Midwest Gateway Newsletter

International Council on Systems Engineering

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In This Issue

Good Requirements are Key to Successful System Design

Chapter-Sponsored Tutorial Provided Insight into Why and How to Write Good Requirements

by Carol Wilke

With a full house of 47 engineers, the chapter's Spring Tutorial on Requirements Definition and Management was successfully completed on 9 May. Judging from the level of participation during the tutorial and comments received after the session, attendees learned both why and how to write good requirements.

The tutorial was presented by Ms. Ivy Hooks President of Compliance Automation, Inc. (CAI). Ms. Hooks teaches classes, conducts audits, and provides consulting to government and industry in all areas of requirements management. She is widely recognized for her work with requirements and has published numerous papers on the subject in various technical journals. Ms. Hooks drew on her experiences from a 20-year career at NASA to provide concrete evidence of projects where poor requirements had led to cost and schedule overruns.

Writing good requirements is hard work and requires a disciplined approach from both management and the technical team. Class participants learned just how hard the work was through a series of exercises done in small groups. With over seven different answers from seven different groups, it was obvious that even designing an automated system that lights candles is not easy when the requirements are not explicitly stated! These examples helped drill in the point that asking the right questions in a way that the customer can understand is one crucial piece of developing a system that works to the customer's satisfaction.

The tutorial was divided into three sections: Why, What, and How. The "Why" and "What" sections seemed especially useful to participants who need to start with the basics – why is requirements definition and management necessary (and how do I convince my management of that) and what makes a requirement "good" (or not so good). The "How" section appealed directly to those already in the trenches of requirements definition by listing strategies to elicit and document good requirements as well as pitfalls to avoid.

Mike Miles, a staff engineer at Caterpillar Incorporated, found that the tutorial provided needed data on the usefulness of dollars spent in the requirements phases of projects. In a later conversation about his overall impressions of the tutorial, Mr. Miles noted that many commercial system developers, Caterpillar included, are needing to define and develop systems that are more automated and more complex. These companies are often just now realizing that a more methodical, process-based systems engineering approach is needed to capture and manage requirements. For him, the tutorial provided useful empirical data that can be used to convince his management of the need for a defined requirements management process. He is talking with Ms Hooks about conducting a similar workshop at Caterpillar.

Bill Gold, an engineering manager at The Boeing Company, found the "How" section to be the most useful. From his perspective, the credible empirical data shown by Ms Hooks in the Why and What sections

backed up the points she made while relating more personal experiences on various NASA projects. But, since he has been convinced of the need for requirements management for some time, he felt that the more directly practical discussions of the "How" section would prove more useful. In particular, Mr. Gold cited the small group discussions during the exercises as giving him new perspectives on how to elicit requirements. He also felt that Ms Hooks' discussion of specification outlines, the structure of a good requirement and her checklist for requirements capture would be useful. Mr. Gold did, however, mention that he expected more discussion of performance-based specifications (a hot topic among Defense contractors these days) than was given.

The tutorial was held on the main campus of Washington University in St.Louis. Thanks are due to Dr. Christopher Byrnes, Dean of Engineering and Applied Science at the university, for offering use of these facilities. Also, thanks are due to Ralph Lambert, Clint Moor and Richard Schwadron for organizing the event.

Planning for the chapter's Fall Tutorial is in work, so watch for an announcement this summer.

Points for Discussion

This issue of the Midwest Gateway Newsletter introduces a new feature: Points for Discussion. Our intent is to foster discussion among chapter members concerning interesting or controversial ideas within the field of Systems Engineering. Each set of articles will try to advance discussion of a single point within Systems Engineering, and will often end in a series of questions that may spark further debate.

The first article in this series was written by Dr. Mark Maier, from the University of Alabama at Huntsville. Dr. Maier should be familiar to many members of the Midwest Gateway Chapter; in October 97, he led a chapter-sponsored tutorial based on his book, "The Art of Systems Architecting". The article printed here originated from virtual discussions via the INCOSE discussion listserver.

See the Editor's note at the end of this article for ways that you can join in the discussion.

Engineering: An Art or a Science?

by Dr. Mark Maier

Effective engineering is a mixture of art and science. By science I mean those aspects that can be rigorously studied through repeatable experiment and deductively connected to underlying theory, generally through mathematics. By art, I mean the application of human judgment whose decisions cannot be validated through the use of science.

Satellite orbits are a matter of nearly pure science; the aesthetics of painting are a matter of almost pure art.

Most engineering design problems require (for effective solution) a mixture of art and science. At times the weight of which is needed will change. The design of vacuum tubes was once largely an art, it is now largely a science.

We know quite a lot about how to improve the scientific side of our practice. Do careful experiments, build models based on underlying physics, improve those models until the models closely match the experiment, and go to the next level. Inspiration or art is often required to get the right model or formulate tractable experiments, but the feedback of experiment-model provides solid quality control. In those fields where we can readily perform repeatable experiments, identify sources of variation, and have solid theory on which to build models, we can make rapid progress on the science side (think semiconductors). In those fields where doing repeatable experiments is hard, and where we have layered theories with considerable uncertainty at all levels, scientific progress is hard and often uneven (think economics and medicine).

What about the art part? How do we improve the part of our practice that is not scientific? It seems to me that most people recognize the important role of the art part, but have quite different attitudes about how we can improve practice on this side. I would characterize attitudes as falling, roughly, into one of the following camps:

1. Skill in the engineering art is fundamentally personal and based on personal experience. It is pointless to try to teach, study, or codify it. Those who practice widely and deeply, and have the right innate talents, will learn the art well; others will not.
2. The best way to deal with art problems is to turn them into problems with scientific form, even if they lack complete scientific content. Find theories that seem applicable and deduce from them, even if the theories are shaky. Essentially, the idea is to try to do things in a scientific manner, even while knowing it is not really scientific, and hoping that the effort will produce better results and better science quickly and reliably.

3. The art side of the problem can be codified through loose rules or pragmatic principles, which for purposes of this discussion I will call heuristics. Furthermore, documentation, study, and consultation of these heuristics are effective at improving the art side of the practice.

I call Position 3 the "Heuristic Hypothesis." It says that the principles of the art side of engineering can be documented; that consulting these documented heuristics is effective for practice, teaching, and learning; and that documented heuristics are more useful than the undocumented or even unconscious ones that engineers use everyday. This hypothesis also says that such an approach is better than an imitatively scientific approach, at least for art-like problems. It is, however, a hypothesis, and not a scientific one. It cannot be proved or disproved; we can only observe whether or not it is supported by the weight of experience. Of course, most things can't be formally proved or disproved, only supported or not by the weight of evidence.

In practice, one uses documented heuristics as an assist in uncertain design choices. They cannot be used rigorously or absolutely as following them is no guarantee of success. They require wisdom to use effectively. The hypothesis says they are a CRUTCH to an engineer's wisdom, not a replacement for it.

Let's take a very simple example. Suppose we are designing a computer-based control system for a chemical processing plant that includes a user interface. Among all the objectives for the system, consider three:

1. The main sensing and control loop for the system has to update faster then once every 0.1 seconds.
2. The user interface must respond quickly enough, so that a user can make changes to the system in 30 seconds. Beyond that, faster is better, but user satisfaction returns are diminishing.
3. The system will likely be changed fairly regularly (new hardware, new control algorithms), so it is important that the system be easy to modify.

Now, how will these objectives be dealt with? In the first case, designing a sensing and control loop within a cycle time constraint is reasonably well understood. The design is done when it can be determined, by analysis and/or measurement, whether or not the system cycles deterministically in 0.1 seconds. There is plenty of science to be applied to this problem readily to be found in books. The second objective is not quite as clear cut – scientifically designing for and measuring user satisfaction isn't easy – but at least we've got an objective measure to work with – user changes can be made in 30 seconds. So, as we design, we can count the number of steps the operator must take to make changes, etc.

The third objective is the tough one. Do heuristics have some role? Definitely. After all, what do we know about making systems more modifiable? We can't prove modifiability; its meaning is context-dependent and uncertain. But induction from experience (coupled with measurements) tells us a lot. For example, building system components with low coupling and high cohesion reduces the defect count and maintenance cost. Indeed, this effect has been measured, though we cannot say conclusively what the effect will be in any particular case.

So an engineer comes to me and says "Here is my design and here is the proof it will cycle in 0.1 seconds". Unfortunately, it is a bunch of components that use only global variables and have only coincidental cohesion (the worst on the scale). Do I say "Good job. It will run right, and tough for them about upgrades." No, because I know some other pragmatic principles (learned from experience; I'd call them heuristics) that can help meet the third objective while still meeting the first. One is "High coupling may be necessary for high performance, but poor cohesion almost never is". I also know that good modularity frequently helps performance, if the partitioning is drawn to isolate time-critical and computationally-intensive sections. By isolating these sections, it is easier to direct careful attention to them and to parcel out some chunks to a real expert in algorithms or high performance design.

Even with regard to the first two objectives, heuristics provide useful guidance. For example, a set of heuristics for high performance design recommends the following steps:

1. Don't think about optimizing for speed without a quantitative timing budget.
2. First produce a high quality design (cohesion, modularity, etc.) and determine its performance, then apply performance improvements to the subsections which perform inadequately or which use most of the timeline.
3. Optimize code that is known to work rather than try to debug code that has been optimized.
4. Look for fundamental improvements (faster hardware, better algorithms, time-space tradeoffs, etc.), before resorting to code tuning or other "tricks".

Returning to the original line of thought, I argue the following points:

1. Effective engineering (especially systems engineering) is a mixture of art and science

2. An effective means of improving practice in the art side (not the science side), is by explicitly documenting and studying pragmatic principles inducted from practice.

I believe that the only serious argument that can be made against point 1 is by defining away anything that doesn't fit the scientific model as not being engineering. I think that is a cop-out and entirely unrealistic.

Point 2 on the value of documented heuristics is much more open to debate. While we can debate it, I think that it might be more interesting if those who oppose this point of view would propose an alternative.

Even if we accept both points, we have lots to do. Recognizing the role of art is no excuse for doing the science badly, or for failing to recognize which is which. Deciding that documenting heuristics is a good idea is just the barest start. Which ones should be documented? How do we classify them and "validate" them? How should they best be used on real system projects? Are prescriptive heuristics closely tied to modeling and are process models the most useful (or only useful) sort? Or, can much more general heuristics be used as well? Given the large number of heuristics already around (books, best practices lists, etc.), why don't we make better use of them?

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Editor's Note: Your thoughts on this article, and any answers to these questions are requested. Send responses to the Midwest Gateway Newsletter, c/o Carol Wilke, Editor. (Mail address is MS 270 3647, PO Box 516, St. Louis, MO 63166; e-mail address is carol.e.wilke@boeing.com). All responses will be forwarded to Dr. Maier and considered for inclusion in the next edition of this Newsletter.

If you have contributions or ideas for other Points of Discussion, please contact the editor.

Chapter Meeting Reviews

Ford Tour Offered Insight into Complex Manufacturing Process

By Jeff James

On 28 April 98, approximately 20 members of the Midwest Gateway Chapter attended a tour of the Ford Hazelwood, MO Assembly Plant, which is currently producing the Explorer sport utility vehicle. The tour was hosted by Stella Mueller, Employee Resource Coordinator, who was an excellent tour guide.

The two hour tour started with an informative video on Ford's facility, which included an overview of the painting process. Following a quick introduction, Ms Mueller led us on a walk-through of the facility. If the entire production line were walked, one would have traveled 20 miles; our group covered only a fraction of the complete length of the line.

Ms Mueller ended the tour with a question and answer period. Reactions by participants were quite positive. Having a chance to see how other companies produce products is always an enlightening experience. Stay tuned for a planned announcement of another company plant tour this fall.

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The Engineering of Innovation

Those of you who were unable to attend our March meeting missed a real treat. Tom Cummings, of Invention Machine Corp., provided an entertaining insight into the world of invention using his company's innovative engineering solution process and toolset. Comments from the members attending indicated that we started the year on a high note.

INCOSE Symposium Plans

9th Annual Symposium to be Held in Brighton, England in '99

by Carol Wilke

Are you working on a draft paper for INCOSE's 1999 Sympoisum? Now is the time to get those ideas kicking around, because the submission deadline, 2 Oct 98, is only four months away.

The theme for this symposium, to be held in Brighton, England on 6-10 June 99, is "Systems Engineering: Sharing the Future". Due to its location, this symposium promises to provide new and exciting insights into how Systems Engineering is practiced outside North America, particularly in Europe. And remember, round trip airplane fares from the Midwest to London can be had for as little as $400, so costs for attending the symposium should be no greater than in past years.

The actual Call for Papers for this Ninth Annual symposium is reproduced at the end of this Newsletter. Any chapter members who have paper ideas but would like to pursue collaboration with other members on the actual paper generation are welcome to contact chapter president, Bob Scheurer.

From The President's Desk

by Robert P. Scheurer

As professionals, we strive to put out our best effort in most everything we do. Obviously, being consistent in producing excellence is the hard part. At INCOSE and particularly in your Midwest Gateway Chapter, we've been working hard this year to produce the services you need as you strive for excellence in your careers as well as in your lives.

At the International level, we have the newly-formed Center of Excellence, dedicated to raising the level of understanding and technology of this "thing" we call Systems Engineering. At the local level, we recently completed an excellent tutorial by Ivy Hooks on Requirements Definition and Management. Based on the results of the tutorial survey, it appears that the day was time well spent. Thanks to Ralph Lambert, Clint Moor, and Richard Schwadron for producing an enthusiastically received and sold-out tutorial with 47 participants. Thanks also to Dean Bristow, who has agreed to chair the tutorial effort for the Fall. Let Dean know (314-232-7166) if there is something in particular related to Systems Engineering that you would like to learn more about via a tutorial.

When we look forward to the lazy, hazy days of summer, we plan to spend a little time relaxing and enjoying the fruits of the labors of some of our local members. Without stealing all the thunder of our Programs Chair, Jeff James, I'd like to briefly hint of what's coming up in the next three months. As you know, the annual International Symposium is in Vancouver, Canada this year. Congratulations to two of our members, Carol Wilke and Don Hess, who had papers accepted and subsequently will be making the trip to the Great Northwest (or Southwest if you're from Canada). Back in the Midwest, we will be privileged to hear Carol's and Don's presentations as part of our annual "Dry Run" of Symposium Papers in July. Please plan on attending so that they can receive quality feedback in "fine-tuning" their performances.

One of the untapped resources of the Midwest Gateway Chapter is the vast region of membership. Did you know that we have members from throughout the Midwest, including from the states of Kansas, Missouri, Illinois, Indiana, and Ohio? Obviously, getting to a Chapter Function is a formidable challenge to those members far outside the St. Louis area. Fortunately, technology can help solve these kinds of problems, with the INCOSE web sites (www.incose.org and www.aae.uiuc.edu/incose), listservers, and e-mail. We will be attempting to reach out to these more distant members, along with building our local membership base, with some new and innovative initiatives later in the year.

As I stated in a previous monthly e-mail message, the times we live in today are fast-paced and very dynamic. Membership in professional societies such as INCOSE can help us to see that we're not alone in dealing with all the changes. As you consider another year of membership with INCOSE, I urge you to act today and renew your membership -- better yet, become actively involved. We've been having a good time and learning much at the chapter events this year. With your participation, we can continue to learn better ways for consistently producing excellence.

Communications Committee

Chapter Website is Up-to-date

Have you visited the Midwest Gateway Chapter website lately? The website is hosted through the University of Illinois at www.aae.uiuc.edu/incose . On the site is general information on INCOSE, and the Midwest Gateway Chapter, and a list of systems engineering resources. Also available through this website are a year's worth of editions of this Newsletter in printable form. If you have ideas on other uses for this website, please contact the Communications Committee Chair, John Adrian.

In addition to our website, the chapter has been sending regular e-mails to the members, including meeting notices and a monthly missive from our chapter president. If you have not been receiving chapter e-mails, please forward your e-mail address to John at john.p.adrian@boeing.com.

If you have not been receiving chapter mailings, including this Newsletter, at your preferred mail address, please contact John at

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Chapter Business

Highlights of Actions by the Board of Directors

The Board of Directors of the Midwest Gateway Chapter meets regularly on the second Tuesday of each month, with special meetings scheduled when needed.

Any chapter member is welcome to attend. Actions and discussions at recent Board meetings have included:

- Planning for a June social event – a night at the Ball Game to watch the St. Louis Cardinals
- Planning for the Fall Tutorial
- Creation of a brochure describing INCOSE and the Midwest Gateway Chapter for prospective members

Please contact Board Secretary, Don Hess, for more information on particular items or on how to attend future meetings.

Information on how to contact each board member and the chair of each standing committee is listed on the last page of this newsletter.

Upcoming Programs

Mark Your Calendar for These Events

- 5 June, Midwest Gateway Chapter sponsors Night at the Ball Game
- 21 July, Chapter Meeting – Symposium Paper Presentations, Time and Location To Be Announced
- 27-30 July, '98 INCOSE International Symposium in Vancouver, Canada
- 2 Oct, Deadline for submittal of draft papers for '99 INCOSE International Symposium, scheduled for June 99 in Brighton, England
- Late October / Early November, Fall Tutorial. Contact Dean Bristow, at 314-232-7166, with ideas or suggestions for topics.

If you have ideas for upcoming programs, comments on past programs, questions on any of the programs listed or would like to participate on the Programs Committee, contact Jeff James at (314) 233-2869.

Got an Idea?

How to Contribute to this Newsletter

This Newsletter is published four times a year, with the goals of

- providing technical articles of interest to chapter members;
- stimulating discussion on systems engineering issues;
- keeping chapter members informed on upcoming programs and events.

The Newslettter staff is always looking for good articles, information on the technical issues Systems Engineers face on a daily basis, questions you'd like answered about the chapter or the International organization, and topics on which you'd like more information.

You can reach Newsletter editor Carol Wilke at (314) 233-8451. Contributions of articles or announcements, and letters to the editor can be sent to Carol Wilke at carol.e.wilke@boeing.com, or

Carol Wilke

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MS Word 6.0 format is preferred, but we can work with text from most word processing formats, if necessary. For graphics, please call. Please include name, e-mail and mail addresses, and phone number in all correspondence.

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