Accelerating the Development of Senior Systems Engineers

Heidi L. Davidz, Deborah J. Nightingale, Donna H. Rhodes
Massachusetts Institute of Technology (MIT)
77 Massachusetts Avenue, Room 41-205, Cambridge, MA, 02139
617-258-7984, hdavidz@mit.edu

Abstract. As more senior systems engineers are needed to handle the increasing complexity of contemporary systems, there is an increasing need to accelerate the development of these senior professionals. However, the process of efficiently developing a senior systems engineer is not well-understood. To compact this problem, the skill set needed by senior systems engineers continues to broaden as system complexity increases and as system boundaries expand. In order to better understand the mechanisms that most effectively and efficiently develop these individuals, this article discusses enablers, barriers, and precursors to this development process. In addition to reviewing related literature, specific interventions currently used to accelerate systems thinking development are discussed. Findings from ongoing research related to this topic provide preliminary information about current understanding and practice. Better understanding of systems thinking development provides a foundation for educational interventions and employee development in systems thinking for engineering professionals across industry, government, and academia.

INTRODUCTION

As engineering systems become more complex and as industry roles change, companies are more responsible for systems solutions. Within the government and industry, there is an increasing need to develop systems talent. There are not enough senior systems engineers to meet current and future program needs. Accelerating the development of senior systems engineers is an immediate concern.

To address this need to develop senior systems professionals, organizations in academia, industry, and government are reacting with a flurry of activity. As hundreds of systems engineers are being hired, new systems engineering educational degree programs are rapidly emerging. Companies are scurrying to establish systems engineering training and development programs.

However, fundamental questions still remain about how senior systems engineers actually develop. In particular, what are the enablers and barriers to the development of systems thinking in engineers? How can high potential systems professionals be better identified? Are there certain individual characteristics that predict the development of systems thinking? Do certain work groups inhibit the development of systems skills? What organizational environments create better systems engineers? These are questions that many systems professionals debate. Many heuristics are currently in use, but there are insufficient data to support these claims.

In order to address this lack of data, the authors are engaged in ongoing research to better understand how senior systems engineers develop. This paper focuses on how the results of this research can be used to streamline developmental interventions and accelerate the development of senior systems engineers.

SYSTEMS THINKING AND SYSTEMS ENGINEERING

Scope. As the scope and complexity of engineering systems grow, the thinking skills of systems professionals must also evolve. Systems professionals are needed to address a new generation of problems, referred to as systems-of-systems, complex systems engineering, enterprise systems engineering, or engineering systems. Example programs are the Future Combat System and the Joint Strike Fighter. The Engineering Systems Division (ESD) at the Massachusetts Institute of Technology (MIT) is interested in this very large view of systems thinking in the engineering professional.

The ideal hope for this research would be to see how this type of systems professional develops. However, the official job classification for this professional does not exist in many organizations, so this is hard to operationalize. Thus, the operationalized focus of this research has been on the "senior systems engineer", since this a formal job title in the organizations studied. Nonetheless, the role of the "senior systems engineer" has varied across the organizations studied. A person who is considered a senior systems engineer in one company may be considered narrow and inadequate by the standards of another company. What is considered a holistic, systems view is considered a reductionist view when the boundaries of the system are redrawn. Senior systems engineers work at all levels of system boundaries. Due to the embedded nature of systems, the definition of the word "system" is relative.

Common Enablers. Fortunately, key trends have emerged in the data on what enables the development of systems thinking in systems professionals, regardless of where the system boundary is drawn. These key trends are emphasized in this paper. As perceived by the employer, the aptitude of a systems engineer is not always independent of the system in which that professional is working. Although the required skills for a senior systems engineer vary across organizations and across expanding system definitions, there are common enablers to developing these systems professionals.

Adequacy. Although "systems thinking" is necessary for senior systems engineers, it is not sufficient. In addition to systems thinking ability, these individuals must also execute and perform to be successful systems engineers. Nonetheless, in order to accelerate the development of senior systems engineers, one could first enable and expedite the development "systems thinking."

Systems Thinking. The thinking utilized by senior systems engineers is the type of "systems thinking" examined in this study. For this research, the working definition of systems thinking is, "analysis, synthesis, and understanding of interconnections, interactions, and interdependencies that are technical, social, temporal, and multi-level."

Certainly, there are other definitions of systems thinking that have been used. Moti Frank outlines the characteristics of "engineering systems thinking" (Frank 2000), (Frank 2002). Peter Senge uses "systems thinking" as one of five disciplines for a learning organization (Senge 1990), (Senge, Kleiner et al. 1994). Other interpretations of systems thinking are offered in Ludwig von Bertalanffy's open systems theory, Stafford Beer's organizational cybernetics, Russell Ackoff's interactive planning, Peter Checkland's soft systems approach, and C. West Churchman's critical systemic thinking (Flood 1999). Here, the type of systems thinking utilized by senior systems engineers is the type of systems thinking being studied. See a previous article by the authors for a detailed discussion on using "systems thinking" as a valid research construct (Davidz, Nightingale et al. 2004).

FIELD STUDIES

Pilot Studies. In order to gain more insight into possible enablers, barriers, and precursors to systems thinking development, twelve senior systems leaders from the International Council on Systems Engineering (INCOSE) were interviewed. Located in three countries, the subjects represented industrial, academic, and government interests. The results of these exploratory telephone interviews are given in a previous paper by the authors (Davidz, Nightingale et al. 2004).

Field Study Overview. To more formally examine some of the pilot interview assertions about the development of systems thinking in engineering professionals, a field study was designed. Data from this study is used to support or discredit existing heuristics on how senior systems engineers develop. This design of this study is discussed in detail in another paper by the authors (Davidz, et al. 2005).

Here is a summary of this ongoing field study. After working with a point-of-contact to determine a company's interest in participating, the researchers work with a point-of-contact to identify an "expert panel." This group consists of approximately four individuals who are very familiar with the policies and practices of how that company develops senior systems engineers. Depending on the structure of the company, this expert panel may consist of two high-level systems employees, a functional engineering representative, and a human resources representative who leads a systems engineering training program. The members of this expert panel are interviewed individually in order to understand company procedures for developing and assessing systems thinking in engineering professionals.

Next, the expert panel is asked to identify follow-on subjects in three groups: (1) senior systems architects or systems engineers, (2) junior systems architects or systems engineers, and (3) senior technical specialists. Of course, the researchers are most interested in the characteristics and development histories of the senior systems professionals. The other two groups are control groups. The junior systems professionals are studied to determine if certain types of people are drawn to systems roles. The senior technical specialists are studied to determine if being in an organization long enough eventually develops an employee's systems thinking. The follow-on subjects are asked to complete a survey and a one-hour interview. If feasible in the company, the interviewer conducts the interviews blind to each subject's classification. Although the junior subjects are usually easy to identify from age, differences between the senior systems professionals and the senior technical specialists are not always obvious.

This research study allows the researchers to better understand how companies are currently developing senior systems engineers. In addition to understanding individual company strategies for this development, comparisons are also made across companies. Using the interview and survey data, comparisons are made of the characteristics and development histories of two control groups and these senior systems professionals. The interviews also produce rich narratives on how senior systems engineers developed. These individual stories are a rich and fascinating portion of the study. In aggregate, the final result is an analysis of enablers, barriers, and precursors to the development of senior systems engineers. Future research ideas have also been generated.

Analysis. Currently, 131 interviews have been completed in eight participating organizations. Five companies have been through the complete process, and additional companies are in various stages of participation. Most of the organizations are in the aerospace industry in the United States. The organizations vary from being large system integrators to

subsystem suppliers to federally funded research and development centers.

Although the data set continues to grow, several key trends have emerged from the current data set. The procedure used to identify these trends is as follows. Except for a few interviews, all the follow-on interviews are conducted in-person and on-site at the organization. Expert panel interviews are conducted both by telephone and in-person. If possible, interview notes are taken in real time on a computer; however, due to restrictions on recording devices at many of the sites, sometimes extensive hand-written notes are taken during the one-hour interviews and then transcribed into electronic format. The qualitative responses of the interview data are then coded for a content analysis. The survey data is entered in a statistical software package called SPSS for quantitative analysis.

Results. Interestingly enough, although the participating companies deal with systems of varying breadth, key enablers of systems thinking appear across companies. Also, individuals from all the groups – expert panelists, senior systems engineers, junior systems engineers, and senior technical specialists – identify similar enablers and barriers to the development of systems thinking. Since this is the case, it should be possible through coding to eventually produce quantitative results for these qualitative responses.

From these interviews, the enablers of systems thinking fit into three categories: (1) Experiential Learning, (2) Individual Traits, and (3) Organizational Design. This is emphasized in Figure 1. These results are discussed in detail in a previous article by the authors (Davidz, Nightingale et al. 2005).

**Key Enablers of
Systems Thinking**

1. **Experiential Learning**
2. **Individual Traits**
3. **Organizational Design**
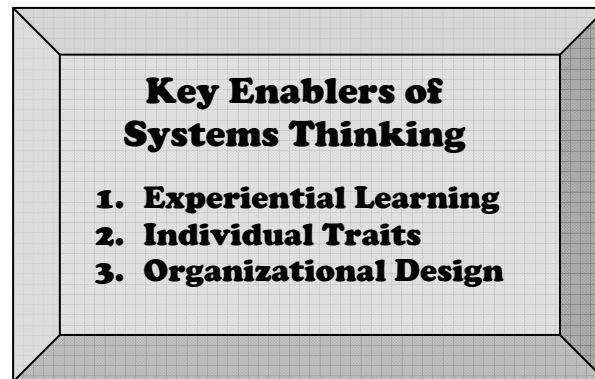
Figure 1: Key Enablers of Systems Thinking

When asked about how "systems thinking" develops, respondents emphasize past experiences. Figure 2 shows subcategories of experiential learning that enable the development of systems thinking. These include: on-the-job-training, working on cross-functional teams, training and education coupled with application, key lessons learned, active mentoring, childhood experiences, and hobbies. When asked if there are certain individual characteristics or innate traits that seem to predict the development of systems thinking, respondents identified multiple characteristics. Figure 3 shows these traits: tolerance for ambiguity, curiosity, openness, strong interpersonal skills, strong communication skills, ability to ask the right questions, ability to navigate complexity, and analytical ability. In addition, it is essential for the organizational incentives and structure to align with any method an organization is using to enable systems thinking development in their employees. Furthermore, feedback mechanisms are needed to know if an intervention is having the desired impact.

This study was a descriptive analysis of current characteristics, rather than a prescriptive

analysis of what characteristics systems professionals should have. Nonetheless, it seems logical that these characteristics are important for senior systems engineers. For example, curiosity and openness are motivations that drive one to learn more about the system context. With on-the-job-training and time in the organization, employees with curiosity may develop a more extensive system understanding than those without this characteristic. Likewise, employees who are open to learning, open to ideas, and open to people, may also develop a more advanced understanding of the system over time.
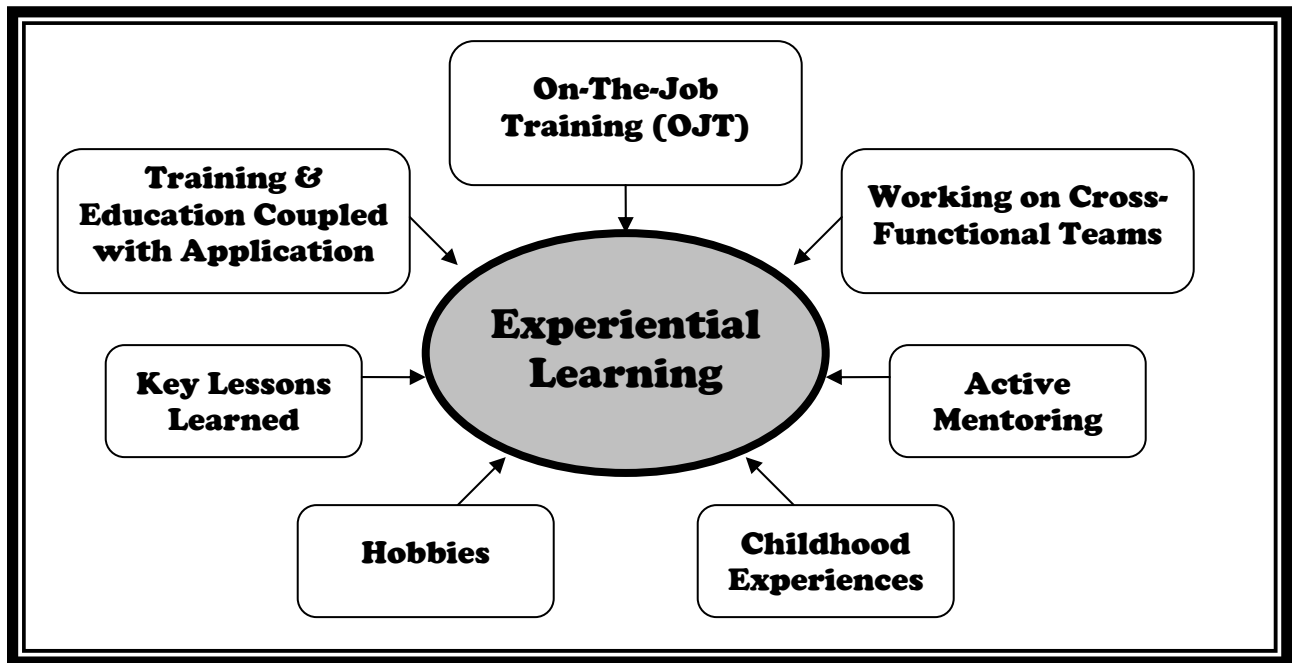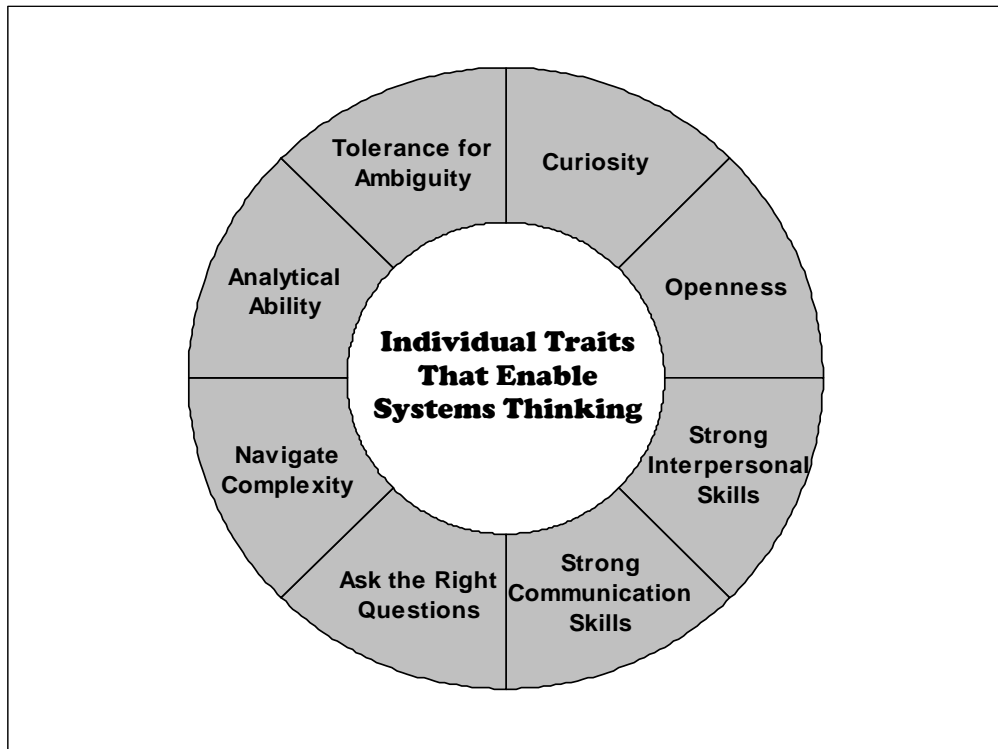

Figure 2: Experiential Learning That Enables Systems Thinking

Figure 3: Individual Traits That Enable Systems Thinking

APPLYING RESULTS TO ACCELERATE DEVELOPMENT

The current results of the field study can be used to accelerate the development of senior systems engineers. Efforts to accelerate this development process can be categorized into four areas: (1) filtering, (2) development programs, (3) job design, and (4) organizational incentives. Ideally, an organization would filter the right people into systems position, use strategic programs to develop them, design work roles to support the development of systems skills, and incentivize employees to continually evolve their systems thinking.

Figure 4: Categories of Efforts to Accelerate the Development of Senior Systems Engineers

FILTERING

The first step in accelerating the development of senior systems engineers is to identify the right people to work in the systems organization. Certainly, there are always exceptional cases. However, if the highest potential individuals are in the systems organization to begin with, it is likely that these employees will blossom into senior systems engineers faster. The field research results and current literature can be used to inform the filtering process.

Observation. During both the pilot interviews and the field study expert panel interviews, subjects were asked how they currently identify high potential systems thinkers. Overwhelmingly, the answer was by observation. Formal test methods are not used. Answers like, "I know one when I see one" or "I know it in my gut" were common, though the interviewer continued to probe into these comments to elicit more specific characteristics.

Since observation is the primary mode of identification of systems potential, it might be best to see an individual actually work in a systems setting. In the field study, behavioral characteristics of individuals were identified as enablers of systems thinking development. Characteristics such as the ability to ask the right questions, the ability to navigate complexity, analytical ability, strong interpersonal skills, and strong communication skills are best determined by observation. High potential systems professionals may be identified by a temporary assignment to a systems group, by a "test" work assignment on a smaller system, by insights an employee contributes in a meeting, or by observations of an employee to see how the person works on a cross-functional team.

Interviews. Of course, when employees are sought from outside the organization, there is not an opportunity to observe the person working in a systems setting. If the filtering mechanism is an interview, the questions may be informed by the field study results. Behavioral based interview questions could determine if the candidate has curiosity, openness, tolerance for ambiguity, strong interpersonal skills, and strong communication skills. Situational interview questions could be used to examine the ability to navigate complexity, ability to ask the right questions in an ambiguous environment, and analytical ability. The interviewer might then ask about outside interests and hobbies, since many participants stressed the importance of multiple interests both inside and outside work as an indicator of systems thinking potential.

Personality. Since personality characteristics such as curiosity, openness, and tolerance for ambiguity were identified as important enablers for systems thinking development in the field study interviews, it might be possible to use a personality test as an identifier of high potential systems professionals. Certainly, additional personality research is needed in this area, and using personality tests as a filtering mechanism is controversial. Nonetheless, there are two studies that indicate this might be possible.

Toshima has produced an integrated aptitude test for systems engineers (SE), which includes intellectual abilities and personality factors (Toshima 1993). This test relates specifically to systems engineers in the information processing context. From this point of view, "the task of the systems engineer is basically to analyze transactions and business functions through Electric Data Processing operations. Thus it can be said that the function of the SE is to integrate and unify various functions so as to establish a complete information processing system." Again, this application refers to a specific, not general, view of systems thinking. Nonetheless, it shows that personality can contribute to systems thinking.

In another study incorporating personality, Cross and Vick (Cross and Vick 2001) use a construct called the interdependent self-construal, which is when individuals define the self in terms of relationships. Though measures of the interdependent self-construal are scarce, the

authors use the Connectedness Scale designed by Rude and Burnham to measure the construct of interdependent self-construal. Women in the United States' culture are generally socialized to construct an interdependent self-construal, and men are socialized to be more independent and autonomous. Nonetheless, in their study linking self-construal to persistence in engineering, the authors found that female engineers were less interdependent than the other women in the sample. The authors point out that, "Members of many ethnic minorities, such as Hispanics, African Americans, and Asian Americans tend to define themselves in terms of close relationships and interdependence with others." Though it seems plausible to say that those with an interdependent self-construal will be strong systems thinkers, one might also test if high scores on the Connectedness Scale predict strong systems thinking performance.

DEVELOPMENT PROGRAMS

Once individuals are in a systems group, the next step is to develop and mature the person's systems thinking. Certainly, organizations currently have development interventions in place; however, the quality of these interventions varies considerably. Feedback mechanisms are usually not in place to know if an intervention is having the desired impact. Most companies have a systems engineering training program or a systems engineering educational degree program; however, most respondents in the field study rank these interventions as the least effective interventions behind on-the-job training, job rotations, and mentoring. For an organization to more strategically invest their development dollars, it is helpful to understand this discontinuity.

Training and Education Coupled with Application. The field study results show that systems engineering training and education programs are most effective when coupled with application and practical experience. Internal systems engineering training programs, educational degree programs, and external educational certificate programs are being used by companies to provide systems engineering training and education. Although some interviewees highly value these interventions, most have a much lower opinion of these programs.

Pairing these types of programs with practical experience may help. Educational settings often use well-bounded situations and well-defined problems, and it is helpful to apply newly learned ideas to a real system where there is ambiguity and disarray. Similarly, if a person encounters problems that require systems thinking in first-hand application, the person is more likely to appreciate the value of systems thinking courses. Decontextualized education in the behavior of systems can expedite one's process of deciphering context, but some level of familiarity with the system context is essential. Coupling training and education with application may provide an opportunity to see how the principles apply in the specific organizational and technical context of interest.

Active Mentoring. In the field study, respondents commented on both formal mentoring programs and informal mentoring. The reviews depended on the level of engagement, the quality of the mentor, and the quality of the match. A strong systems engineering mentor can be invaluable for deciphering both the technical and social system context. Mentoring allows for more sustained, long-term guidance and teaching. Well-designed mentoring may be a key method to accelerate the development of senior systems engineers. However, senior systems engineers are already in high demand, so using their limited time for mentoring may be onerous. Various respondents overcome this limitation by identifying high potential systems professionals and focusing precious mentoring time on them, though this also requires proper filtering mechanisms to identify these individuals.

Feedback Mechanisms. Another concern is how to evaluate the effectiveness of systems thinking development methods. If one wants to accelerate the development process, it is important to have effective interventions and continue to improve those interventions. To evaluate if a systems engineering training program is successful, most expert panelists respond that course feedback forms are the primary method of evaluation. Although some also use manager feedback, long-term metrics are not utilized. Individual performance appraisals may address this, but that depends on the organizational goals and how the appraisals are designed.

Most disturbing is that the interventions and methods organizations are using to address their need for more systems engineers are the same interventions and methods that rank at the bottom of the most effective interventions, as identified by the interviews. During multiple interviews it became apparent that the organization is spending considerable resources on interventions like stand-alone systems training. After training, employees come back and never use that training again. Similarly, some employees go to a systems education program then come back to the organization to a role that does not utilize (or minimizes) their new skills. This seems like a waste of resources and a waste of time in the development process.

JOB DESIGN

On-the-Job-Training. Field study respondents are emphatic about the importance of on-the-job-training in developing senior systems engineers. When it comes to accelerating the development of senior systems engineers, this is the limiting mechanism since on-the-job-training takes considerable time. However, more strategic moves through the organization and well-designed job roles may accelerate the development process.

A common theme in the development of senior systems engineers is for an employee to work in Component Group A, Component Group B, Component Group C or Discipline A, Discipline B, and Discipline C until eventually the employee understands the system interactions from sheer experience. Some senior systems engineers surveyed have worked in one organization for twenty-five to even thirty-five years, moving through various parts of that organization. This brute force method may work for smaller systems in smaller organizations, but as soon as the system boundaries expand and the required pace of development accelerates, this paradigm becomes insufficient. In addition to the interview results, the literature also states that senior employees may be more prone to better systems understanding (Crawley, de Weck et al. 2004). In the field interviews, respondents who worked through multiple roles usually did so in an organic and ad hoc way. More strategic staging of successive job roles may expedite the development process.

Job Role. Working in a role that requires systems thinking of course develops systems thinking. Working in a test or manufacturing environment enables systems thinking, since the daily work tasks require coordination across disciplines and departments. A managerial position forces one to think more systemically, particularly regarding social interdependencies in the system. The products of some organizations are much broader and systemic in scope, so engineers are exposed to more systems considerations. Also, some organizations have engineers work simultaneously on multiple projects at different stages of the life cycle, so they consider multiple life cycle stages simultaneously. These efforts may accelerate the development of systems thinking.

Particularly for complex systems engineering or systems of systems, there are limited positions available that deal with the complete system. Employees who have the talent or the desire to work at a higher systems level often lack the opportunities to gain that experience.

From the organizational viewpoint, it is risky to give those higher level systems positions to a person who does not have proven skills. The most common development method is to give a person a small system to work on and then progressively give them systems of increasing complexity and scope, if they continue to succeed. The ability to ask the right questions and the ability to navigate complexity is then developed in this spiraling way. In order to accelerate this process, the spiraling may be staged in a deliberate way and mentoring and guidance might be given to individuals as they work through systems at each level. One organization participating in the field study is considering a systems simulation trainer to give employees experience at a higher systems level earlier in their careers.

Cross-Functional Teams. Working on a cross-functional team, like an Integrated Product Team (IPT), is often cited as a key enabler to the development of systems thinking for interview respondents. Through these teams, engineers are forced to consider the concerns of neighboring groups. The pace for developing this understanding is much faster than working in each of those organizations in turn. For example, an engineer from System A may consider the perspective and needs of an engineer from System B much faster when they are both working on an IPT than if the System A engineer spent two years in that assignment followed by two years working on System B.

Key Lessons Learned. Systems thinking is also enabled by key lessons learned. If an individual had a first-hand encounter with a serious problem that required systems thinking or if an individual made a grave mistake due to not using a systems perspective, those key lessons burned the importance of systems thinking into that person's mind. Watching the failure or success of others also enabled systems thinking development. To accelerate development, case studies of past experiences might be shared with younger systems employees.

ORGANIZATIONAL INCENTIVES

Organizational Incentives and Structure. In the end, people usually perform as they are incentivized to perform and the organization often dictates the behavior of its employees. Even though some companies in the study have systems development programs in place, the organizational structure does not support the efficient development of senior systems engineers. Unfortunately, many interview respondents reported that there are no incentives in their organization to promote systems thinking. Employees are rewarded as individuals in functional silos, and cross-disciplinary skills are not rewarded, or even culturally discouraged. Working in a reductionist organizational context inhibits the development of systems thinking. Also, the pace of work often prevents the development or practice of systems thinking. As one interview respondent stated, "The tyranny of the urgent prohibits systems thinking." Aligning organizational incentives with systems development programs may accelerate the development process.

Organizational structures like system checklists imbed systems considerations in the design process. When an organization uses a checklist to identify potential interactions before system changes can be made, it takes the variability out of what system interactions any one engineer may consider. Depending on how the checklists are used, these may lead to complacent thought or help junior engineers quickly learn about the system interfaces and interdependencies.

Employee Affect. The affective state of the individual may also contribute to systems thinking performance. Compared to people in negative or neutral states, people who experience positive emotions tend to choose global configurations (Fredrickson 2003). On global-local processing tasks, they tend to see the "big picture" instead of focusing on smaller, local details.

Assessed by self-report or electromyographic signals from the face, positive emotions broaden an individual's momentary mindset. In order to accelerate the development of senior systems engineers, organizations might strive to keep systems engineers happy!

CONCLUSION

As academia, industry, and government race to develop enough senior systems engineers to handle the increasing complexity of contemporary systems, there is an increasing need to accelerate the development of these senior professionals. Ongoing research by the authors examines the process of developing a senior systems engineer. This research captures current company development practices, while also gathering the opinions and development histories of senior systems engineers and two control groups. Using surveys and interviews, the research has identified key enablers of systems thinking development. The results of the research may be utilized in efforts to accelerate the development of senior systems engineers. These efforts are categorized into four areas: filtering, development programs, job design, and organizational incentives. Utilizing the research results and existing literature, this article discusses the mechanisms one might employ to accelerate the development of senior systems engineers.

REFERENCES

Crawley, E., O. de Weck, et al. (2004). System Architecture and Complexity, Internal Report for the Engineering Systems Division, Massachusetts Institute of Technology.

Cross, S. E. and N. V. Vick (2001). "The Interdependent Self-Construal and Social Support: The Case of Persistence in Engineering." Personality and Social Psychology Bulletin 27(7): 820-832.

Davidz, H., D. Nightingale, et al. (2004). "Enablers, Barriers, and Precursors to Systems Thinking Development: The Urgent Need for More Information." International Conference on Systems Engineering/INCOSE, Las Vegas, Nevada, September, 2004.

Davidz, H., D. Nightingale, et al. (2005). "Enablers and Barriers to Systems Thinking Development: Results of a Qualitative and Quantitative Study." 3rd Annual Conference on Systems Engineering Research, Hoboken, NJ.

ESD (2002). Proceedings of the ESD Internal Symposium. Massachusetts Institute of Technology Engineering Systems Division Internal Symposium, Cambridge, MA, MIT Copy Technology Centers.

Flood, R. L. (1999). "Rethinking the Fifth Discipline: Learning Within the Unknowable."

Frank, M. (2000). "Engineering Systems Thinking and Systems Thinking." Systems Engineering 3(3): 163-168.

Frank, M. (2002). "What is "Engineering Systems Thinking"?" Kybernetes 31(9/10): 1350-1360.

Fredrickson, B. (2003). "The Value of Positive Emotions." American Behavioral Scientist 91: 330-335.

INCOSE (2005).

Senge, P. M. (1990). "The Fifth Discipline: The Art and Practice of the Learning Organization."

Senge, P. M., A. Kleiner, et al. (1994). "The Fifth Discipline Fieldbook: Strategies and Tools for Building a Learning Organization."

Toshima, Y. (1993). "Standardization of an Integrated Aptitude Test for System Engineers: Intellectual Abilities and Personality Factors." Japanese Psychological Research 35(4): 182-192.

BIOGRAPHY

Heidi L. Davidz. Ms. Davidz is a Doctoral Candidate in the Engineering Systems Division at the Massachusetts Institute of Technology. Her research identifies enablers, barriers, and precursors to the development of systems thinking in engineers. Prior to her doctoral studies, Ms. Davidz worked full-time at GE Aircraft Engines as a member of the prestigious Edison Engineering Development Program. Through the GE Advanced Courses in Engineering and the University of Cincinnati, she earned a M.S. in Aerospace Engineering. Previously, Ms. Davidz worked full-time as a Test Operations Engineer at Boeing Rocketdyne. She holds a B.S. in Mechanical Engineering from The Ohio State University.

Deborah J. Nightingale. Dr. Nightingale is currently a Professor of the Practice of Aeronautics and Astronautics and Engineering Systems and Co-Director of the Lean Aerospace Initiative. She holds a Ph.D. in Industrial and Systems Engineering from The Ohio State University and M.S. and B.S. degrees in Computer and Information Science. Her research interests are focused on lean enterprise integration, enterprise architecting and organizational transformation. Dr. Nightingale has 30 years of broad-based experience with academia, the private sector and the government. She is a Past-President and Fellow of the Institute of Industrial Engineers and a member of the National Academy of Engineering.

Donna H. Rhodes. Dr. Rhodes is a Senior Lecturer in Engineering Systems and a Principal Research Engineer in the Lean Aerospace Initiative. She holds a Ph.D. in Systems Science from the SUNY Binghamton School of Engineering. Her research interests are focused on systems engineering, systems management, and enterprise architecting. With 20 years of experience, Dr. Rhodes has held senior level management positions at IBM Federal Systems, Loral, Lockheed Martin, and Lucent Technologies in the areas of systems engineering and enterprise transformation. She is a Past-President and Fellow of the International Council on Systems Engineering (INCOSE), and presently is INCOSE Director for Strategic Planning.