Why Does Software Cost So Much? Towards a Causal Model

Bob Stoddard, Principal Researcher and PI

Mike Konrad, Principal Researcher

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Problem

- DoD leadership continues to ask “Why does software cost so much?”
- DoD program offices need to know where to intervene to control software costs

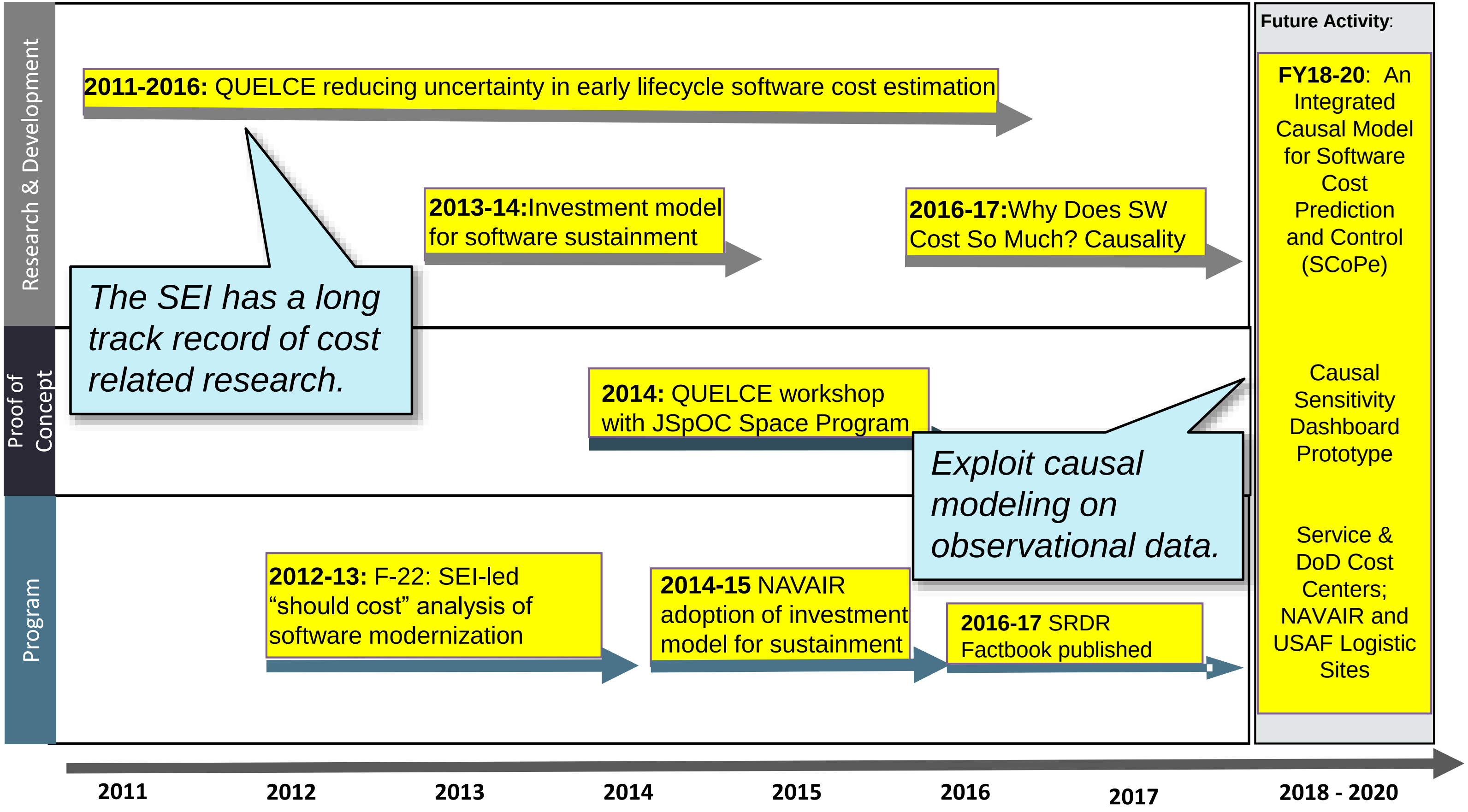
Solution

- An actionable, full **causal** model of software cost factors immediately useful to DoD programs and contract negotiators

Actionable intelligence

- Enhance program control of software cost throughout the development and sustainment lifecycles
- Inform “could/should cost” analysis and price negotiations
- Improve contract incentives for software intensive programs
- Increase competition using effective criteria related to software cost

SEI's Continuing Focus on Improving Cost Estimation



Why Do We Care About Causal Modeling?

Controlling costs requires knowing which "independent factors" actually *cause cost* outcomes, so that we may change cost in a predictable manner.

Just as correlation may be fooled by spurious association, so can regression

We must move beyond correlation to causation, if we want to make use of cause and effect relationships

We can now evaluate causation without expensive and difficult experiments

Establishing causation with observational data remains a vital need and a key technical challenge, but is becoming more feasible and practical.

Significant Progress Toward Practicality

Sewall Wright Path Models (1920's)

Structural Equation Models (1930's)

Social Science Path Models (1960's)

Bayesian Networks (1980's)

Glymour & Spirtes *et al* 1st ed. book on Causality (1988)

Pearl's Probabilistic Reasoning (1988)

Pearl's 1st ed. book on Causality (2000)

1930 1980 1985 1990 1995 2000 2005 2010

The science supporting our research has just emerged.

Glymour & Spirtes *et al* 2nd Edition Book on Causality (2001)

Morgan Counterfactuals & Causality (2007)

Pearl's 2nd Edition Book on Causality (2009)

Morgan Counterfactuals & Causality (2014)

Morgan Handbook Social Science Causal Inference (2014)

TETRAD – An Open Source Tool for Causal Learning

Carnegie Mellon University

http://www.phil.cmu.edu/tetrad/

University of Pittsburgh

http://www.ccd.pitt.edu/

For video tutorials from 2016 summer short course:

http://www.ccd.pitt.edu/training/presentation-videos/

CMU OLI - Causal and Statistical Reasoning

http://oli.cmu.edu/courses/future/causal-statistical-reasoning/

The SEI has connections to these leading researchers.

Research Methodology

Causal modeling will drive science-based cost estimation.

Prior Knowledge

Observational Data

Data: size, task, duration, defects, skills, experience, process, tools

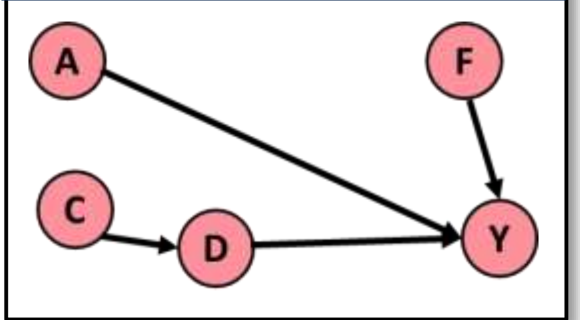
Causal Discovery

using Tetrad, which implements a variety of algorithms

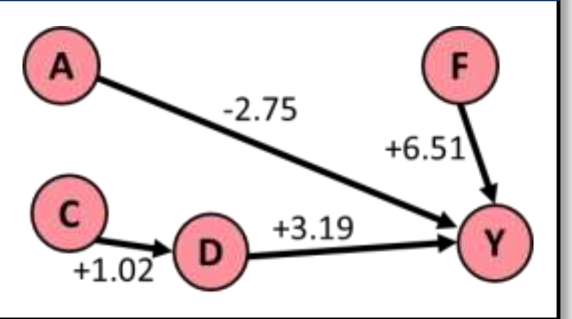
Formulate Hypotheses

using domain knowledge and prior scholar publication

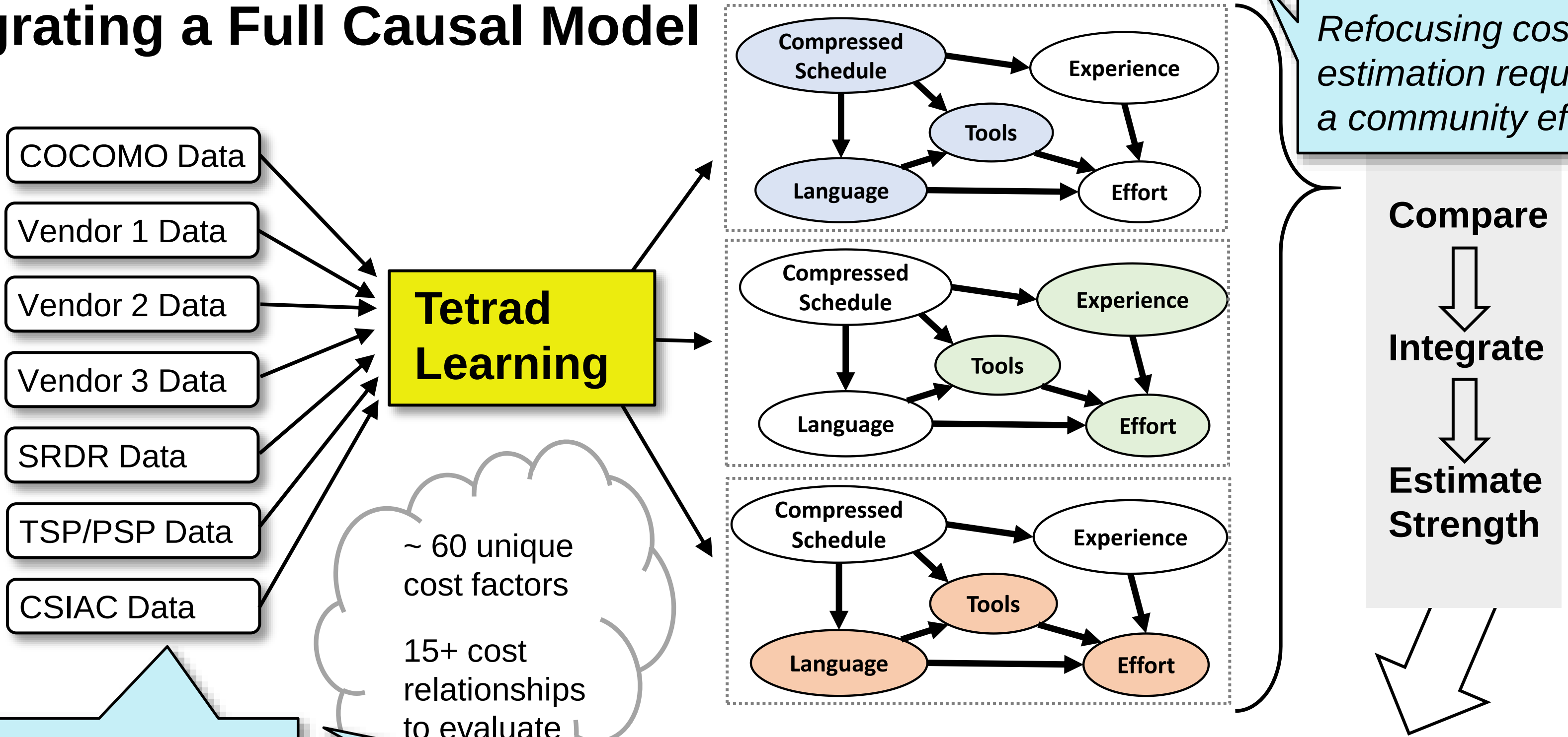
Causal Model (DAG)



Estimated Model (SEM)



Integrating a Full Causal Model



Refocusing cost estimation requires a community effort.

The SEI will collaborate with key parties to help them analyze their data.

New algorithms from campus for stitching models, enabling collaboration

Actionable Sub-Causal Models

Module Effort = f(factor1, factor2, factor3)
Module Post-Development Quality = g(factor1, factor4, factor5)
High-Reliability Module Cost = h(factor4, factor6, factor7)

Key Activities

Engaged with University of Southern California COCOMO research team

- Kickoff and collaborating since August 2017
- Applying causal learning to various datasets including original COCOMO 81 dataset (corrected)
- Supporting two Ph.D. students in their dissertation work

Initial evaluation of SRDR dataset (next two slides)

- Dataset was basis for just-published DoD Software Factbook

Initial evaluation of PSP datasets from SEI TSP Team

- Includes information on every error committed and caught toward program completion

Reanalyzing publicly available datasets

- Comparing our results with results from prior researcher analyses

Initial Results: Explaining Final Effort and Duration[1]

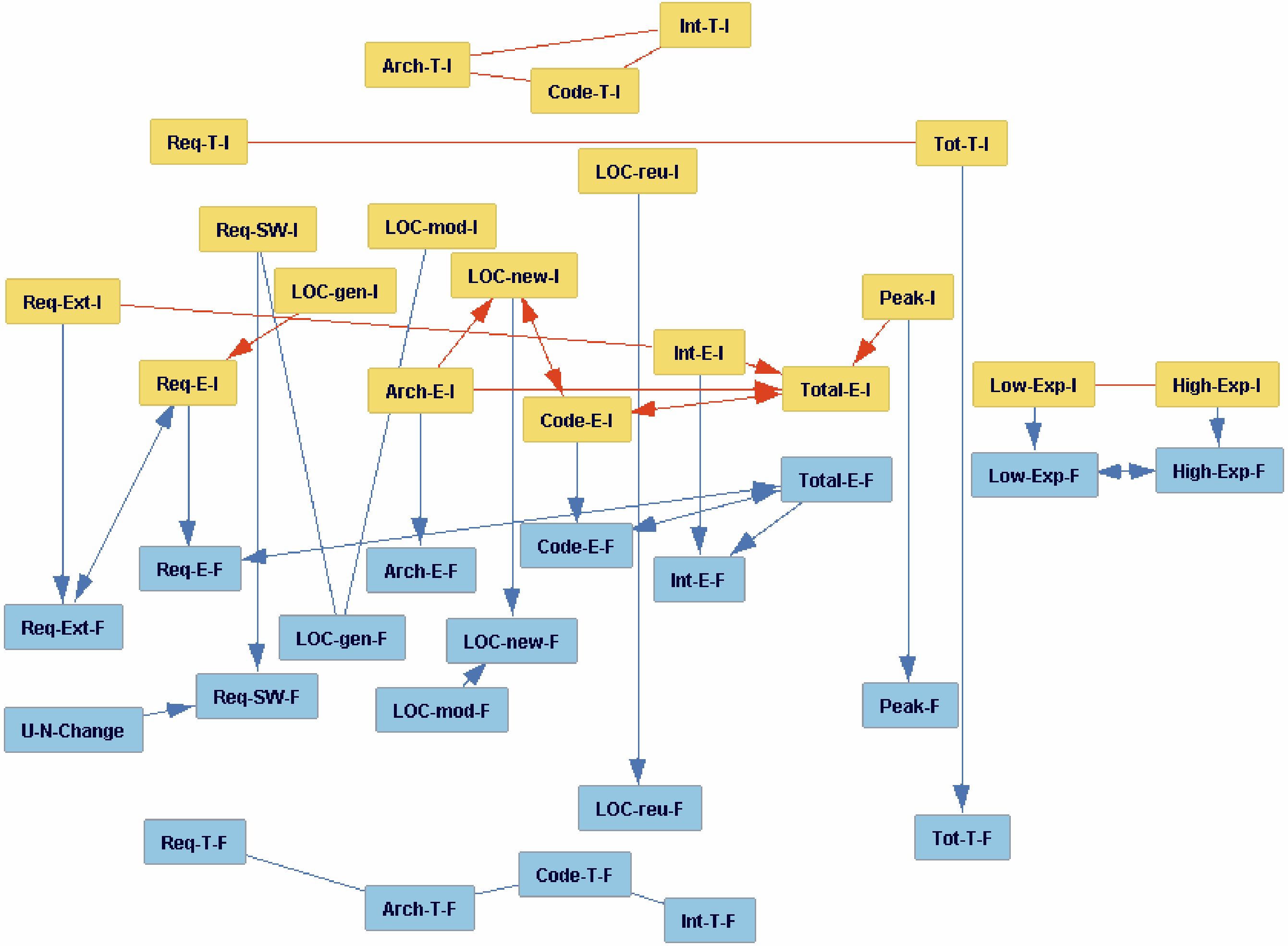
181 pairs of matched initial-final SRDR reports reduced to 134 (complete Req…INT data).

Analyzed with PC with Alpha set to .001.

Key:

Req-Ext-I estimate (initial report)

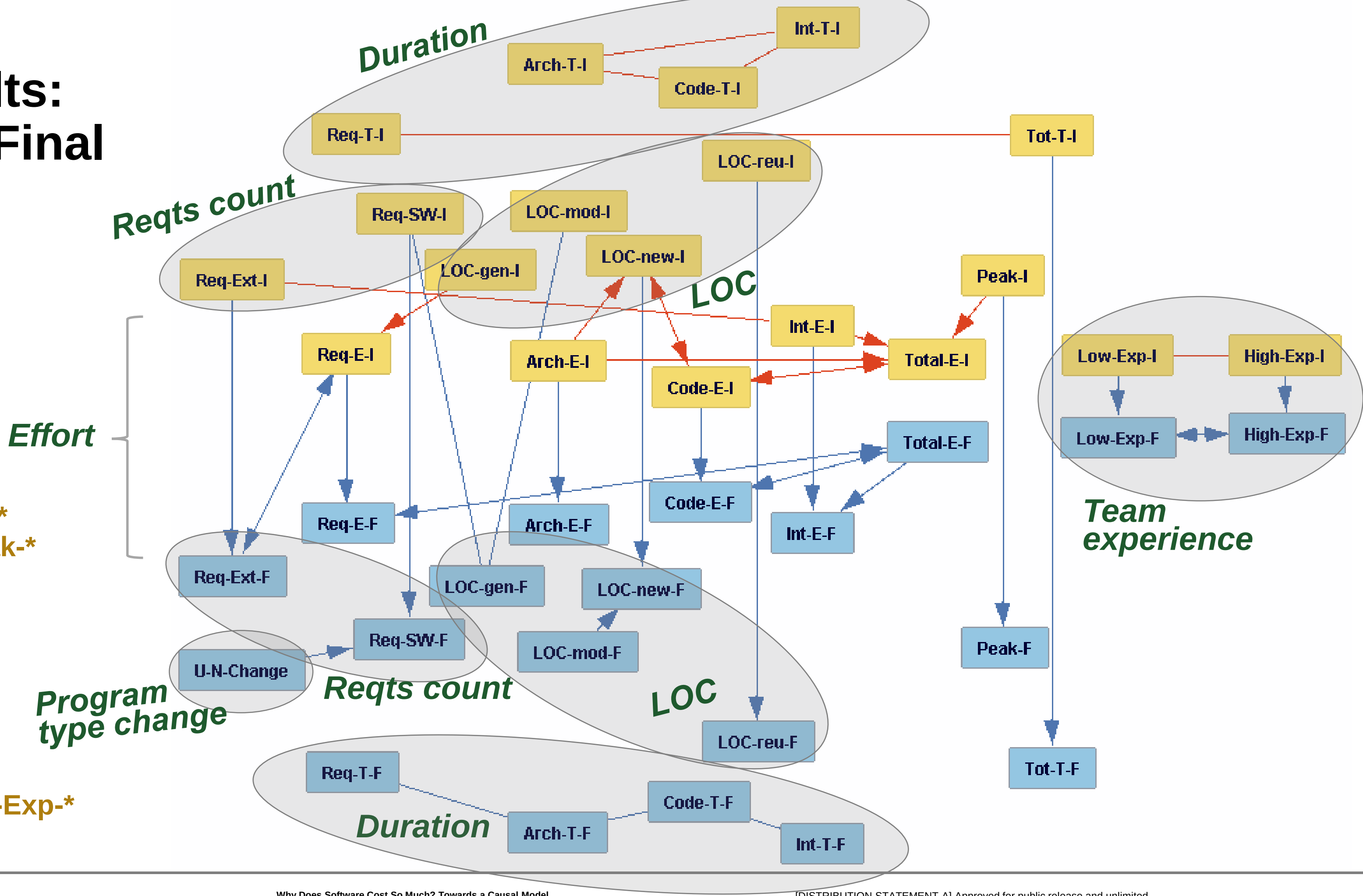
Req-T-F actual (final report)



Initial Results: Explaining Final Effort and Duration[2]

Note 6 distinct islands:

1. Effort and size (2):
   - effort: *-E-*
   - size: LOC-*
   - requirements: Req-*
   - peak time size: Peak-*
   - program changed (upgrade <-> new): U-N-Change
   - code reuse is its own island
2. Duration (3): *-T-*
3. Team experience: *-Exp-*



Early Results Summary

Conventional Wisdom	Not yet checked for generalizability…
TSP/PSP Data Productivity and attention to quality are persistent programmer characteristics.	**TSP/PSP Data** Indeed, past productivity and defect injection rates do have causal effects on effort and defect density of next program.
SRDR Data Effort expended in Req'ts, Architecture, Coding, and Integration drives Total Effort.	**SRDR Data** Architecture effort does not appear to have a causal effect on Total Effort.
COCOMO81 Approximately 25 factors are driving cost.	**COCOMO81** Only software size (ESLOC) has causal effect on cost.
Architecture Data Four architecture pattern violations drive effort and quality.	**Architecture Data** Three of the four architecture pattern violations have a direct causal effect on effort and quality.
USC Cost Data Six key factors were shown to have strong correlation with Total Effort.	**USC Cost Data** Four of six factors have a causal effect on Total Effort. Two new causal factors were also identified.

Artifacts and Accomplishments

Causal models of the factors that drive software effort

- 40-60 factors related to software effort, quality, and schedule
  - Domain, lifecycle, technology
  - Programmer capability
- Estimates of causal relationships for predicting interim and final costs

Causal Learning and Tetrad tooling and training materials

Presentations

- Software & IT-CAST Workshop, Arlington, VA, August 2017
- Invitation to speak at the 2018 ICEAA conference (based on above presentation)

Use and early results obtained by USC research collaborators

Bottom Line and Future Vision

The time is right for applying causal learning to improve cost estimation

- Causal learning has come of age from both a theoretical and tooling standpoint
- Causal models lend themselves to actionable intelligence better than models based on correlation

May lead to ways to improve control of software programs

- Identifying practices, methods, and tools that improve how software is built

Our research provides a rare opportunity

- Bring a diverse community of DoD programs, contractors, and cost estimation researchers together in a joint effort to improve understanding of software costs
- Working with world-class causal learning researchers

SEI will extend this research in FY18-20 to other SW cost-related factors

- Programmer, team, technology, organization, contractor, and acquisition risk factors
- In collaboration with multiple other cost estimation researchers

Contact Information

Presenter / Point(s) of Contact

Bob Stoddard, PI

Mike Konrad

Principal Researchers

Email: rws@sei.cmu.edu, mdk@sei.cmu.edu

Telephone: +1 412.268.1121 (Bob) +1 412.268.5813 (Mike)

Other SEI Team Members

Bill Nichols

Dave Zubrow

CMU Contributors

David Danks

Madelyn Glymour

Kun Zhang

USC Contributors

Jim Alstad

Barry Boehm

Anandi Hira