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COST MODELING TECHNIQUES FOR DESIGN MATURITY

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MR. RUHLAND: It is a pleasure to be here and not have something controversial to talk about, because I didn't have anything to do with generating any numbers here. So I'm just talking philosophically.

The first point I'd like to make is I'm in a very delightful position at JPL: I'm never right and I'm never wrong, because before a project comes in, my estimate is always too high; once it's through the door, it's too low. But, then, I'm never wrong because they never do the project that was estimated.

As a matter of information, Figure 10-3 shows some things that we have available at JPL. I'd like to say that they're only available to the government. They are not available to contractors; maybe they are lucky.

The first one is a model on re-entry heatshields, aerodynamic decelerators, and the integration problems particular to that. The model only works with the second model shown on the figure and I would like to point out the date, 1970, which makes it old. I would also like to point out the development of this model was funded by Dan Herman, as a matter of fact, in one of his studies, and we did a grand total of two man-months of effort on it and now use it as a guide for trade-offs.

In general, I want to talk about what drives subsystem costs and how maturity affects it (c.f. Figure 10-4). Basically, given a technology base, the cost is driven by the number of interfacing subsystems. The more interfacing subsystems you have, the higher the price tends to go. Subsystem costs are also driven by: the design and software maturity and I am using "maturity" the way some people might use inheritance; the test effort; and changes in the interfacing subsystems. And, cost avoidance items are hardware

RE-ENTRY VEHICLE COST ESTIMATING

AVAILABLE REPORTS AT JPL

- RE-ENTRY SUBSYSTEM COSTS (REF. 1) INCLUDE
  - HEAT SHIELD
  - AERODYNAMIC DECELERATOR
  - VEHICLE INTEGRATION (R/V TO S/C)
- TO BE USED IN CONJUNCTION WITH BASIC COST MODEL (REF. 2)

REFERENCE

1. F. E. Hoffman, "Cost Prediction Model for Unmanned Space Exploration Missions -- Entry Structure Cost Parameters," R-1434, dated April 24, 1970.

2. F. E. Hoffman, et al., Cost Prediction Model for Unmanned Space Exploration Missions, PRC R-1298, dated December 15, 1969

Figure 10-3

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COST MODELING TECHNIQUES FOR DESIGN MATURITY

SUBSYSTEM COST

GIVEN A TECHNOLOGY BASE

SUBSYSTEM COST DRIVEN BY:

- NUMBER OF INTERFACING SUBSYSTEMS
- DESIGN MATURITY
- SOFTWARE MATURITY
- TEST EFFORT
- CHANGES IN INTERFACING SUBSYSTEMS
- HARDWARE AVAILABILITY } COST AVOIDANCE
- SOFTWARE AVAILABILITY } COST AVOIDANCE
- SUPPORT EQUIPMENT AVAILABILITY } COST AVOIDANCE
- LEVEL OF DOCUMENTATION

Figure 10-4

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availability, software availability, and support equipment availability. These are the true inheritors. Finally, the level of documentation has a cost impact. For example, we can track in Viking some of the effects of the level of documentation. All these things have to be considered if we are ever going to have a low-cost approach in doing business.

At the laboratory, we have developed internal to the cost-estimating people - we tried to hide this from the JPL'ers so I hope they are not taking notes - a maturity index as shown on Figure 10-5. The basic concept of the maturity index is to bracket the level of the subsystem, its status. It begins at the highest index represented by existing, qualified hardware, or that which is in active production, i.e. you are going to do the same thing the same way. It proceeds then, the next step down, to either a modification of the hardware or which you have to qualify because there is a new environment that's different in some way, or you have to replicate the qualified design. We find when we analyze the cost data that if you can't get onto an existing line you can't achieve the inheritance that you would like.

Next, down the maturity index scale is extending the subsystem capability using qualified piece parts. For example, making a bigger computer out of the same piece parts. Or either of the items from the index above, where you have to qualify the modification or extend the time. As you spread out in time, you pick up more cost and this starts getting subjective. There is no question; trying to cost maturity or to take into account maturity requires subjectivity, it requires a great deal of understanding of what you are trying to do, and it takes a great deal of open-channel communication with the technical and project people to keep you informed of the actions and status.

The lower end of the maturity index is zero, where we have never done the subsystem before, new technology is required and we bracket to that level.

COST MODELING TECHNIQUES FOR DESIGN MATURITY

DESIGN MATURITY (HARDWARE)

SUBSYSTEM STATUS

MATURITY INDEX (MI)					
100	EXISTING QUALIFIED HARDWARE OR ACTIVE PRODUCTION (A)				
.75	MODIFICATION OF A (B)		A, BUT REQUIRING QUALIFICATION	OR	REPLICATE QUALIFIED DESIGN (C)
.50	EXTENDED CAPABILITY USING QUALIFIED PIECE PARTS	OR	(B) OR (C) REQUIRING QUALIFICATION	OR	WITH TIME
.25	KNOWN TECHNOLOGY	OR	MI=50 WITH TIME		
0	NEVER BEEN DONE BEFORE/NEW TECHNOLOGY				

Figure 10-5

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Figure 10-6 shows the effect of maturity on cost. One of the major points is that design changes flow toward the less mature subsystem. This is not really a continuous curve, it is a continuous curve for purposes of modeling. Actually, there are great pressures not to change the design if you have a high maturity level. There are great pressures at the very low levels of maturity (and high cost amplifier levels) to force the design toward higher maturity indices, so you tend to have a cost amplifier that goes up from the lower right and it sort of settles toward the middle. The most important point is that the inflection point tends to move with the changes in the interfacing subsystems. For example, if you have an existing computer but you are changing everything around it you are going to have to spend more money on the computer anyway.

This is the basic approach, philosophically. We have developed the CER's on this and we have tested it and it seems to be working fairly well.

The second most important cost driver that we tried to model is the test effort as shown on Figure 10-7. The test program is structured by the mission and the design complexity, the mission and program risk avoidance (or acceptance) and by design maturity of the system and subsystems. Someone, at some level, has to say, "I will accept less testing and more risk to save cost." I can verify for example that, with time, at JPL we have been willing to do less testing on the Mariner machine because we understand it better. The designers understand it better. The general structure of a test program tends to be directed towards detecting design and fabrication defects at each level. You test at the vehicle level, the system, subsystem, assembly, and at the piece part level with a minimum of some kind of screening. And accepting, or neglecting testing at any one of those levels is a major cost driver. It is a programmatic decision, a risk.

EFFECT OF DESIGN MATURITY

- CHANGES FLOW TOWARDS LESS MATURE SUBSYSTEMS
- ABILITY TO RETAIN DESIGN DEPENDS ON MATURITY OF INTERFACING SUBSYSTEMS
- COST AMPLIFIER RELATIVE TO MATURITY

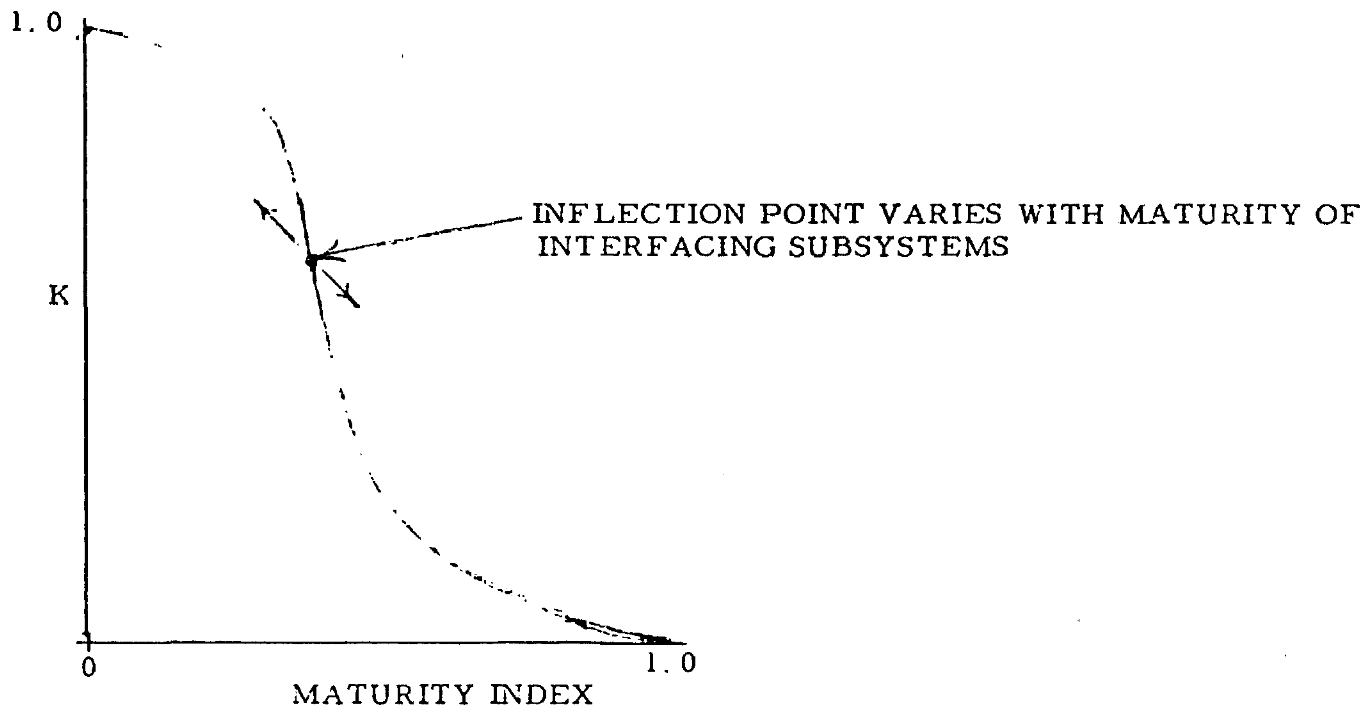

Figure 10-6

COST MODELING TECHNIQUES FOR DESIGN MATURITY

TEST EFFORT

- O TEST PROGRAM STRUCTURED BY:
  - -MISSION AND DESIGN COMPLEXITY
  - -MISSION AND PROGRAM RISK AVOIDANCE (OR ACCEPTANCE)
  - -DESIGN MATURITY

- O GENERAL STRUCTURE TESTS DIRECTED TOWARDS DETECTING DESIGN AND FABRICATION DEFECTS AT EACH LEVEL
  - -VEHICLE
  - -SYSTEM
  - -SUBSYSTEM
  - -ASSEMBLE
  - -PIECE PART (SCREENING)

Figure 10-7

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We have also developed a CER on which we have been working with regard to the effect of test level on cost. I show a sanitized picture of this on Figure 10-8. Basically, it results from the following things: As the number of test levels increases, the number of interfaces, the number of tests and support equipment increases. That is a direct cost driver. The impact is directly dependent on design maturity and, in general, it tends to look like the two curves on the figure. As the number of tests and test levels increase, the cost amplifier goes up exponentially because you pick up increasing integration costs, increasing support equipment costs, etc. Design maturity, however, can lower the cost amplifier as shown. But also you must not forget that with maturity the number of tests also comes down. You can't forget that this tendency to push down is directly affected by constraints and risks in management. To lower the cost for example by removing subsystem people from the project before you complete system testing, you are accepting a risk. If you don't want to accept the risk, you have got to expend the money necessary to continue to support the subsystem people.

That is really all I had to go over in a general presentation. I didn't realize this was to be an open meeting and I had prepared a presentation containing numbers that I am unable to release to an open session.

MR. VOJVODICH: Thank you very much, Bill. Do we have any questions?

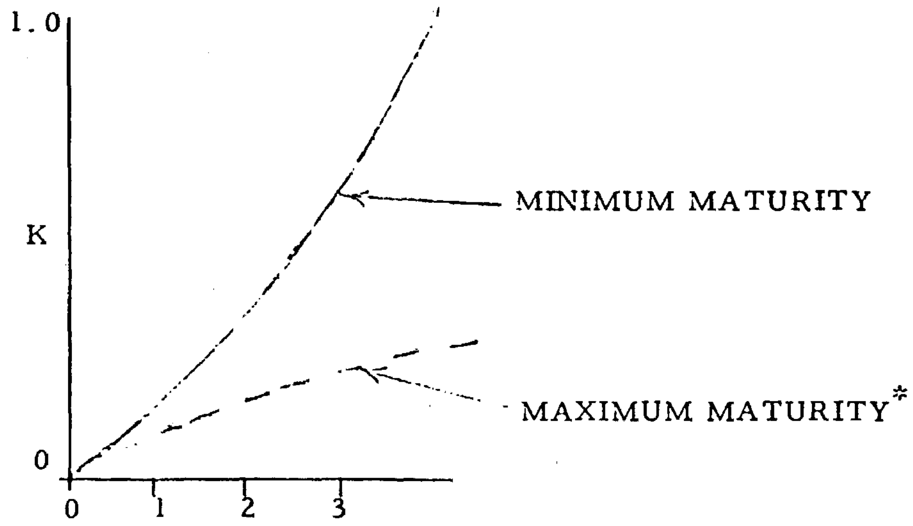
MR. CASANI: Yes, Let's see, Bill, you made a comment on the reduced level of testing you have experienced at JPL. Could you be more specific? We have looked at the series of Mariner programs. Is the percentage of total dollars that is being spent on testing decreasing?

MR. RUHLAND: The percentage has not been decreasing because as the design goes down, the testing goes down somewhat in parallel. So you might say that it's tending to stay a constant

COST MODELING TECHNIQUES FOR DESIGN MATURITY

EFFECT OF TEST LEVEL

- AS NUMBER OF TEST LEVELS INCREASE THE NUMBER OF INTERFACES, THE NUMBER OF TESTS AND SUPPORT EQUIPMENT INCREASE
- THE IMPACT IS DIRECTLY DEPENDENT ON DESIGN MATURITY
- COST AMPLIFIER GENERALIZE PROGRAM COST



NUMBER OF TESTS (NOT INCLUDING SCREENING OR BREADBOARD)

*THIS CAN BE CONSTRAINED BY RISK AND MANAGEMENT

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Figure 10-8

percentage of a reduced number. Because of maturity, you have an interaction in the cost of the design and the testing: You do less design and you do less testing. So the testing costs have gone down on a normalized basis, but they tend to stay the same percent because the design cost comes down.

MR. SEIFF: I found your presentation to be really a dream because it looks like you are trying to quantify something that has been generally something of a black art, you know, sort of a guessing game. I was just wondering how far this quantification goes in terms of - take a new program like this one that is being discussed here. Do you actually proceed from a set of charts? The ones you showed us were qualitative; they had no numbers on the axes.

MR. RUHLAND: I painted the numbers off.

MR. SEIFF: You take a set of charts and apply them, subsystem by subsystem, and end up with a final estimate. Do you then try to bring judgmental factors in at that point or how do you actually do this; and what has been your experience in predicting the accuracy of the end result?

MR. RUHLAND: We try to push the subjectivity to the farthest front point that we can, and we quantify all the operations thereafter. The subjectivity comes from a dialogue with the technical people, trying to understand what they mean when they say they are inheriting this or they are expanding that, and to turn it into an input factor. But we have been doing this for six years now. We started trying to track inheritance six years ago and we have been learning. We did terribly for a while and we finally got down to something that I think is working right now. A priori it tracks about thirty missions, when you use the maturity factor, within about a three-percent band. On a new project it's probably tracking twenty percent but how much of that is the model and how much of that is understanding of the project? What I said in the beginning wasn't a joke; it's literally true. The project I estimate with a model, before there is a project office is never done. When you get a project office and they see the problems they've got and they really try to buy the hardware that they can't get now, the project is restructured. So, literally, they never do the project that is estimated by the model before the fact. Now, at JPL I track every project until completed. I continuously re-estimate and I can see it coming in. They change and we converge. If you don't know the project, you can't get the cost.

MR. HERMAN: Just one question: On MJS what was the variance between __________'s estimate and the estimate as submitted by your model?

MR. RUHLAND: We came within plus or minus five percent on the mean. I don't remember precisely. I think it might have been plus or minus four percent, so that is an eight percent band width.

MR. HERMAN: Is the project that you modeled the project that Boyster and Meyers are implementing now?

MR. RUHLAND: Pretty much. I have done a couple more model runs since. I do a minimum of one model run on every project a year, and the last model run I did, I talked to Hickock and the people and we got the deltas and changes, and we went through there. There were not many changes in the assumptions to make a model run, number one; they were very close. The numbers still tracked about the same way.