007
  - Covariance reduces to 0
- Straight sum of variance is appropriate.



Reference: Probability Methods for Cost Uncertainty Analysis, Paul Garvey, 1999.

SERRA Model—Inputs



Significant Inputs

Mission Type

Launch Vehicle/Manned

Options

☑ Schedule Risk

Schedule Drivers

	Units	Low	Most Likely	High
Development Start Year	1961+	2007	2007	2007
Engineering Mgmt	6 to 100	25	25	25
Funding Availability	25 to 75	75	75	75
Manufacturing Methods	6 to 100	50	50	50
Power Generated	Watts	12000	12000	12000
Reusable	yes/no		yes	
Crewed	yes/no		yes	
Post-Apollo Man-Rated	yes/no		yes	
Parallelization	yes/no		yes	

Analyze

SERRA Model—Outputs

		Design	Manuf	Total
Duration (months)	μ	24.5	26.9	51.4
	σ^2	31.54	68.67	100.21
	P =	3.17096	3.24729489	3.92028
	Q =	0.22674	0.3009655	0.19308

Summary Results

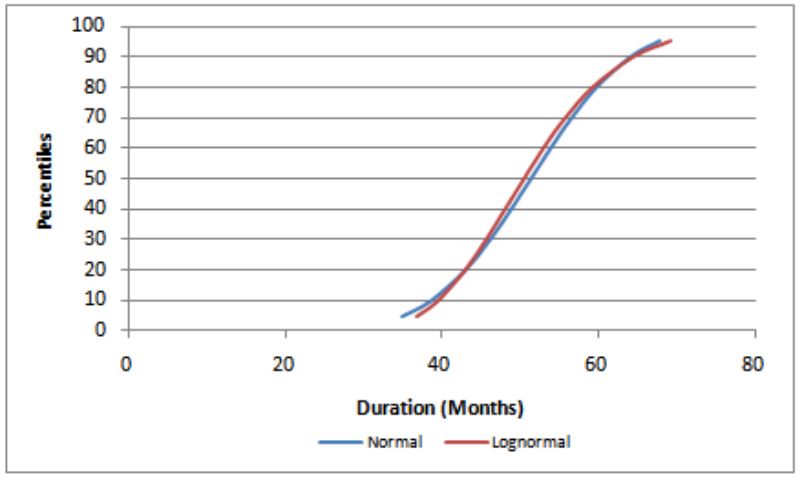
Outputs of Lognormal:

	Design	Manuf	Total
Mean	24.5	26.9	51.4
Median	23.8	25.7	50.4
Mode	22.6	23.5	48.6
σ	5.6	8.3	10.0
5th	16.4	15.7	36.7
10th	17.8	17.5	39.4
20th	19.7	20.0	42.9
30th	21.2	22.0	45.6
40th	22.5	23.8	48.0
60th	25.2	27.8	52.9
70th	26.8	30.1	55.8
80th	28.8	33.1	59.3
90th	31.9	37.8	64.6
95th	34.6	42.2	69.3

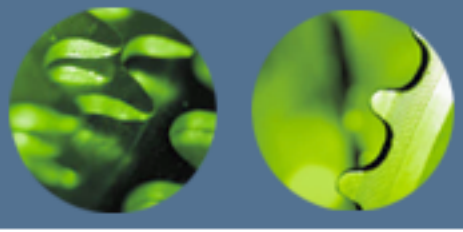
Outputs of Normal:

	Design	Manuf	Total
Mean	24.5	26.9	51.4
Median	24.5	26.9	51.4
Mode	24.5	26.9	51.4
σ	5.6	8.3	10.0
5th	15.2	13.3	34.9
10th	17.3	16.3	38.5
20th	19.7	19.9	42.9
30th	21.5	22.6	46.1
40th	23.0	24.8	48.8
60th	25.9	29.0	53.9
70th	27.4	31.3	56.6
80th	29.2	33.9	59.8
90th	31.6	37.5	64.2
95th	33.7	40.5	67.8

Tabular Results

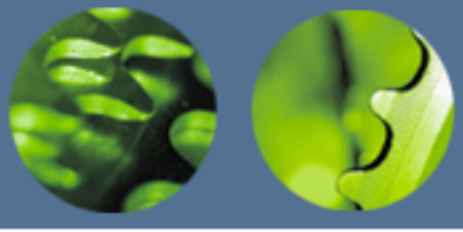


Graphical Results



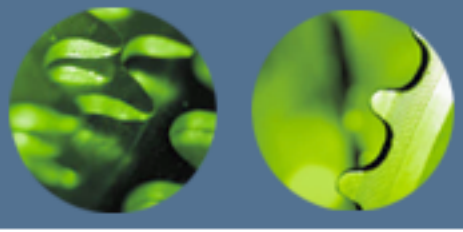
Conclusion

- Objective of this task was to investigate feasibility of SERs
  - Valid SERs have been generated & applied in existing joint confidence level analyses
  - Statistically significant results achieved
  - SERs employed in a model for immediate use
- Future work
  - Integrate into future version of NAFCOM
  - Refine SERs with new missions, additional effects



SERRA Model

- Schedule Estimating Relationships Risk Assessment (SERRA) model available for distribution
- Excel-based implementation of SERs
- Contact George Culver (george.a.culver@saic.com) for a copy



SUPPORTING DATA

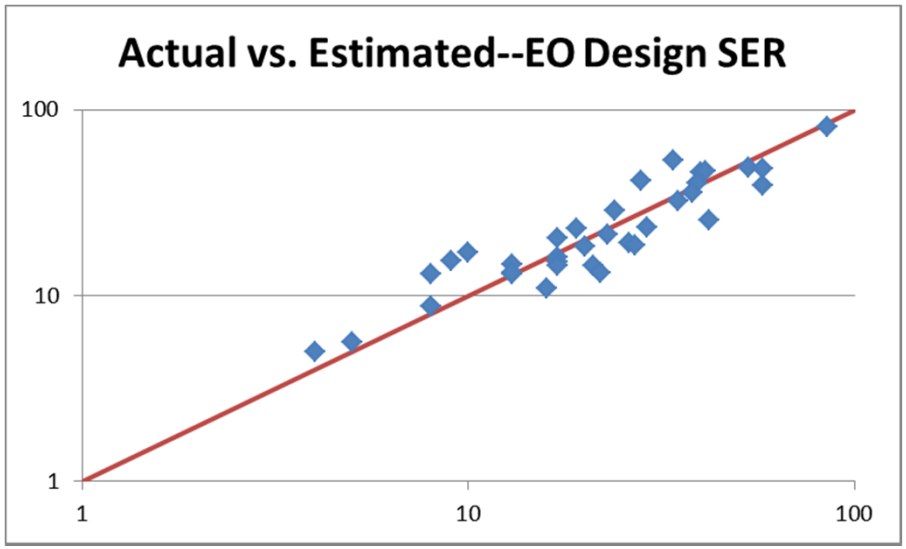
Earth Orbiting SER Regression

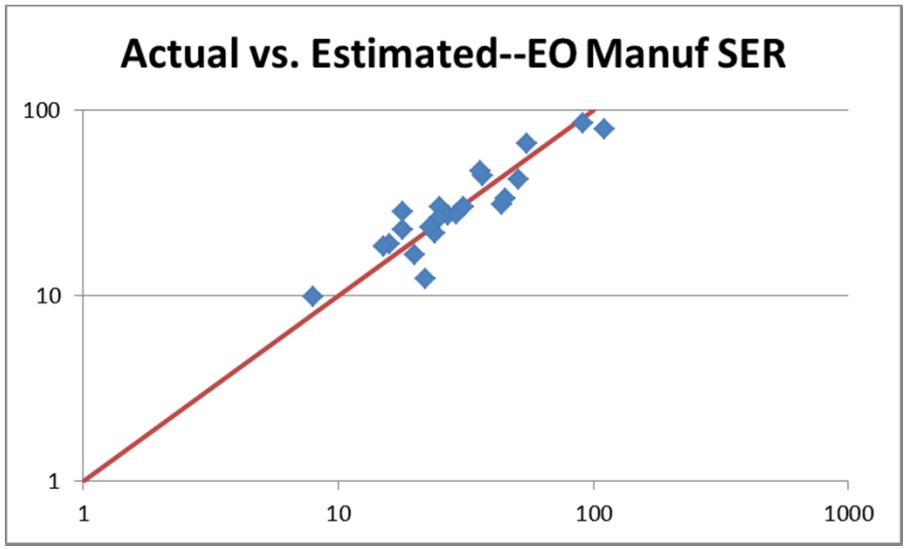
$$Start\_CDR\_Dur = 69.274[(DryWt - 50)/5000 + (NumInst - 1)/12 + MaxData/1024]^{0.203} TestAppr^{-0.488} ManufMethods^{-0.138} StartYr^{0.206} DesignLife^{0.158} StreamEM^{-0.260} Observatory^{0.729} CommSat^{0.443} Military^{-0.415}$$

F Test p-value = <0.001
Pearson R^2 = 0.826
Est Std Error = 0.329

$$CDR\_Delivery\_Dur = 0.551 EngrMgmt^{0.504} StartYr^{0.555} DesignLife^{0.212} Observatory^{0.156} CommSat^{-0.399} Military^{-0.437} Bus^{-0.441}$$

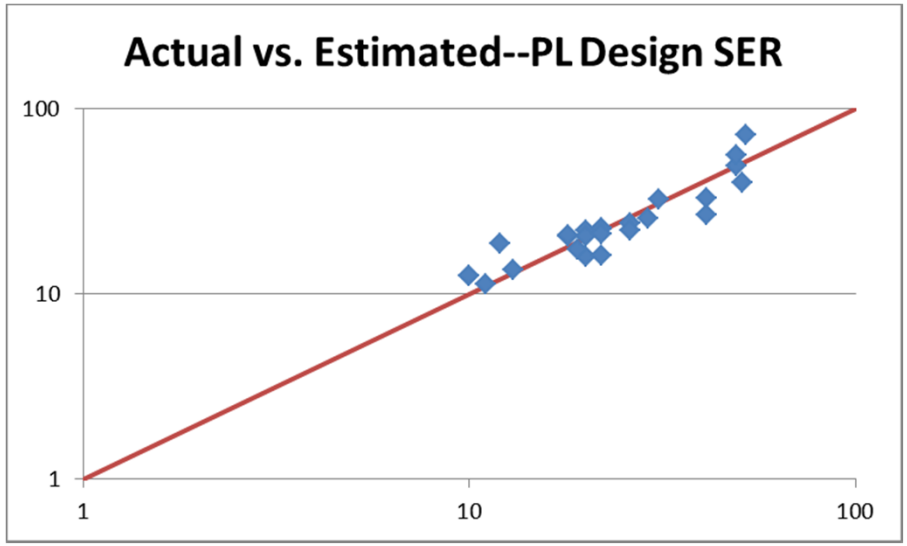
F Test p-value = <0.001
Pearson R^2 = 0.856
Est Std Error = 0.306

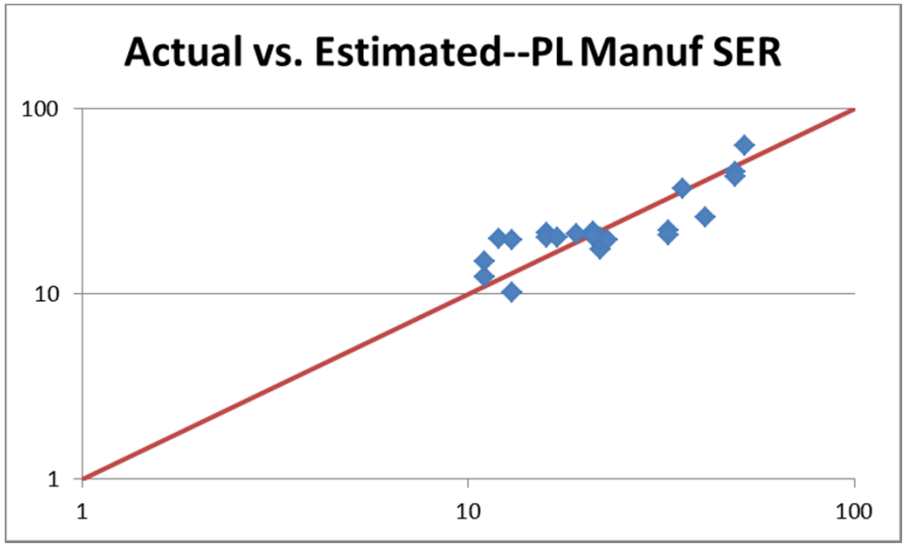




Planetary SER Regression

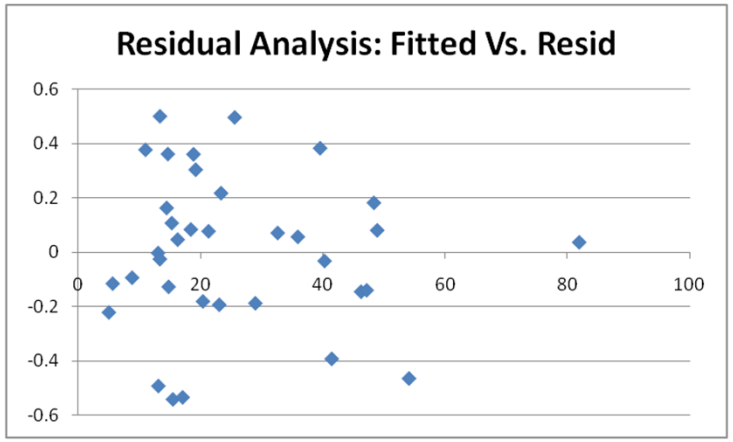
$Start\_CDR\_Dur = 0.759 FundAvail^{0.420} StartYr^{0.337} DesignLife^{0.229} StreamEM^{-0.393} RTG^{0.599}$	F Test p-value = <0.001 Pearson R^2 = 0.804 Est Std Error = 0.227
$CDR\_Delivery\_Dur = 5.279[(DryWt-100)/4000 + (NumInst-1)/12 + MaxData/256)]^{0.065} StreamEM^{-0.824} StartYr^{0.613} RTG^{0.376}$	F Test p-value = <0.001 Pearson R^2 = 0.751 Est Std Error = 0.301



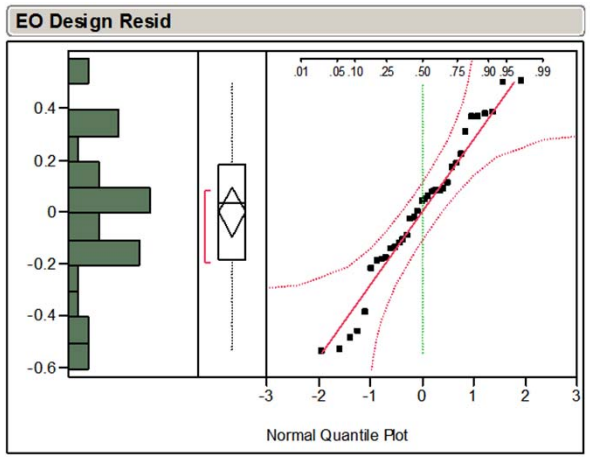


EO SER Residual Analysis—Acceptable

EO Design SER

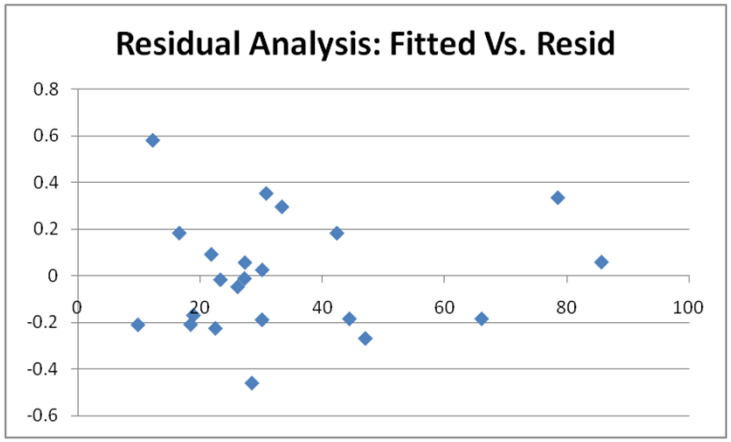


Equal Variance Assumption: No significant trend evident, assumption valid.

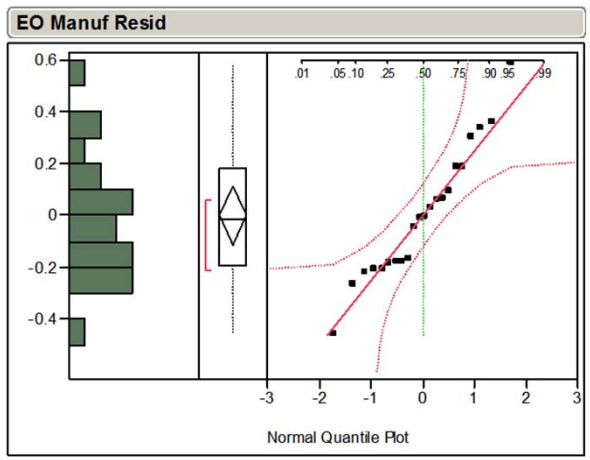


Normality Assumption: Log residuals normally distributed.

EO Manufacturing SER



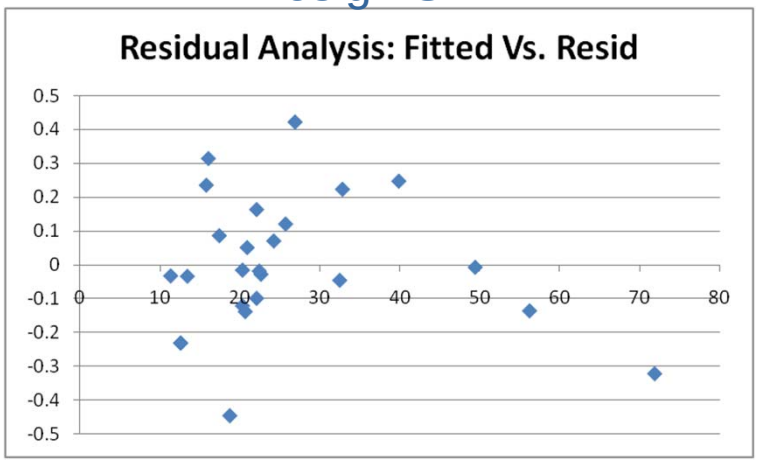
Equal Variance Assumption: Slight decreasing trend evident (cone), however assumption valid.



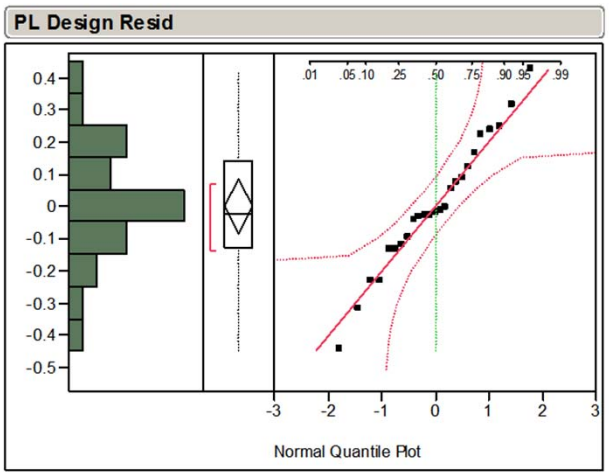
Normality Assumption: Log residuals normally distributed.

PL SER Residual Analysis—Acceptable

PL Design SER

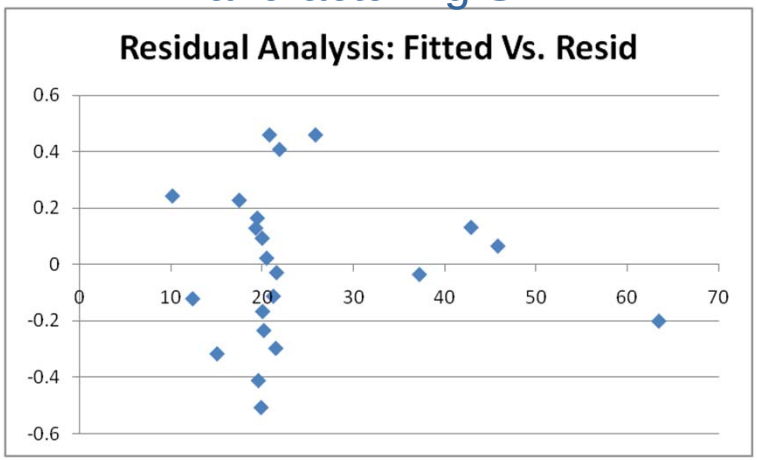


Equal Variance Assumption: No significant trend evident, assumption valid.

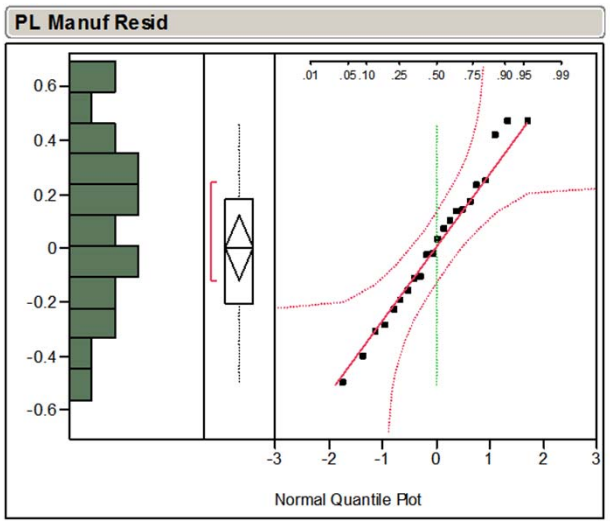


Normality Assumption: Log residuals normally distributed.

PL Manufacturing SER



Equal Variance Assumption: Slight decreasing trend evident (cone), however assumption valid.



Normality Assumption: Log residuals normally distributed.