

# Characteristics of Successful Systems Engineers, Systems Architects and IT Architects

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**Abstract.** This paper compares the findings of three researchers striving to identify individual characteristics, attributes and enabling traits germane to successful systems engineers, systems architects and Information Technology (IT) architects. The three researchers are from the USA – the West (Di Carlo et al., 2006), Australia – the East (Frampton et al., 2005) and Israel – the Middle East (Frank, 2006). Two studies' findings are based on an analysis of data collected in the field. The third study's findings emerged from an organic synthesis of literature review, colloquia, and personal experience. The comparison was performed by aligning the findings of the three authors, and yields a list of cognitive characteristics, aptitudes, personality traits and experiences of successful systems professionals operating in different organizational and national cultures. The current paper discusses the methodology of the aforementioned studies, the findings of each study, and the comparison results, as well as recommendations for utilization of the findings and future work.

## INTRODUCTION

As the complexity of systems continues to increase and as the impact of systems issues continues to grow, more organizations are in need of excellent systems professionals. Many have observed the phenomenon of an engineer with especially excellent abilities to see the systems view and to perform at the systems level, what we call *engineering systems thinking*. What is *engineering systems thinking* and what distinguishes engineers who possess this ability from other engineers who do not? Is it an innate talent or rather an aptitude or skill that can be acquired or learned?

The study of the characteristics of the systems professional is still relatively young. Perhaps in the future, neuro-physiological brain studies could be used to study engineers with a high capacity for engineering systems thinking. Currently, the method used to study this phenomenon has been to identify the pertinent characteristics as the studies discussed in this paper have done.

## METHODOLOGY

**The first study.** The primary aim of the first study (Frank, 2002) was to identify the relevant

characteristics of engineers who exhibit high capacity for engineering systems thinking (CEST). This study was carried out in four stages. The first stage involved a pilot study in which 11 in-depth, open and non-structured interviews were conducted with key figures in the Israeli hi-tech industry. In the second stage, the researcher assumed the role of 'the-observer-as-participant,' conducting on-site observations at two hi-tech companies. This second stage involved 17 semi-structured interviews and the content analysis of 14 lectures that were given in a seminar on systems engineering. The third stage of the study consisted of a survey based on a pilot questionnaire (N=31) and a final questionnaire (N=276). The selection of subjects in the first three stages of the study was based on two primary assumptions. These were: (1) senior systems engineers have a high capacity for engineering systems thinking and (2) the appraisal of supervisors and peers is a valid information source. The fourth stage was a follow-up of the previous stages. The idea was that the findings of this latter phase would strengthen (or weaken) the conclusions of the earlier stages. Forty-six systems engineers, from all levels, participated in this phase. The data collection tool was the same questionnaire used in the third stage (with minor changes). The difference between the two questionnaires was that in the third stage, the survey was conducted in written form, while in the fourth stage face-to-face interviews were conducted.

The qualitative-naturalistic inquiry paradigm, in which data collection is based principally on interviews and observations, was found to be suitable for the first, second and fourth stages, since the purpose of the research was to examine processes (and not only final outcomes) within the study participants' natural environment. The number of interviews and observations conducted during the first and second stages was not pre-determined. The criteria for concluding the data collection was saturation; that is, when it became clear that adding new subjects did not significantly alter the findings, the interviews were brought to a close. All the data collected from the interviews was transcribed and the raw data analyzed by 'content analysis', which according to Silverman (2000) "defines the analysis units and establishes the categories (outstanding repeated elements) for

analyzing the raw data". A triangulation strategy was employed in the first, second and fourth stages, i.e., categories not found in at least three interviews or in three different data collection techniques were omitted.

**The second study.** The second study (Frampton et al., 2005) used qualitative, interview-based, techniques to develop an initial understanding of the characteristics that distinguish more effective IT Architects from those who are less so. The use of interviews for this process is appropriate as there is no existing general framework for this area of research and also because this process is primarily focused on the individuals performing these roles. In particular, the use of semi-structured interviews has been shown to be both appropriate and successful (Denzin & Lincoln, 2003; Minichiello, 1995). The combination of focus achieved through pre-determined questions together with the openness of topic-driven questions is conducive to the exploration and discovery of unexpected but relevant material. In particular, fourteen IT architects were interviewed. All of these IT Architects had a minimum of five years' on-the-job experience, had received specific commendations from their clients for project completion, and had been involved in, or responsible for designing more than five projects; all of which had budgets of more than AUD 250,000 (Australian dollar). In addition, the subjects were chosen with the aim of maximizing the range of industries and backgrounds. Their current employers ranged from a single-person boutique consultancy to an international organization with over 20,000 employees spread out over 30 countries. The span of industries included government, IT services and outsourcing, software product development, distribution, and financial services. The main areas of questioning were: (1) *What do IT Architects think makes them and other IT Architects good at their job?* (2) *What do IT Architects look for when choosing to train and hire other IT Architects?* A list of key characteristics was derived from analysis of the interviews, as well as secondary sources such as IT Architect job descriptions. This analysis was based on grounded theory and the use of coding (Strauss & Corbin 1997). One key aspect of this study is that, in contrast with most prior related work, the individuals studied were all active industry practitioners working on a variety of projects with a variety of organizations and industries, all of which were located in Australia.

**The third study.** The third study (Di Carlo et al. 2006) is a counterpoint to the two preceding studies. This study began as an exploration of whole-brain thinking with an emphasis on creativity. The inquiry began when the author, who had been studying the behavior of highly regarded systems professionals, realized with an "aha!" that his most admirable subjects

exhibited an enviable degree of integration or interplay between step-by-step linear thinking (often denoted as 'left-brain thinking'), and integrative holistic thinking (often denoted as 'right-brain thinking'). The term 'ambidextrous thinker' was ascribed to such talented individuals. Thus, this ongoing project proposes that whole-brain or ambidextrous thinking is germane to systems architecting, and sets out to explore the field. As it turns out, this is neither a novel nor isolated idea. For example, Rechlin, whom in this author's imagination, fathered the modern concept of systems architecting, described systems architecting as a 'world' with a lot of right brain reasoning – a kind of gestalt process, with 'taste' and above all creativity (Rechlin, 1991). As for pervasiveness, at the conference (CSER 2006) where the preliminary findings of this project were first presented, many a speaker indeed uttered the words 'whole-brain thinking'.

The *process* employed by this inquiry can be described as one of inductive reasoning "a process of truth estimation in the face of incomplete knowledge which blends information known from experience with plausible conjecture." (Klir, G. J., 1985) The process is purposefully *not* deterministic, but fluid and open-ended, and striving to stay holistic. 'Nuggets' of wisdom are mined from various disciplines through ostensibly indiscriminate literature reviews, colloquia, and personal experience. Furthermore, in striving to avoid the proverbial pitfall of not seeing the forest for the trees, this process, also strives to favor a tack that is, as much as possible, more top down than bottom up. Preliminary insights indicate that the development of *creative* systems architects remains a rather personalized journey filled with (and fueled by) passion, style, personal preference, and student-mentor relationships.

## FINDINGS

**Introduction.** Eighty-three categories were identified by Frank (2002). These characteristics were further broken down as follows: sixty-one categories related to characteristics of successful systems engineers: Fifteen related to the knowledge demanded of system engineers, thirty-one referred to the skills demanded of system engineers, while fifteen dealt with the behavioral competencies demanded of system engineers. The remaining twenty-two categories were then broken down as follows: ten referred to the definition of engineering systems thinking, four dealt with various types of systems thinking, and eight categories referred to the processes by which systems thinking capability is acquired. In a later stage (Frank, 2006), the characteristics of successful systems engineers were consolidated and classified as follows: ten refer to cognitive characteristics, eleven relate to abilities, ten categories deal with behavioral

competencies, and fifteen categories relate to knowledge. The latter classification is presented in the tables below.

The study by Frampton et al. (2005) identified 30 characteristics. The key required capability of IT Architects is communication, while being a generalist is far preferable than being a technical specialist. While the importance of communication was expected, other characteristics, including the requirement for specific personality traits are interesting, previously unreported, and valuable for selection and development of IT Architects. Capabilities identified as critical such as conceptualization and analysis appear suitable for educational focus and thereby could result in improvements in IT Architects' performance. It is also clear from this study that capabilities alone are not sufficient and other non-technical attributes of IT Architects are required, or as one interviewee stated – "aptitude makes the difference, not the technical qualifications".

As mentioned above, the third project is an ongoing inquiry that remains, for the time being, in a divergent state. Yet, some preliminary emphasis was tentatively coaxed out of the myriad of identified strategies, to feed and facilitate comparisons. These high-ranking strategies are singled out relying on recurrence and plausibility.

**Comparison of Results.** The tables below compare the characteristics identified in the three studies. A triangulation criterion was used to determine which findings to include in the tables. Each cell in the table lists the identified characteristic, and the rank of that characteristic within the study. For each study, the top five ranked characteristics are highlighted. This keeps the results in perspective, both within the study and across studies.

Comparing the findings of different studies with different objectives and methods is a complex undertaking (in and of itself challenging as a system). For example, individual characteristics that enable systems thinking development are not necessarily the same as characteristics of successful systems engineers, systems architects, IT architects, or whole-brain thinkers. For example, Davidz (2005) found individual traits enabling systems thinking in engineers – strong

communication and interpersonal skills, openness, curiosity, tolerance for ambiguity, analytical ability, and ability to navigate complexity and ask the right questions. All these individual traits are mentioned in our union list but our list also contains other pertinent characteristics. In addition, the tabulated cognitive characteristics (see table 1) are all related to systems thinking, thus there is some overlap between "characteristics of successful systems engineers, systems architects and IT architects" and "individual traits enabling systems thinking" but the two lists are not identical.

Comparison and consolidation of the studies was performed in three steps. In the first step, we examined the detailed descriptions of each of the top thirty characteristics in each study (If the study identified less than thirty characteristics then all of the characteristics were examined). In the next step we used this detailed information about each identified characteristic to align the characteristics with each other; this led to the initial creation of the table. In the third step, we attempted to obtain a consensus among the studies' authors regarding this alignment. This third step was performed through a multi-pass consensus approach using material from the underlying studies to explain finer details relating to contested characteristics. At all times, where applicable, ranking information from each study was maintained.

The four tables published in this paper present the basic characteristics that emerged from the aforementioned triangulation, and are accompanied by a more detailed discussion of similarities and differences. Table 1 presents the general *cognitive characteristics* of successful systems professionals, Table 2 presents the *capabilities* of successful systems professionals, Table 3 presents the *behavioral competencies* and *individual traits* of successful systems professionals, and Table 4 presents the *background and knowledge* of successful systems professionals.

In each of the four tables we tried to list the characteristics in order of importance. Since we did not develop a unified ranking index it is certainly possible that a specific characteristic is ranked high in one study and relatively low in another.

Systems Engineers (Frank, 2006)	IT Architects (Frampton et al., 2005)	The Whole-Brain Thinking Project (Di Carlo et al., 2006)
Understanding the whole system and seeing the big picture (Rank=3)	Generalist (Rank=2)	Whole-brain thinking (Rank=1)
Understanding interconnections (Rank=6)		
Understanding complex systems (Frank & Waks, 2001)		
Thinking creatively (Rank=19)	Creative (Rank=6) Entrepreneurial (Rank=30)	Taking joy in the creative process; <i>freedom</i> to freely associate
Understanding systems without getting stuck on details; tolerance for ambiguity and uncertainty (Rank=21)		High tolerance for ambiguity; ability to design in the infeasible realm, tolerance for incompleteness (Rank=4)
Understanding the implications of a proposed change (Rank=23)	Analysis (Rank=10)	
Understanding a new system/concept immediately upon presentation (Rank=22)		
Understanding analogies/parallelism/isomorphism between systems (Rank=25)	Abstraction (Rank=30)	
Understanding systems synergy (Rank=10)		
Understanding the system from multiple perspectives (Rank=17)	Ability to see/understand from multiple viewpoints (Rank=20)	Being multifaceted; a generalist's perspective (Rank=3)
	Analysis (Rank=10)	

**Table 1: General cognitive characteristics of successful systems professionals**

Systems Engineers (Frank, 2006)	IT Architects (Frampton et al., 2005)	The Whole-Brain Thinking Project (Di Carlo et al., 2006)
Analyzing the needs/concept of operations/requirements (requirements analysis) (Rank=5)	Business related (Rank=16)	
Conceptualizing the solution (Rank=4)	Conceptualization (Rank=2)	Abstract thinking; ease of thinking at abstract levels, delayed formulation (Rank=3)
Generating the logical solution - functional analysis (Rank=16)		
Generating the physical solution – architecture synthesis (Rank=20)		
Seeing the future (Rank=11)	Visionary (Rank=10)	Having grand visions that extend beyond one's life; a sense of vision
Using simulations and systems engineering tools (Rank=14)	Problem solving (Rank=12)	
Optimizing (Rank=7)		Attain optimality through quantitative analysis based effort
Using systems design considerations (Rank=15)		
Conducting/leading trade studies and providing several alternatives (Frank & Elata, 2005)		Observing deeply and recognizing the limitless possibilities; to seek multiple solutions

**Table 2: Capabilities of successful systems professionals**

Systems Engineers (Frank, 2006)	IT Architects (Frampton et al., 2005)	The Whole-Brain Thinking Project (Di Carlo et al., 2006)
Management skills (Rank=2). Including: team leader; building and controlling the work plan; taking into consideration non-engineering factors such as economic/business considerations and political issues	Middle-ground (Rank=4) Planning (Rank=21) Management/leadership (Rank=21)	Charisma
	Business related (Rank=16) Pragmatic (Rank=21)	
	Situational politics (Rank=4)	
Good human relations, team player, good communication and interpersonal skills (Rank=8)	Communication skills (Rank=1)	Communication skills; a tempered ego; the ability to read people well
	Negotiation (Rank=21) Multiple roles (Rank=21)	
Autonomous and independent learner; strong learning skills (Rank=9)	Self-reflective (Rank=30)	
Curious, innovator, initiator, promoter, originator (Rank=15)	Open-minded (Rank=4)	(Child-like) curiosity; detachment from static results
	Curious (Rank=21)	
	Identify IT opportunities (Rank=21)	
Willing to deal with systems (Rank=10)	Passionate (Rank=9) Enthusiastic (Rank=21)	Enthusiasm; intense honest work with high throughput; drive; a strong will to succeed; strong intentions for making lasting impacts (Rank=2)
Ask good questions (Rank=18)		
See failures and errors as challenges for development, not as “the end of the road” (Frank & Elata, 2005)	Resilient (Rank=12) Strong-willed/persistent/determined (Rank=30)	Tolerance for failure; the willingness to backtrack
	Integrity (Rank=30)	Self-driven; confidence; discipline

**Table 3: Individual traits of successful systems professionals**

Systems Engineers (Frank, 2006)	IT Architects (Frampton et al. 2005)	The Whole-Brain Thinking Project (Di Carlo et al., 2006)
Interdisciplinary knowledge (Rank=1)	Generalist (Rank=2)	Being multifaceted; a generalist's perspective (Rank=3)
Broad experience - job rotation, systems work roles (Rank=7)	Broad experience (Rank=6)	A level of technical expertise (Rank=5)
Formal SE and systems thinking courses/programs (Rank=11)	Education (Rank=21)	

**Table 4: Knowledge and background of successful systems professionals**

## THE UNION LIST

The union of the studies' findings yields 38 characteristics of successful systems engineers, systems architects and IT Architects. It is unlikely that a successful systems professional would possess all of these characteristics. Systems and IT engineering are broad and multifaceted fields. Systems engineers, for example, are not required to perform all systems engineering roles at once. Engineers may be considered as "successful systems engineers" even if they do not demonstrate all of the characteristics listed in the tables. It is more likely that a certain systems professional possesses part of the listed characteristics and is employed in a position that requires these specific characteristics. The union list of the 38 characteristics is presented as ordered in the four tables and not necessarily in order of *overall* importance.

**1. Understanding the Whole System and Seeing the Big Picture.** According to Frank (2006), successful systems engineers understand the whole system beyond its elements, sub-systems, assemblies and components, and recognize how each element/sub-system/assembly/component functions as part of the entire system. Frampton et al. (2005) state that successful IT Architects have more than superficial knowledge about many different interests, in particular as regards approaches, techniques, technologies and products. They are able to consider issues from a range of perspectives and points of view, to understand them, appreciate their differences, and thus draw upon appropriate and varied concepts and values. Similarly, Di-Carlo et al. (2006) found whole-brain thinkers to be multifaceted and to possess a generalist's perspective. In Davidz's (2005) study, the item "thinks broadly/sees the big picture" is ranked first among "individual characteristics that enable systems thinking development". Thus, all of the studies refer to the necessity of seeing the whole in the process of problem solving; as Senge (1994) said: "Systems thinking is a discipline dealing with seeing the whole."

**2. Understanding Interconnections; Closed-Loop Thinking; Understanding Complex Systems.** Frank (2006) found that successful systems engineers understand the interconnections and the mutual influences and interrelations among system elements/sub-systems/assemblies/components/parts.

They demonstrate a closed-loop (circular) view of causality rather than straight-line (linear) thinking, and when are asked to analyze the possible reasons that cause a given system failure, they usually provide several possible explanations. They do not simply submit a list of likely reasons (sometimes dubbed a

"laundry list") but make it clear that they understand both that the effect usually feeds back to influence one or more of the causes and that the causes themselves affect each other. According to Davidz (2005), systems thinking involves one individual's thinking about the system's interactions, interrelationships, and interdependencies of a technical, social, socio-technical or multi-level nature.

**3. Thinking Creatively.** According to Frank (2006), successful systems engineers are capable of creative-lateral-divergent-heuristic thinking in the raising-ideas stages of a project, and logic-convergent-algorithmic-analytical thinking in the implementation stages. They are able to offer workable creative/innovative original solutions, and transform a creative concept into a realizable idea. Similarly, Frampton et al. (2005) found that successful IT Architects are able to think outside the box, have unusual ideas and innovative thoughts, and are able to put things together in new and imaginative ways. In addition, they habitually create and innovate something of recognized value around perceived opportunities. According to Di-Carlo et al. (2006), creative whole-brain thinkers take joy in the creative process and are characterized by the freedom to freely associate. In the study conducted by Davidz (2006), the item "think out-of-box" was ranked fifteenth among "individual characteristics that enable systems thinking development".

**4. Understanding Systems without Getting Stuck on Details; Forest Thinking; Tolerance for Ambiguity and Uncertainty.** According to Frank (2006), successful systems engineers are able to conceptually and functionally understand the system, even without understanding all its minutiae. They avoid getting snagged by the details. They are able to understand the whole/overall picture and continue to act without fully understanding all of the system's details. Such engineers feel comfortable with ambiguity and working in unclear conditions and uncertain environments; not knowing all the details does not disturb them or hinder their efforts to solve a systems problem. Di-Carlo et al. (2006) found that creative whole-brain thinkers have a high tolerance for ambiguity and incompleteness. They are able to design in the infeasible realm. In the study conducted by Davidz (2006), the item "tolerance for uncertainty" ranked fifth among "individual characteristics that enable systems thinking development".

**5. Understanding and Seeing the Implications of Proposed Changes to the System.** Frank (2006) found that successful systems engineers understand the system as a whole and are capable of anticipating and dealing with all implications (including side effects) of changes in the system — engineering and non-engineering alike

— both those initiated by the contractor and those required by the customer. Similarly, Frampton et al. (2005) also found that the ability to analyze the impact of changes was critical for successful IT Architects.

**6. Understanding a New System/Idea/Concept Immediately Upon Presentation.** According to Frank (2006), successful systems engineers understand and are able to describe the operation, purposes, applications, advantages, and limitations of a new system/sub-system/idea/concept immediately after receiving an initial explanation.

**7. Understanding Analogies and Parallelisms between Systems.** Again, according to Frank (2006), successful systems engineers are able to compare and draw parallels between different disciplines. They are able to learn, infer, and draw conclusions from one discipline and apply these conclusions to another. They know how to relate and find resemblances and common ground between different disciplines, and project from their prime specialization to other disciplines related to the project/system under consideration. According to Frampton et al. (2005), successful IT Architects understand different problems and see what was common in them thereby bringing prior or previously-used solutions to them.

**8. Understanding Systems Synergy.** General Systems Theory holds that all systems are similar in certain ways. Therefore, if synergy exists in all systems, then it certainly exists in man-made technological systems. According to Frank (2006), successful systems engineers are able to derive the synergy of a system from the very integration of the subsystems under his/her responsibility and are able to identify the synergy and emergent properties of combined systems.

**9. Understanding the System from Multiple Perspectives.** Frank (2006) found that successful systems engineers avoid adopting a one-dimensional view. They are able to describe a system from all relevant perspectives that go beyond the mere engineering level. A well-known approach for categorizing the required views distinguishes between operational views, system views, and technological views. According to Frampton et al. (2005), successful IT Architects are able to see/understand from multiple viewpoints. They are able to consider issues from a range of perspectives and points of view, to understand them and to draw upon appropriate concepts and values in arriving at a critical assessment of them. They are also aware of the differences of these viewpoints. Being multifaceted ranked third in the study by Di-Carlo et al. (2006).

**10. Analyzing the Need.** According to Frank (2006), successful systems engineers understand and are able to analyze customer (or market) needs, constraints, limitations, priorities, and capabilities. They see the big picture and understand the mission/goal and tasks of the

customer/organization. Similarly, Frampton et al. (2005) found that awareness of business implications and context is important for IT Architects and the success of the systems they design.

**11. Analyzing and/or Developing the Concept of Operations.** According to Frank (2006), successful systems engineers understand and are able to analyze and/or develop the operational concept (CONOPS - concept of operations), goal, objectives, and uses of the required system (or the solution it could provide); that is, what the system should do and what it will do. They understand the operational environment and how a given system functions with its operator/s, recognizing that the human element is part of the system.

**12. Requirements Analysis.** According to Frank (2006), successful systems engineers understand and are able to perform requirement analysis including capturing source requirements, defining requirements, formulating requirements, ensuring that each requirement does not sub-optimize the system, generating System Requirements Documents (SRD), “translating” the concept of operations and the requirements into technical terms and preparing system specifications, validating the requirements, tracing the requirements, and ensuring that all needs, goals and external interfaces (context diagram) are covered by the requirements.

**13. Conceptualizing the Solution.** Frank (2006) found that successful systems engineers are able to top-down generate a conceptual end-to-end solution, prior to any detailed design or analysis. According to Frampton et al. (2005), successful IT Architects have the ability to visualize complex structures in their mind, or invent or contrive an idea or explanation and formulate it mentally. Di-Carlo et al. (2006), indicate that whole-brain thinkers are at ease when thinking at abstract levels, and in Davidz’s (2006) study, the item “abstract thinking” ranked fifth among “individual characteristics that enable systems thinking development”.

**14. Generating the Logical Solution Functional Analysis.** According to Frank (2006), successful systems engineers are able to generate the logical solution by conducting functional analyses. They are able to “translate” the requirements and the system specifications into a Functional Flow Block Diagram (FFBD), in which each block represents a determined function. They are also able to allocate/decompose the functions into system elements, sub-systems, assemblies and components. Generating the FFBD requires them to determine the interfaces and flows among the blocks/functions.

**15. Generating the Physical Solution – Architecture Synthesis.** According to Frank (2006), successful systems engineers are able to generate the physical solution and design the architecture of the system. Part of this process involves allocating the functions to

hardware and/or software configuration items (CI), and determining the physical location of each CI.

**16. “Seeing” the Future.** Frank (2006) found that successful systems engineers are able to “forecast, anticipate and foresee the future”. In the long-term they demonstrate technological vision and are able to analyze future customer/market needs and technological developments. In the mid-term they analyze the system life cycle from the first idea to the final decommissioning and take into consideration the various possible solutions at each stage. In the short-term they are able to analyze expected and/or unforeseen difficulties, problems, risks and change requests. Similarly, Frampton et al. (2005) found successful IT Architects are able to imagine how an organization, system, and industry will be developed in the future, and thus, to plan accordingly. They are able to take a macro view of the entire domain, not just the specific minutiae of the immediate domain. According to Di-Carlo et al. (2006), creative whole-brain thinkers have a sense of vision, indeed grand visions that extend beyond one's own life.

**17. Using Simulations and Systems Engineering Tools.** According to Frank (2006), successful systems engineers are able to design, build and use simulations (including simulators, models, mock-ups, simulations running on standard work station, etc.). They are aware of both the advantages and limitations of simulation. They are able to define, use and build systems engineering tools. According to Frampton et al. (2005), successful IT Architects are able to apply rules, procedures, techniques, and/or principles to solve complex problems.

**18. Optimizing.** According to Frank (2006), successful systems engineers understand optimization considerations and decide when to trade-off and compromise in three dimensions – engineering, cost and schedule, and operational. According to Di-Carlo et al. (2006), successful systems professionals are able to attain optimality through quantitative analysis-based effort.

**19. Using Systems Design Considerations.** According to Frank (2006), successful systems engineers are able to apply systems design considerations. Examples found in the studies are: generating a Built-In-Test (BIT) concept, comparing decentralized and centralized design options, offering client-server architecture, considering interface and dependence minimization, considering re-use of already developed configuration items, and using appropriate standards.

**20. Conducting Trade Studies and Providing Several Alternatives.** Frank (2006) found that successful systems engineers are able to successfully take part in or lead trade studies and feasibility studies. In the trade study report they usually offer a number of alternative solutions. According to Di-Carlo et al. (2006),

successful systems professionals seek out multiple solutions, observe deeply, and recognize the limitless possibilities.

**21. Management Skills; Team Leader.** According to Frank (2006), successful senior systems engineers aspire to manage and are able to lead interdisciplinary teams (sometimes called IPDT – Integrated Product Development Teams). Successful system engineers are able to bring together into cooperative professional activity expert systems engineers from different disciplines. According to Frampton et al. (2005), successful IT Architects are able to stand between the IT [department] and the [rest of the] business, or between other organizations or political units. They are able to select an appropriate course of collective action to achieve a future state of affairs. This includes assessing the present state, setting goals, gathering and analyzing information, evaluating information, developing budgets, making decisions, and acting.

**22. Building and Controlling the Work Plan.** According to Frank (2006), successful systems engineers are able to bring together all activities under their responsibility to successful completion of the mission/project. This includes tracing and controlling the missions/projects under their responsibility by building, controlling and managing a work plan containing a tasks list, schedule, milestones, design reviews, status meetings, activities for identifying bottlenecks, etc. Similarly, Frampton et al. (2005) found that successful IT Architects are able to plan, organize, direct, coordinate, control, and evaluate the use of people, money, materials and facilities to accomplish missions and tasks.

**23. Defining Boundaries.** Frank (2006) found that successful systems engineers know how to set up proper boundaries and allocate tasks to the various teams, departments, partners, different contractors in such a way that each of them finds it possible to cope with their assigned tasks.

**24. Taking into Consideration Non-Engineering Factors.** According to Frank (2006), successful systems engineers are aware that, when preparing proposals or designing solutions, one must bear in mind non-engineering considerations such as ecological/environmental, marketing, “political”, organizational, economical, personal issues, personality styles, business, re-use opportunities and different viewpoints. Frampton et al. (2005) also found that successful IT Architects understand the purposes, objectives, and strategies of the business as well as the implications of this information. They understand the politics of the particular situation, including the organization and work environment, and how they may influence the architects and the people who interact with them.

**25. Good Human Relations; Team Player; Communication Skills; Interpersonal Skills.**

According to Frank (2006), successful systems engineers are characterized by good communication and interpersonal skills and are able to collaborate with others, are strong team players, and establish trusting relations with customers, colleagues, partners, vendors, and sub-contractors. According to Frampton et al. (2005), successful IT Architects have exemplary oral, visual, written and presentation skills including interpretation or translation between different groups. They are skilled in dispute resolution, and negotiating courses of action for individual or collective advantage, while crafting outcomes, which serve mutual interests. Di-Carlo et al. (2006), emphasize strong communication skills and the ability to read people well. In a study conducted by Davidz (2006), the item "strong communication skills" is ranked fourth among "individual characteristics that enable systems thinking development", and the item "strong interpersonal skills" was ranked eleventh.

**26. Autonomous and Independent Learner; Strong Learning Skills.** Frank (2006) found that successful systems engineers are capable of autonomous and independent self-learning and take responsibility for acquiring new knowledge. They are capable of learning whatever is required for the job, including know-how from other disciplines. Frampton et al. (2005) emphasize the ability to consider aspects of your own performance, attitudes and behaviors in order to change or enhance future outcomes. In the Davidz (2006) study, the item "strong intellect" is ranked fifteenth among "individual characteristics that enable systems thinking development".

**27. Curious, Innovator, Initiator, Promoter, Originator.** According to Frank (2006), successful systems engineers are curious and open-minded, and usually have broad interests, beyond the limited area of their expertise. They are uninhibited and do not find it difficult to think under pressure. They do not "freeze up", nor are they "afraid" to think and dare. They are willing to cope with (new) areas outside their area of expertise. They do not stop thinking and initiating. They are constantly on the watch trying to determine what else can be done and where additional/new opportunities may emerge. According to Frampton et al. (2005), successful IT Architects are able to identify opportunities that IT could provide to the business, or that might assist or add additional value. They are open-minded and eager to investigate and learn or learn more (often about others' concerns). Di-Carlo et al. (2006) found that creative whole-brain thinkers display (child-like) curiosity and are detached from static results. In the study conducted by Davidz (2006), the item "curiosity" is ranked third among "individual characteristics that enable systems thinking

development", while the item "open-minded" is ranked second in the same list.

**28. Willing to Deal with Systems.** According to Frank (2006), successful systems engineers have the desire and interest to work with systems. They "love" working on the systems level and with its respective issues. Not every engineer aspires to be a systems engineer and to deal with systems. Frampton et al. (2005) found that successful IT Architects show great excitement, interest, passion, and desire in their work. Di-Carlo et al. (2006) placed great emphasis on enthusiasm. Davidz (2006) refers to "motivation" among "individual characteristics that enable systems thinking development".

**29. Ask Good Questions.** According to Frank (2006), successful systems engineers constantly question the information they are given; this ability to ask good questions is a managerial tool that helps to avoid oversights and enables the asker to see the whole systems picture. In the study conducted by Davidz (2006), the item "questioning" is ranked seventh among "individual characteristics that enable systems thinking development".

**30. See Failures not as "the End of the Road".** Frank (2006) found that successful systems engineers see failures, problems, and errors as challenges and opportunities for development, rather than "the end of the road". Frampton et al. (2005) name this characteristic resilience – the ability to recover readily from adversity, depression, or the like and the inclination to persist. Di-Carlo et al. (2006) emphasize tolerance for failure and the willingness to backtrack.

**31. Integrity.** Frampton et al. (2005) found that successful IT Architects are characterized by honesty, reliability, and fairness, developed in a relationship over time.

**32. Self-Confidence.** Di-Carlo et al. (2006) found creative whole-brain thinkers to be self-confident. Davidz (2006) also refers to self-confidence among "individual characteristics that enable systems thinking development".

**33. Discipline.** Di-Carlo et al. (2006), found that creative whole-brain thinkers are disciplined in their work. Davidz (2006) also refers to "disciplined" among "individual characteristics that enable systems thinking development".

**34. Analytical.** According to Frampton et al. (2005), successful IT Architects are able to break material down into its component parts to see interrelationships. Davidz (2006) refers to "analytical" among "individual characteristics that enable systems thinking development".

**35. Outgoing/Extrovert.** Davidz (2006) refers to "extrovert" among "individual characteristics that enable systems thinking development".

**36. Interdisciplinary Knowledge.** According to Frank (2006), successful systems engineers possess wide, diversified, multidisciplinary and interdisciplinary knowledge. Usually, they have a B.Sc. in one main area (an “anchor”) and become specialists in this field. However, they also acquire knowledge in additional areas. The knowledge in these other areas need not be equal to that of a specialist. In the additional areas successful systems engineers possess general knowledge and understanding; they become familiar with the jargon and professional language of other disciplines (relevant to their job and tasks), are able to communicate with people from different fields and disciplines and ask intelligent relevant questions. Similarly, Frampton et al. (2005) found successful IT Architects have more than superficial knowledge about many different interests, in particular as regards approaches, techniques, and technologies and products. As one of their interviewees said “when people are overly specialist it doesn’t make you good for this sort of work.” According to Di-Carlo et al. (2006), systems professionals are multifaceted and possess a generalist’s perspective. Davidz (2006) lists “wide range of interests” among “individual characteristics that enable systems thinking development”.

**37. Broad Experience.** Frank (2006) found that successful systems engineers usually execute a wide range of jobs, which enables them to become acquainted with many systems and technologies, learn from others’ experiences, be involved in systems-related issues, work with senior systems engineers, and develop a capacity for engineering systems thinking. Frampton et al. (2005) found that successful IT Architects have broad experience in all facets of the software development life cycle. They found that usually more than ten years of significant experience was required to perform the role, including existing systems maintenance and project management. Di-Carlo (2006) indicates that a level of technical expertise is required of creative whole-brain thinkers. Davidz (2006) refers to “wide and varied background” in the “individual characteristics that enable systems thinking development” and specifically ‘mechanical aptitude’.

**38. Education.** Frank (2006) and Frampton et al. (2005) found that successful systems engineers and IT Architects have appropriate education for the role whether formal (academic programs, courses, seminars, workshops, etc.) or informal (on-the-job training, conferences, experiential learning, working with senior systems professionals, etc.).

## DISCUSSION

Upon comparing the results in the tables, it is very interesting that items such as creativity, tolerance for ambiguity, curiosity, and strong communication skills appear across studies. However, it is not necessarily

true that this is a comprehensive list of the characteristics that are necessary for successful systems professionals. It is also not clear to what extent each of these characteristics is “necessary”, or to what extent a professional, who is lacking one *high-ranking* “necessary” characteristic, can compensate with one or more of the other characteristics. In particular, different combinations of characteristics may be more appropriate for different project types, client environments, and also influenced by the composition of the teams involved, as well as workplace infrastructure and prevailing culture.

This area is both of interest and value for practitioners, educators, and researchers alike. To date, there have been two major types of studies within the area. The first could be described as ‘holistic’ and draws from extensive experience, expertise, involvement in real-world situations, and the recognition and inclusion of influences seemingly outside the ‘technical’ area of the systems profession. One of the studies discussed here is indeed holistic in nature (Di Carlo 2005). Other examples include recent works by Jakobsson & Kingston (2006) and Eriksen (2006). One strength of the holistic approach is the possible breadth of coverage, and opportunistic and fluid exploration of different aspects of the role. In comparison, the other two studies presented in the current paper (Frampton, 2005, Frank 2006), along with the study by Davidz (2006), which is also discussed, are more focused, repeatable and ‘scientific’. This approach also has advantages in that any results are oriented towards measurement.

While this paper has presented a comparison of three different studies exploring the desired characteristics of systems professionals from different areas, it is still only a small step towards achieving a deep and thorough understanding of what characteristics are really required for successful systems professionals. The inclusion and synthesis of other related material such as the INCOSE Systems Engineering Handbook (INCOSE 2006) and the Open Group’s Information Technology Architect Certification criteria (Open Group 2006) would serve to increase the coverage of the present research. Furthermore, the inclusion of material on skills required for Systems of Systems (Jakobsson & Kingston, 2006) would also add to the coverage of this research. While Frank (2006) and Frampton et al. (2006a, 2006b) have explored the development of the identified characteristics through education, there has been only limited work in this area thus far. Further exploration and research into the development of these characteristics would be both useful and beneficial for employees, educators, and professionals alike.

The development of a comprehensive, validated, agreed upon, and broadly utilized model of the characteristics

that systems professionals must acquire and maintain is an important objective for both academics and practitioners who are concerned with improving the identification and development of critical systems people. The consolidated characteristics presented within this paper are a useful and necessary step towards the development of such a model. This consolidation, and the clear identification of the breadth of professional domains which these characteristics are relevant to, is also an important contribution. The similarities noted between those characteristics identified for Systems Engineers (working with hardware and software using their own techniques, training, and methods), and those characteristics identified for IT Architects (who work primarily with software and often different methodologies), is also an interesting and valuable finding. This information is of importance as it suggests that these independently arrived-at results may be made to complement one another. In addition, this paper lays a foundation for a convergence of pertinent characteristics and a platform for viable joint research, while possibly allowing for a reduction in duplicated efforts. Practical contributions of the work presented in this paper will be discussed in the section "recommendations for using findings" below.

#### **RECOMMENDATIONS FOR USING FINDINGS**

From a theoretical point of view, the comparisons made in the current paper contribute to the already existing theoretical body of knowledge of systems engineering, systems thinking and IT architecture. At a practical level the integrated list of characteristics may become keystones for developing (1) training classes, university programs and curricula for constructing systems thinking in engineers, engineering students and IT Architects, (2) plans for accelerating the development of these same professionals through job design, job rotations, and development programs, (3) a test for assessing the Capacity for Engineering Systems Thinking or 'fit for the roles'. This test may then be used for selection, filtering, screening, placement, and classification of candidates for systems engineering and/or IT Architect positions, and (4) a guide for forming optimal teams (e.g.. complementary pairings to compensate for individual deficiencies).

#### **CONCLUSION**

As the complexity of systems continues to increase and as the impact of systems issues continues to grow, more organizations are in need of excellent systems professionals. The study of the characteristics of the systems professional is still relatively young. The current paper presents a comparison between the findings of three researchers striving to identify

individual characteristics, attributes and enabling traits germane to successful systems engineers, systems architects and Information Technology (IT) Architects. The union of the findings of these studies results in 38 characteristics of successful systems engineers, systems architects and IT architects. It is unlikely that any one individual systems professional will possess all these characteristics.

Further research validating the consolidated findings of this comparative study would enhance the value of the findings to date and also serve to deepen the knowledge within the field, while providing additional valuable information for industry when selecting and developing systems professionals.

#### **REFERENCES**

- Davidz, H. "Accelerating the Development of Senior Systems Engineers." Paper presented at *INCOSE 2005, the 15<sup>th</sup> International Symposium of the International Council on Systems Engineering*. (Rochester, NY. July 10-15, 2005).
- Davidz, H. "Enabling Systems Thinking to Accelerate the Development of Senior Systems Engineers." Unpublished Ph.D. thesis submitted to the Engineering Systems Division, Massachusetts Institute of Technology (Boston, MA. February 2006).
- Denzin, N. K. & Lincoln, Y. S. *Collecting and interpreting qualitative materials*, 2nd ed. Sage, Thousand Oaks, CA, 1993.
- Di-Carlo, T. & Khoshnevis, B. "Whole-Brain Thinking in Systems Architecting." Paper presented at *CSE2006, Conference on Systems Engineering Research*. (Los Angeles, CA. April 7-8, 2006). University of Southern California.
- Eriksen, T, 'Survey of the use of systems architecture in the development of complex technical systems - Exemplified by the autonomous underwater vehicle Hugin', paper presented to Fifth European Systems Engineering Conference, Edinburgh, Scotland, 18-20 September, 2006.
- Frampton, K. , Carroll, J. M. , and Thom, J. A. "What Capabilities Do IT Architects Say They Need?" In the proceedings of the *10th United Kingdom Academy for Information Systems (UKAIS)*. , March, 22-24, Newcastle, England. 2005.
- Frampton, K, Thom, JA, Carroll, JM & Crossman, B, 'Information Technology Architects: Approaching the Longer View', in T Ryan & K Kaiser (eds), *44th SIGMIS Computer Personnel Research Conference*, April 13-15, ACM Press, Claremont/Pomona, CA, USA, 2006a.
- Frampton, K, Thom, JA & Carroll, J. 'Enhancing IT Architect capabilities: Experiences within a university subject', paper presented to Australasian Conference on Information Systems (ACIS2006), Adelaide, South Australia, Australia, 6-8th December, 2006b

Frank, M. "Knowledge, Abilities, Cognitive Characteristics and Behavioral Competences of Engineers with high Capacity for Engineering Systems Thinking (CEST). " *Journal of Systems Engineering*, 9(2), 91-103, 2006.

Frank M. "Characteristics of engineering systems thinking: A 3-d approach for curriculum content. " *IEEE Transaction on Systems, Man, and Cybernetics, Part C*, 32 (3), 203-214, 2002.

Frank, M. & Waks, S. "Engineering systems thinking: A multifunctional definition. " *Systemic Practice and Action Research*, 14(3), 361-379, 2001.

Frank, M. & Elata, D. "Developing the Capacity for Engineering Systems Thinking (CEST) of freshman engineering students. " *Journal of Systems Engineering*, 8(2), 187-195, 2005.

INCOSE, *Systems Engineering Handbook*, 3rd edn, International Council on Systems Engineering, 2006.

Jakobsson, A & Kingston, G, 'Systems Skills for Design and Assessment of Complex Defence System of Systems', paper presented to 11th Systems Engineering Test & Evaluation Conference (SETE 2006), 25-27 September, Melbourne, Victoria, Australia, 2006.

Klir, G. J., *Architecture of Systems Problem Solving*, Plenum Press, New York, 1985

Minichiello, V. *In-depth interviewing: principles, techniques, analysis*, 2nd ed. Longman, Melbourne, Australia, 1995.

Open Group, *Information Technology Architect Certification Version 2.0*, The Open Group, [http://www.opengroup.org/itac/cert/docs/ITAC\\_Conformance\\_Requirements.pdf](http://www.opengroup.org/itac/cert/docs/ITAC_Conformance_Requirements.pdf), 2006.

Rechtin, Eberhardt. *Systems Architecting, Creating & Building Complex Systems*. New Jersey: Prentice Hall PTR, 1991

Silverman, D. "Analyzing talk and text," in *Handbook of qualitative research*, 2<sup>nd</sup> edition, N. K. Denzin, Y. S. Lincoln (Editors), Sage Publications, Thousand Oaks, CA, pp. 821-834, 2000.

Strauss, AL & Corbin, JM 1997, *Grounded theory in practice*, Sage Publications, Thousand Oaks, CA, USA.

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