The 1989 NASA Space Exploration Initiative Cost Risk Estimate and Related Issues

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Introduction

- This paper examines cost related issues that arose during and after performing the 1989 cost risk estimate for returning to the Moon and going on to Mars (The Space Exploration Initiative (SEI))
- An Issue is something that requires effort to be expended
  - Because effort is expended there is an associated cost
  - Thus, issues are cost drivers
- This paper describes
  - how the cost risk estimate was performed
  - issues that arose from that process
  - issues that arose from follow-on personal research driven by performing that estimate
- The observations and perspective contained in this paper are personal and may differ from the perspective of the SEI project and NASA

Cost Risk Background

- In the 1980's, NASA Langley Research Center (LaRC) used the PRICE models for cost estimates but they did not have a cost risk capability
- In 1989, LaRC was the only NASA center using Monte Carlo simulation to provide a cost risk estimate for every cost estimate
- To perform the cost risk estimates LaRC had developed a model using PRICE-like parameters that had a Monte Carlo simulation capability
- The NASA Johnson Space Center (JSC) was using the Advanced Mission Cost Model (AMCM) for the Moon-Mars cost estimate but it did not have a cost risk capability
- JSC desired a cost risk estimate for SEI
- I pointed out to JSC that applying Monte Carlo using the parameters of a completed project did not represent the risk at the conceptual stage of the project
  - The LaRC cost risk process used parameters that represented the project at the conceptual stage

Cost Risk Estimate Background

- In 1989 I was asked by JSC to perform the 90-Day Study cost risk estimate of returning to the Moon and going on to Mars - The Space Exploration Initiative (SEI)
- I spent approximately two months at JSC performing this estimate
- I had the able support of
    - The team at JSC architecting the mission
    - The team at JSC estimating the cost
    - ECON and K Cyr of JSC putting together the Advanced Mission Cost Model (AMCM)
    - Bob Fairbairn back at the Langley Research Center

Five Technical Characteristics of a Cost Risk Model

- The statistical uncertainty associated with the derived cost estimating relationships (CERs)
  - The LaRC cost risk model did not yet include this uncertainty
- The uncertainty of the parameters applied to the CERs
  - These were determined through interviews with the project engineers
  - This interview process is what captures the risk at the conceptual stage of development
- The probability distributions
  - Beta distributions were used for the input parameters
  - Best case, most likely case, and worst case parameter values were determined from the engineer interviews and from prior experience
  - Correlation between distributions was included
- Project risks defined in a risk register
  - In 1989, LaRC projects did not have a risk register
  - Consequently, the LaRC Cost Estimating Office (CEO) had not developed the methodology to use a risk register for cost risk
  - SEI did not have a risk register anyway, so using a risk register was out of the picture
  - Note, however, that a parameter distribution on an input parameter has an effect that is similar to that of a risk register
- Process recursion
  - When the desired result of a process is unsatisfactory, it must be performed again
  - Research required to include this was not ready at that time
  - Had it been complete, there were no process definitions and no data

Cost Risk Estimate Challenges

- Obtaining travel to perform the estimate
- Obtaining parameters for our cost risk model
  - Calibrating manufacturing complexities from the JSC AMCM model estimate
  - Extending manufacturing complexities to 1989 and beyond
  - Interviewing the project engineers
    - JSC Engineers were not familiar with the PRICE-like parameters
- Obtaining computing resources
  - Used four Macintosh SE/30 computers used by JSC secretaries during the day
- Extending and testing the software to perform the estimate
- Understanding and estimating operations cost
  - Largely, the understanding of Moon and Mars operations came from several University of Texas graduate students and a software game they wrote
  - Operations data was very sparse
  - Operations data with an analogy to the Moon and Mars environments did not exist

Root Cause Cost Drivers

- Number of Astronauts
  - Drives the size of the community
- Energy
  - Required to move mass to the community
  - Required to keep the community alive
- Mean time between failure (MTBF)
  - Drives the need for mass to the community
  - Is critical for Mars
    - A 99% chance of success requires approximately a 250-300 year MTBF for each critical string for the 2.5-3 year round trip
      - What is the typical MTBF for equipment – particularly in a dust environment?
      - What is the MTBF for an Astronaut?
        - » How many Astronauts are required?
          - How much mass is required per Astronaut?
- Ability to live off of the land
  - Reduces the need for mass to the community
- Technical complexity
  - Drives the difficulty in creating the mass required by the community
- Robustness
  - Faultless operation over a wide range of parameters reduces cost
- Process recursion
  - Effort expended to do something over again substantially increases cost

Cost Risk Estimate Resources

- Cost estimation is far more than inputting parameters into a regression equation model. It requires a thorough understanding of the system being estimated and the system performing the estimate.

- Resources read to understand the scope of SEI
  - Ley, W. (1951). The Conquest of Space, Viking Press, New York, NY.
  - Von Braun, W. (1962). The Mars Project, University of Illinois Press, IL.
  - Ley, W. (1964). Engineers Dreams, Viking Press, New York, NY.
  - Dyson, F. (1979). "Pilgrims, Saints, and Space Men", Disturbing the Universe, Harper and Row Publishers, New York, NY.
- Resources studied to understand the colonization of the Moon and Mars
  - Miller, J. (1978). Living Systems, McGraw Hill Book Company, New York, NY.
  - Miller, J. (1987). "Applications of Living Systems Theory to Life in Space," Presented at the NASA-NSF conference *The Human Experience in Antarctica: Applications to Life in Space, Sunnyvale, CA, USA, 17 August, pp. 231-259.*
  - Miller, J. (1990). "The Timer", *Behavioral Science*, Vol. 35, Issue 3, pp 164-196.
- Background resources that define the cost technology used, approximated, or contemplated.
  - PRICE H & S Manuals, PRICE Systems, Mount Laurel, NJ.
  - Dean, E., D. Wood, A. Moore, and E. Bogart (1986). "Cost Risk Analysis Based on Perception of the Engineering Process" *Proceedings of the Eighth Annual Conference of the International Society of Parametric Analysts*, Kansas City, MO, 12-16 May.
  - Econ and K. Cyr, Advanced Mission Cost Model, http://cost.jsc.nasa.gov/AMCM.html .
  - Webb, D. (1990). "Cost Complexity Forecasting: Historical Trends of Major Systems" *Journal of Parametrics*, Vol. X, No. 4, December, pp. 67-95.
  - Dean, E. (1989). "Analysis of Complexity for Future Systems," presented at the *PRICE Symposium*, San Francisco, CA, 7-9 February.
  - Fairbairn, R. (1990). "A Method for Simulating Partial Dependence in Obtaining Cost Probability Distributions," *Journal of Parametrics*, Vol. X, No. 3, October, pp. 17-44.
  - Unal, R., E. Dean and A. Moore (1990). "Space Transportation System Operations and Support Cost Modeling Approach," *Journal of Parametrics*, Vol. X, No. 4, December, pp. 35-50.

Operations

- When you acquire a system, you are acquiring the whole life cycle of the system, not just it's development
- After the 90-Day Study cost risk estimate, I was asked to join the SEI logistics team
  - I performed a study using submarines as a model for Moon and Mars community logistics
  - Each submarine is a community
  - Each submarine carries a large part inventory
  - There is a submarine tender ship for every so many submarines with a large number of machines and parts on board for repairs
  - Submarines do not stay under water nearly as long a time as space communities will experience – particularly on Mars
  - My conclusions were that for the Moon and Mars
    - The planned number of astronauts for initial communities on Mars was inadequate
      - What is the MTBF of an Astronaut?
      - How long in time is a round trip to Mars?
    - Logistics costs would be considerably more than we had estimated
      - What is the mass required per Astronaut?

Colonization

- When you acquire a system, you are acquiring the whole life cycle of the system, not just it's development
- Initial communities on the Moon and Mars are analogous to the establishment of Jamestown, Plymouth, The Lost Colony, and Mormon Utah
  - Humans will be delivered by a transportation mechanism through a medium requiring time to arrive and return
  - Supplies must be adequate for their survival and the growth of their community
  - Because humans are involved, these communities are living systems
  - Thus, we must fully understand these living systems to estimate their cost

The WBS for a Living System

1. The **input transducer** brings information into the system [bring in, information]
2. The **ingestor** brings material-energy into the system [bring in, material-energy]
3. The **internal transducer** receives and converts information brought into system
4. The **channel and net** distributes information throughout the system [distribute, information]
5. The **decoder** prepares information for use by the system [prepare for use, information]
6. The **timer** maintains the appropriate spatial/temporal relationships
7. The **associator** maintains appropriate relationships between information sources
8. The **memory** stores information for system use [store, information]
9. The **decider** makes decisions about various system operations [decide on, operations]
10. The **encoder** converts information to a needed and usable form [convert, information]
11. The **reproducer**, with information, carries on reproductive functions
12. The **boundary**, with information, protects system from outside influences
13. The **distributor** distributes material-energy for use throughout the system
14. The **converter** converts material-energy into suitable form for use by the system
15. The **producer** synthesizes material-energy for use within the system mass-energy
16. The **storage** stores material-energy used by the system
17. The **motor** handles mobility of various parts of the system
18. The **supporter** provides physical support to the system
19. The **transducer** handles information output of the system
20. The **extruder** handles material-energy discharged by the system

A function is an [action upon, object]

Living System WBS Levels

1. Supranational systems: organizations of societies with a supraordinate system of influence and control
2. Societies: these are loose associations of communities, with systematic relationships between and among them
3. Communities: they include both individual persons and groups, as well as groups which are formed and are responsible for governing or providing services to them
4. Organizations: these involve one of more groups with their own control systems for doing work
5. Groups: these contain two or more organisms and their relationships
6. Organisms: there are three kinds of organisms: fungi, plants and animals. Each has distinctive cells, tissues and body plans and carries out life processes differently
7. Organs: the principle components are cells, organized in simple, multi-cellular systems
8. Cells: a basic building block of life

Cost Related Issues

- Until cost can be substantially reduced, creating communities on the Moon and Mars will be impractical
  - This drove my research from 1990 through 1998
- As long as we estimate hardware and software with no insight into how the cost arose, our estimates provide no guidance to design teams for reducing cost
  - Cost arises through the execution of processes [action upon, object] or [do, something]
- Much of the substantial costs of the living systems is currently allocated to wraps with no insight as to how they arose
- Until system developers focus on reducing cost, we will get what we have always got
  - There are tools that can be used to reduce cost
  - Nine years of my research into how to reduce cost is summarized at http://valuemanagement.us/dfcaadmin/dfca/ - a republication of a large part of my NASA Design for Competitive Advantage web site
  - In recent years Lean and Lean Six Sigma have added additional tools
- To become a part of the focus on reducing cost, cost estimators need to develop accurate target costing
  - To focus on root cause cost drivers
  - To focus on the cost of processes

Research Required to Establish a Community on Mars

- More cost effective energy
- Increased MTBF in a Mars environment
- Means to live off of the land in the Mars environment
- An improved understanding of living systems and related costs in the Mars environment
- More cost effective genopersistation
  - The processes
    - To bring into being
    - To maintain
    - To evolve, and
    - To retire
- Design for robustness
- Design for quality

Conclusions

- Cost estimating is far more than applying someone's cost model – it requires, at a substantial level of detail, that we understand what we are estimating and how we are estimating it
- There is a substantial amount of research required before we set foot on Mars
  - Cost understanding
  - Cost estimating
  - Cost reduction
  - Genopersistation
  - Living Systems
  - Technology

Additional Important Resources

- Meisl, C. (1989). "Advanced Life Cycle Cost Modeling," *Journal of Parametrics*, Vol. IX, No. 1, January, pp. 74-102. Emblemsvag, J. (2003). Life-Cycle Costing, John Wiley and Sons, Inc., Hoboken, NJ.
- Smart, C., G. Reese, L. Adams, A. Batchelor and A. Redrick (2007). "Process-Based Cost Modeling," *Journal of Parametrics*, Vol. XXV, No. 1, Spring, pp. 79-100.
- Dean, E. (1993). " Genopersistating the System," presented at the *AIAA 1993 Aerospace Design Conference, Irvine CA, 16-19 February, AIAA-93-1031.*
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- Yang, K. and B. El-Haik (2009). Design for Six Sigma, 2nd ed., McGraw Hill, New York, NY.
- Jugulum, R. and P. Samuel (2008). Design for Lean Six Sigma, John Wiley and Sons, Inc., Hoboken, NJ.