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Enabling Research Synergies through a Doctoral Research Network for Systems Engineering

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Abstract. As contrasted with traditional engineering and science fields, doctoral research in systems engineering is characterized by several unique factors. These include the relatively young tradition of systems engineering academic programs, the necessity for hybrid research methodologies, the existence of strong links with industry and government, and a non-traditional makeup of students in regard to their background, experience levels, and career goals. The International Council on Systems Engineering (INCOSE) has set strategic objectives and policies to encourage doctoral level research in systems engineering, and has recently undertaken an initiative to create a doctoral student research network. This paper describes the motivations for and formation of the Systems Engineering and Architecting Doctoral Student Network (SEANET), and presents findings from a survey conducted at the 2006 inaugural workshop event. While limited, this survey gives insight into the demographics of students and underscores the essential role of a network in motivating, encouraging and shaping doctoral research in systems engineering. Implications are discussed based on three key findings from the survey. These include: (1) the pool of systems engineering doctoral students is largely non-traditional; (2) students identified attending workshops and access to data as the two most pressing issues that professional societies can help with; and (3) doctoral students in systems engineering have a high diversity of career interests. Professional societies play an important role in encouraging and enabling systems engineering research, and sponsorship of a research network is an effective mechanism for this goal given that such societies can provide a neutral venue for this interchange.

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1. SYSTEMS ENGINEERING DOCTORAL RESEARCH

Doctoral programs around the world have a common purpose and process. First, the PhD is assumed to be a research degree, and its primary purpose is teaching junior scholars to conduct sound, rigorous research. Second, the operating model is one of mentorship. Typically, students work under the tutelage of their advisors, learning the intricacies of research, and becoming increasingly independent scholars. Within this framework there is, of course, considerable variation among disciplines and universities. Depending on the discipline and university, students may begin to conduct supervised research during their first term and see their advisor nearly every day. They conduct research in laboratories, with teams of students, faculty, and postdoctoral fellows. In other cases, each scholar may work in isolation, and meetings with advisors may be infrequent. Consequently, the experiences of students across disciplines vary depending on whether their research is lab-based (e.g., biological science), library-based (e.g., information science), or field-based (e.g., social science).

Four significant characteristics that distinguish doctoral students in systems engineering from other disciplines are:

1. The relatively young tradition of systems engineering academic programs (Fabrycky 2005) and the associated research methodologies (Valerdi and Davidz 2007)
2. The strong links with industry and government
3. The non-traditional makeup of students
4. The wide range of professional opportunities available after graduate school

This paper discusses how these characteristics can be leveraged through a doctoral student network to ultimately enhance the field of systems engineering.

In recent years, systems engineering has received increased focus and expanded its footprint on a global scale. Many new university academic and research programs have been developed in response to the higher demand for systems approaches and skilled engineers (Brown, 2000; Ng, 2004; Fabrycky, 2005). These programs exhibit some diversity in structure, alignment within the university, and focus areas for curriculum and research. This ranges from programs embedded in dedicated departments for systems engineering to programs that co-exist within other fields such as industrial engineering. Furthermore, systems engineering and related programs have been categorized into two general categories: SE Centric and Domain Centric SE (Fabrycky 2005). A number of these schools have established doctoral programs for systems engineering, however most are in early stages of development and may benefit from interaction with faculty and students from other institutions. This serves as a primary motivation for the creation of a doctoral research network for systems engineering.

2. INCOSE SEANET INITIATVE

As a professional society, INCOSE has set strategic objectives and policies to encourage doctoral level research in systems engineering. As a significant step, it has initiated the Systems Engineering and Architecting Doctoral Student Network (SEANET). The potential for a doctoral network may be greatest when it is realized as an enabler for doctoral research through the collaborative efforts of all of the stakeholder organizations. The authors view professional societies as the preferred owners for such networks, as they can effectively act as a 'neutral broker' to involve the other organizational stakeholders. A research network can add value in many ways, for example:, defining the nature of systems engineering research, aiding the formulation of good research hypotheses, and "right sizing" of dissertation topics. It can also increase the probability of success for doctoral students by providing strategies for avoiding mistakes in managing their doctoral programs. Such mistakes have been well documented and can serve as valuable lessons for future students who are concerned about managing their advisor, evaluating opportunity costs, and building an asset base of research skills (Grover 2001).

SEANET brings together students from several universities with similar yet complementary interests; provides additional mentoring through INCOSE Fellows and other technical leaders; and provides collaboration and publication venues. As the first step towards this goal, a pilot workshop of SEANET was held January 29-30, 2005 at the INCOSE International Workshop in Tampa, FL (Rhodes, 2005). The pilot workshop was attended by eight doctoral students from five universities[2], SEANET mentors, and INCOSE senior leaders from industry, government, and academia.

[2] Pilot program students came from Loughborough University (one), Massachusetts Institute of Technology (two) , Stevens Institute of Technology (two), University of South Australia (one), and University of Southern California (two).

These individuals represent the first social network that links mentors and students from multiple organizations. As shown by the solid lines in Figure 1, some of the individuals had pre-existing relationships mostly within mentors. Through the interchange of the pilot workshop, many new linkages were established between the involved participants as shown by the dashed lines.

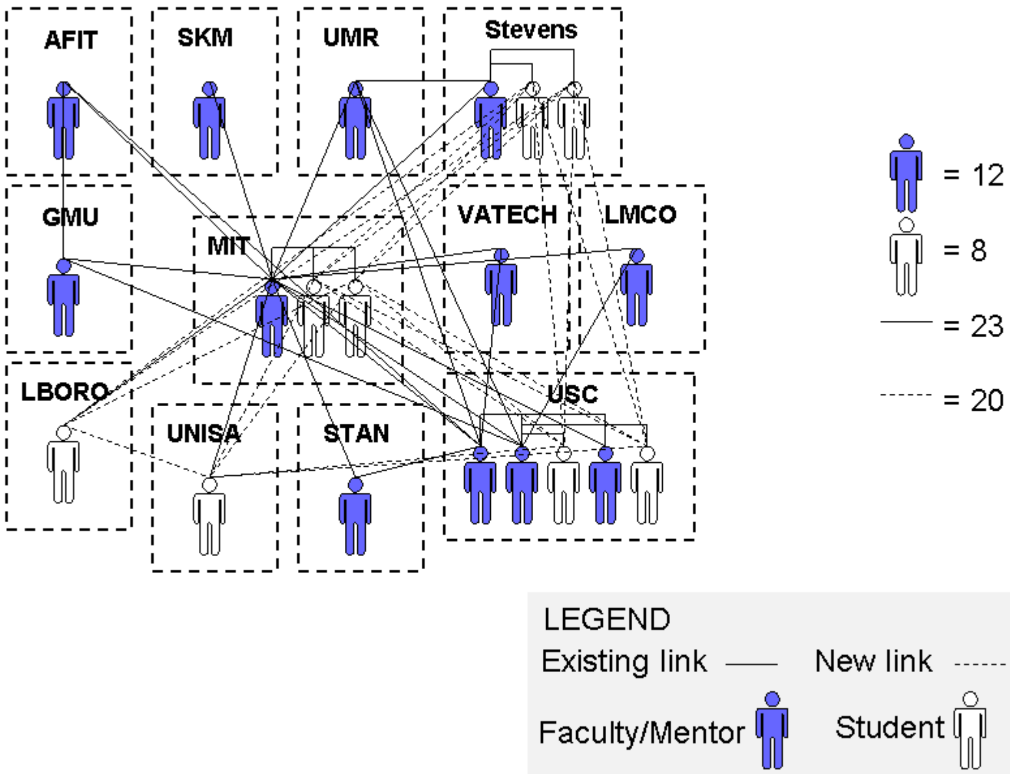

Figure 1. SEANET Social Network in January 2005.

Both mentors and students had the opportunity to exchange ideas and establish new links based on their common interests. Through their intellectual pursuits in the systems community, the mentors were able to provide ideas and valuable feedback to students in the network while gaining new knowledge about doctoral research at academic institutions. During the session, various observations and perceptions were gathered using a structured discussion and captured in meeting notes.

It was observed that each student involved in this initial meeting had some industry experience, and that this may be a beneficial, but not mandatory, asset for doing systems engineering research. It was noted that there is a difficult challenge for students to go from the broad systems perspective to a specific dissertation-scope topic. This may be one aspect of how a doctoral network can help shape the student's research project, although there is also a risk that exposure to a wider network and more ideas could unnecessarily expand their scope. The balance has to be carefully managed by the students and their advisors to ensure that their involvement in SEANET is value added.

An issue for systems engineering research challenge is whether systems engineering in its present form is sufficient to address some of the difficult topics discussed in research sessions. The mentors noted that this meeting accentuated the issues of intellectual content and strategic directions for systems engineering, recently discussed by several INCOSE Fellows (International Council on Systems Engineering March 2006). It also underlines deeper issues in the challenges of systems engineering as an academic field (Dixit & Valerdi, 2007). Mentors suggested that students be encouraged to include in their dissertation some justification for their research in context of overall systems engineering state of the art and practice, and how it contributes to the intellectual basis.

Mentors and students felt the network may provide a means to begin to build a composite picture of all of the diverse research that is going on in the field of systems engineering, and can help to characterize and give validity to doctoral worthy research. The feedback to students (via mentors and others students) could accelerate the progress perhaps in both time to completion (for students struggling with finding a research topic) and in knowledge building. Modern systems research involves new linkages into diverse areas of all sciences, including cognitive science, social science, and others. The network can potentially drive new synergies in this regard but careful consideration must be taken towards issues of research methodology, especially in mixed-methods research.

The students found SEANET to be an excellent forum to share research ideas and gain valuable feedback and advice. Specifically, the network allowed the students to see the overlap in various research topics, to understand what it takes to complete a PhD in systems engineering at different academic institutions, and to receive additional validation that they have a good research topic as perceived by a wider systems community as well as their immediate committee and university. The network also provided greater student access to researchable ideas, as well as new research contacts.

One concern that was raised during the initial phase of SEANET was whether a student's university program would perceive the network as a positive influence for the student rather than as intruding on the territory of the individual school and advisors. During the 2006 workshop, this concern was discussed and all graduate students reported only positive feedback from their personal advisors and committees.

Students confirmed that they would like a voice in the evolution and management of the network, as well as in coalitions of universities and other initiatives focused on advancement of the field. Their involvement provides a good opportunity to articulate ideas in the early phase of their research. Students noted that there are different issues of importance at different times in their doctoral lifecycle – coursework, qualifying exams, and dissertation/defense, and that each issue will require unique mentoring and support needs at each of these major phases.

One student noted that INCOSE can have significant influence on shaping the way students think about systems engineering. Another student, who was in the final semester of his doctoral program, noted "*I wish I had the opportunity to participate in this three years ago". S*tudent suggestions for ideas for network activities included: identification of the value of a doctoral degree in systems engineering; students from different universities co-authoring a paper on a theme; development of categorized lists of recommended readings; sharing research plans (including reading lists) so that new students can learn from these; conducting (via telecom) dry runs of dissertation defenses to help prepare students for actual defense; establishing web-based resources and communications; and developing the "business case" for individual/university involvement in the network. As SEANET evolves, the alumni of the program will play an important role in ensuring program support. An expectation is that participating in the network as a student will create the natural desire to contribute to this program, and continued participation will enable the new graduate to stay in touch with the next wave of systems research.

In 2006, the network was opened to a broader pool of interested students through a full day workshop comprised of talks and interactive activity, which will be described in the next section.

2.1. INAUGURAL SEANET WORKSHOP

In April 2006, the first SEANET Workshop was convened at the University of Southern California campus in conjunction with the 4th Annual Conference on Systems Engineering Research (CSER). Students invited were currently enrolled or planned to enroll in systems engineering or related doctoral programs including programs as: Systems Architecting & Engineering, Industrial & Systems Engineering, Engineering Management, and Engineering Systems. Thirty-one doctoral students from fourteen universities representing six different countries participated in the workshop. These included Cranfield University, Delft University of Technology, George Mason University, Massachusetts Institute of Technology, Naval Postgraduate School, Norwegian University of Science and Technology, Royal Institute of Technology in Stockholm, Southern Methodist University, Stanford University, Stevens Institute of Technology, University of Cambridge, University of Missouri at Rolla, University of South Australia, and University of Southern California.

The detailed agenda for the workshop is provided in Appendix A and a summary of the breakout sessions is provided in Appendix B. These interactive sessions introduced a new cohort of SEANET participants and provided the opportunity to openly share their thoughts and concerns about specific aspects of their PhD journey. Participants overwhelmingly identified these sessions as their favorite component of the workshop because of the free flowing discussion and informal interaction with their peers and leading experts in the field who facilitated.

The research topics of the SEANET workshop attendees provide a glimpse into the current research landscape and research approach. The student research exhibited a high degree of diversity in topics as provided in Appendix C. It was also noted that some research hypotheses were clearly articulated, while in other cases they were still in the early stages. This was based strongly on the individual students' stage in the PhD journey. Another factor that varied widely was the degree of academic rigor, a topic that leaders in the systems engineering academic community need to address. A common factor was that systems engineering students seriously consider the research impact of their work; however, the articulation of the intellectual merit of the research appears to be underdeveloped. The development of comprehensive research methodologies and the validation of research results also appear to be significant shortfalls.

Despite these challenges, the proximity to CSER provided an opportunity for students to obtain feedback from conference attendees. A selected subset of SEANET participants presented posters showcasing their doctoral research at the CSER welcoming reception. The posters were useful for introducing research and triggering discussions among conference attendees. One student presenter felt his early research was shaped by discussions with attendees. Another more advanced student's work led to a discussion on a potential future university/corporation joint research project. The poster session also served as an opportunity for conference attendees to learn about systems engineering research while giving visibility to SEANET.

The most significant outcome from the inaugural SEANET workshop was the resultant expanded social network provided in Figure 2. The network represents a notional record of the new and existing links between participants.

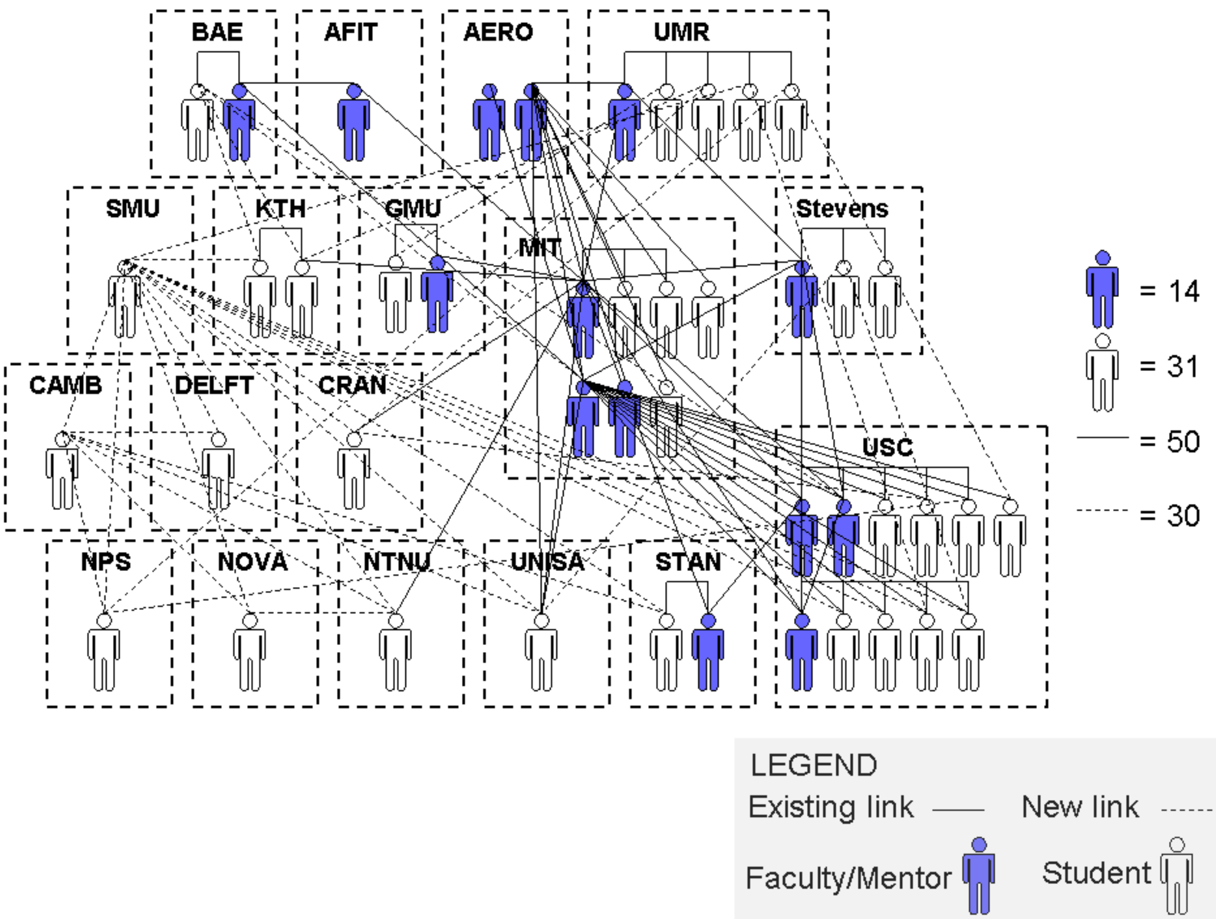

Figure 2. SEANET Social Network in April 2006.

The most significant property of the network as it evolved from January 2005 (Figure 1) to April 2006 (Figure 2) is the number of new inter-organizational links that came about as a result of the workshop. Some of the links that are shown in Figure 1 persisted to Figure 2. However, there was an influx of new people from the same organization which introduced new links. Between the two events, two students that participated in the pilot program completed their PhDs and joined new organizations. This allowed them to continue their involvement in SEANET, but now as mentors, and share their experiences as recently minted PhDs.

Another relevant property of the network is that it incorporates academic, industry, and government organizations. This is a reflection of how research in systems engineering research is unique because it can involve aspects that cross organizational boundaries.

2.2. SEANET STUDENT PROFILES

The National Science Foundation reports that there were approximately 656,500 doctorates in science and engineering in the U.S. in 2001 (NSF 2004). Of this number, 113,000 – or 17% - fall under the engineering category. Unfortunately, systems engineering does not have its own classification and the number of existing systems engineering PhDs is likely distributed among NSF's seven subcategories of engineering[3], making the level of fidelity needed to evaluate systems engineering PhDs unavailable. Moreover, it is likely that PhDs in other disciplines (e.g., aerospace, mechanical) have systems engineering functions in their jobs.

The latest engineering indicators show that there are approximately 5,000 PhD degrees being awarded in the U.S. each year out of 35,913 worldwide (NSF 2006, p. 117-118). Some have estimated that there are less than 50 systems-related PhD degrees per year (Brown and Scherer 2000) but it would be difficult to verify this number. In growing the doctoral network, the initial approach for identifying doctoral students is through conferences such as CSER and INCOSE as well the network of SEANET mentors.

The 2006 SEANET workshop was a key opportunity to sample the student demographic. In addition to establishing a network, there was interest in obtaining student input in identifying challenges

[3] Science and Engineering subcategories are aerospace/aeronautical, chemical, civil, electrical/computer, materials/metallurgical, mechanical, and other.

and opportunities facing them. For this purpose, a survey was administered to the thirty one participants which resulted in three key findings.

Finding #1: The pool of systems engineering doctoral students is largely non-traditional.

The average work experience of the sample of doctoral students was nine years, which is slightly more than other engineering disciplines. One third of the SEANET participants identified themselves as "seasoned" systems engineers with more than 20 years experience. This trend appears to exist in other fields as well. For example, it is reported that nearly two-thirds of all PhD students throughout Australia are 30 years or older (Simonds 1998) which is also the median age of doctoral students in the arts and sciences in the U.S. (Golde and Dore 2001). But what is unique about systems engineering doctoral students is their diverse engineering backgrounds, as shown in Figure 3. The most prevalent fields were clustered around the popular engineering disciplines of Civil, Computer Engineering/Software Engineering, Electrical Engineering, and Mechanical Engineering. It is expected that this diversity of disciplines is representative of the systems engineering community at large and a necessary reality to solve the interdisciplinary challenges of complex systems. The interdisciplinary profile of the sample is also reflected in the diversity of research topics presented at the SEANET workshop as discussed in the next section.

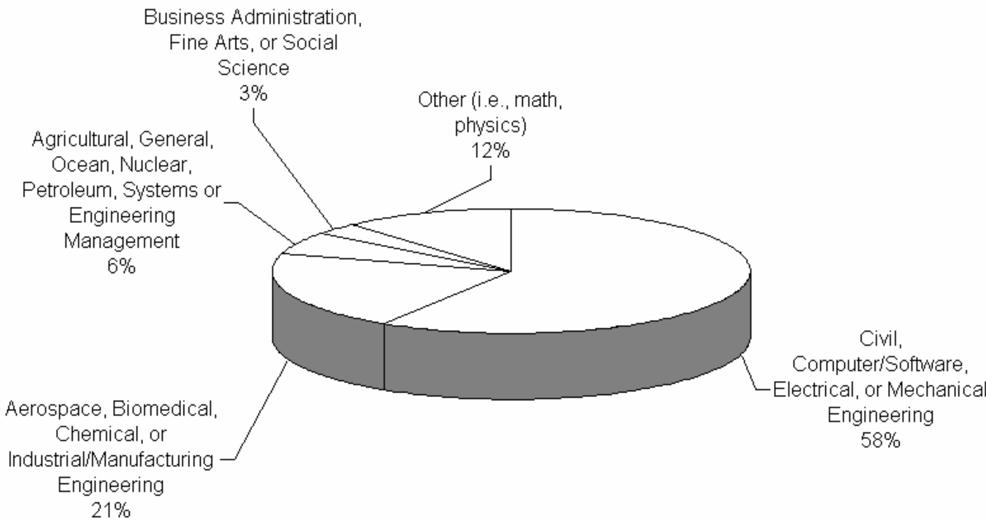

Figure 3. Distribution of Undergraduate Degrees Of SEANET Students.

Finding #2: Students identified "workshops" and "data access" as the two most pressing issues a professional society can assist with.

As shown in Figure 4, when presented with five options, SEANET students expressed their top two needs as: (1) more workshops, particularly on research methods, and (2) access to data from companies. Despite what some might think, student funding is not the most important challenge faced by doctoral students, although travel funding for conferences was identified as highly desired.

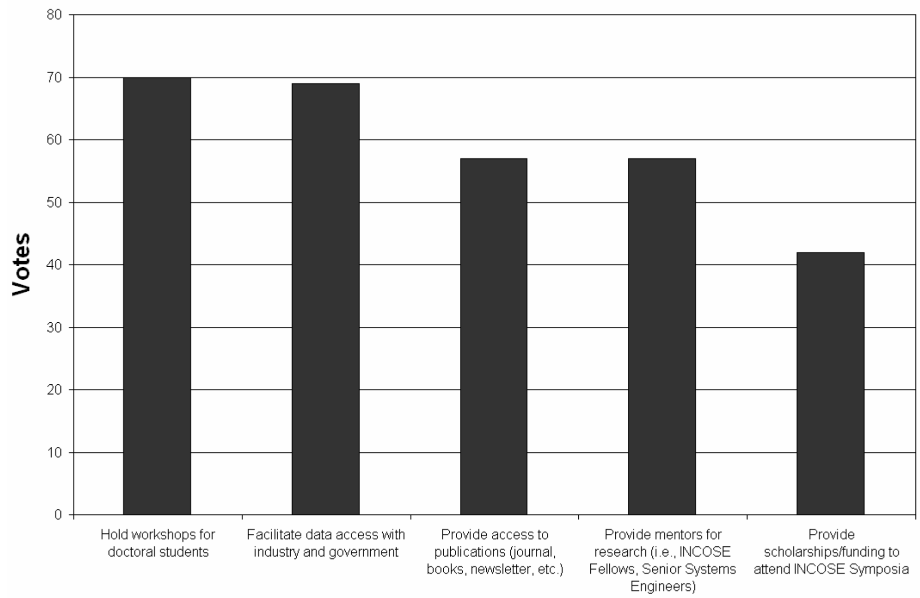

Figure 4. What Professional Societies Can Do To Help Doctoral Students.

Finding #3: Doctoral students in systems engineering have diverse career interests across academia, industry, and government.

The sample of thirty-one students had a relatively even distribution across the various career options, as shown in Figure 5. Studies have found that the proportion of doctoral students interested in an academic career varies greatly across disciplines, and that students in the disciplines with strong connections to industry are the least interested in faculty careers. A national survey of over four thousand doctoral students in eleven disciplines across twenty-seven universities found that doctoral students in philosophy have the highest interest in faculty jobs (88.7%) while doctoral students in chemistry have the lowest (36.3%) (Golde and Dore 2001). The average interest level in faculty jobs across eleven disciplines surveyed by Golde and Dore was 60.7% which is significantly higher than the 25% reported by SEANET participants. By comparison, the average proportion of engineering PhDs entering academia has consistently been around 50% (TNA 1997). In part, this may be because graduates of systems engineering PhDs have many more options for employment in industry and government, and such positions are challenging and well compensated.

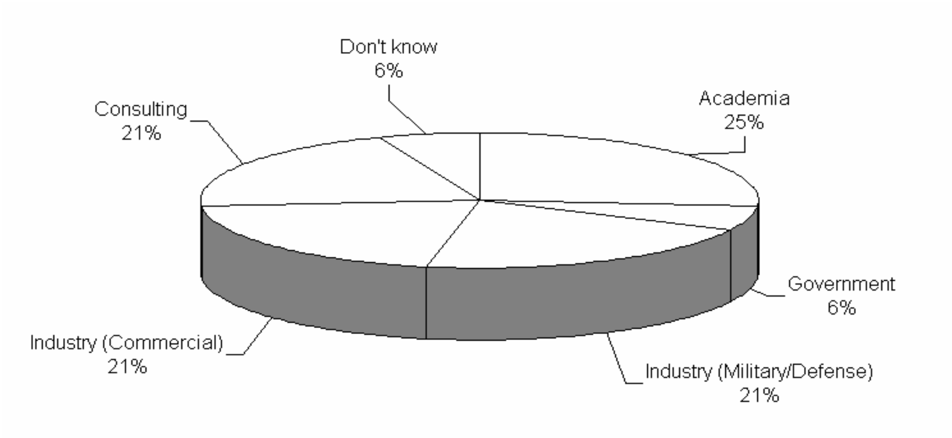

Figure 5. Career Plans of SEANET Participants.

Two employment-related considerations are important for systems engineering doctoral studies. The first has to do with academic employment. Studies have shown that nearly 60% of the engineering PhDs employed in academia work in non-research institutions (NSB 1998). However, this statistic may not represent the academic employment environment for systems engineering PhDs, as the majority of systems engineering academic programs are at PhD-granting institutions (Brown and Scherer 2000; Fabrycky and McCrae 2005) and therefore most of the faculty jobs in systems engineering are available at these research institutions.

The second is related to employment in industry and government, as illustrated in the US national situation. At the doctoral level, there has been decreasing participation of US citizens and permanent residents in engineering. Although the overall number of doctoral degrees earned by US citizens and permanent residents has almost doubled during the period 1966 to 2004, the proportion of engineering doctoral degrees earned by US citizens and permanent residents dropped from 84% in 1966 to about 60% in 2004 (CPST 2006). Increased security concerns in the U.S. post-9/11 economy, especially in the defense sector, imply a need for more US citizens to be encouraged to pursue PhDs in systems engineering.

The three findings gleaned from the survey results have important implications for academic programs in systems engineering and related organizations. First, academic programs need to allow for diverse backgrounds in undergraduate training. Flexibility in curricula should account for the mixed preparation of students entering doctoral studies in systems engineering. Second, there is a need to establish some consensus on what fundamental knowledge all doctoral students should posses. This will help establish common ground across the community of researchers. Third, academic programs must leverage the fact that seasoned students may bring useful industry experience to the classroom and their research. Systems engineering doctoral programs should establish ways to use industry experience to enhance the relevance of the research and subsequently have a greater impact in industry. Fourth, academic training needs to be responsive to students choosing a diverse range of career fields. It was shown that only 25% of systems engineering doctoral students plan to pursue careers in academia and the remainder will gravitate towards jobs in government and industry. This presents significant challenges in the balance of theoretical and applied training they receive during their academic training. An important partner in addressing these challenges is the corresponding technical society that best fits the student's research focus and application domain.

2.3. ESSENTIAL ROLE of PROFESSIONAL SOCIETIES

Professional and industry societies such as INCOSE, the American Society for Mechanical Engineering (ASME), IEEE Systems Council, SAE International, Institute for Industrial Engineering (IIE), Institution of Engineering and Technology (IET), Institute for Operations Research and Management Science (INFORMS), and many others are the center of gravity of various engineering fields. Therefore, they are ideal venues to foster dialogue about the evolution of doctoral programs, provide opportunities to help students explore careers in and out of academia, showcase innovations in publications and conferences, collect discipline-wide data on career outcomes and options, and most importantly provide an avenue for advancing the state of doctoral research.

Furthermore, the diverse and experienced membership of a professional society includes the experts who can identify a broad range of challenges and opportunities for research oriented toward having real-world impact. Systems engineering professional societies in particular have a position of influence in the systems community because of the diverse membership from industry, government and academia. This influence can be put to strategic use by championing areas of research; promoting the value of qualitative research paradigms and methods to complement the more traditional quantitative ones; and providing researchers with access to the real world laboratory.

As previously noted in finding #2, sponsorship of doctoral level scholarships[4] can encourage doctoral researchers. However, in surveys of doctoral students there is evidence that a more important role of the professional society is in providing mechanisms for knowledge sharing, and research data gathering and validation. The underlying role of professional societies is to enable growth of the SEANET social network to enable doctoral student success.

3. EVOLVING SEANET

In keeping with the INCOSE goal of sponsoring an annual doctoral student event, the 2nd SEANET workshop was held in conjunction with the 2007 INCOSE Symposium in San Diego, CA. The workshop took place at San Diego State University and was attended by twenty-four doctoral students from nine universities representing four countries. Also participating were INCOSE mentors, including five fellows and three SEANET alumni. Representatives from several universities that were previously not part of the network were in attendance, including Air Force Institute of Technology, Old Dominion University, Tel Aviv University, University of Detroit, and Virginia Tech.

The involvement of new universities indicated the opportunity for SEANET to continue growing as the greater academic community learns about the network. The workshop format (see Appendix D) was very similar to the inaugural workshop, including the birds-of-a-feather sessions offered in parallel on topics such as publication strategies, research methods, converging on a dissertation topic, and mixed methods research. In the evening, a poster session was held at the symposium conference center which provided an opportunity for doctoral students to showcase their research to INCOSE leadership boards.

In an effort to continue collecting demographics of the systems engineering doctoral student population, the same survey as the prior year was administered. The basic demographics were consistent with the 2006 workshop results, and students identified similar challenges in doing systems engineering research such as:

- the difficulty of performing data collection in industry;
- the process of selecting the best research method to address the research question at hand;

[4] Such as the INCOSE Foundation and Stevens Doctoral Award for Promising Research in Systems Engineering and Integration

- being part of a small cohort in small systems engineering departments or in a department from a different discipline;
- the broad scope of the systems engineering discipline;
- proving the systems engineering can be equally rigorous as other engineering disciplines;
- validation of research hypotheses; and
- balancing domain/content research with general systems engineering design.

Based on two years of workshop experience and discussions with current students, it appears that the Spring timeframe offers a better opportunity for students to attend this type of event. At the time of publication, the authors are developing the plans for the 3rd SEANET Workshop to be held in April 2008 at University of Southern California in conjunction with the 2008 Conference on Systems Engineering Research (CSER), with an additional informal networking event at the 2008 INCOSE Symposium.

There are a number of considerations for the evolution of SEANET, the most pressing being the scalability issue. Lacking infrastructure to implement a highly managed doctoral network, appropriate strategies must be developed. One strategy may be a more federated approach, where regional SEANET groups could meet and also engage (perhaps virtually) with the larger group. The breadth of topics for students in the SEANET also needs to be considered. The first workshop showed high diversity in topics; it is not yet known if there should be some organizing structure and defined topics, or if there should be a dynamic self-organizing approach. There is ongoing discussion related to what groups in INCOSE can provide as a support system for doctoral students, and what the points of engagement should be. To date, many of the INCOSE Fellows have played an enabling role for SEANET, and have committed to playing a continuing role in future events. There may also be an important role for leaders of the technical working groups of INCOSE. A sensitive issue is how an individual student can be guided by a variety of INCOSE experts without creating conflict or confusion with student's own research advisors and academic department. Collaboration with other systems engineering organizations should also be considered in the long term strategy.

The authors intend to continue to collect data to further characterize the doctoral researcher profile, gain additional insight into the enablers and barriers for doctoral level research, and gather information to support long term planning.

4. CONCLUSIONS

Systems engineering doctoral research is essential to furthering the field in regard to advancing theory, creating new knowledge and evolving the methods for addressing contemporary systems challenges. INCOSE has initiated the SEANET doctoral student network to encourage doctoral research. While some positive results have been achieved, challenges remain in scaling the research network and achieving full involvement of all beneficial organizational entities who are stakeholders in systems engineering research.

Three years of experience with this doctoral research network suggests that the supply of potential doctoral students is quite healthy, but that PhD academic programs are for the most part in quite early stages of maturity. Formation of informal and formal networks of university leaders to establish dialogue and collaboration is one positive step. These include the INCOSE Academic Council which brings together senior level academics; the INCOSE systems engineering department heads group; and the Council of Engineering Systems Universities (CESUN)[5].

The SEANET experience also suggests that there may be a need to step back and evaluate current research to determine how well it is aligned with needs of the systems engineering field from academic, government, and industry perspectives. Our understanding of the research (International Council on Systems Engineering October 2006) and other similar events in the systems community. A thorough evaluation of where we are presently focusing research in respect to the expressed needs of the systems community is highly desirable.

Traditionally, doctoral programs are targeted to develop the next generation of faculty, but if this were the case in the systems engineering field, less that 25% of the students would be well-served in these programs in regard to future career goals. Professional societies play a vital role in identifying, motivating, encouraging, and sharing doctoral research within the context of the opportunities and challenges of the industry practice of SE where, according to our preliminary SEANET data, a majority of doctoral graduates plan to work. As an international organization, INCOSE is uniquely positioned to provide enabling mechanisms for doctoral research on a global scale. While it is yet to be fully realized, the INCOSE SEANET has high potential for linking doctoral researchers across the world to enable

[5] CESUN is a collaborative network of universities; information can be found at www.cesun.org

research synergies, as well as to further the maturation of both the systems engineering research agenda and research methodologies.

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APPENDIX A. SEANET 2006 Workshop Agenda

The workshop agenda included a senior faculty keynote; a junior faculty keynote, a doctoral student perspectives panel; a professional perspectives panel., and breakout discussion groups.

Keynotes. In the first keynote, Dr. Barry Boehm, TRW Professor of Software Engineering at USC shared his thoughts on Systems Engineering research and publication from a senior faculty perspective. The second keynote was given by Dr. Annalisa Weigel, Assistant Professor of Aero/Astro and Engineering Systems at MIT, as a facilitated discussion around the motivation behind doing a PhD and challenges of doing research from a junior faculty perspective.

Student Perspectives Panel. In this panel, Jo Ann Lane of USC, Dr. Adam Ross of MIT and Dr. Heidi Davidz of The Aerospace Corporation shared stories from their journeys through their respective PhD programs. Lane spoke of her experience as a 2nd year PhD student, Ross shared his strategy for preparing for his thesis defense, and Davidz provided insights into her recent thesis defense experience.

Professional Perspectives Panel. Mark Wilson (then) Director of the Center for Systems Engineering at AFIT, Dr. Rashmi Jain of Stevens Institute of Technology, Samantha Brown of BAE Systems UK, and Malina Hills of The Aerospace Corporation each shared their views on research opportunities and challenges at the intersection of industry/academia/government.

Six Birds of a Feather Breakout Groups. At the start of the workshop, students were asked to sign up for one of six groups for a topical discussion. Each of the groups was led by two or more mentors. The topics included: (1) Strategies for research and publication; (2) Career decisions and job search; (3) Developing research topics and hypotheses; (4) Applied doctoral research in industry and government ; (5) Strategies for multi-disciplinary research; and (6) Wildcard topics. Summaries of the six sessions are provided in Appendix B.

Acknowledgement. Sincere thanks goes to the SEANET panelists and participants for their enthusiastic involvement. The USC Systems Architecting & Engineering program provided facilities for the SEANET workshop. Stan Settles, Barry Boehm, and Georgia Lum provided logistical support. INCOSE provided funds for hospitality.

APPENDIX B. Summaries from SEANET 2006 Workshop Breakout Sessions

Group A: Strategies for Research & Publication

Facilitated by Dr. Barry Boehm, notes by Apurva Jain

This group discussed strategies for publications for doctoral candidates, identifying the following success-critical factors for publishing: 1) Clear introduction that positions the research in the landscape of software or systems engineering (Where are you going to hang your coat?); 2) Crisp conclusions in terms of contributions to the body of knowledge, and a good sketch of future research paths; 3) The T-shape research metaphor -- a little breadth and diversity, and a significant depth; 4) Publishing intermediate technical reports -- helps with copyright, serves as a good reference to conference papers that severely limit the paper length; and 5) Know the conference's program committee, they are your audience.

Group B: Career Decisions & Job Search

Facilitated by Dr. Annalisa Weigel and Heidi Davidz, notes by Steve Winkler

The group discussed looking for a job with a PhD, and talked about how some companies/managers may be looking for a PhD, but the job might be ill suited for a PhD. They talked about the need for the job applicant to evaluate the job just as the company needs to evaluate the applicant. A question was asked about how to get a company to respond to a resume sent to them. Three methods were stated. a) write the resume for the job description b) call the company/manager to help sell yourself c) write a cover letter which explains why a system engineer is applying for job description which does not states system engineer wanted. We also talked about using the PhD to get a job in academia, and the 2 to 3 year window after getting a PhD as best (based on the time it takes for papers; after this time it may look like the person is no longer doing active research and writing). The group also discussed teaching System Engineering principles in the class room.

Group C: Developing Research Topics and Hypothesis

Facilitated by Dr. Rashmi Jain and Dr. Stan Weiss, notes by Art Dhallin

The group discussed the topic of research question and hypothesis, and each gave a brief synopsis of their research. Discussions focused on how to define a research question; the major finding from this was that it was very important to narrow the question appropriately. Also discussed was turning questions into hypotheses, and the need to be careful of the number of hypotheses because of the limitations on data collection.

Group D: Applied Doctoral Research in Industry & Government

Facilitated by Mark Wilson and Samantha Brown, notes by Jared Fortune

The group discussed two primary topics: 1) Industry/Academia need to understand how to introduce PhD's into industry as well as have academic research be directed towards the needs of Industry. In addition, industry/academia need to communicate better in the sense that agreement should be reached on what is past/bleeding edge technology; 2) PhDs need to more effectively market themselves. An answer needs to be developed for the question: how does a PhD fit into an organization? Further, PhDs should provide the expert view, which is essential for understanding system complexity.

Group E: Multidisciplinary Research

Facilitated by Dr. Stan Settles, notes by Eric Honour

The group discussed how the bigger problems in systems engineering are always socio-based, rather than purely technical. They talked about how to do multi-disciplinary research – it is a creativity issue. As an example, the Systems Architecting class at USC is intentionally kept at strategic levels – heuristics, the merger of art and technology. Another topic of discussion was the problems of validity – SE research papers should identify threats to validity and how the researcher has addressed them. Another issue that the group highlighted was the time and cost to gather the information and the language differences among the multi disciplines (and how to discover them). Multi-disciplinarity leads to issues in system development.

Group F: Wildcard

Facilitated by Dr. George Friedman, notes by John Colombi

Regarding general system modeling, the group felt there needs to be continued effort toward a unifying model. This may aggregate or abstract set theory, graph theory, together with other organizational or social science models. The group discussed attributes of disciplined engineering (and other) academic backgrounds, which "best" supports Systems Engineering. The group discussed how academic backgrounds with many logical abstractions could well serve systems engineers.

APPENDIX C. SEANET 2006 Student Research Topics (listed alphabetically)

- A Comprehensive Tool for IT Organizational Modeling and Assessment
- Challenges of Delivering SE Education to UK Acquisition Community
- Change Impact Analysis at Interface of System and Embedded SW Design
- Cognitive Support Mechanisms for SE Tasks
- Controlled Experimentation and Causal Hypotheses Testing: A Framework for Pre-Acquisition Validation of Proposed Technologies
- Decision Analysis
- Developing a Theory for Value-Based Software Engineering
- Emergence in Space Systems Architectures
- Evaluating the Business Value of IT Investment Scenarios
- Formalizing Informal Stakeholder Inputs Using Gap-bridging Methods
- Impact of Organizational Dynamics on SW-Intensive SoS Effort & Schedules
- Intelligent Agents and Artificial Life (analysis from SE Perspective)
- Loose Couplers in Systems of Systems
- Managing Unarticulated Value
- Net-Centric Domain Adaptive “Plug and Play” Control System for Advanced Manufacturing
- On Depleting Supply of Nurses and Potential Impact on Quality of Service in VA Hospitals in LA
- OTS Integration Analysis with iStudio
- Predictive Modeling of Lean Six Sigma Implementations
- Real Options Approach in Weapon Systems Acquisition
- Right-Brain Modes in Systems Architecting and Engineering
- SE Application to Eco-Industrial Parks via Pattern Language
- SE Approach to Research, Analyze, Model, Simulate Interdependence of Container Shipping
- System Architecture of Attitude Control Subsystems for Satellites

- Standards-based Architecture for the Capture and Retrieval of SE Project Information
- System Architecture within Aerospace Industry
- Systems Engineering and Engineering Management Optimization
- Systems Engineering Return on Investment
- Understanding Socio-technical Systems: A Design Perspective

APPENDIX D. Brief Synopsis of SEANET 2007 Workshop

A similar format was used for the 2007 workshop, and was chaired by Dr. Donna Rhodes of MIT and Dr. Ricardo Valerdi of MIT. A keynote presentation was given by Professor Wolt Fabrycky, Virginia Tech Emeritus Professor of Virginia Tech, covering ten important topics. A presentation on the PhD journey was given by research graduate Dr. Melissa Sampson, now of United Launch Alliance. Dr. Regina Griego of Sandia National Labs gave remarks on career opportunities for doctoral graduates.

Four Birds of a Feather Breakout Groups. Birds-of-a-feather sessions were held on the topics of publication strategies, research methods, converging on a dissertation topic, and mixed methods research. These sessions were led by Dr. Barry Boehm of USC, Dr. Wolt Fabrycky of Virginia Tech, Dr. George Friedman of USC, Dr. Andres Sousa-Poza of ODU, Dr. Heidi Davidz of Aerospace Corporation, Dr. Adam Ross of MIT, and Dr. Melissa Sampson.

Acknowledgement. Sincere thanks goes to the 2007 SEANET speakers, mentors, and participants for their enthusiastic involvement. Dr. Barry Boehm and Dr. George Friedman provided important mentoring continuity from the previous two events. Jo Ann Lane of USC provided valuable assistance in planning the 2007 event and arranging for use of the San Diego State University facilities. INCOSE provided support for hospitality.

Donna H. Rhodes received her Ph.D. in Systems Science from the T.J. Watson School of Engineering at SUNY Binghamton. She is a senior lecturer and principal researcher at MIT in the Engineering Systems Division (ESD). She is the director of the MIT ESD Systems Engineering Advancement Research Initiative (SEAri), and is also affiliated with the Lean Aerospace Initiative (LAI). Prior to joining MIT, she had 20 years of experience in the aerospace, defense systems, systems integration, and commercial product industries. Dr. Rhodes has been very involved in the evolution of the systems engineering field, as well as the development of several university graduate programs. She is a Past President and Fellow of the International Council on Systems Engineering (INCOSE), and is a recipient of the INCOSE Founders Award and several INCOSE Distinguished Service Awards. Dr. Rhodes initiated the INCOSE SEANET effort in 2005 and continues to serve as the chair of the network.

Ricardo Valerdi is a Research Associate at the Lean Aerospace Initiative and the Systems Engineering Advancement Research Initiative at MIT. He is also a Visiting Associate at the Center for Systems and Software Engineering at USC. Formerly he was a Member of the Technical Staff at the Aerospace Corporation in the Economic & Market Analysis Center and a Systems Engineer at Motorola and at General Instrument Corporation. He earned his BS in Electrical Engineering from the University of San Diego, MS and PhD from USC. He is a member of INCOSE and serves as Associate Director for International Growth. Dr. Valerdi participated in the 2005 pilot program of the INCOSE SEANET and now serves as co-chair of the network.