# SIE 464-564 Cost Estimation

Mon & Wed 3:00 PM – 4:15 PM
AME S212
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This course focuses on principles of **cost modeling**, **measurement systems**, and **forecasting** with specific emphasis on parametric models. Approaches from the fields of hardware, software and systems engineering are applied to a variety of contexts (risk assessment, judgment & decision making, performance measurement, process improvement, adoption of new tools in organizations, etc.). Material is divided into five major sections: cost estimation fundamentals, parametric model development and calibration, advanced engineering economics principles, measurement systems, and behavioral economics/forecasting.

## Course Description

Each section will include analysis of theoretical principles that have motivated the state of the practice as well as a review of applicable methodologies. Where appropriate, case studies will be used for more detailed exploration of critical issues and examples from Sabermetrics (using baseball data) will be introduced to enhance discussions. Selectively, guest speakers will be invited to share their perspectives on the development, use, and evaluation of cost models and complementary approaches. Students are encouraged to leverage their interests into individual projects that involve developing and validating their own cost model.

## Rationale

The objective of this course is to provide future technical leaders the necessary tools and evaluation techniques to reason about the economic impact of their decisions for the technologies and products they develop.

Technical leadership requires an understanding of three major areas (including but not limited to): technology, economic factors, and human decision making. This course assumes a background in some area of technology that can be analyzed from a cost perspective. This course will explore the more challenging – and often overlooked – domain of cost estimation and incorporate methodologies from established engineering disciplines to explore the impact of: continuous process improvement, economies of scale, present value, risk and decision analysis, etc. This will be done in the context of new challenges in complex engineering systems and new approaches introduced by process maturity models, evolutionary development, and systems architecting and engineering.

**Learning objectives** [measurable outcome]

1. Build awareness of phenomena that influence cost of engineering systems across a variety of contexts [homework]
2. Understand the practical application of cost modeling and its role in government and industry [homework, final project]
3. Use cost models to develop cost estimates [homework, midterm]
4. Learn the financial vocabulary and effective methods for communicating with non-technical audiences [homework, midterm]
5. Employ data-driven decision making to make economic choices between design alternatives [final project]
6. Understand the methods used to develop and validate cost models and associated limitations [homework]
7. Identify enterprise-wide cost issues involving strategy, knowledge, policy, process, etc. [homework, final project]
8. Communicate technical results in clear and concise writing style [final project]
9. Develop an appreciation for the controversial issues in the area of cost estimation [homework]
10. Develop a cost model [final project]

**Required Course Texts**

Valerdi, R., *The Constructive Systems Engineering Cost Model (COSYSMO): Quantifying the Costs of Systems Engineering Effort in Complex Systems*, VDM Verlag, 2008.

Hubbard, D. W., *How to Measure Anything: Finding the Value of Intangibles in Business*, Wiley, 2014. (3rd Edition)

**Optional Course Text**

Boehm. B. W., et al, *Software Cost Estimation with COCOMO II*, Prentice-Hall, 2000. (Note: I will provide the necessary chapters for those who do not want to purchase the book)

**Class Schedule**

| Lecture | Homework due & Readings |
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| **Lecture 1 (Jan 13) – Intro and course overview**<br><br>Course overview<br>▪ Syllabus review<br>▪ Cost estimation activity<br>▪ Motivation for this course/Deepwater video<br>▪ Cost, schedule, and performance<br>▪ History of parametrics<br>▪ Cost estimation theories<br>▪ Life-cycle cost & total ownership cost<br>▪ DMAIC TS | **Required**<br>Little, T., Schedule Estimation and Uncertainty Surrounding the Cone of Uncertainty, IEEE Software, 2006.<br><br>**Optional**<br>May, L. J., Major Causes of Software Project Failures, Crosstalk, 1998.<br>GAO-04-642, Lack of Disciplined Cost-Estimating Process Hinders Effective Program Management, 2004. |
| **Jan 18 – no class (Martin Luther King Jr Holiday)** | |

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| **Lecture 2 (Jan 20, 25) – Cost Estimation Approaches**<br>▪ Basic concepts of software development<br>▪ Spectrum of cost estimation approaches (parametric, activity-based, analogy, expert based, etc.)<br>▪ The estimation process (NASA example)<br>▪ Software cost estimation with COCOMO II and commercial models<br>▪ Tool demo: online COCOMO II | **HW#1:** Cost estimation in the news, 7 wonders of the modern world & COCOMO Intro (due Jan 27)<br><br>**Required**<br>Boehm, B. W. et al, Software Cost Estimation with COCOMO II, 2000 (Chapters 1 and 2 only).<br><br>**Optional**<br>NASA Cost Estimating Handbook, 2008.<br>ISPA Parametric Handbook (4th Ed.).<br>Hihn, J., Griesel, A., Bruno, K., Fouser, T., Tausworthe, R., Mental Models of Software Forecasting, NASA JPL.<br>Jorgensen, M., Practical Guidelines for Expert Judgment Based, Software Effort Estimation, IEEE Software, May/June 2005. |
| **Lecture 3 (Jan 27, Feb 1) – Sizing and Work Breakdown Structures**<br>▪ The Sizing Problem<br>▪ Function points<br>▪ Work Breakdown Structures<br>▪ Measurement, metrics and associated terminology<br>▪ 10 deadly sins of cost estimation<br>▪ Evaluating software models | **HW#2:** Cost estimation with COCOMO II, comparison of cost estimation approaches, DMAIC (due Feb 3)<br><br>**Required**<br>Boehm, B. W., Valerdi, R., Lane, J. and Brown, A. W., "COCOMO Suite Methodology and Evolution," CrossTalk - The Journal of Defense Software Engineering, 18(4), 20-25, 2005.<br>Jorgensen, M., Boehm, B. W., Rifkin, S., Software Development Effort Estimation: Formal Models or Expert Judgment? IEEE Software, March/April 2009.<br><br>**Optional**<br>McConnell, S., 10 Deadly Sins of Software Estimation, Construx, 2002.<br>Kitchenham, B., A., Pickard, L., Linkman, S., Jones, P., A Framework for evaluating a software bidding model, Information and Software Technology, Vol. 47, 2005, pp. 747-760.<br>Park, R. E., A Manager's Checklist for Validating Software Cost and Schedule Estimates, CMU/SEI-95-SR-004, 1995.<br>Kemerer, C., An Empirical Validation of Software Cost Estimation Models, Communications of the ACM, Vol. 30, No. 5, May 1987. |
| **Lecture 4 (Feb 3, 8) – Advanced Cost Modeling Concepts**<br>▪ Systems engineering cost estimation (COSYSMO)<br>▪ Data collection, statistical data analysis, and calibration (M&Ms)<br>▪ Bayesian approximations of historical data and expert opinion<br>▪ Threats to validity<br>▪ Model integration<br>▪ Bayesian Belief Networks<br>▪ Final project brainstorming | **HW#3:** Sizing and WBS (due Feb 10)<br><br>**Required**<br>Valerdi, R., *The Constructive Systems Engineering Cost Model (COSYSMO): Quantifying the Costs of Systems Engineering Effort in Complex Systems*, VDM Verlag, 2008. (Chapters 1 and 3)<br>Hubbard, D. W., *How to Measure Anything: Finding the Value of "Intangibles" in Business*, Wiley, 2010. (Chapters 1, 2, 3 and 9)<br><br>**Optional**<br>Jones, C., Measurements, Metrics, and Industry Leadership, May 2007.<br>Ross, M., Software Size Growth and Uncertainty<br>Fricker, R. D. The mysterious case of the blue M&M's. *Chance*, No. 4, pp. 19-22, 1996. |
| **Lecture 5 (Feb 10, 15) - Economic Principles**<br>▪ Diseconomies of scale<br>▪ Cognitive decision making<br>▪ Reuse<br>▪ Productivity<br>▪ Cost risk analysis<br>▪ Trade studies<br>▪ Value articulation<br>▪ Earned value/project staffing profiles<br>▪ Leading indicators vs. lagging indicators<br>▪ Learning curves<br>▪ Real options | **HW#4:** Cost analysis fundamentals (due Feb 18)<br><br>**Required**<br>Hubbard, D. W., *How to Measure Anything: Finding the Value of "Intangibles" in Business*, Wiley, 2010. (Chapter 14)<br><br>**Optional**<br>Wang, G., Valerdi, R. and Fortune, J., "Reuse in Systems Engineering," IEEE Systems Journal, 4(3), 376-384, 2010.<br>Canbäck, S., Bureaucratic Limits of Firm Size: Empirical Analysis Using Transaction Cost Economics, PhD thesis, Brunel University, 2002.<br>GAO-07-96, DoD Needs to Take More Action to Address Unrealistic Initial Cost Estimates of Space Systems, 2006.<br>Wright, T. (1936). Factors Affecting the Cost of Airplanes, *Journal of Aeronautical Science, 3(4)*, 122-128. |

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| **Modeling Data (Feb 17, 22)**<br>**From Bath University (United Kingdom)**<br>▪ Descriptive vs. Inferential statistics<br>▪ Regression analysis (using baseball data)<br>▪ IBM Watson Analytics | |
| **Lecture 6 (Feb 24, 29) - Measurement Systems**<br>▪ Measurement frameworks<br>▪ Goal Question Metric<br>▪ Capability maturity<br>▪ Balanced scorecard<br>▪ Malcolm Baldridge<br>▪ Metrics selection and definition process<br>▪ Practical software measurement | **HW#5:** Application of economic principles, regression (due Feb 26)<br><br>**Required**<br>Hubbard, D. W., *How to Measure Anything: Finding the Value of "Intangibles" in Business*, Wiley, 2010. (Chapter 8)<br>Kaplan, R., Norton, D., "The Balanced Scorecard - Measures that Drive Performance" Harvard Business Review, 1992.<br>Basili, V. R., Caldiera, G., Rombach, H. D., The Goal Question Metric Approach, Encyclopedia of Software Engineering, pp. 528-532, John Wiley & Sons, Inc., 1994.<br><br>**Optional**<br>Banker, R., Chang, H., Kemerer, C. F., Evidence of Diseconomies of Scale in Software Development, Information and Software Technology, Vol. 36, No. 5, pp. 275-282.<br>Seaver, D., Fast Function Points<br>Goldenson, D. R., Jarzombek, J., Rout, T., Measurement and Analysis in Capability Maturity Model Integration Models and Software Process Improvement, CrossTalk, July 2003.<br>Natwick, G., Integrated Metrics for CMMI and SW-CMM, CrossTalk, May 2003.<br>McGarry, J., Card, D., Jones, C., Layman, B., Clark, E., Dean, J., Hall, F., Practical Software Measurement: Objective Information for Decision Makers, Addison-Wesley, 2001. |
| **Lecture 7 (March 2, 7) – Enablers and barriers to adoption of process improvement**<br>Midpoint course evaluation<br>▪ Technology acceptance model<br>▪ Adoption of innovations<br>▪ ROI of process improvement<br>▪ Cost model adoption process<br>▪ Barriers for process improvement<br>▪ Stakeholder negotiations<br>▪ Cost estimation and negotiation | **Required**<br>Rico, D. F., ROI of Technology Readiness Assessments Using Real Options: An Analysis of GAO Data from 62 U.S. DoD Programs<br>Valerdi, R., Cultural Barriers to the Adoption of Systems Engineering Research, 2nd Asia-Pacific Conference on Systems Engineering, Yokohama, Japan, September 2008.<br><br>**Optional**<br>Valerdi, R., Miller, C., From Research to Reality: Making COSYSMO a Trusted Estimation Tool in Your Organization, INCOSE Symposium, 2007.<br>Bayer, J., Melone, N., A Critique of Diffusion Theory as a Managerial Framework for Understanding Adoption of Software Engineering Innovations, Journal of Systems and Software, Vol, 9, pp. 161-166, 1989.<br>Mah, M., Marriage of Estimation & Negotiation, STQE<br>Boehm, B. W., Theory-W Software Project Management: Principles and Examples, IEEE Transactions on Software Engineering, Vol. 15, No. 7, 1989. |
| **Lecture 8 (March 9) – Risk Estimation & Project Management**<br>▪ Cost estimation heuristics<br>▪ Cost risk (probabilistic)<br>▪ Cost risk (knowledge-based)<br>▪ Portfolio risk management<br>▪ Cost estimation guidance<br>▪ Descriptive and inferential statistics<br>▪ Earned Value Management Systems<br>▪ Detailed case studies | **HW#6:** Cost Risk Analysis (due March 13)<br><br>**Required**<br>Valerdi, R., Systems Engineering and Program Management Strategies, draft Chapter 5.<br>Hubbard, D. W., *How to Measure Anything: Finding the Value of "Intangibles" in Business*, Wiley, 2010. (Chapters 4 and 6)<br>Valerdi, R., Heuristics for Systems Engineering Cost Estimation, *IEEE Systems Journal*, 2010.<br><br>**Optional**<br>Garvey, P., *Probability Methods for Cost Uncertainty Analysis*, Marcel Dekker, 2000. |

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| **March 14, 16 – no class (Spring Break/MLB Spring Training)** | |
| **Lecture 9 (March 21, 23) – Decision Analysis, Value-based engineering, Psychometrics, Project Dynamics**<br>▪ Value-based engineering<br>▪ Psychometrics & measurement scales<br>▪ Data validity & reliability<br>▪ Examples from baseball<br>▪ Software project dynamics | **HW#7:** Organizational aspects of cost estimation (due March 24)<br><br>**Required**<br>Hubbard, D. W., *How to Measure Anything: Finding the Value of "Intangibles" in Business*, Wiley, 2010. (Chapters 7 and 11)<br>Silver, N., *The Signal and the Noise: Why So Many Predictions Fail — but Some Don't*, Penguin Press, 2012. (Intro and Chapter 1)<br><br>**Optional**<br>Abdel-Hamid, T. K., Madnik, S. E., The Dynamics of Software Project Scheduling, Communications of the ACM, Vol. 26, No. 5, 1983.<br>Guilford, J. P., Psychometric Methods, McGraw-Hill, 1954.<br>Lewis, M., Moneyball: The Art of Winning an Unfair Game, W. W. Norton & Company, 2003. |
| **Lecture 10 (March 28) – Human Side of Estimation**<br>▪ Heuristics and biases<br>▪ Cost model estimation errors and limitations of approaches<br>▪ Optimism in estimation<br>▪ Calibrating optimism<br>▪ Effect of estimates on project performance | **HW#8:** Midterm question (due March 30)<br><br>**Required**<br>Hubbard, D. W., *How to Measure Anything: Finding the Value of "Intangibles" in Business*, Wiley, 2010. (Chapters 5 and 12)<br>Tversky, A., Kahneman, D., Judgment under Uncertainty: Heuristics and Biases, Science, Vol. 185, No. 4157, pp. 1124-1131, 1974.<br>Silver, N., *The Signal and the Noise: Why So Many Predictions Fail — but Some Don't*, Penguin Press, 2012. (Chapters 2, 3)<br><br>**Optional**<br>Valerdi, Yang, Optimism in Schedule Estimation<br>Valerdi, R., "Cognitive Limits of Software Cost Estimation," 1st IEEE Conference on Empirical Software Engineering & Measurement, September 2007, Madrid, Spain.<br>Aranda, J., Easterbrook, S., "Anchoring and Adjustment in Software Estimation," Proceedings of the 10th European software engineering conference, Pages: 346 – 355, 2005.<br>Flyvbjerg, B., Holm, M. S., Buhl, S., Underestimating Costs in Public Works Projects: Error or Lie?, Journal of the American Planning Association, Vol. 68, No. 3, 2002.<br>Peeters, D., Dewey, G., "Reducing Bias in Software Project Estimates," Crosstalk – The Journal of Defense Software Engineering, April 2000.<br>Jorgensen, M., Sjoberg, D. I. K., Impact of Effort Estimates on Software Project Work, *Information and Software Technology*, 43(5), 939-949, Dec 2001. |
| **Guest lecture (March 30)** | |
| **Midterm (April 4, 6)** | |
| **Lecture 11 (April 11, 13) – Forecasting**<br>▪ Prediction markets<br>▪ Weather prediction<br>▪ Earthquake prediction<br>▪ Extrapolation<br>▪ Bayesian inference | Silver, N., *The Signal and the Noise: Why So Many Predictions Fail — but Some Don't*, Penguin Press, 2012. (Chapters 4, 5, 6, 7, 8) |
| **Lecture 12 (April 18, 20) –** Sabermetrics<br>▪ Moneyball<br>▪ Sandlot statistics<br>▪ Simpson's paradox<br>▪ Ballpark effects<br>▪ Playoff predictions | |
| **Lecture 13 (April 25, 27) –** Guest lectures | DMAIC report due |
| **Lecture 14 (May 2, 4) –** Course Overview | Final paper due |

**Basis of grade (SIE 464)**

| Component | Weight | Notes |
|---|---|---|
| Quality, participation, and creativity | 10% | Based on in-class participation (or out of class contributions from distance students) and quality of assignments |
| Homework | 16% | 8 assignments @ 2% each |
| Midterm | 40% | April |
| Final project | 30% | **5-6 pages** |
| DMAIC Report | 4% | 2-3 pages |

**Basis of grade (SIE 564)**

| Component | Weight | Notes |
|---|---|---|
| Quality, participation, and creativity | 10% | Based on in-class participation (or out of class contributions from distance students) and quality of assignments |
| Homework | 16% | 8 assignments @ 2% each |
| Midterm | 40% | April |
| Final paper | 30% | **8-10 pages** |
| DMAIC Report | 4% | 2-3 pages |

**Homework assignments**
There are eight homework assignments worth a total of 16% of your grade. Assignments must be 2-3 pages in length (single spaced) and must be submitted (via course drop box on D2L) on the date indicated in the syllabus.

**Final Project**
The final project should be summarized in a report between 5 and 10 pages long (plus or minus 20%; clarity of understanding and evidence of independent thinking are much more important than length) single spaced 12-point font. Projects should be a result of individual effort only. Students are expected to develop their own cost model and are encouraged to select a technical area that interests them. Proposals for final projects, which is a homework assignment, will serve as an opportunity to negotiate the topic and scope of the final paper.

**Tools Laboratory**
Students will have access to three commercial cost models and one open source cost model: TruePlanning (PRICE Systems), SEER (Galorath, Inc.), Costar (Softstar Systems), and COCOMO II (USC) for homework assignments and final projects.

**Midterm Exam**
An exam will be administered approximately halfway through the semester to assess progress on learning objectives. Rather than testing memorization, the focus will be on the application of concepts from the first half of the class. Questions for the midterm will be a combination of questions generated from student inputs and instructor-generated questions.