Standard Processes for Software Cost Estimation Saves 6 Effort-Months Per Proposal

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In the continental United States, there are two primary launch ranges used to support U.S. Government (DoD and NASA/JPL [Jet Propulsion Laboratory]) and other government-sponsored launches and missions. Vandenberg Air Force Base (30th Space Wing), located in southern California, just north of Santa Barbara, is responsible for all Department of Defense space and missile launch activities on the West Coast. The Eastern Launch Range at Cape Canaveral, Florida (45th Space Wing), supports similar missions, but is also responsible for launching the world-renown Space Shuttle. Both ranges launch a myriad of expendable vehicles including the Athena, Atlas, Delta, Pegasus, and the Titan, as well as supporting Force development and evaluation of all intercontinental ballistic missiles. Two ranges are needed to avoid launching over populated areas. They are further distinguished by the orbits in which they launch satellites – Vandenberg launches satellites destined for near polar orbits, while Cape Canaveral launches those for equatorial orbits.

Both bases serve as vast tracking, telemetry and command complexes whose electronic and optical tracking systems collect and process launch-related data for a variety of users. Prior to launching a spacelift mission, the trajectory of the vehicle or missile is carefully analyzed to determine the limits of a safe launch. Sensors are deployed around the world to track of the progress of the launch vehicle and the data they generate is delivered over a wide area network to mission command. Mission controllers carefully track the progress of the launch vehicle and, if it moves outside safe boundaries, they destroy it. In the early 1990s, surveys of spacelift launch facilities at both Cape Canaveral and Vandenberg indicated a need for extensive repairs and replacements of many supporting elements. Much of the hardware was obsolete, which made it difficult to operate and maintain.

In 1993, the Air Force initiated the Range Standardization and Automation (RSA IIA) Program, a long-term effort to modernize the nation's two spacelift ranges and more specifically, the complicated high-tech systems tracking and data systems each range uses known as the Spacelift Range System (SLRS). In late 1995, Lockheed Martin Mission Systems, located in Santa Maria, California, was chosen to conduct the RSA program with the goal to provide safe mission execution and staunch customer support, standardize designs and interfaces, and improve flexibility, capacity and responsiveness of the SLRS.

To help achieve this goal, Lockheed Martin has implemented a structured software cost estimation process that is saving them an estimated six effort-months per proposal, and with up to three proposals submitted per year, the savings have become quite substantial. The majority of the time-savings arises from the fact that

the new cost estimation process provides a consistent method that is understood and accepted by the customer, the Air Force Space & Missile Systems Center, greatly reducing the need for discussion and rework of estimates. Additional efficiencies are derived from the estimating process itself, because the new method automates the large amount of manual data entry and calculations that were needed in the past.

Previously, each product team had the option of selecting its own cost estimation method, which meant that a considerable amount of explanation was required when estimates were presented to the customer and changes often had to be made. By implementing the new method, each product team now estimates the size of its project and helps determine parameters that are used to estimate productivity based on a knowledge base of completed programs. This method has recently been accepted as a best practice in the company, and will lead to much broader use.

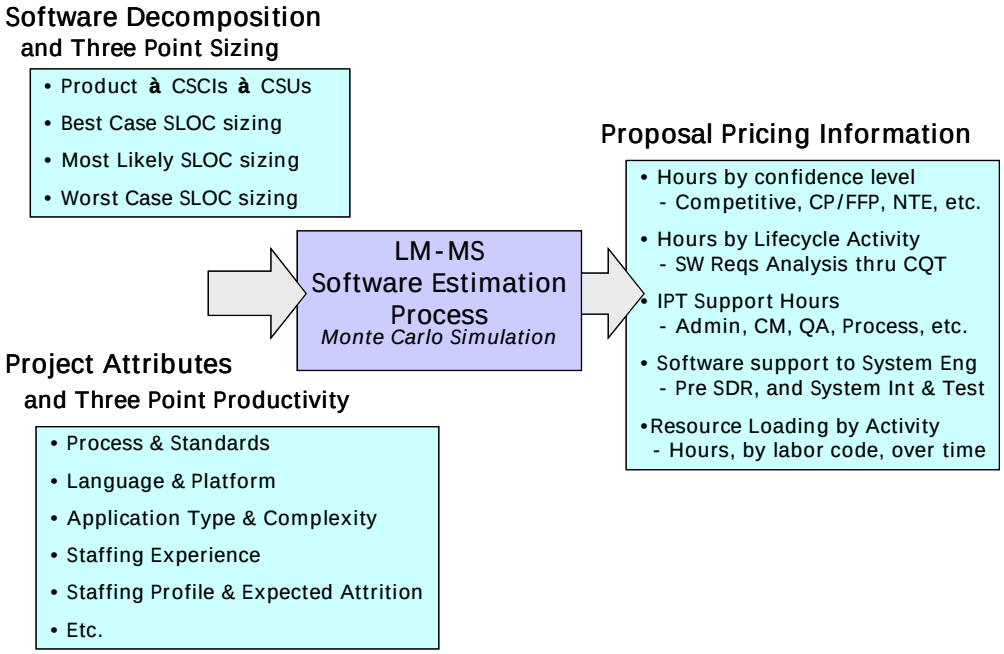
Previous cost estimation method

The RSA IIA program requires several major software proposals a year, each of which begins with the development of a technical solution. Typically six product groups might be required to participate, such as flight analysis, which models the successful launch boundaries; flight operations, which tracks the launch vehicle; networking, which transports data from the sensors to mission control; etc. In the past, each of the product groups used its own estimating method. Some would simply make an engineering judgment call by directly estimating the number of hours that would be required. Some would base their estimate on the size of the team that they felt would be needed. Even when two groups used the same basic approach, the details of their methods were different so the estimates were not directly comparable. The estimates were all calculated on spreadsheets that took a fair amount of time to complete. Before the estimates were presented to the customer, management would typically review the estimates and often asked for them to be redone one or more times. Each time they were redone a considerable amount of effort was involved in reconfiguring and checking the spreadsheets.

Once management signed off, the estimates were compiled into a proposal and presented to the customer. Since the different pieces of the proposal were generated by different methods, there was considerable room for discussion on why one method was used in one part of the proposal and another method elsewhere. Often the assumptions used by the different product groups were not fully documented. The meeting would usually involve a total of 6 to 12 people, last a full day and end with the client requesting another iteration of the estimate from some or all of the product groups. Several people from each of these groups would then spend a couple of days collecting information, revisiting their assumptions and recalculating their spreadsheets. Then the revised quotation would need to go back through the management review chain. It would be presented at another meeting the following week that would occupy all of the same participants for another day. Typically three or four such meetings would be required to finalize the proposal, not to mention many days of effort on the part of the product teams that had to recompute their estimates over and over again.

Implementing a structured approach

I had originally been responsible for the structured software cost estimating process for Lockheed Martin's Western Development Labs in San Jose and was asked to establish the same process for the RSA IIA program. There are several basic advantages to the structured approach. First, providing a consistent and systematic method that is understood and agreed to by everyone involved in the process eliminates the need to revisit methods and assumptions for every proposal. Second, the use of a standardized approach makes it possible to implement software that can substantially reduce the time otherwise required to enter data and manipulate spreadsheets. There are several commercial tools available for structuring cost estimates but the customer in this project made it clear that they preferred SEER-SEM from Galorath Incorporated (www.galorath.com). A unique advantage of SEER-SEM is that it includes a database of thousands of completed projects from client-server, embedded, distributed, and stand-alone systems, varied MIS applications, graphics, and signal processing environments. This database makes it possible to begin generating accurate estimates immediately, even when little or no historical records are available.



Software estimation model (SWEM) in use at Lockheed Martin Mission Systems, Space Support Systems

The process that I developed for the Space Support Systems operation in Santa Maria works as follows. Each product group starts by producing a technical description that is broken into the smallest pieces that are possible at this early stage. The engineers then provide three estimates for the size of each block of code:

Sample RSA IIA Software Estimation Model (SWEM) SLOC Input Sheet

Subsystem A	New Development									Modified Code					
	Hours			Ada			SQL			Changed Code			Unmod Code		
	Opt	ML	Pes	Opt	ML	Pes	Opt	ML	Pes	Opt	ML	Pes	Opt	ML	Pes
Component A															
Training	120	160	200												
Sub-component 1				180	200	240				214	225	236			
Sub-component 2				95	100	105									
Sub-component 3				135	150	195							475	500	525
Sub-component "N"				90	100	110									
	324		20	558		18				225		5	500		10
Component B															
Test Bed setup	840	884	928												
Sub-component 1							400	500	600						
Sub-component 2							713	750	788						
	884		18				1250		44						
Component C															
Sub-component 1										450	500	600	170	200	260
Sub-component 2										95	100	105	90	100	120
										617		31	313		20

most likely, optimistic and pessimistic. The engineers also are all responsible for determining parameters that are used by SEER-SEM to estimate the productivity rate for the project. An example of a typical parameter is one that measures the level of formality of the program. A manned space flight, for example, requires a very formal program run to military standards so that high-level designs, detailed designs and test plans are presented at standup presentations that require a considerable amount of preparation. The majority of military programs, on the other hand, now use high-grade commercial standards that simply involve technical interchange meetings that demand much less preparation. Other input parameters that are included in the software estimation model are the application type, language, application complexity, development method, and experience level of the project team. Users enter probability levels for each parameter so that the risk of changes in these parameters can be incorporated into the final cost estimates. The parameter settings are then reviewed over the entire proposal to ensure each component is accurate relative to others.

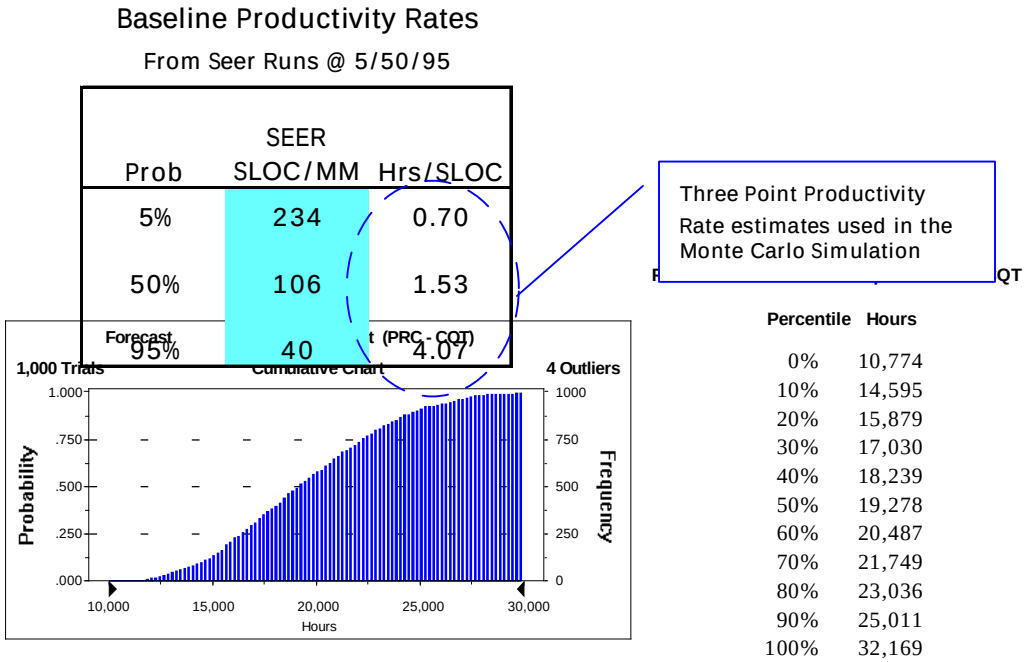
SEER Parameter Settings

System Components		*Predominate Language*	*Team Experience*	*Safety Critical*	*Reqmts Changes*	*Real - Time*	*Time Critical*	*Complex Displays*
Subsystem A	component a	*Ada*	Avg	Yes	small non-crit	10%	35%	Yes
	component b	*Ada*	Avg	Yes	Occasional	70%	50%	Yes
Subsystem B	component a	*C++*	Avg	Yes	small non-crit	No	60%	Yes
	component b	*Ada*	Avg	Yes	Occasional	No	None	Yes
Subsystem C	component a	*SQL*	Avg	No	Occasional	No	25%	No

Example SWEM input parameters overview

Understanding the risk involved

SEER-SEM then accesses its extensive knowledge bases to identify programs similar to the ones that are being estimated and generates productivity rate predictions that include a probability range for the potential rate based on the uncertainty factors entered by the estimators. These estimates, along with the estimates for the size of

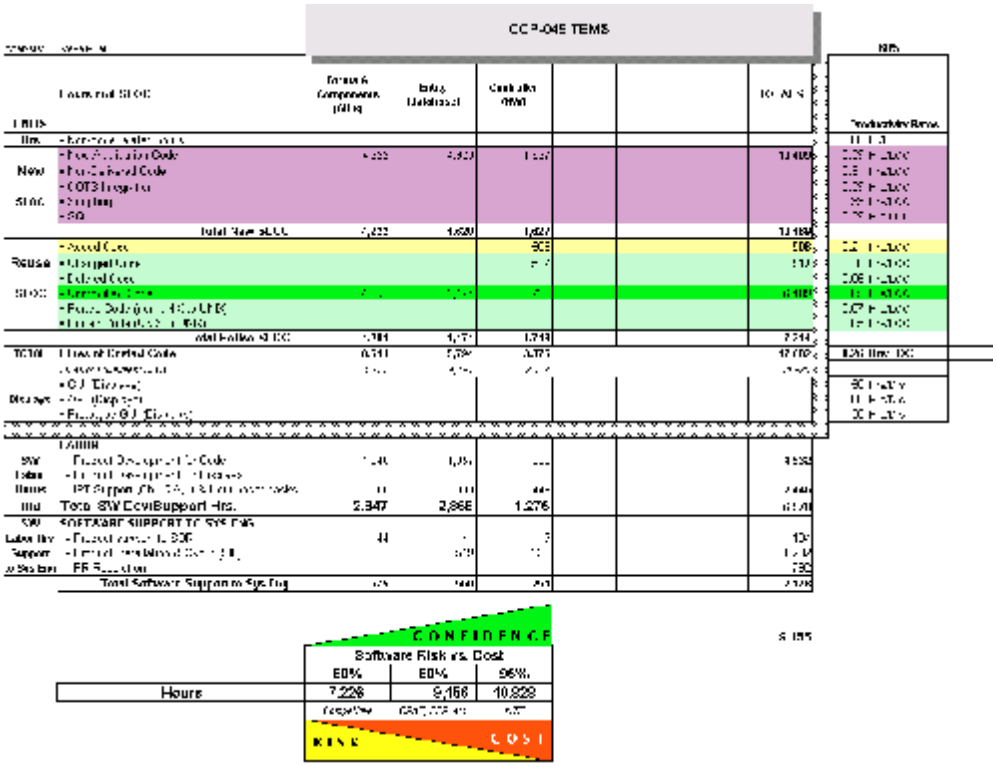


the project generated earlier, are then entered into a Crystal Ball, a Monte Carlo simulation program that performs statistical analysis on the estimate to determine the range and probabilities of all possible outcomes of the model. The population of results is then presented as an overall probability distribution for the simulation. For example, management might be told that that they can have a 50% level of

confidence that the program will take 20,000 hours or less, a 90% level of confidence that it will take 25,000 hours or less and a 100% level of confidence that it will take 32,000 hours or less.

Output of Monte Carlo simulation

The SWEM produces a Software Bid Summary summarizing the categories and size of the required SLOC along with the productivity rates from the Monte Carlo Simulation. It's then up to management to determine how much risk to assume in making the estimate.



SWEM Software Bid Summary

Post contract award, the SWEM is re-run periodically throughout the development lifecycle. This allows the early input estimates of size, product complexity and team composition to be replaced with actuals and/or more accurate estimates. The updated model supports management assessment of the effort to date as well as the estimate to complete.

This new approach has dramatically improved the efficiency of the cost estimation process," said Ed Butt, RSA IIA Program Director for Lockheed Martin. "Both our program managers and our customers understand the process and have confidence in it so there is not that much to discuss," he said. "The only areas that typically come into question are the input parameters and the program size estimates. We can make changes in these areas and rerun the model in less than an hour. The result is that we nearly always come to an agreement in the initial meeting, saving something on the order of six-effort months that would otherwise be involved in additional meetings and reworking the estimates." Ralph Tourino, vice president, Missions Systems' Space Support Systems, added that this process represents a significant step forward in the acceptability of software bids by our customer, and also in our ability to accurately predict program performance. "That's why we have

approved this method as a 'best practice' within Lockheed Martin," he said. "We are already in the process of implementing it in other divisions."

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