ASCoT

Strategic Investment Division | Jet Propulsion Laboratory

The NASA Analogy Software Cost Tool Suite: Expanding our Estimation Horizons

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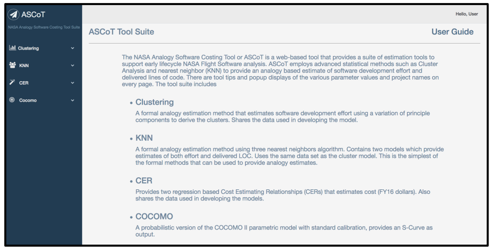

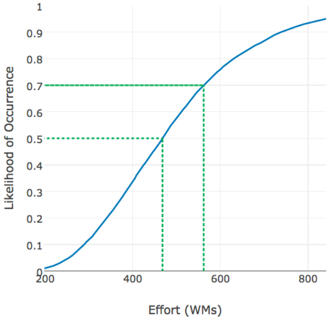

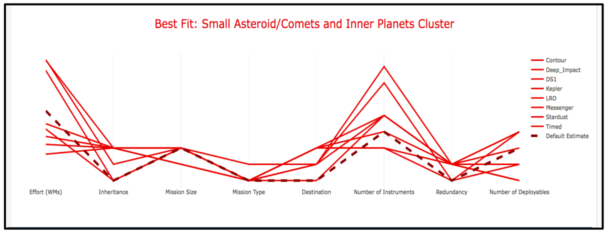

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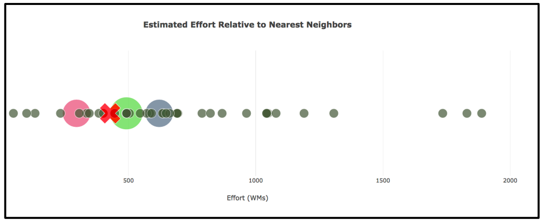
2018 NASA Cost Symposium
NASA GSFC



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ASCoT Introduction

- Is the first NASA developed web-based cost tool available via ONCe
  - Log-in to ONCe and fire it up
  - Provides users many advantages in developing quick software costs estimates with only a few high level input parameters
- The purpose of ASCoT is to
  - Supplement current estimation capabilities
  - Be effective in the very early lifecycle when our knowledge is fuzzy
    - uses high level systems information (Symbolic Data)
  - Be usable by Cost Estimators, Software Engineers and Systems Engineers
- Currently provides four different estimation methods
  - PCA based clustering
  - Knn for analogy-based effort estimates,
  - Two simple CER cost model
  - COCOMO II

ASCoT Background

- ASCoT has been under development for 4 years based on 10 years of research
- Methodology handles
  - small sample sizes and noisy data
- Previous talks and papers described the research approach and activities
  - ICEAA 2014, 2015
  - NASA Cost Symposium 2014, 2015, 2016
  - IEEE Aerospace 2016, 2017, 2019 (forthcoming)
  - Numerous research publications in IEEE Software, lead by Dr. Tim Menzies et.al.

ASCoT – What's New

1. Major changes to the user interface including
   - Single log-in
   - Greatly Improved on-line help and rollover tips
   - Clusters are now labeled with a descriptive names
   - CER model documentation is more complete and provides predication confidence interval
   - Import and export inputs
   - Download all graphics
   - Numerical inputs now have a determined range and inconsistent combinations of inputs have been disallowed
2. Nearest Neighbor (Knn) Analogy Estimator can now estimate with any number of inputs
3. Updated data for Contour, Stereo, Messenger, New Horizons, Solar Probe Plus and Van Allen Probes
4. User Guide

ASCoT - What's The Same

- ASCoT has been under development for 4 years based on 10 years of research
- Previous talks and papers described the research approach and activities
  - ICEAA 2014, 2015
  - NASA Cost Symposium 2014, 2015, 2016
  - IEEE Aerospace 2016, 2017, 2019 (forthcoming)
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Reminder: What We Learned So Far

- There are a variety of models whose performance are hard to distinguish (given currently available data) but some models are better than others
- If one has sufficient data to run COCOMO or a comparable parametric model then the best model is the parametric model
- When insufficient information exists then a model using only system parameters can be used to estimate software costs with 'acceptable' reduction in accuracy. The main weakness is the possibility of occasional very large estimation errors which the parametric model does not exhibit.
- Use MRE to supplement standard statistical evaluation metrics
- Use median over average when possible
- While a nearest neighbor method performs as well as clustering models based on MMRE, clustering handles outliers better and provides a structured model that supports cost analysis and not just prediction

"ASCoT" Key Estimation/Analysis Components

Analogy

Cluster Analysis
- Clustering
- Development Effort Estimate

Updated

Knn Analysis
- Nearest Neighbor
- Development Effort and SLOC Estimate

Major Update

Regression Analysis
- Linear Regression
- Development Cost Estimate

Updated

COCOMO II
- Verified Reproduction
- Cost/Effort

- Knn now can estimate with any number of inputs
- COCOMO II is a reproduction and uses traditional inputs
  - Will be linked to Analogy Cluster Model in future release

Data Sources

- Where the data came from
  - CADRe
  - NASA 93 – Historical NASA data originally collected for ISS (1985-1990) and extended for NASA IV&V (2004-2007)
  - Contributed Center level data
  - NASA Software Inventory
  - Project websites and other sources for system level information if not available in CADRe

Missions by Destination

Total of 51 missions with data
- 47 can be used in at least 1 of the estimation models

Missions by Destination
- Earth – 23
- Asteroids/Comets – 7
- Inner Planets– 17
- Outer Planets - 4

Earth	Asteroids/Com	Inner	Outer
Van Allen Probe	DS1	Mars Odyssey	GLL
OCO	Stardust	Genesis	JUNO
SDO	Deep Impact	MRO	New Horizons
SMAP	OSIRIS REX	Maven	Cassini
GPM Core	Dawn	Messenger	
NuStar	NEAR	Solar Probe Plus	
GEMS	Contour	LRO	
GLORY		Grail	
GOES-R		LCROSS	
GEOTAIL		LADEE	
EO1		Kepler	
Aqua		Stereo	
GLAST		MPF	
NOAA-N-Prime		MER	
NPP		MSL	
LDCM		Phoenix	
RHESSI		Insight	
TIMED			
IRIS			
MMS			
HST			
GRO			
WISE			

Data Summary – Key Metrics

- Effort, Lines of Code and Productivity by Destination

Destination	# of Records	Effort (Months)		Logical Delievered LOC	
		Median	S.D.	Median	S.D.
Astreroids/Comet	7	546	373	143,000	35,189
Earth	23	499	466	62,000	39,986
Inner	17	664	435	122,000	133,765
Outer	4	620	411	54,000	21,633

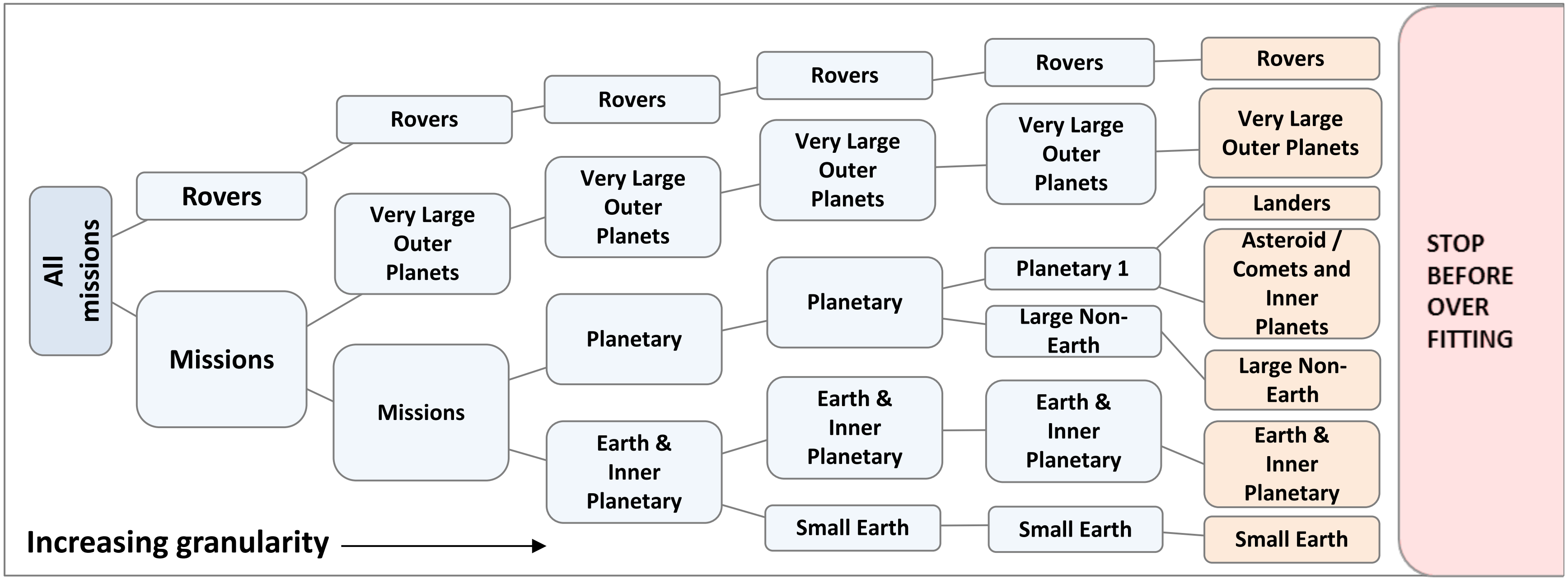
- Number of Deployable and Instruments by Destination

Destination	Instrument		Deployable	
	Median	Range	Median	Range
Astreroids/Comet	3	2-5	1	0-3
Earth	3	1-10	2	0-8
Inner	4	3-10	2	0-10
Outer	10	7-12	3	0-8

Clustering Analysis

- By gradually increasing the granularity of our clusters, while maintaining robustness to avoid overfitting, we were able to find logical separation between groupings of missions

- In some cases, Earth and non-Earth missions mix – this is mostly due to low heritage and high deployable missions, also – different planetary and asteroid/comet missions mix based on size and number of instruments



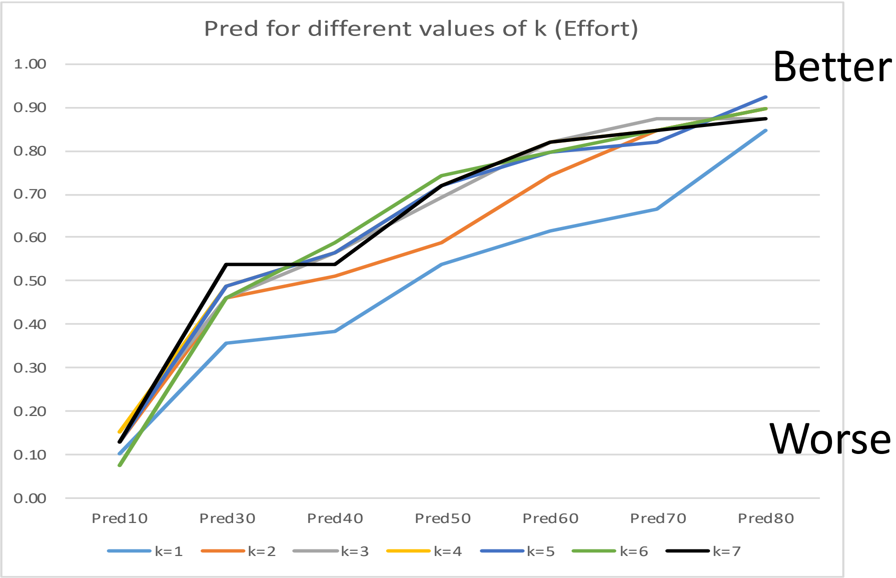
Cluster Parameter Summary

Cluster	Mission Cost Median	Mission Cost Range	Software Inheritance	Destination	Mission Type	flight Computer Redundancy	Number of Instruments	Number of Deployabes	Development Work Months Median	Development Work Months Range
1	$321M	$170M - $500M	High-Very High	Earth	Orbiter	Single String	1 to 4	0 to 4	492	230 to 870
2	$824M	$420M - $1,250M	Medium to High	Earth & Inner Planets	Orbter	Dual String - Cold backup	2 to 6	2 to 8	603	340 to 790
3	$292M	$220M - $550M	Medium	Asteroid/Comets & Inner Planets	Orbiter/ Flyby	Dual String - Cold backup	2 to 7	0 to 3	525	450 to 1040
4	$548M	$630M - $820M	High-Very High	Inner Planet (Mars)	Lander	Dual String - Warm backup	4 to 5	2 to 3	728	630 to 820
5	$696M	$550M - $850M	High-Very High	Planets & Asteroids/Comet	Orbiter/ Flyby	Dual String - Cold backup	3 to 9	0 to 3	641	400 to 690
6	$1,123M	$420M - $2,600M	None-Low	Inner Planet (Mars)	Rover	Dual String - Warm backup	3 to 10	6 to 10	1735	1000 to 1890
7	$2680M	$2,300M - $3,000M	None-Low	Outer Planets	Orbiter/ Flyby	Dual String - Warm backup	11 to 12	4 to 8	978	650 to 1300

Nearest Neighbor Effort Prediction Results

Low is best   High is best

Knn=	MdMRE	Pred50
1	0.47	0.54
2	0.38	0.59
3	0.37	0.69
4	0.31	0.72
5	0.31	0.72
6	0.31	0.74
7	0.28	0.72



- As MRE and Pred are non-parametric statistics it is difficult distinguish performance between 3 to 7 neighbors
  - Knn = 1 or 2 are clearly poor performers
- Decided to go with 3 neighbors as it was the minimum acceptable

Effort Estimation – Key Variables

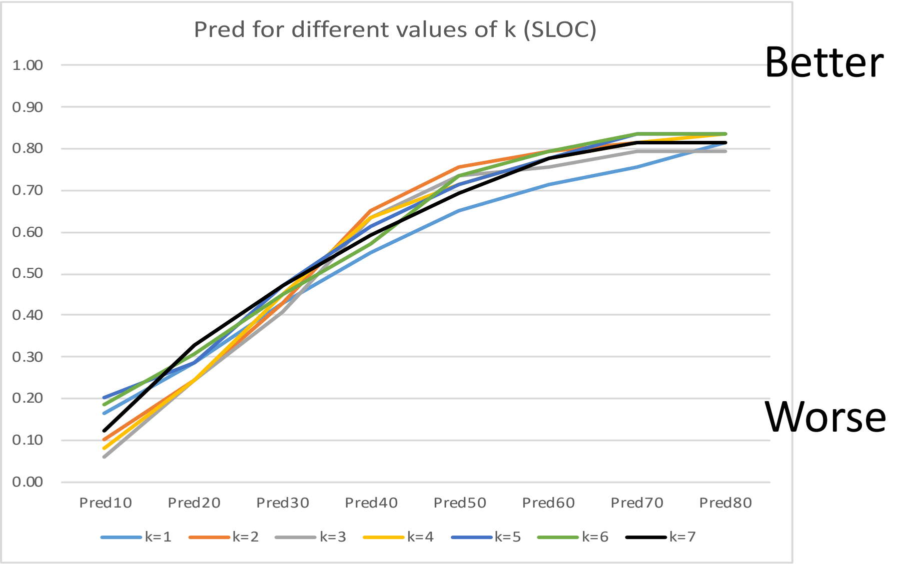
- Using all parameters has the highest MedMRE
- Best One parameter
  1. Mission Type
  2. Inheritance
- Best Two parameters
  1. Mission Type and Redundancy
  2. Mission Type and Inheritance
- More than two parameters
  1. Mission Type, Inheritance, Redundancy, Mission Size, Destination
  2. Destination and Number of Instruments increases MedMRE the least when using 4 to 7 input

Nearest Neighbor LOC Prediction Results

Low is best

High is best

Knn=	MdMRE	Pred50
1	0.35	0.65
2	0.34	0.76
3	0.31	0.73
4	0.31	0.71
5	0.32	0.71
6	0.32	0.73
7	0.33	0.69



- LOC estimation is basically indistinguishable between 2 to 7 neighbors
- Decided to go with 3 neighbors to make it consistent with the effort model and had not other criteria to use

LOC Estimation – Key Variables

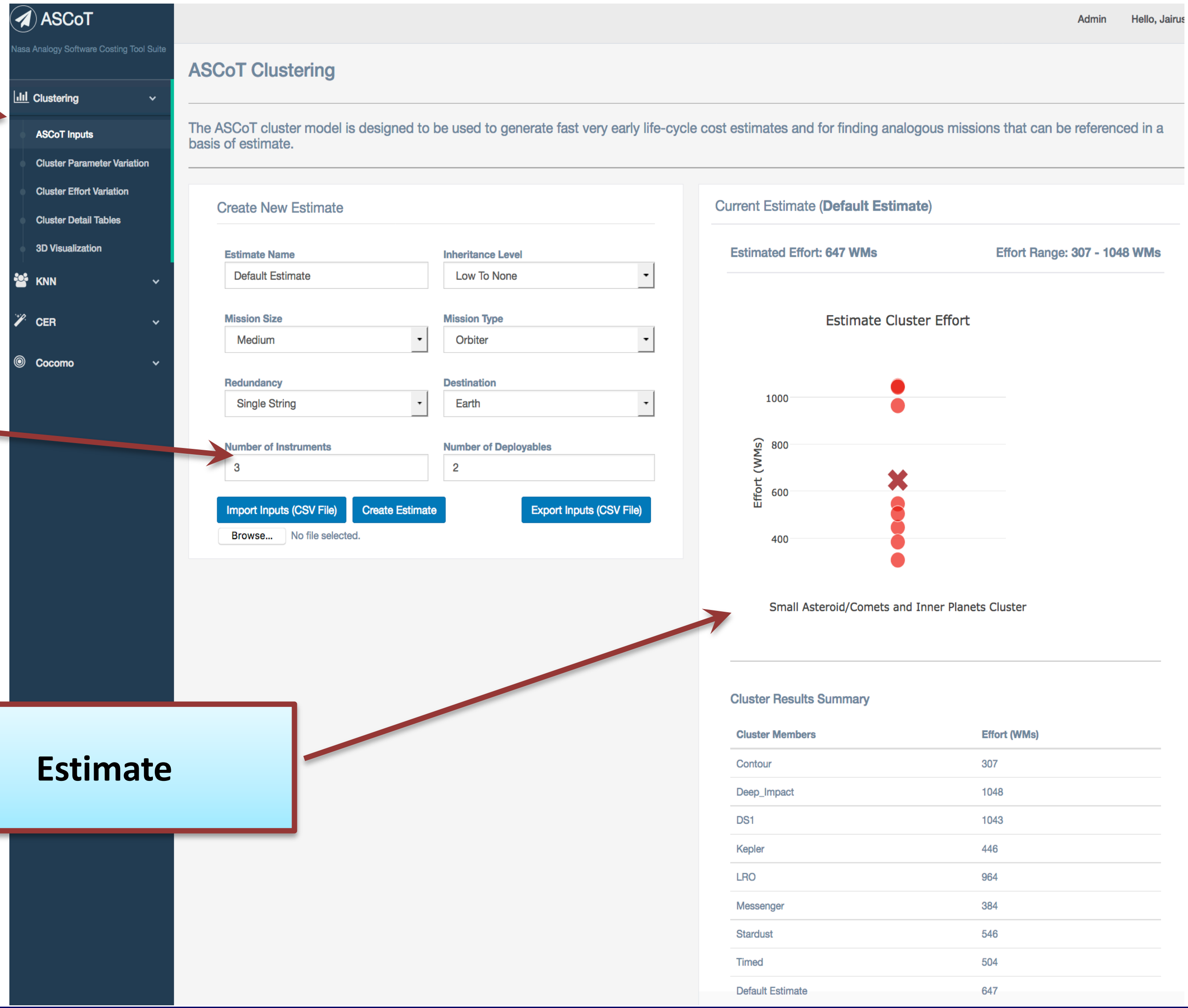
- Using all parameters has the highest MedMRE
- Best One parameter
  1. Mission Type
  2. Redundancy
- Best Two parameters
  1. Mission Type and Redundancy
  2. Mission Type and Destination
- More than two parameters
  1. Mission Type, Destination, Number of Instruments, Number of Deployables
  2. However, Redundancy or Mission Size increases MedMRE <u>the least when using 4,5 or 6 inputs</u>

ASCoT Web Model :
Analogy Cluster Model Main View

Left Hand Navigation Menu with Analysis Types

Model Inputs

Estimate



ASCoT Web Model:
Analogy Cluster Model Parameter View

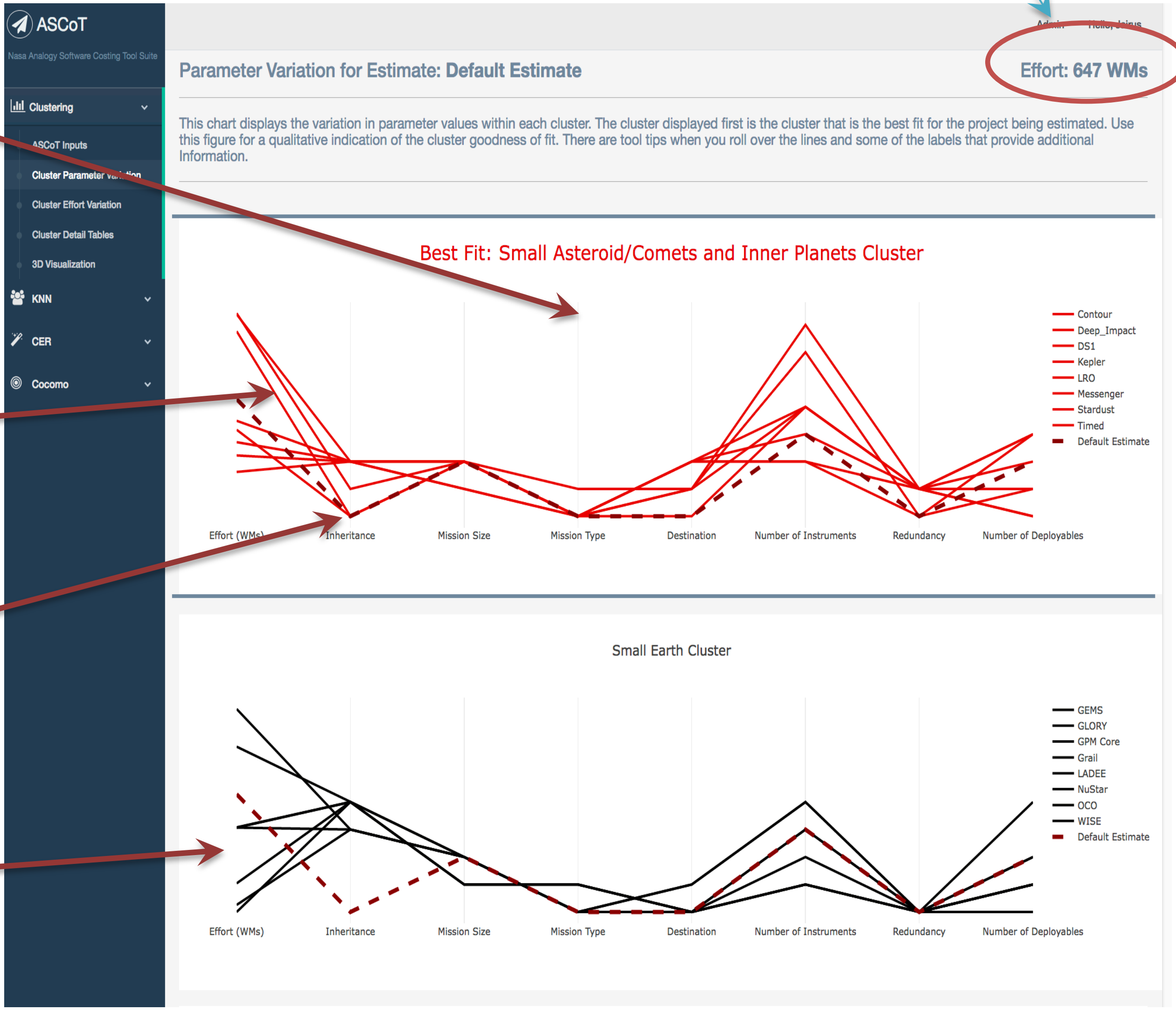
Cluster Effort Months Result (Median)

Top graph compares the User Inputs vs Cluster members

1 Line per Mission in the Cluster plus 1 Line for User Inputs

Where lines overlap, User Inputs align with values for Missions in the Cluster

Other reference Cluster compared to User Inputs are less aligned



ASCoT Web Model: KNN Model Main View 1

Model Inputs

KNN Effort Estimator

The K-Nearest Neighbor Regression Algorithm is a simple non-parametric method used to estimate the total effort to produce the flight software of a mission based on similar missions. Using 7 inputs, the model assigns a distance metric that ranks each mission in order of similarity to the estimate mission.

Create New Estimate

Estimate Name: Default Estimate

Inheritance Level: Medium

Mission Size: Large

Mission Type: Orbiter

Redundancy: Dual String - Cold backup

Destination: Earth

Number of Instruments: 3

Number of Deployables: 2

Import Inputs (CSV File) | Create Estimate | Export Inputs (CSV File)

Browse... No file selected.

Current Estimate

Estimated Effort: 428 WMs

KNN Results Summary

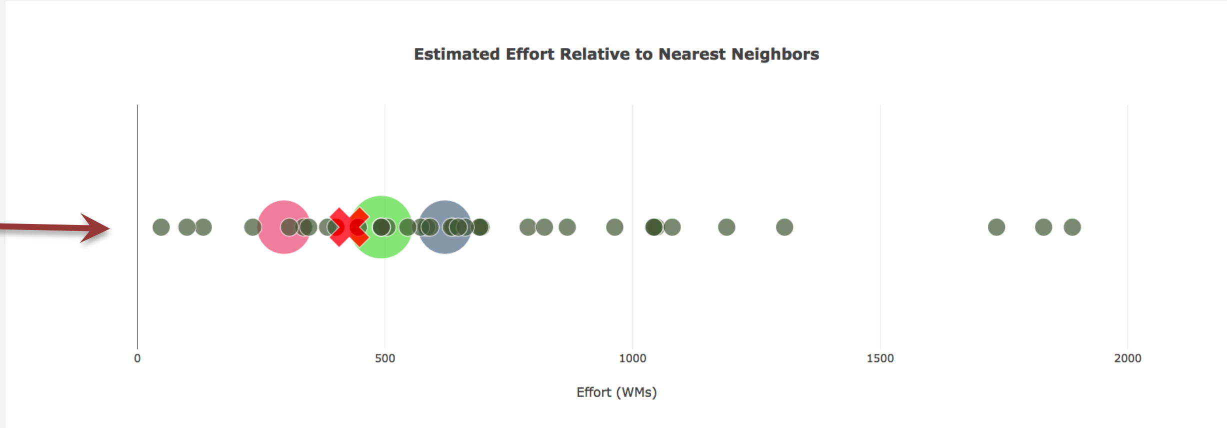
Neighbors	Effort (WMs)	Distance
Van Allen Probe	296	0.21
GRO	492	0.35
Solar Probe Plus	621	0.43

Estimate

ASCoT Web Model: KNN Model Main View 2

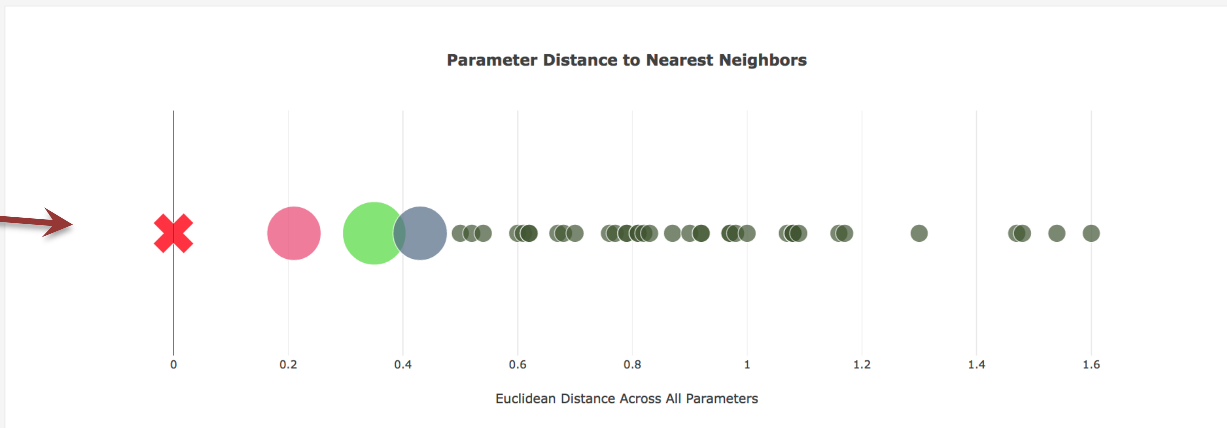
Results: Estimated Effort Compared to Nearest Neighbors and all other Missions

This chart displays the variation in Software Effort for all missions. The X indicates the effort of the estimate mission. Nearest Neighbors are shown in color and sized relative to Mission Size.



Results by Euclidian Distance

This chart displays the Euclidean distance from the estimate mission for all missions in the data set. Nearest Neighbors are shown in color and sized relative to Mission Size.



ASCoT Web Model: Cost Regression View

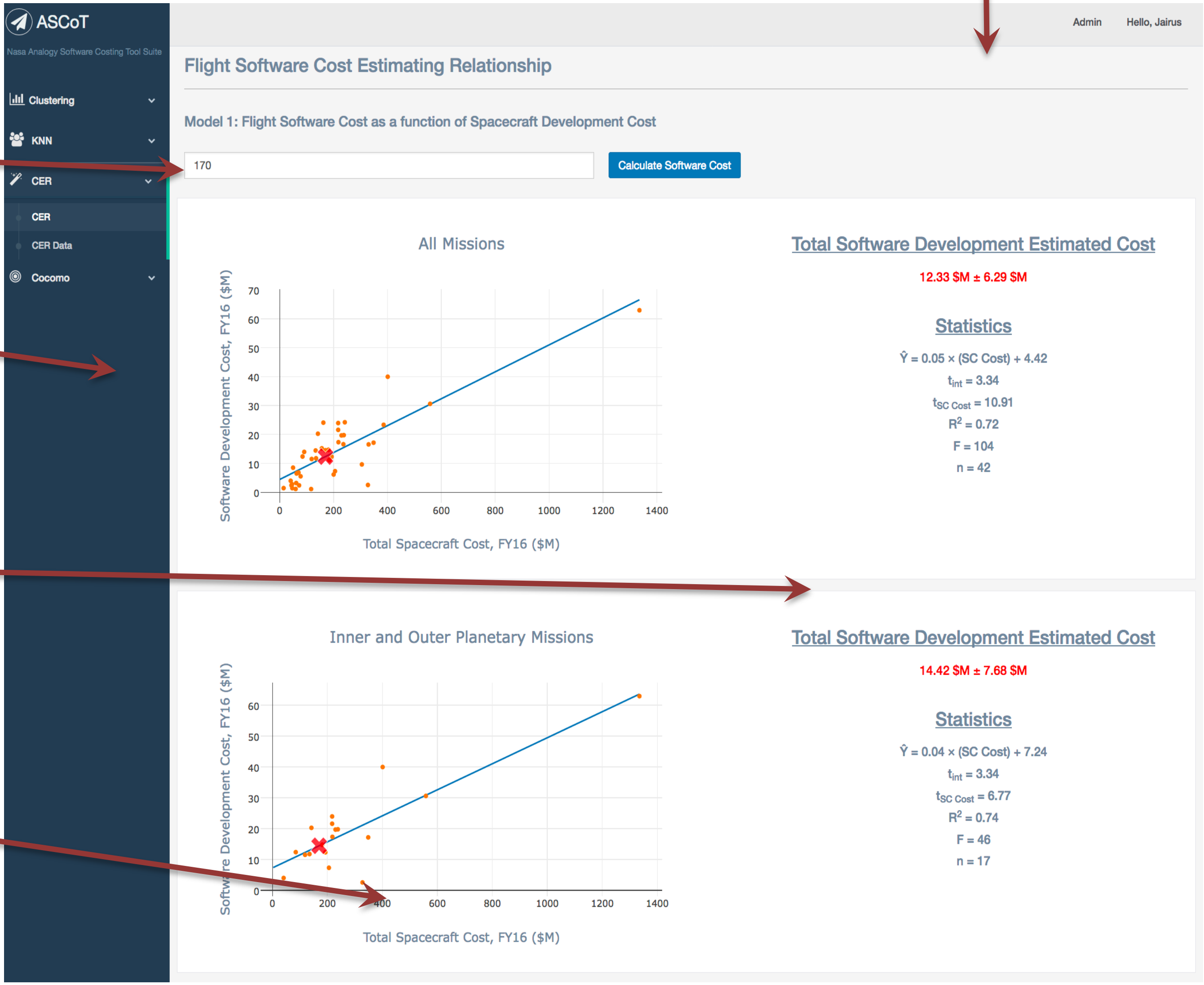
Regressions shown for "All Missions", "Planetary Missions", and "Earth Orbiting Missions"

User Input of Total Spacecraft Cost

Y-Axis = Software Dev Cost
X-Axis = Spacecraft Cost

CER Statistics

Regression shown for "Planetary Missions" Only



ASCoT Break Out Session

mini-tutorial

and

more on what is under the hood

Thursday

For Time and Place Check the Schedule

Back Up

Data Items Overview

Data Item	2017
Total development effort in work months	41
Flight Software Development Cost	43
Flight System Development Cost	43
Logical Lines of Code (LOC)	
Delivered LOC	51
Inherited LOC (Reused plus Modified	44
COCOMO Model inputs (See Appendix A for the parameter definitions) - Translated from CADRe which has SEER model inputs becauase the SEER data items are very	19
Systems Parameters	
Mission Destination (Asteroid/Comets, Earth, Inner (planetary), Outer	51
Multiple element (probe, etc…)	51
Number of Instruments	51
Number of Deployables	51
Flight Computer Redundancy (Dual Warm, Dual Cold, Single String)	51
Software Reuse (Low, Medium, High)	44
Software Size (Small, Medium, Large, Very Large)	51

ASCoT Publications & Presentations

Publications: Conference

2. IEEE Aerospace
   - Improving and Expanding NASA Software Estimation Methods, 2016 Aerospace Conference, Big Sky, Mt., March 2016.
   - NASA Analogy Software Cost Model: A Web-Based Cost Analysis Tool, , 2017 Aerospace Conference, Big Sky, Mt., March 2017.
2. Automation in Software Engineering (ASE)
   - Data Mining Methods and Cost Estimation Models: Why is it so hard to infuse new ideas? , Automation in Software Engineering 2015, Norman, Nebraska, Nov. 2015.
1. International Cost Estimation and Analysis Association (ICEAA)
   - NASA Software Cost Estimation Model: An Analogy Based Estimation Method, 2015 International Cost Estimation and Analysis Association (ICEAA) Professional Development & Training Workshop, San Diego California, June 2015
   - A Next Generation Software Cost Model, 2014 International Cost Estimation and Analysis Association (ICEAA) Professional Development & Training Workshop, Denver Colorado , June 2014.

Publications: Journal

1. **Empirical Software Engineering**
   - Negative results for software effort Estimation, Empirical Software Engineering, Nov 2016. Menzies, Yang, Mathew, Boehm, Hihn
1. NASA Cost Symposium
   - ASCoT R2: A web-based model of the NASA Analogy Software Costing Tool, Goodbye Excel", 2016 NASA Cost Symposium, NASA Glen Research Center, August. 2016. J. Hihn and J. Johnson
   - NASA Software Cost Estimation Model: An Analogy Based Estimation Method. 2015 NASA Cost Symposium, NASA Ames Research Center, August 2015. J. Hihn and J. Johnson.
   - A Next Generation Software Cost Model: A look under the Hood. 2014 NASA Cost Symposium, NASA Langley Research Center, August 2014. J. Hihn and J. Johnson.
2. COCOMO Workshop
   - NASA Analogy Software Costing Tool-ASCoT, 31tst International Forum on COCOMO and System/Software Cost Modeling,USC, October 2016. J. Hihn & M. Saing
   - Just How Good is COCOMO and Parametric Estimation?, , 29th International Forum on COCOMO and System/Software Cost Modeling, USC, October 2014. Hihn et al.

Effort Estimation with Data Mining Methods References

"Active Learning and Effort Estimation: Finding the Essential Content of Software Effort Estimation Data" by Ekrem Kocaguneli and Tim~Menzies and Jacky Keung and David Cok and Ray Madachy. IEEE Transactions on Software Engineering (pre-print) 2013 . .

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"Exploiting the Essential Assumptions of Analogy-Based Effort Estimation" by E. Kocaguneli and T. Menzies and A. Bener and J. Keung. IEEE Transactions on Software Engineering pages 425-438 2012 . Available from http://menzies.us/pdf/11teak.pdf .

"Local vs. Global Lessons for Defect Prediction and Effort Estimation" by Menzies, T. and Butcher, A. and Cok, D. and Marcus, A. and Layman, L. and Shull, F. and Turhan, B. and Zimmermann, T.. IEEE Transactions on Software Engineering pages 1 2012 . Available from http://menzies.us/pdf/12localb.pdf .

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"On the Value of Ensemble Effort Estimation" by Kocaguneli, E. and Menzies, T. and Keung, J.. IEEE Transactions on Software Engineering 2011

"Exploring the Effort of General Software Project Activities with Data Mining" by Topi Haapio and Tim Menzies. International Journal of Software Engineering and Knowledge Engineering pages 725-753 2011

"Stable Rankings for Different Effort Models" by Tim Menzies and Omid Jalali and Jairus Hihn and Dan Baker and Karen Lum. Automated Software Engineering December 2010 . Available from http://menzies.us/pdf/10stable.pdf .

"Case-Based Reasoning for Reducing Software Development Effort" by Adam Brady and Tim Menzies and Oussama El-Rawas and Ekrem Kocaguneli and Jacky Keung. Journal of Software Engineering and Applications 2010 . Available from http://menzies.us/pdf/10w0.pdf .

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"Explanation vs Performance in Data Mining: A Case Study with Predicting Runaway Projects" by Tim Menzies and O. Mizuno and Y. Takagi and Y. Kikuno. Journal of Software Engineering and Applications pages 221-236 November 2009

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