
Early Phase Software Cost and Schedule Estimation Models



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June 10, 2015



Acknowledgement

- Dr. Shu-Ping Hu, Tecolote Research
- Dr. Brian Flynn, Technomics



Outline

- Introduction
- Experimental Design
- Data Analysis
- Descriptive Statistics
- Effort Models
- Schedule Models
- Conclusion

Introduction



Problem Statement

- Software cost estimates are more useful at early elaboration phase.
- The need for early phase estimating models has been plagued by 2 systemic problems:
 1. None of the popular size measures such as function points analysis (FPA) and sources lines of code (SLOC) are provided until after preliminary design review.
 2. Mainstream cost models typically use FPA and SLOC as size predictor.



Significance of Proposed Study

- This study will remedy these limitations in 3 ways:
 1. Introduce effort and schedule estimating models for software development projects at early elaboration phase
 2. Perform statistical analysis on parameters that are made available to analysts at early elaboration phase such as
 - **Estimated** functional requirements
 - **Estimated** peak staff
 - **Estimated** Effort
 3. Measure the direct effect of functional requirements on software development effort



Research Questions

Question 1:

Does estimated requirement relate to actual effort?

Question 2:

Do estimated requirements along with estimated peak staff relate to actual effort?

Question 3:

Does estimated effort relate to actual development duration?

Question 4:

Are estimating models based on Estimated Size more accurate than those based on Final Size?

Experimental Design



Quantitative Method

- A non-random sample was used since NCCA had access to names in the population and the selection process for participants was based on their convenience and availability (see next slide)
- This study focused on projects reported at the total level **rather than by CSCIs**, as requirements count at elaboration phase are provided at the aggregate level
- To minimize threats to validity the analysis framework focused on estimated inputs rather than final inputs



Instrumentation

- Questionnaire:
 - Software Resource Data Report” (SRDR) (DD Form 2630)
- Source:
 - Cost Assessment Data Enterprise (CADE) website:
http://cade.osd.mil/Files/Policy/Initial_Developer_Report.xlsx
http://cade.osd.mil/Files/Policy/Final_Developer_Report.xlsx
- Content:
 - Allows for the collection of project context, company information, requirements, product size, effort, schedule, and quality



Sample and Population

- Empirical data from 40 very recent US DoD programs extracted from the Cost Assessment Data Enterprise:

<http://dcarc.cape.osd.mil/Default.aspx>

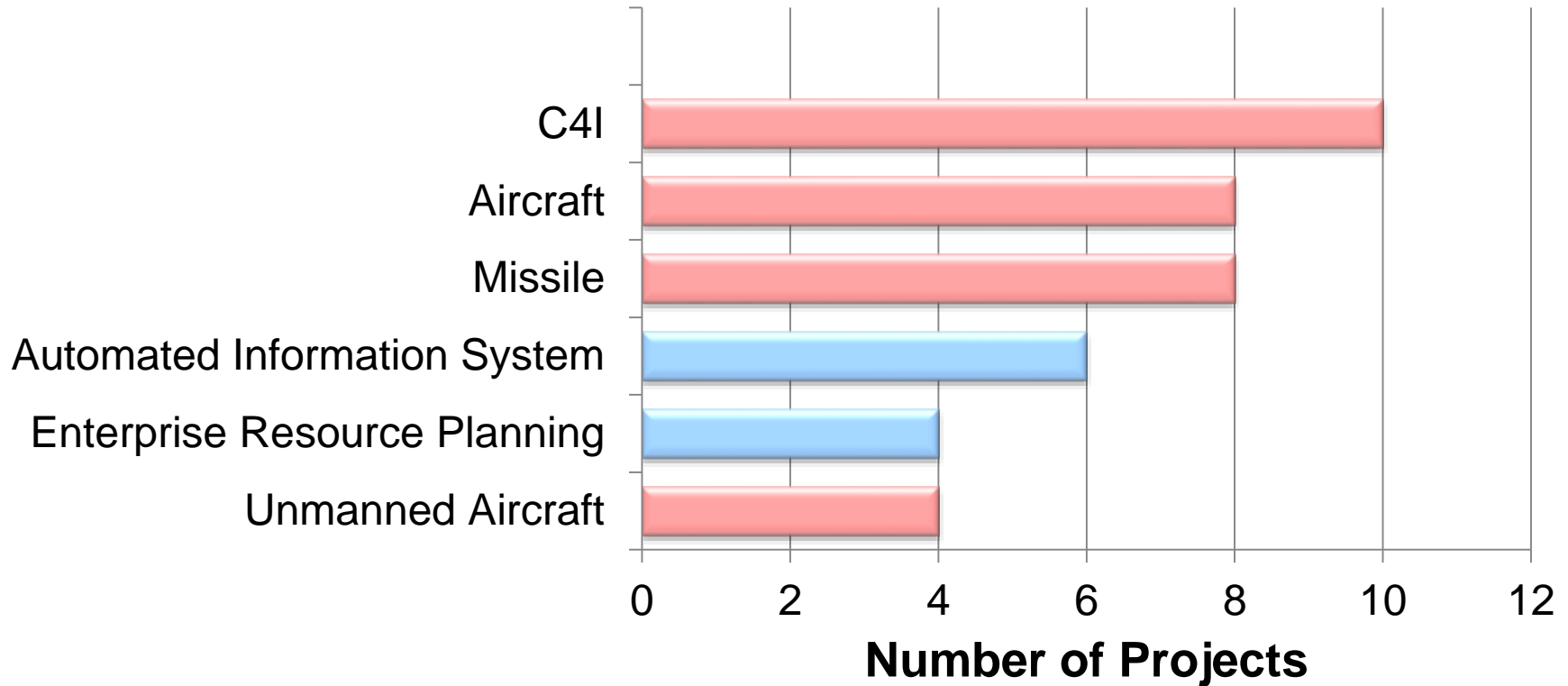
Each program submitted:



SRDR Initial Developer Report (**Estimates**)
&
SRDR Final Developer Report (**Actuals**)





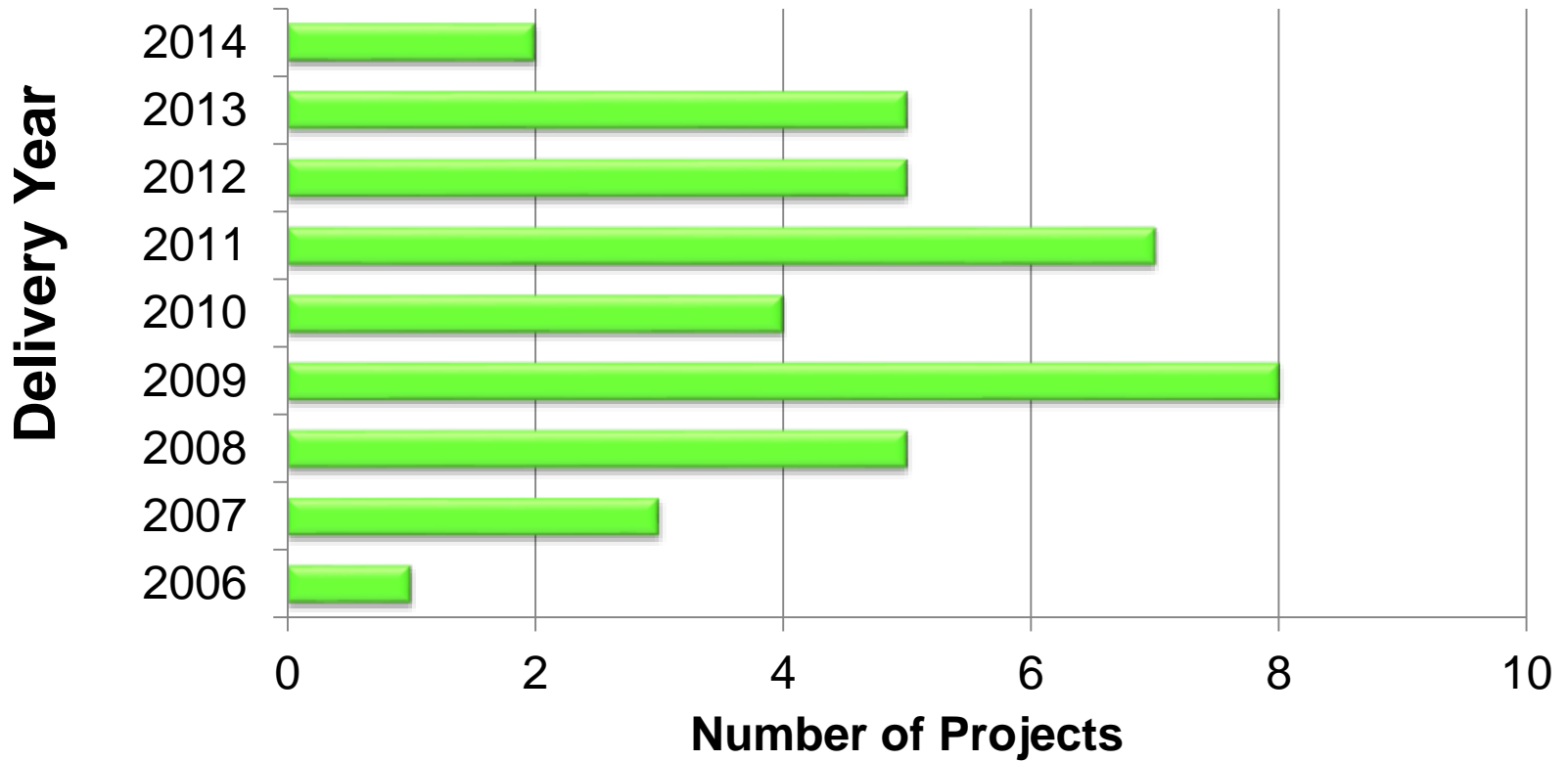
Operating Environments



-  Major Automated Information Systems (AIS)
-  Major Defense Systems



Project Delivery Year



Projects were completed during the time period from 2006 to 2014



Model Reliability and Validity

- Accuracy of the Models verified using five different measures:

Measure	Symbol	Description
Coefficient of Variation	CV	Percentage expression of the standard error compared to the mean of dependent variable. A relative measure allowing direct comparison among models.
P-value	α	Level of statistical significance established through the coefficient alpha ($p \leq \alpha$).
Variance Inflation Factor	VIF	Indicates whether multicollinearity (correlation among predictors) is present in a multi-regression analysis.
Coefficient of Determination	R^2	The Coefficient of Determination shows how much variation in dependent variable is explained by the regression equation.
F-test	F-test	The value of the F test is the square of the equivalent t test; the bigger it is, the smaller the probability that the difference could occur by chance.

Data Analysis



Pairwise Correlation Analysis

- Variable selection based on Pairwise Correlation
 - Pairwise Correlation chosen over structural equation modeling as the number of observations (40) was far below the minimum observations (200) needed
 - Variables examined:

Actual Effort

Actual Duration

Estimated Total Requirements

Actual Total Requirements

Estimated New Requirements

Actual New Requirements

Estimated Peak Staff

Actual Peak Staff

Scope

Volatility

Estimated Effort



Pairwise Correlation Analysis

	Actual Effort	Actual Duration	Estimated Total REQ	Actual Total REQ	Estimated New REQ	Actual New REQ	Estimated Effort	Actual Peak Staff	Estimated Peak Staff
Actual Effort	1.0	0.6	0.7	0.7	0.7	0.5	0.6	0.4	0.4
Actual Duration	0.6	1.0	0.4	0.4	0.5	0.3	0.2	-0.2	-0.2
Estimated Total Requirement	0.7	0.4	1.0	0.9	0.9	0.7	0.6	0.2	0.2
Actual Total Requirement	0.7	0.4	0.9	1.0	0.8	0.8	0.6	0.3	0.3
Estimated New Requirement	0.7	0.5	0.9	0.8	1.0	0.9	0.7	0.2	0.2
Actual New Requirement	0.5	0.3	0.7	0.8	0.9	1.0	0.5	0.5	0.4
Estimated Effort	0.6	0.2	0.6	0.6	0.7	0.5	1.0	0.6	0.6
Actual Peak Staff	0.4	-0.2	0.2	0.3	0.2	0.5	0.6	1.0	1.0
Estimated Peak Staff	0.4	-0.2	0.2	0.3	0.2	0.4	0.6	1.0	1.0
RVOL	0.1	0.1	0.0	0.0	0.5	0.2	0.1	0.1	0.1
Scope	0.2	-0.1	0.1	0.1	0.4	0.3	0.1	0.4	0.4

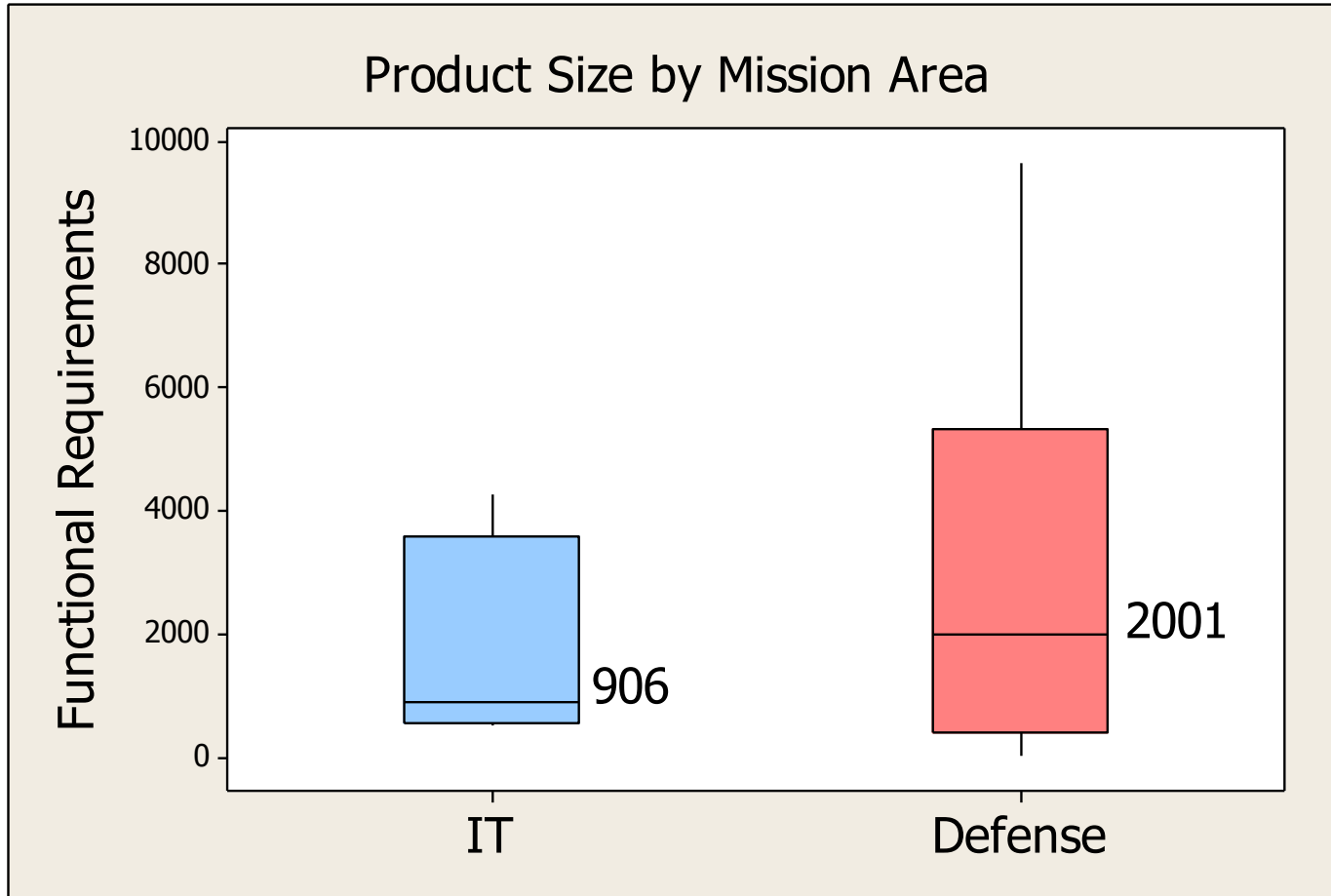
■ Strong Correlation
 ■ Moderate Correlation
 ■ Weak Correlation

- ❑ Estimated Requirements should be considered in the effort model, as it is strongly correlated to Actual Effort
- ❑ Estimated Peak Staff should also be considered in the effort model, as it is correlated to Actual Effort
- ❑ Although estimated effort is weakly correlated to actual duration, it was still chosen based past literature

Descriptive Statistics



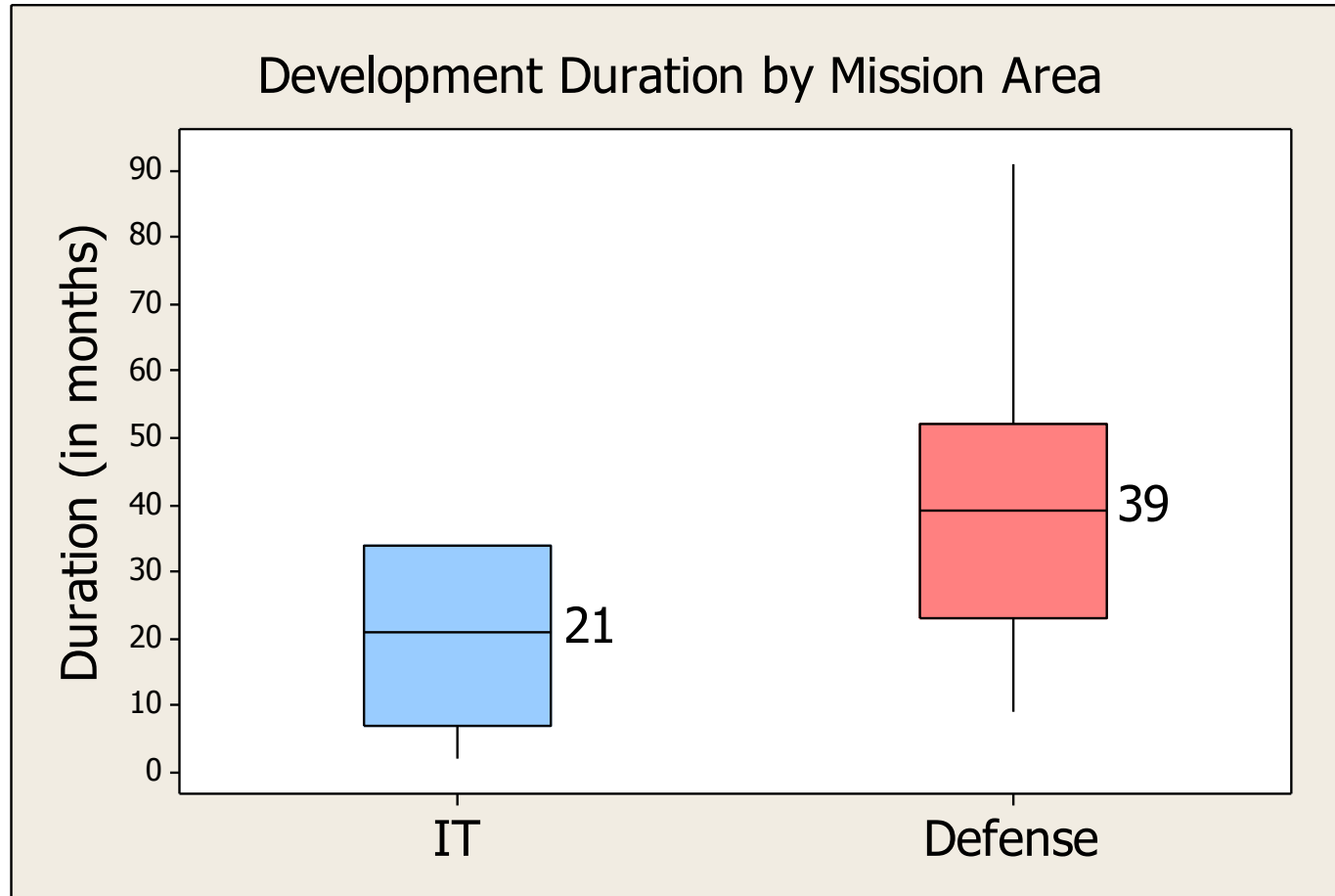
Project Size Boxplot



Observation: higher requirements count for defense projects



Project Duration Boxplot

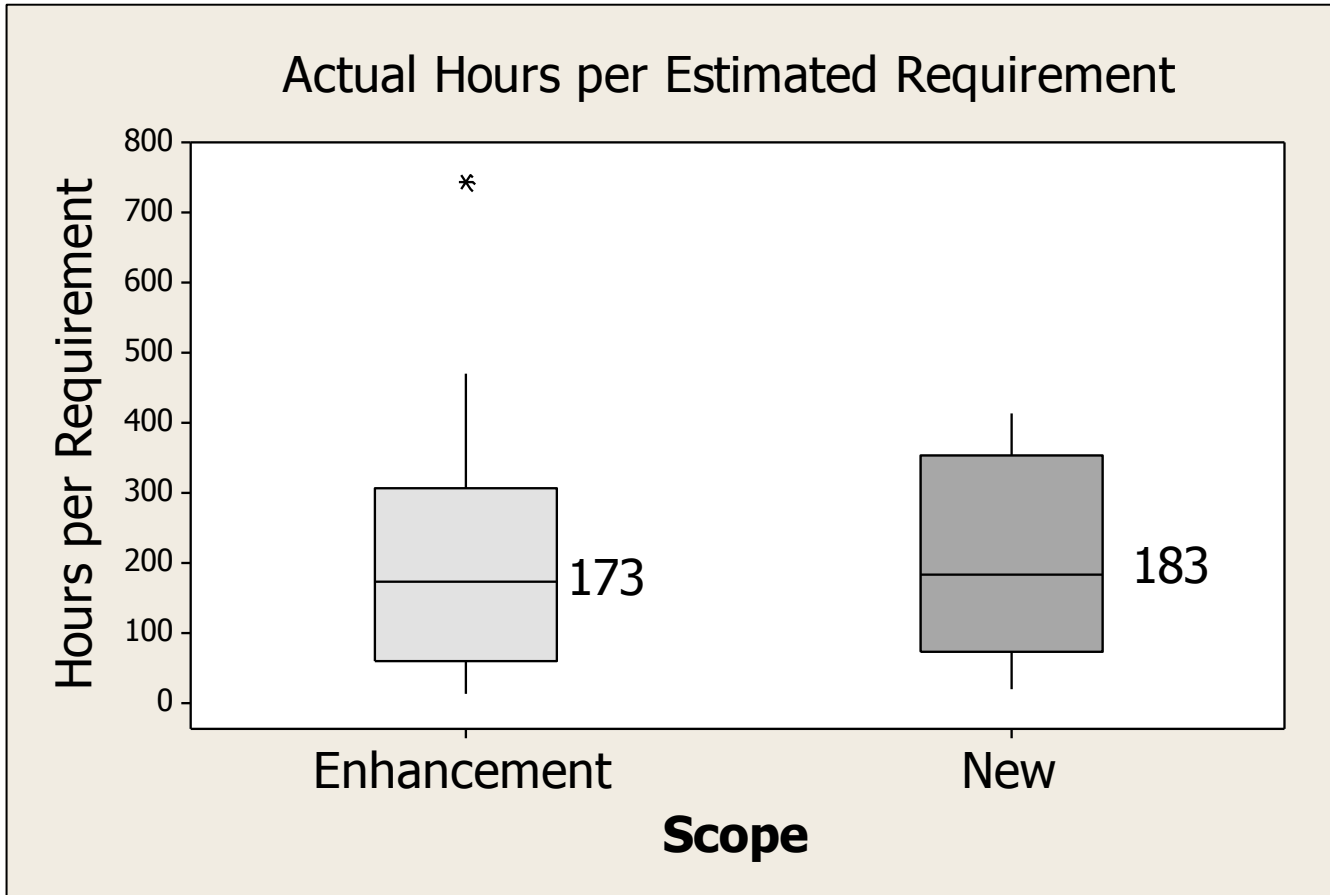


Observation: longer duration for defense systems due to interdependencies with hardware design and platform integration schedules.



Productivity Boxplot

New vs Enhancement

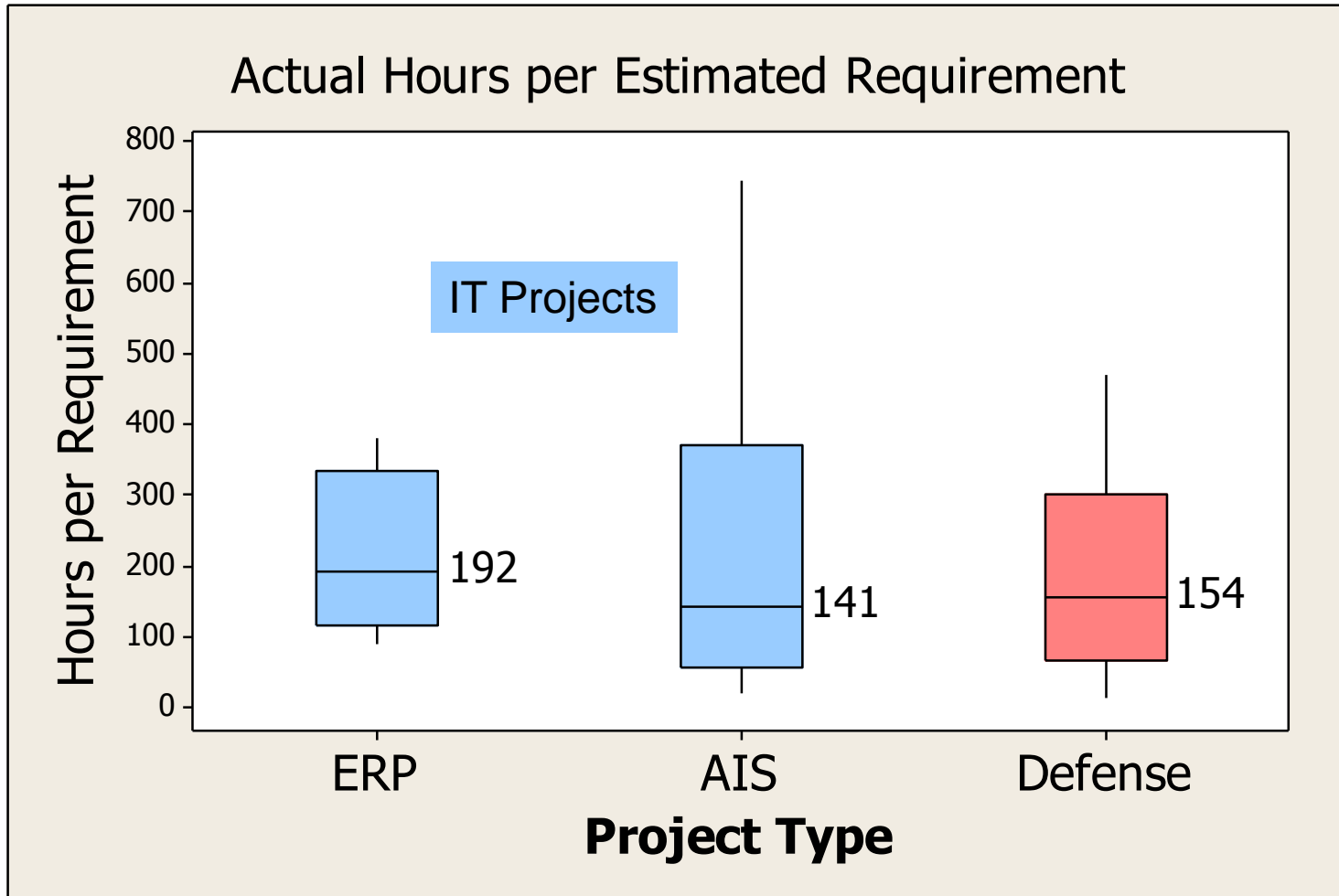


Observation: No significant difference between new and enhancement projects



Productivity Boxplot

IT vs Defense Projects



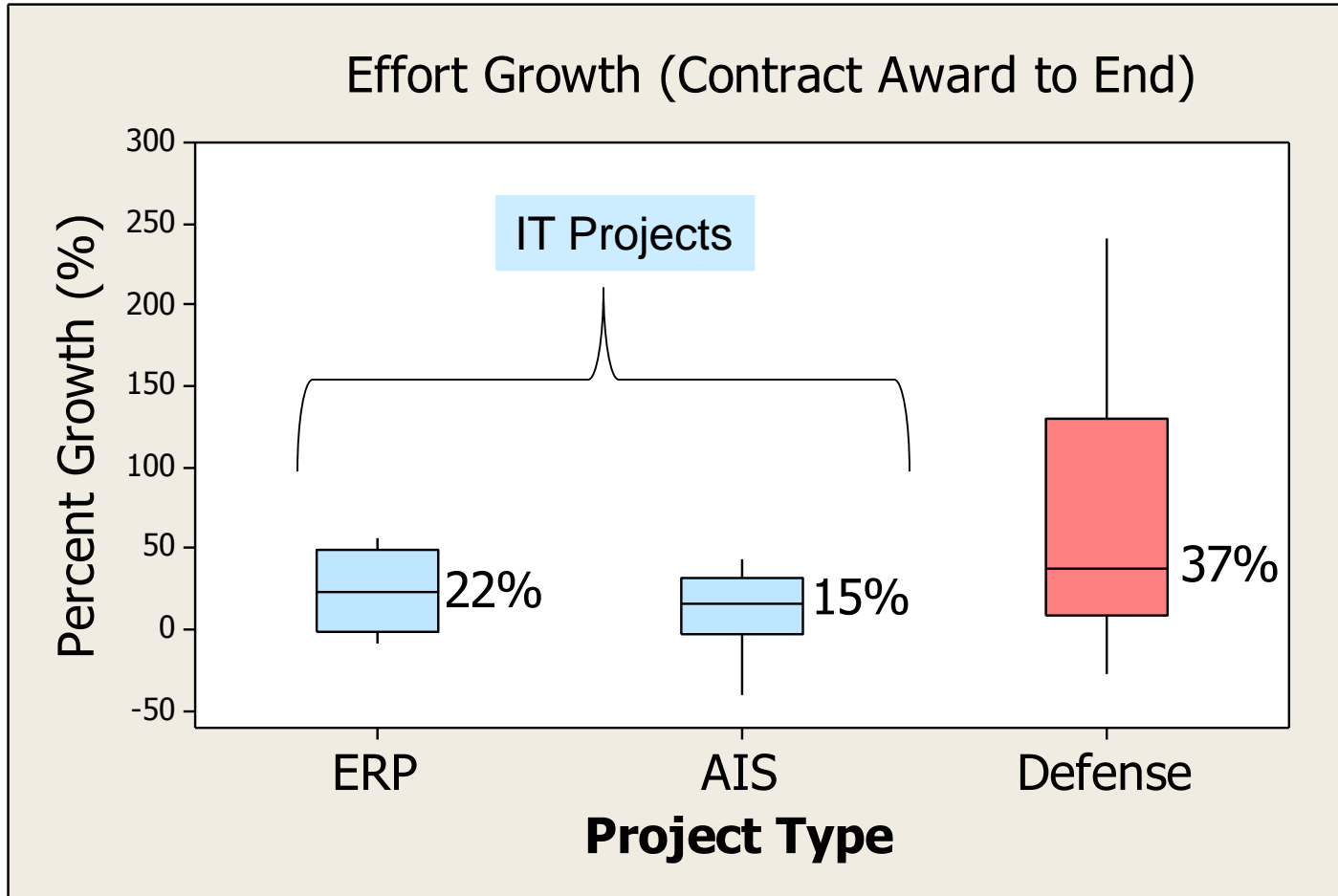
Observation:

- ERP shows higher “hours per requirement” due to challenges with customizing SAP/Oracle



Effort Growth Boxplot

Contract Award to End



Observation: No significant difference between Defense and IT projects

Effort Models



Effort Model Variables

Variable	Type	Definition
Actual Effort	Dependent	Actual software engineering effort (in Person-Months)
Actual Total Requirements	Independent	Total Requirements captured in the Software Requirements Specification (SRS). These are the final total requirements at end of contract.
Estimated Total Requirements	Independent	Total Requirements captured in the Software Requirements Specification (SRS). These are the estimated total requirements at contract award.
Actual Peak Staff	Independent	Actual peak team size, measured in full-time equivalent staff. Only include direct labor.
Estimated Peak Staff	Independent	Estimated peak team size at contract award, measured in full-time equivalent staff. Only include direct labor.



Effort Model 1: using Estimated REQ

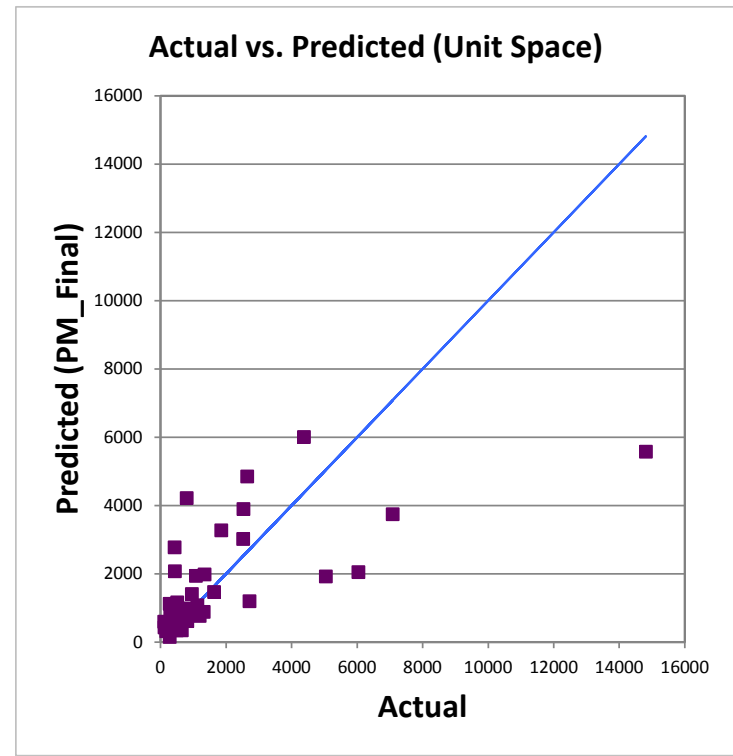
Equation:

Model Form	N	R ²	CV	Mean	MAD	REQ Min	REQ Max
$PM = 22.37 \times eREQ^{0.5862}$	40	76	64	1739	58	25	13900

Where:

- PM = Actual effort (in Person Months)
- eREQ = Estimated total requirements

Variable	Coeff	T stat
Intercept	22.37	1.8262
eREQ	0.5862	7.3870





Effort Model 2: using Actual REQ

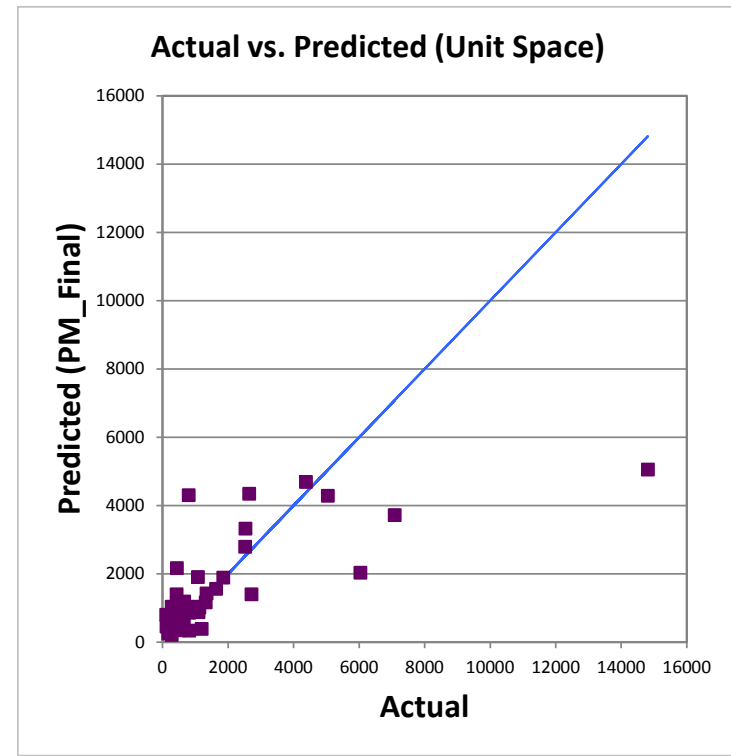
Equation:

Model Form	N	R ²	CV	Mean	MAD	REQ Min	REQ Max
PM = 29.08 x aREQ ^{0.5456}	40	74	54	1739	55	35	12716

Where:

- PM = Actual effort (in Person Months)
- aREQ = Actual total requirements

Variable	Coeff	T stat
Intercept	29.08	1.7464
aREQ	0.5456	6.600





Effort Model 3: using Estimated REQ and Staff

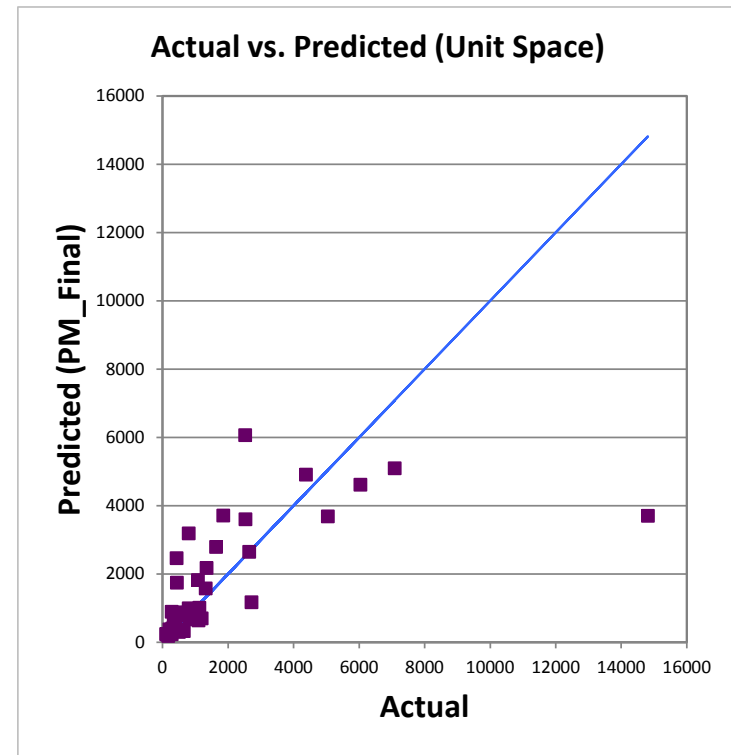
Equation:

Model Form	N	R ²	CV	Mean	MAD	REQ Min	REQ Max
$PM = 11.82 \times eREQ^{0.4347} \times eStaff^{0.4269}$	40	78	54	1739	47	25	13900

Where:

- PM = Actual effort (in Person Months)
- eREQ = Estimated total requirements
- eStaff = Estimated Peak Staff

Variable	Coeff	T stat
Intercept	11.82	1.8790
eREQ	0,4347	4.7140
eStaff	0.4269	3.5372





Effort Model 4: using Actual REQ and Staff

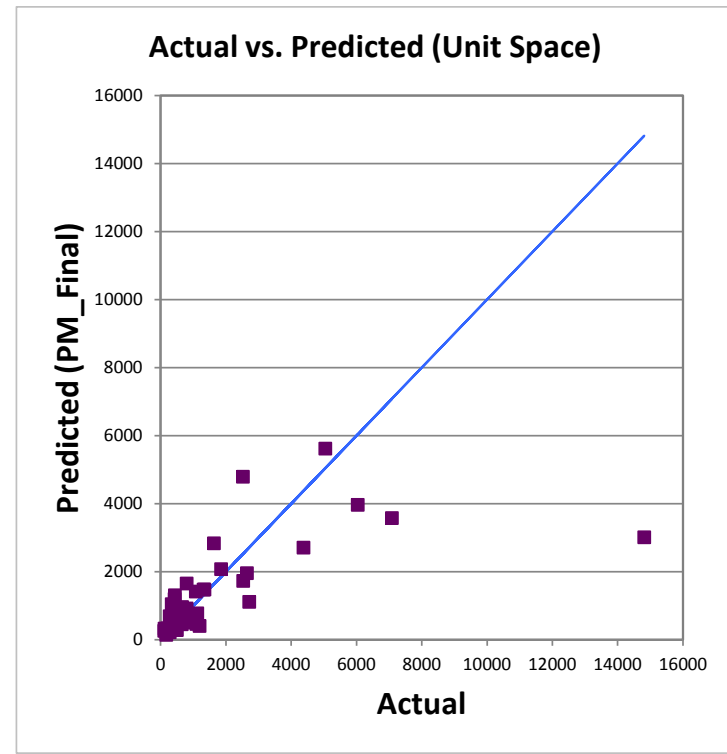
Equation:

Model Form	N	R ²	CV	Mean	MAD	REQ Min	REQ Max
$PM = 17.01 \times aREQ^{0.3006} \times aStaff^{0.5124}$	40	66	50	1739	57	35	12716

Where:

- PM = Actual effort (in Person Months)
- aREQ = Actual total requirements
- aStaff = Actual Peak Staff

Variable	Coeff	T stat
Intercept	17.01	5.8891
aREQ	0.3006	3.3815
aStaff	0.5124	4.2866



Schedule Models



Schedule Model Variables

Variable	Type	Definition
Actual Duration	Dependent	Actual software engineering duration (in Months) from software requirements analysis through final qualification test
Actual Effort	Independent	Actual software engineering effort at the end of the contract
Estimated Effort	Independent	Estimated software engineering effort at contract award.



Schedule Model 1: using Estimated Effort

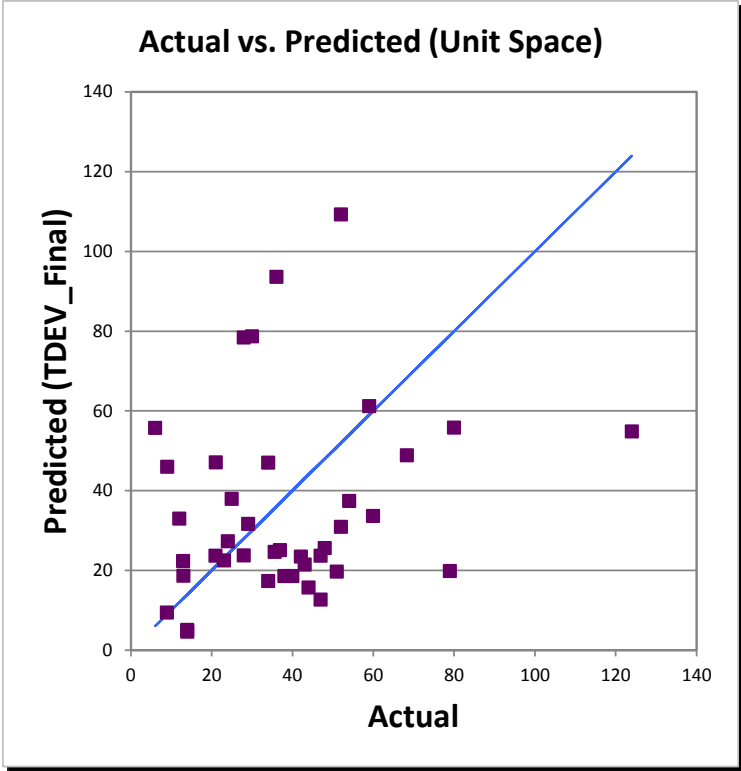
Equation:

Model Form	N	R ²	CV	Mean	F-stat	PM Min	PM Max
$TDEV = ePM^{0.5290}$	40	94	60	38	683	17	7132

Where:

- TDEV = Actual Duration in Months
- ePM = Estimated Effort (in Person Months)

Variable	Coeff	T stat	P value
ePM	0.529	26.14	0.0000





Schedule Model 2: using Actual Effort

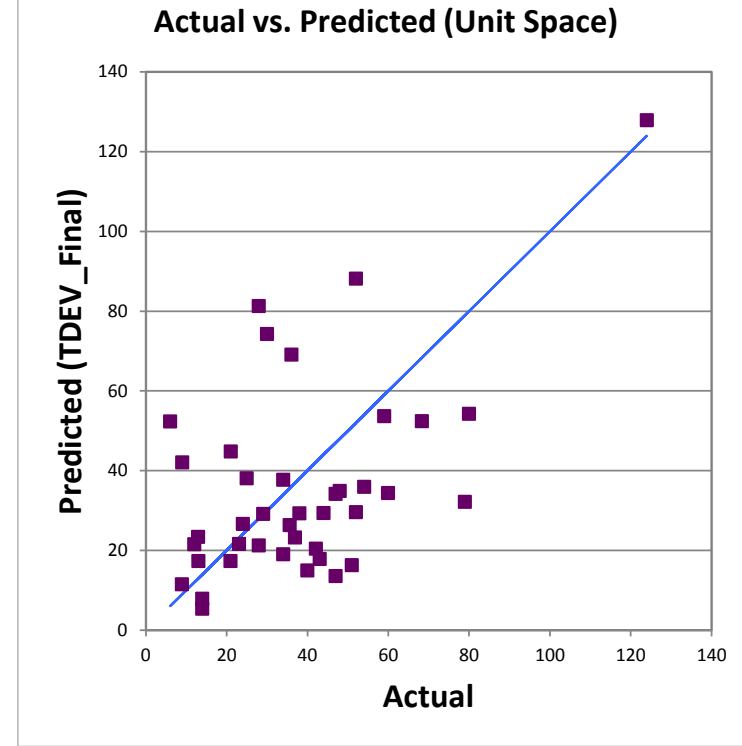
Equation:

Model Form	N	R ²	CV	Mean	F-stat	PM Min	PM Max
TDEV = $aPM^{0.5051}$	40	95	48	38	887	27	14819

Where:

TDEV = Actual Duration in Months
 aPM = Actual Effort (in Person Months)

Variable	Coeff	T stat	P value
aPM	0.529	26.14	0.0000



Conclusion



Primary Findings

- **Estimated** functional requirements is a significant contributor to software development effort.
- Variation in effort becomes more significant when **estimated** peak staff is added to the effort model.
 - Thus, the effect of estimated functional requirements on effort shall be interpreted along with estimated peak staff.
- **Estimated** effort is a significant contributor to development duration.



Model Usefulness

- ❑ Effort models based on **estimated** requirements and **estimated** peak more appropriate at early elaboration phase.
- ❑ Effort Models based on **final** requirements and **final** peak staff more appropriate after Critical Design Review, once requirements have been stabilized
- ❑ Productivity Boxplots (effort per requirement) are useful for crosschecking estimates at Preliminary Design Review
- ❑ Appropriate for both, Defense and IT projects



Study Limitations

- Since data was collected at the aggregate level, the estimation models are not appropriate for projects reported at the CSCI level.
- Do not use *Effort Models 1 through 4* if your input parameter is outside of the effort model range.
- Do not use *Schedule Models 5 & 6* if your input parameter is outside of the schedule model range.



Future Work

- Develop similar effort and schedule estimation models using data reported at the CSCI level.
- Examine the impact of functional requirements along with requirements volatility, process maturity, and percent reuse.