FOUR LAYERS APPROACH FOR DEVELOPING A TOOL FOR ASSESSING SYSTEMS THINKING

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ABSTRACT

To perform successfully systems engineering tasks, systems engineers need a systems view, in other words, a high capacity for engineering systems thinking (CEST). A tool for assessing systems thinking of engineers, once validated, may be used for systems engineering workforce selection and development, developing systems engineering curriculum, education, and training programs, as well as a standard tool for assessing systems engineers' competencies. Since there is no known way of directly 'measuring' systems thinking in general and CEST in particular, an indirect method is needed. This paper proposes an idea for developing an indirect means, i.e. a questionnaire for assessing the CEST of systems engineers. The idea is composed of four logic layers.

Keywords: Systems Engineering, Systems Thinking, Engineering Systems Thinking, Capacity for Engineering Systems Thinking (CEST), Interest Inventory.

INTRODUCTION

Systems engineering is an interdisciplinary field of engineering that focuses on how to design and manage complex engineering projects over their life cycles. Systems thinking is what makes systems engineering different from other kinds of engineering and is the underpinning skill required to do systems engineering (Beasley & Partridge, 2011). Engineering Systems Thinking is a major high-order thinking skill that enables individuals to perform systems engineering tasks (Frank, 2000; 2002).

To perform successfully systems engineering tasks, systems engineers need a systems view, in other words, a high capacity for engineering systems thinking (CEST). The main characteristic of systems engineers possessing high CEST is the ability to see the whole picture and identify the system emergent properties, capabilities, behaviors, and functions without looking at the detail. It is assumed that CEST is a measurable and consistent quality of personality, and it can be used to distinguish among individual engineers.

Systems thinking seeks to address and solve complex problems by understanding the system parts and their interactions within the context of the whole system, rather than in isolation (Hitchins, 2003). Systems thinking is a discipline for seeing the whole. It is a framework for seeing interrelationships and repeated events rather than things, patterns of change rather that static ‘snapshots’. Systems thinking is the perception of the ‘constructs’ underlying complex problems (Senge, 1994).

Systems thinking is considered a high order thinking skill. The simplest thinking skills are learning facts and recall. Higher order skills include critical thinking, creative thinking, analysis, problem solving, and systems thinking.

The battery for assessing CEST of individuals comprises a set of paper-and-pencil, field, and lab tests. This paper discusses one of the paper-and-pencil tests – an interest inventory – considering rationale, principles, uses, and stages of development, and presents some examples and results of studies aimed at checking its reliability and validity.

HOW TO ASSESS CAPACITY FOR ENGINEERING SYSTEMS THINKING (CEST) BY A PAPER-AND-PENCIL QUESTIONNAIRE: THE IDEA

The Assessing Need

A tool for assessing systems thinking of engineers, once validated, may be used for systems engineering workforce selection and development, developing systems engineering curriculum, education, and training programs, as well as a standard tool for assessing systems engineers' competencies. Such a tool may be used for selection, filtering, and screening of candidates for systems engineering job positions, and for placing the 'right person in the right job'. The tool may be used also as an instrument for evaluating the effectiveness of systems engineering curriculum and training programs.

Since there is no known way of directly 'measuring' systems thinking in general and CEST in particular, an indirect method is needed. For example, IQ tests are paper-and-pencil indirect tests for 'measuring' the intelligence of individuals. This paper proposes an idea for developing an indirect means, i.e. a questionnaire for assessing the CEST of systems engineers. The idea is composed of four logic layers.

The First Layer

As stated above, engineering systems thinking is a major high-order thinking skill that enables individuals to perform systems engineering tasks (Frank, 2000; 2002). We are dealing here with a thinking skill, so it is relevant to discuss the common methods of ‘measuring’ other thinking skills such as intelligence and creativity.

An intelligence quotient, or IQ, is a score derived from one of several standardized tests designed to assess intelligence. One of the common ways for assessing intelligence is by separately assessing abilities such as arithmetic, spatial imagery, reading, vocabulary, memory, and general knowledge and then weighting the individual scores to one general index (the IQ). For example, The WAIS-III version of the Wechsler Adult Intelligence Scale was released in 1997. It provided scores for Verbal IQ, Performance IQ, and Full Scale IQ, along with four secondary indices – Verbal Comprehension, Working Memory, Perceptual Organization, and Processing Speed. The Verbal Comprehension Index (VCI) included the following tests: Information, Similarities, and Vocabulary. The Working Memory Index (WMI) included: Arithmetic, Digit Span, and Letter-Number Sequencing. The Performance IQ (PIQ) included six tests and also provided two sub-indexes: perceptual organization and processing speed. The Perceptual Organization Index (POI) included: Block Design, Matrix Reasoning, and Picture Completion. The Processing Speed Index (PSI) included: Digit Symbol-Coding and Symbol Search (Kaufman and Lichtenberger, 2006).

The current version of the test, the WAIS-IV, which was released in 2008, is composed of 10 core subtests and five supplemental subtests, with the 10 core subtests comprising the Full Scale IQ. With the new WAIS-IV, the verbal/performance subscales from previous versions were removed and replaced by the index scores. The General Ability Index (GAI) was included, which consists of the Similarities, Vocabulary, and Information subtests from the Verbal Comprehension Index and the Block Design, Matrix Reasoning, and Visual Puzzles subtests from the Perceptual Reasoning Index. The GAI is clinically useful because it can be used as a measure of cognitive abilities that are less vulnerable to impairments of processing and working memory (Pearson, 2008).

There are four index scores representing major components of intelligence: Verbal Comprehension Index (VCI), Perceptual Reasoning Index (PRI), Working Memory Index (WMI), and Processing Speed Index (PSI). Two broad scores are also generated, which can be used to summarize general intellectual abilities: Full Scale IQ (FSIQ), based on the total combined performance of the VCI, PRI, and WMI, and PSI General Ability Index (GAI), based only on the six subtests that the VCI and PRI comprise.

A similar approach can be found in creativity tests. For example, Torrance (1984), building on Guilford's work, created the Torrance Tests of Creative Thinking (TTCT) based on four scales: Fluency – the total number of interpretable, meaningful, and relevant ideas generated in response to the stimulus; Flexibility – the number of different categories of relevant responses; Originality – the statistical rarity of the responses; and Elaboration – the amount of detail in the responses. The third edition of the TTCT in 1984 eliminated the Flexibility scale from the figural test, but added Resistance to Premature Closure and Abstractness of Titles as two new criterion-referenced scores on the figural. To the five norm-referenced measures that he now had (fluency, originality, abstractness of titles, elaboration and resistance to premature closure), Torrance added 13 criterion-referenced measures: emotional expressiveness, story-telling articulateness, movement or actions, expressiveness of titles, syntheses of incomplete figures, synthesis of lines and circles, unusual visualization, extending or breaking boundaries, humor, richness of imagery, colorfulness of imagery, and fantasy (Cramond et al., 2005).

The Second Layer

From IQ and creativity assessing approaches, we have learned that the first stage of developing a tool for assessing systems thinking in engineers should be decomposing the 'engineering systems thinking' to factors that can be separately assessed. But how is this done? In order to answer such a question, let us consider one of the approaches taken in Leadership research.

There are a vast number of books, articles, and studies available which attempt to identify the competencies and qualities of effective leaders. For example, Morrison (2000) presents a global leadership model, while Jokinen (2005) reviews and discusses the main findings of previous leadership studies aimed at identifying characteristics and competencies of effective and successful leaders.

Thus, we can see that a basic approach for understanding the 'leadership phenomenon' is to identify the competencies of successful leaders. It is suggested here that, in the same manner, in order to understand the 'engineering systems thinking phenomenon', we should try to identify the competencies and characteristics of engineers who are systems thinkers. But how can we know which engineers can be considered as systems thinkers as the tool for assessing CEST has not been developed yet?

The Third Layer

As mentioned above, to perform successfully systems engineering tasks, systems engineers need a systems view, in other words, a high capacity for engineering systems thinking (CEST). Thus, for the sake of this study, we may hypothesize that successful systems engineers are characterized by high Capacity for Engineering Systems Thinking (CEST). That is to say, successful systems engineers are systems thinkers. This hypothesis should be reconsidered when the development of the systems thinking assessment tool has been completed. In order to understand the 'engineering systems thinking phenomenon', let us try to identify therefore the competencies and characteristics of successful systems engineers.

In actual fact, this has already been done. Frank (2006) aimed at identifying the characteristics of successful systems engineers. The study included observations of systems engineers who were evaluated – by at least three peers and two supervisors – as being ‘successful’. Eighty-three, which later aggregated to 34 competencies, of successful systems engineers were identified in this study. These 34 competencies were classified into:

- Ten cognitive characteristics – understanding the big picture, interconnections, systems synergy, multiple perspectives, systems without getting stuck on details, implications of proposed change, a new system or concept immediately upon presentation, analogies and parallelism between systems, limits to growth and thinking creatively. All these 10 characteristics are related to systems thinking.
- Eleven abilities – analyzing the need, analyzing/developing the concept of operations, requirements analysis, conceptualizing the solution, generating the logical solution (functional analysis), generating the physical solution (architecture synthesis), ‘seeing’ the future, using simulations and systems engineering tools, optimizing, using systems design considerations, leading trade studies.
- Ten individual traits – management skills, team leader, building and controlling the work plan, defining boundaries, taking into consideration non-engineering factors, good human relations, team player, good communication skills, good interpersonal skills, autonomous and independent learner, strong learning skills, willing to deal with systems, curious, innovator, initiator, promoter, originator, asks good questions.
- Three dealing with multidisciplinary knowledge and experience.

Thus, the content validity of the proposed tool can be achieved by basing its items on the finding in the latter study (Frank, 2006). Each competency of successful systems engineers, found in that study, may be separately assessed by a single item or several items of the proposed tool and then the individual scores weighted to one general index.

The Fourth Layer

One of the findings by Frank (2006) is that in order to be a successful systems engineer, one must have both a will and an interest in being a systems engineer. In addition, as mentioned, successful systems engineers possess a high capacity for engineering systems thinking (CEST). Thus, the three components discussed here – success in a systems engineering position, an interest in systems engineering positions and CEST – are all interrelated. The will and interest to be a systems engineer basically means the desire and interest to be involved in job positions that require CEST. In other words, we may hypothesize that there is a high positive correlation between the engineering systems thinking extent (CEST) of an individual and his/her interest in what is required from successful systems engineers. Figure 1 is a simple concept map that depicts the relationships between these three components:

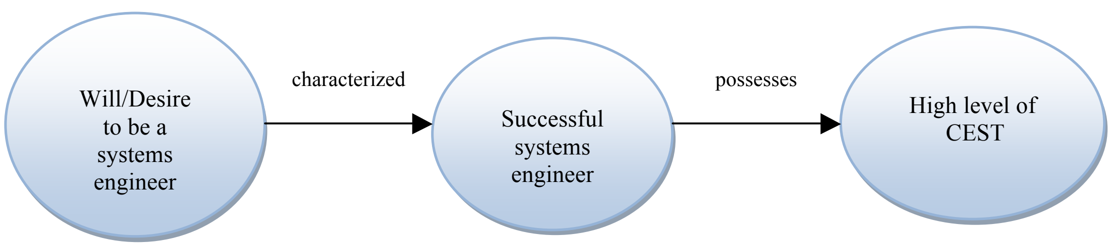

Figure 1. The relationships between the desire, successful SE and CEST

If this hypothesis is supported, then it enables developing a method for assessing the extent of CEST of individuals. This is because interests may be assessed by an interest inventory which is very common and frequently used to help people choose a profession, and as a selection tool (to determine whether a certain individual is suitable for a certain role) in the recruitment process (Anastazi, 1988**).**

ASSESSING THE INTERST FOR ENGINEERING POSITIONS' REQUIRED CAPACITY FOR ENGINEERING SYSTEMS THINKING (CEST)

Frank (2010) introduces a tool for assessing interest for systems engineering positions and other engineering positions' required capacity for engineering systems thinking (CEST). Usually, the items in interest inventories deal with preferences, specifically likes and dislikes regarding a diverse group of activities, jobs, professions or personality types. Likewise, the items included in the tool discussed in this chapter refer to ranges of likes and dislikes regarding systems engineering activities, various disciplines and knowledge required from systems engineers, systems engineering activities and types of people involved in projects.

In its present version, the tool consists of 40 pairs of statements. For each pair, the examinee has to choose between the two statements according to his/her preference. The examinee checks answer "A" if he/she prefers the first statement or answer "B" if he/she prefers the second statement. In order to improve the questionnaire's reliability, questionnaire items were reorganized, so in some cases "A" represented the systems thinking answer and in other cases "B" represented the systems thinking answer. Each "A" answer receives 2.5 points, while each "B" answer receives no point. Thus, the range of the scores is 0-100.

VALIDATING THE TOOL – RESULTS OF RECENT STUDIES

Four types of validity have already been checked in a series of studies of pilot studies – content validity, contrasted groups validity, concurrent validity and construct validity (Frank, 2010). Here are results of additional study. Koral Kordova, Ribnikov & Frank (2015) identified the factors that influence the development of systems thinking among systems engineers. In this study, contrasted group validity was determined by comparing the grades of two contrasted groups - systems engineers and domain engineers such as software and hardware engineers. It was found that there is a significant difference between the average scores of CEST among systems engineers and domain engineers (Sig=0.000).

Moreover, a significant correlation was found between supervisors' ranking in relation to these engineers' systems thinking capabilities and the average score they achieved on Frank's questionnaire (Sig=0.000, r=0.855). This finding is determined the concurrent validity. Construct validity was checked by factor analyses.

In addition, while they were filling out the questionnaire, the engineers themselves were asked to evaluate their desire to engage in systems-related projects; a significant correlation was found between this evaluation and the results of Frank' questionnaire (Sig=0.000, r=0.763).

CONCLUSIONS

Every enterprise strives to fill positions in the organization with employees who have the best chance to succeed. Employees are also interested in entering positions that fulfill their aspirations. Selection and screening processes can help match the interests of both parties, thus contributing both to the organization and the individual. The selection process for systems engineering positions should reliably predict those employees who can succeed and reject those who are likely to fail. Out of the employees who can succeed as systems engineers, it is necessary to choose those who have the highest chance of succeeding.

From the organization's point of view, rejection of candidates who might have succeeded in systems engineering positions can be critical, especially under conditions of an ever-increasing shortage of systems engineers. Likewise, placing engineers who later fail in systems engineering positions is also an expensive error, taking into consideration the necessary training which will be invested and the subsequent damage which might be caused to the projects in which they are involved. The tool presented in this paper may be used for selection, filtering, screening of candidates for systems engineering job positions, and for placing the 'right person in the right job'.

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