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Preface

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COL Christian Patterson was the commander of ERDC and the director was Dr. David W. Pittman.

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Abstract

In this study, we used a structural equation modeling method to investigate the relationship between systems engineers and engineering managers' Systems-Thinking (ST) skills preferences and their Personality Traits (PTs) in the domain of complex system problems. As organizations operate in more and more turbulent and complex environments, it has become increasingly important to assess the ST skills preferences and PTs of engineers. The current literature lacks studies related to the impact of systems engineers and engineering managers' PTs on their ST skills preferences, and this study aims to address this gap. A total of 99 engineering managers and 104 systems engineers provided the data to test four hypotheses posed in this study. The results show that the PTs of systems engineers and engineering managers have a positive impact on their level of ST skills preferences and that the education level, the current occupation type, and the managerial experience of the systems engineers and engineering managers moderate the main relationship in the study.

Introduction

Practitioners such as engineering managers and systems engineers have to address the increasing challenges of today's socio-technical systems while maintaining and elevating performance under increasing complexities and pressures to reduce workforce, resources, and costs. These challenges include (Ackoff, 1995; Boardman & Sauser, 2006; Keating, 2008): 1) a high level of *integration* where systems are combined operationally, managerially, or geographically to produce new goals, 2) *ambiguity* stemming from a lack of clarity to support decisive action and commitment to alternative courses of action, 3) *uncertainty* caused by incomplete knowledge of systems and the unintended consequences they experience, and 4) *interdependence* where there is mutual influence among systems and their related elements making analysis difficult. These four elements are likely to escalate as we grapple with the interdisciplinary system problems of the 21st century, which blur the lines between technical, social, organizational, managerial, and policy considerations (Boardman & Sauser, 2006; Churchman, 1968, 1971, 1979; Deming, 1982; DeLaurentis, 2005; Drucker, 1954, 2012a,b; Gorod, Sauser, & Boardman, 2008; Jaradat, Keating, & Bradley, 2018). Ackoff (1971, 1995) clarified that in treating complex system problems, the focus should be on the whole system and not the parts. In response to these challenges, it is necessary to develop qualified practitioners who can take a more holistic "systemic" approach when dealing with complex system problems, as suggested by Churchman's (1968) book "The Systems Approach."

In addition to the importance of systems thinking in the domain of complex systems, there is an increasing trend in social-personality psychology research devoted to understanding how an individuals' personality traits, preferences, cognition, and social behavior can affect how they address complex system problems (Brown & Moskowitrz, 1998; Freeman, Dale, & Farmer, 2011; Schmidt & Richardson, 2008; Schuldberg & Gottlieb, 2002; Spivey, 2007; Vallacher, Read, & Nowak, 2002; Warren, 2006). For example, Mumford and his colleagues (2000) suggested that an individual's PTs might have an impact on his/her leadership ability in dealing with complex systems problems. According to the socio-technical systems theory, "Socio-technical system design is based on the premise that an organization or a work unit is a combination of social and technical parts and that it is open to its environment" (Appelbaum, 1997, p. 453). Organizations need a joint optimization design to more effectively handle complexity, emergence, and turbulence in a work environment (Appelbaum, 1997; Jaradat et al., 2019). The systems thinking paradigm, in conjunction with systems theory laws and principles and socio-technical systems theory, is the basis for the proposed theoretical model for testing the four hypotheses of this study.

Failures in socio-technical systems can result from non-technical as well as technical elements and can be related to organizational and individual issues where individuals are an essential contributor to the failure. These failures can be classified as having socio-technical aspects stemming from both technical and social, policy, politics, and power elements as well as interactions between those elements (Ackof, 1971, 1994, 1995;; Jaradat et al., 2018; Katina, Keating, & Jaradat, 2014; Frank, 2006; Clegg, 2000; Checkland, 1981). Practitioners' ST skills preferences are necessary for the development of rigorous solutions to avoid these failures in socio-technical systems. Thus, studying the practitioners' ST skills preferences creates several combinations that lead to the effective management of complex multidimensional systems. For example, the assessment of ST skills preferences can help engineering managers to build engineering teams with specific skillset preferences and then effectively match their skillsets with the appropriate problem-solving technique to minimize the waste of workforce and resources and reduce costs. Similarly, Deming (1982), in his book "Out of the Crisis," developed a systems-thinking approach that consists of 14 principles for the transformation of American style management. His principles were guided many engineering managers on how to manage the waste of human resources, the products' quality, materials, and machine-time in their organizations.

Although much has been written about systems thinking and personality indicators, few empirical investigations have covered the impact of PTs on systems engineers and engineering managers' ST skills preferences and their implications for systems engineers and engineering managers. This study, which aims to investigate this impact and its implications, focuses on four demographic factors, educational level, current occupational type, managerial experience, and work experience, and will study their effects on the relationship between PTs and ST skills preferences. Systems-thinking skills preferences and PTs might determine how systems engineers and engineering managers respond to different situations in solving socio-technical system problems.

This study is essential for researchers and academics because it will address two main gaps in the literature. First, it will provide data to address the literature gap in the complex system domain by presenting comparisons and potential relationships between systems engineers and engineering managers' ST skills preferences and personality traits. Second, by considering the impact of demographic factors such as educational level, current occupation type, managerial experience, and work experience, the study could show that these factors do affect a systems engineer and engineering manager's PT and ST skills preferences. In this study, we have developed four main hypotheses based on the literature. To test these hypotheses and to investigate these relationships and comparisons, a valid ST skills preferences instrument (Jaradat, 2015; Jaradat et al., 2018) and the Myers Briggs Type of Indicator's (MBTI) instrument (Keirsey & Bates, 1984) are used in this study.

The development of the research hypotheses is presented below and is followed by the research design and methodology, and the different analysis techniques, including structural equation modeling, used to investigate the validity and reliability of the theoretical model. The paper concludes with a discussion, implications, and future research.

Background and Hypotheses Development

A thorough review of the literature from the 1980s to 2018 revealed that there had been several studies focused on the following research areas: (1) the theory of systems thinking (Ackof, 1994; Checkland, 1981,1999; Jaradat et al., 2018; Senge, 1991, 2004), (2) systems dynamics (Gorod, Sauser, & Boardman, 2008; Keating et al., 2003), (3) the role of systems thinking in solving complex system problem domains (Checkland, 1981,1999; Deming, 1982; Drucker, 2012a,b; Lawrence et al., 2019), (4) the systems approach (Ackof, 1995; churchman, 1968,1979; Hossain et al., 2019a,b), and (5) comparisons of different ST tools used primarily in education (Frank, 2006; Lawrence et al., 2019; Richmond, 1993; Stirgus et al., 2019). For example, Senge (1991) defined systems thinking as "a conceptual framework, a body of knowledge and tools that have been developed over the past fifty years, to make the full patterns clearer, and to help us see how to change them effectively" (P.7). This section will focus on introducing the ST survey instrument and personality assessment tool used for data collection.

The ST skills preferences instrument (with $\alpha = 0.81$), developed by Jaradat (2015) and Jaradat et al. (2018), measures individuals' ST skills preferences in dealing with complex system problems. This instrument uses seven dimensions (see Exhibit 1), which were developed using grounded theory coding. The instrument consists of 39 binary questions culminating in seven preferential categories/systems skills dimensions that determine an individual's inclination toward a Holistic or Reductionist thinking skills preferences profile. By taking the instrument, each participant obtains a profile consisting of seven scores and seven letters corresponding to the seven ST dimensions.

Myers and Briggs, who were inspired by Jung's psychological types, developed an instrument called "The Myers-Briggs Type Indicator." The MBTI instrument is considered "one of the most comprehensive theories explaining human personality" (Tucker & Kroeger, 2010, p. 22; Myers, 1962; Myers & McCaulley, 1985). The MBTI construct consists of four main scales. The *Extraversion-Introversion* scale describes energy utilities. The *Sensing-Intuition* scale describes perception. The third scale, *Thinking-Feeling,* describes judgment, and the last scale, *Judging-Perceiving,* describes an orientation.

Comparing the definition of the ST skills preferences dimensions (shown in Exhibit 1) and the four MBTI dimensions, there are hypothetically some linkages between the two. The *Sensing-Intuition* scale of the MBTI corresponds to the *Systems world view*, *Complexity*, and *Uncertainty* dimensions of the ST skills preferences instrument; the *Extraversion-Introversion* scale and the *Interaction* and *Independence* dimensions show similar characteristics; linkage can also be seen between the *Judging-Perceiving* scale and *Flexibility* and *Change* dimensions and between the *Thinking-Feeling* scale and *Systems worldview* and *Uncertainty* dimensions. Based on the literature, we can also hypothesize that demographic factors such as education level (Assaraf & Orion, 2005; Bawden, Macadam, Packham, & Valentine, 1984; Betts, 1992; Dolansky & Moore, 2013; Richmond, 1993), current occupation type (Cable & Judge, 2003; Tetlock, Peterson, & Berry, 1993; Williams, 2004; Zhao & Seibert, 2006), and Managerial Experience (Porter, 2008; Bureš & Čech, 2007; Furnham & Stringfield, 1993) might impact the relationship between PTs and the ST skills preferences.

In this study, the MBTI instrument was used to measure systems engineers and engineering managers' PTs, the ST skills preferences instrument was used to measure systems engineers and engineering managers' ST skills preferences, and four demographic factors were added as additional variables to the proposed theoretical model. Details of the development of the hypotheses and the theoretical model are discussed below.

Exhibit 1. Seven Dimensions of the "ST Skills Preferences Instrument" (Jaradat, 2015, Fig. 4)

Less Systemic (Reductionist)	Dimension	More Systemic (Holistic)
Simplicity (S): Avoid uncertainty, work on linear problems, prefer the best solution, and prefer small-scale problems.	***Level of Complexity***: Comfort with multidimensional problems and limited system understanding.	**Complexity (C)**: Expect uncertainty, work on multidimensional problems, prefer a working solution, and explore the surrounding environment.
Autonomy (A): Preserve local autonomy, a trend more toward an independent decision and local performance level.	***Level of Independence***: Balance between local-level autonomy versus system integration.	**Integration (G)**: Preserve global integration, a trend more toward dependent decisions and global performance.
Isolation (N): Inclined to local interaction, follow a detailed plan, prefer to work individually, enjoy working in small systems, and interested more in cause-effect solution.	***Level of Interaction***: Interconnectedness in coordination and communication among multiple systems.	**Interconnectivity (I)**: Inclined to global interactions, follow a general plan, work within a team, and interested less in identifiable cause-effect relationships
Resistance to Change (V): Prefer taking few perspectives into consideration, over-specify requirements, focus more on internal forces, like short-range plans, tend to settle things, and work best in a stable environment.	***Level of Change***: Comfort with rapidly shifting systems and situations.	**Tolerant of Change (Y)**: Prefer taking multiple perspectives into consideration, underspecify requirements, focus more on external forces, like long-range plans, keep options open, and work best in a changing environment.
Stability (T): Prepare detailed plans beforehand, focus on the details, uncomfortable with uncertainty, believe the work environment is under control, and enjoy objectivity and technical problems.	***Level of Uncertainty***: Acceptance of unpredictable situations with limited control.	**Emergence (E)**: React to situations as they occur, focus on the whole, comfortable with uncertainty, believe the work environment is difficult to control, and enjoy non-technical problems.
Reductionism (R): Focus on particulars and prefer analyzing the parts for better performance.	***Systems Worldview***: Understanding system behavior at the whole versus part level.	**Holism (H)**: Focus on the whole, interested more in the big picture, and interested in concepts and abstract meaning of ideas.
Rigidity (D): Prefer not to change, like determined plans, not open to new ideas, and motivated by routine.	***Level of Flexibility***: Accommodation of change or modifications in systems or approach.	**Flexibility (F)**: Accommodating to change, like a flexible plan, open to new ideas, and unmotivated by routine.

Hypotheses Development and the Proposed Theoretical Model

The literature is replete with studies related to the effects of personality theory and systems thinking on organizational outputs; however, there remain essential gaps that warrant further attention (Abbas, Sajid, & Mumtaz, 2018; Bradley & Hebert, 1997; Toshima, 1993; Williamson, Lounsbury, & Han, 2013).

- There is a lack of research investigating the relationship between systems engineers and engineering managers' personality traits (PTs) and their level of systems-thinking (ST) skills preferences in the domain of complex systems.
- There is a literature gap regarding the impact of demographic factors such as education level, current occupation type, managerial experience, and work experience on systems engineers and engineering managers' PTs and ST skills preferences in the domain of complex systems. In other words, there is currently nothing in the literature that simultaneously tests all of the mentioned demographic variables to provide a better understanding of the relationship between systems engineers and engineering managers' PTs and ST skills preferences.

In this study, four hypotheses are tested to address these gaps. The first hypothesis explores the impact of systems engineers and engineering managers' PTs on their ST skills preferences when engaging complex system problems (the main relationship of this study). The second hypothesis involves the moderation impact of systems engineers and engineering managers' education levels in dealing with complex systems. The third hypothesis intends to investigate the impact of systems engineers and engineering managers' current occupation type on the relationship between PTs and ST skills preferences. The fourth hypothesis explores the potential impact of managerial experience on systems engineers and engineering managers' PTs and ST skills preferences. In addition to enriching the current body of literature, testing these hypotheses can provide insights for systems engineers and engineering managers by investigating the relationship between personality traits and systemic skills preferences and studying the impact of this relationship on systems engineers and engineering managers' tendencies in solving socio-technical system problems.

Toshima (1993) emphasized that the intellectual abilities and personality traits of Japanese systems engineers are correlated with their level of performance. Linder and Frakes (2011) investigated the correlation between individuals' personality types using MBTI and 17 important systems thinking practices among members of professional organizations, professionals, and graduate-level students. Their study showed that there are correlations between several systems thinking practices and four dimensions of MBTI assessment. Drucker (1954) introduced a systemic approach "management by objective" to assist organizations in achieving a better quality decision-making process. We are reminded by Keating et al. (2003) and Steward (1981) that conventional planning techniques do not adequately address these complex systems. Engineers and engineering managers are charged with operating in complex systems, often working in a parallel system where multiple tasks are coinciding, as stated by Eppinger (1991). As such, the systems skills preferences and PTs of individual systems engineers and engineering managers are integral in addressing these complex systems.

Buffinton, Jablokow, and Martin (2002) mentioned that the personality traits of team members have a potential role in problem-solving styles and interpersonal dynamics of project teams. Toshima (1993) concluded that both intelligence and personality characteristics affect systems engineers' job performance. Abbas et al. (2018) found a relationship between personality traits and knowledge sharing and innovation among engineers. Williamson et al. (2013), who determined the personality traits for engineers for innovation and technology development, found that engineers followed only two of thirteen personality traits when they were compared with non-engineers. Balkis and Isiker (2005) found a close relationship between different thinking styles and the personalities of university students. Zhang (2000; 2001; 2002) found that the thinking styles and personality traits of university students are related. Dragoni and his colleagues (2011) found a highly positive correlation between executives' cognitive abilities (similar to personality traits) and their strategic thinking competency. In a similar study, Soleimani et al. (2018) found that there is a relationship between MBTI personality type of undergraduate students and their cognitive-metacognitive strategies usage in a reading comprehension test. Davidz and Nightingale (2008) showed that participants' personality characteristics positively affect the development of systemic thinking. Since thinking styles and strategic thinking dimensions are in some aspects similar to ST skills preferences dimensions, we hypothesize that a potential relationship between ST skills preferences and PTs of systems engineers and engineering managers might exist.

H_1: There is a relationship between systems engineers and engineering managers' Systems-Thinking Skills Preferences and their Personality Traits (PTs) in the domain of complex systems.

In his studies, Frank (Frank, 2001; Frank & Elata, 2005; Frank & Kordova, 2009) investigated the correlation between the capacity for engineering systems-thinking and project-based learning of freshman engineering students and senior engineering management students.

These studies showed that a student's capacity for engineering systems-thinking could be improved and developed through project-based courses and curricula. Several other studies have investigated the individuals' systemic thinking in different educational levels, such as high school level, undergraduate level, and so on. For instance, Assaraf and Orion (2005) showed the correlation between high school students' systemic capabilities and knowledge in earth system education. Betts (1992) emphasized the need for a systemic approach in elementary and secondary education. Richmond (1993) investigated the impact of systems thinking on the educational process, thinking paradigm, and learning tools in the education systems. Consequently, we hypothesize that systems engineers and engineering managers' education level might have an impact on the main relationship of the study. In this study, the education level of systems engineers and engineering managers was considered as having a doctorate's degree, a master's degree, a bachelor's degree, or other degrees such as high school diploma, associate degree, and some college credits.

H_2: Systems engineers and engineering managers' education levels moderate the positive effects of Personality Traits (PTs) on their Systems-Thinking Skills Preferences.

Different studies have shown the importance of PTs for various occupations. For instance, various studies found managers with different PTs have differences in their thought processes, leadership styles, and performance (Cable & Judge, 2003; Tetlock et al., 1993; Williams, 2004; Zhao & Seibert, 2006). Wasson (2015) and Frank (2001, 2006) and others have emphasized that systems engineers must have distinct abilities and characteristics to deal with complex system problem domains effectively. Eisner (2008) compared the knowledge and skills required in planning, designing, and constructing complex systems by different practitioners, including systems engineers, engineering managers, and project managers. Results showed that different occupants possess distinct skills, behaviors, and characteristics. Therefore, we hypothesize that:

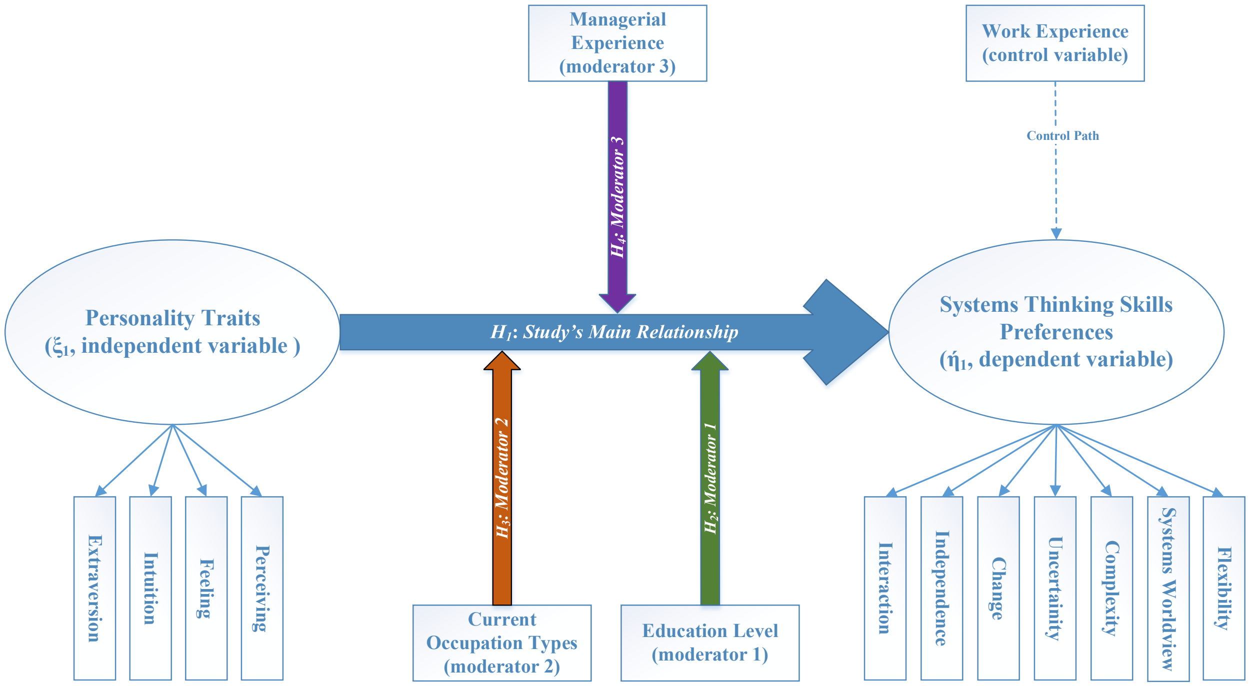
H_3: Systems engineers and engineering managers' current occupation type moderates the positive effect of Personality Traits (PTs) on their Systems-Thinking Skills Preferences.

Porter (2008) stated that managerial experience affects the level of managers' systems approaches concerning corporate social responsibility issues. Ackoff (1994) emphasized that managers need whether through "a direct experience" or "an abstraction extracted from experience by analysis" to confront "situations that consist of complex systems of strongly interacting problems" (p. 184). He categorized these types of problems as *messes*. Mumford and his colleagues (2000) discussed the impact of a leader's career experience on solving the complex social problems in an organization. Bureš and Čech (2007) emphasized the effect of managerial experience on teaching systems thinking concepts. In their 1993 study, Furnham and Stringfield found a correlation between the MBTI personality traits and the managerial experience of Chinese and European managers at an Asian-based international airport. From these studies, we assume that managerial experience might affect the relationship between systems engineers and engineering managers' PTs and ST skills preferences. To investigate only the impact of systems engineers and engineering managers' managerial experience, we controlled the variable "work experience" in the theoretical model, which will be explained in detail in the study variable section. As a result, we hypothesize that:

H_4: Systems engineers and engineering managers' managerial experience, controlled by their Work Experience, strengthens the relationship between Personality Traits (PTs) and their Systems-Thinking Skills Preferences.

Based on the literature provided and the development of hypotheses, Exhibit 2 provides the proposed theoretical model of the study.

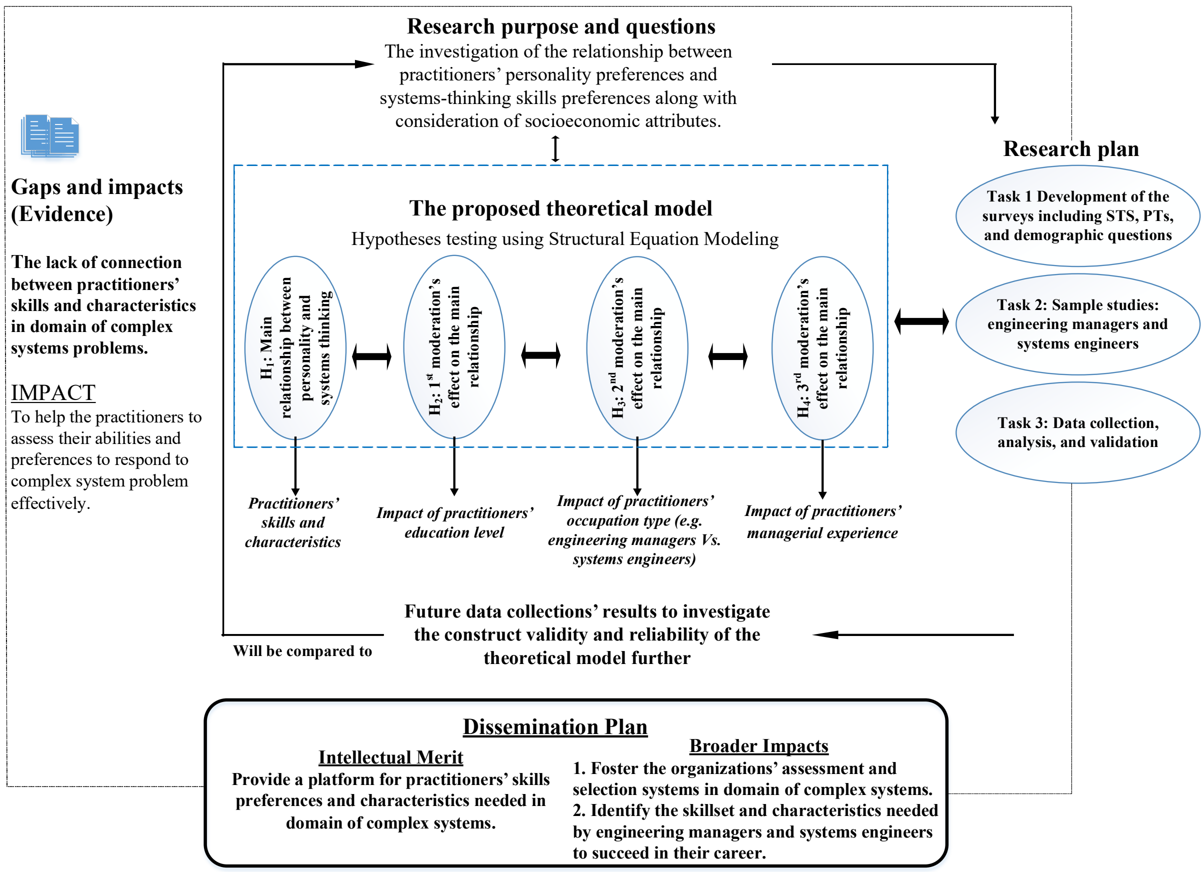
Exhibit 2. The Theoretical Model of the Study



Methodology

The primary objective of this study is to investigate the relationship between systems engineers and engineering managers' PTs and their ST skills preferences through the proposed theoretical model. To test the hypotheses of the theoretical model, the methodology section is divided into three phases: 1) identification of the study sample and data collection procedures, 2) introduction of study variables, and 3) validation of the theoretical model. Exhibit 3 presents the research methodology framework.

Exhibit 3. The Research Methodology Framework



Sample and Data Collection Procedure

The dataset used to test the study hypotheses came from 203 engineering managers and systems engineers working in a complex work environment. The organizations were selected based on one criterion – the complexity of their work environment. To determine the level of work environment complexity, short interviews with several senior managers were conducted. The interview process included four main questions to answer how complex is the work environment based on the complex system attributes such as uncertainty (incomplete knowledge of complex systems and unexpected influences that add uncertainty), lack of clarity (due to the variable nature of a complex system, there can be uncertainty when deciding how to take actions and make decisions.), emergence (because complex systems cannot be predicted, there are often unexpected behaviors or patterns that can only be seen after they occur.), interdependence (complex systems are marked by the interactions between various components of the system).

The types of questions were open-ended questions and close-ended questions. For example, a question was asked—Please describe your work environment in terms of keeping up with changes in the production lines. Another question was about how large the scale of their systems is. Nvivo was used as a tool to collect the interview dataset. Nvivo was also used to scripting the interview' questions. Based on the interviews, twelve organizations were defined as organizations with a complex work environment and were included in the study. The distribution of organizations that were a source for the data is as follows: military and defense agencies (n =5), manufacturing (n = 3), service (n= 2), and systems engineering consultants (n = 2). To test the hypotheses, four demographic factors were collected and included educational levels, current occupation type, managerial experience, and work experience (see Exhibit 4).

Based on the literature, there are many recommendations with regard to the sample size needed for an effective SEM analysis. A general rule of thumb is that a "critical sample size" of 200 provides a stable parameter estimate and has sufficient power to test a model. We searched further in the literature and found that one of the most common recommendations for sample size is provided by Nunnally and Bernstein's (1994) rule of 10, which indicates that we should have 10 observations for each indicator in our model. According to the study's theoretical model, shown in Exhibit 2, there are 15 indicators including, four independent variables (MBTI dimensions), three interactional terms (namely, education level, current occupation type, and managerial experience), one control variable (work experience), and seven dependent variables (7-dimensions of ST skills). Consistent with Nunnally and Bernstein's rule of 10, the necessary sample size of the study should be 150, while the actual sample size of the study is 203.

Additionally, Bentler and Chou (1987) argue that an accurate sample size calculation should be based on free parameters of the model where we should have at least five cases for each parameter estimate (including error terms as well as path coefficients). In our proposed theoretical model, we have 16 path coefficients (four λ_{xi}, seven λ_{yj}, and five β_k) and 12 error terms, and according to Bentler and Chou's suggestion, we need 140 samples. The sample size of the study is 203. In conclusion, the selected sample size of the study is consistent with three well-known recommendations in the literature. Moreover, the selected sample size is consistent with the parsimonious fit provided for the study's theoretical model.

An email invitation to participate in the study was sent to the targeted organizations, along with a web-link survey. The respondents filled out the demographic questions and the 39-question ST skills preferences instrument in approximately 10 minutes. Some participants took more than 10 minutes to fill out the survey, but not exceed 15 minutes.

. A few days later, a follow-up email sent to the participants to complete the second survey. It took approximately 17 minutes to complete the 70-question MBTI instrument adopted by Keirsey and Bates (1984). The reason for collecting data in two different periods was to reduce the possibility of the common method bias in the data collection phase. The survey's response rate was 55 percent, which resulted in a total of 203 completed responses from systems engineers and engineering managers. Responses were recorded using Qualtrics, and identity confidentiality was assured according to the IRB protocol. Prior to analysis, common method bias was tested in the confirmatory study, and the associated result indicated that common method bias is not a substantial concern in the study.

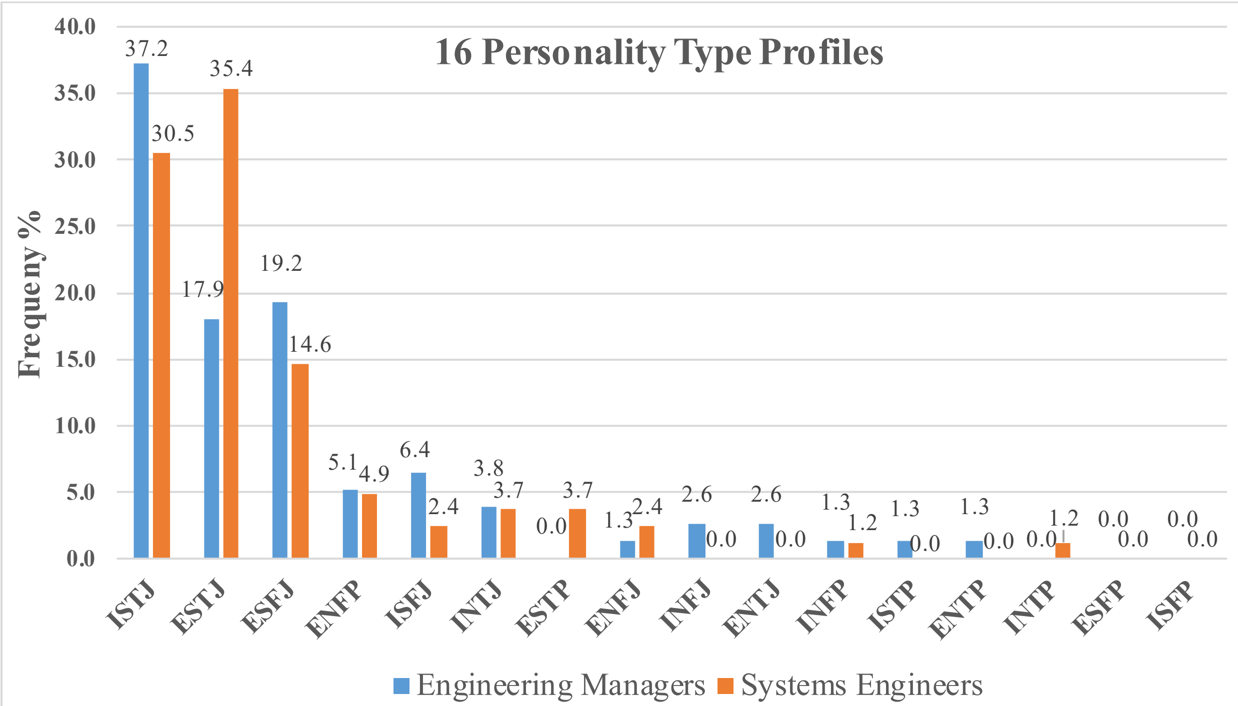
Exhibit 4. Sample Characteristics

Demographic information		Sample size classified by occupation type	
		Engineering managers	Systems engineers
Occupation type		99	104
The education level	Doctorate	8	17
	Master	63	58
	Bachelor	18	24
	Others	10	5
managerial experience (years)	5 and below	14	13
	6 to 10	17	12
	11 to 15	8	11
	16 to 20	15	11
	21 and above	45	57
work experience (years)	5 and below	1	2
	6 to 10	6	6
	11 to 15	6	5
	16 to 20	4	2
	21 and above	82	89

Note: Others refer to those who have completed some college credit/high school diploma/training associate certificate

Exhibit 5 shows the frequency of different personality type profiles found in the study's sample. The personality type profile with the highest frequency among engineering managers is ISTJ with 37.2 percent, and the second and the third highest are ESFJ and ESTJ with 19.2 and 17.9 percent. These three profiles account for 74.4 percent of all engineering managers' personality type profiles. For systems engineers, ESTJ is the most frequent profile with 35.4 percent, and ISTJ and ESFJ are the second and third most frequent with 30.5 and 14.6. These three profiles include 80.5 percent of systems engineers' personality profiles. The results were consistent with studies of Keirsey and Bates (1984) and Wideman (1998), whose studies categorized ISTJ and ESTJ managers as leaders and ESFJ managers as both leaders and followers. Additionally, McCaulley (1990), Schneider, Smith, Taylor, and Fleenor (1998), and Krumwiede and Lavelle (2000) identified the two most frequent personality type profiles of American managers in business and industry as the ISTJ and ESTJ profiles.

Exhibit 5. The Personality Type Profiles of Engineering Managers and Systems Engineers



Study Variables

The variables listed below are developed in the proposed theoretical model (see Exhibit 2)

Latent Dependent Variable

The "Systems Thinking Skills Preferences" is an abstract theoretical variable and cannot be directly measured; therefore, we used a latent variable (unobservable variable) to indirectly measure it through the seven observed variables associated with the seven dimensions of the ST instrument. This latent variable indirectly measures the practitioners' overall systemic skills preferences based on the seven dimensions, which resulted from an extensive systematic review using grounded theory in the domain of complex systems. The seven dimensions are 1) level of *Complexity*, 2) level of *Independence*, 3) level of *Interaction*, 4) level of *Change*, 5) level of *Uncertainty*, 6) level of *Systems Worldview*, and 7) level of *Flexibility*. Exhibit 6 indicates the detailed definition of each dimension with a simple description of each. The latent variable, which will be used to assess a practitioner's overall systemic thinking, is called "Systems Thinking Skills Preferences."

Exhibit 6. The Detail Definition of Seven Dimensions of ST Skills Instrument with Examples

Dimension	Detail Definition	Simple Description
Level of Complexity	This level describes an individual's inclination to work in complex systems. Complexity and simplicity are notated as (C) for Complexity (S) for Simplicity. • Appreciate and assess the degree of complexity (no full control). • Have the ability to distinguish the characteristics of complex system problems and understand the limitations of traditional systems engineering. • Identify and address the external influences that constrain the complex problem domain. • Be able to align between the nature of the problem, the methodology taken, and the context where complex systems operate. • Grasp multidisciplinary problems.	If an individual is on the "complexity" spectrum (C), s/he probably tends to accept working solutions, enjoys working on problems that have not only technological issues but also the inherent human/social, organizational/managerial, and political/policy dimensions, and expects and prepares for unexpected events. In contrast, if an individual is on the "simplicity spectrum" (S), s/he probably prefers to work on problems that have clear causes, prefers one best solution to the problem, and enjoys working on small scale problems
Level of Independen ce	The second pair of preferences deal with the level of autonomy and describes an individual's comfort level in dealing with integration. Autonomy and integration are notated as (G) for integration or (A) autonomy. • Appreciate and embrace autonomy. • Draw the difficulties autonomy brings to the complex problem domain. • Balance the tension between autonomy and integration. • Possess the ability to bargain and negotiate to address complex systems objectives.	An individual might find that s/he agrees with some of the attributes under the "autonomy" preference as well as with some attributes under "integration" preference. This could be quite true and natural. If an individual often leans toward making independent decisions, s/he still might tend to make dependent decisions in certain kinds of problems even though s/he actually prefers making independent decisions.
Level of Interaction	The third pair of preferences, which pertains to the level of interaction, describes the type of work environment an individual would prefer, either (I) Interconnectivity or (N) Isolation. • Identify and understand the purpose of integration. • Orchestrate and possess the ability to work across heterogeneous systems (i.e., people and culture). • Provide inputs to identify new risk behaviors and areas where changes need to be considered. • Possess interdisciplinary knowledge. • Pay close attention to the interactions and interdependencies among the systems from a holistic viewpoint. • Coordinate (teamwork), communicate (sharing data and information), and work closely (with other heterogeneous systems) to achieve the overall purpose.	Some individuals might agree with every attribute related to the "interconnectivity" preference and agree with little with "isolation". These individuals would probably lean more toward the "interconnectivity" preference indicating that they enjoy working on problems within a team and are less interested in clear identifiable cause-effect solutions. This does not mean that individuals who prefer to work individually on problems are wrong or somehow inferior; it only shows the different levels of systems thinking with respect to working in complex problem domains.
Level of Change	The fourth pair of preferences deal with the level of change. This level describes an individual's inclination to make changes when dealing with complex system problems. The preference pairs are notated as (Y) for tolerant of change and (V) as resistance to change. • Trace and map the ongoing change in needs, technology, and social infrastructure. • Focus on the whole instead of the traditional sequential treatments (life cycle). • Take multiple relevant perspectives into consideration. • Explore the environment and look for new-outside opportunities to deal with the pace growth of complex systems.	"Tolerant of change" individuals prefer to work in changing environments while "resistance to change" individuals lean more toward stable environments. Some individuals are likely to consider multiple viewpoints before making a decision, and others assume that these different perspectives could create distractions. Again there are no bad or good systems thinker types; it solely depends on the nature of the problem. If the problem has a large number of stakeholders, it is preferable to assign it to individuals who enjoy working in changing environments.

	• Have the ability to distinguish between the SoS need and the system aggregation need. • Be able to formulate rapid shifting solutions.	
Level of Uncertainty	The fifth pair of preferences deal with the level of uncertainty and ambiguity. This level describes an individual's preference for making decisions as (E) emergence or as (T) stability. • Identify and inspect all aspects (non-technical) of the problem. • Explore the environment to deal with emergence. • Think in a holistic way and avoid obsession with details. • Prepare by designing for flexibility and adaptability in the system. • Appreciate the high level of uncertainty. • Avoid an optimal solution and consider a range of satisficing solutions.	Individuals who agree with the emergence preference are more likely to focus more on the whole in solving problems instead of using a reductionist technique to focus on specific techniques. If individuals agree with half the "emergence" attributes and half the "stability" attributes, the way they choose to deal with problems is not as clear. To clarify again, there are no good or bad combinations; there are only variations from one individual to another. At this point, at least, this research cannot tell if one combination is better than others.
Level of Systems Worldview	The sixth pair of preferences deal with the level of looking at the problem. This level describes an individual's inclination to looking at the problem in complex systems as (H) holism or as (R) reductionism. • Recognize holism as a new paradigm of thinking. • Identify and assess all aspects of the problem. • See the big picture and understand the system as a whole unit. • Focus on the whole and avoid looking at the tiny detail. • Demonstrate an understanding of the laws and principles relevant to the problem under study. • Treat the problem as a whole and avoid thinking in the "cause and effect" paradigm.	An individual whose answers fall into the (H) category is probably more interested in big picture concepts and ideas than his (R) counterpart, who would prefer to focus on particulars and details. However, the nature of complex system problems, their context and surrounding environment determine the way a problem should be managed. In some problems focusing on the parts is vital for determining the right –best solution, but for other problems, this technique might worsen the overall performance of the system.
Level of Flexibility	The last pair of preferences deal with the level of flexibility. This level describes an individual's preference for making decisions as (F) Flexibility or as (D) rigidity. • Appreciate the importance of flexibility and adaptability as functions to deal with emergence and uncertainty. • Recognize the importance of having a flexible design to add, adjust or remove any of the systems' components. • Remain open to all ideas. • Encourage the dissemination of plans and ideas. • Possess the ability to accommodate any changes or modifications in ensemble systems.	An individual may find her/himself displaying attributes from both preferences with perhaps a clear predisposition toward the "emergence and complexity" preferences but also a slight tendency toward the "flexibility" preference.

The score calculation for each of the seven dimensions of ST skills preferences is conducted as follows. Each dimension of the ST skills instrument has five binary questions (in some dimensions, six binary questions). Each binary question has a more systemic answer (counted and coded one) and a less systemic answer (counted and coded zero). After coding all the binary questions, one aggregate score is calculated for each dimension, which is the sum of the coded binary questions divided by the total number of questions in one dimension. To unify the scores across the seven dimensions, the percentage of each aggregate score is calculated. For example, the complexity dimension consists of six binary questions. The level of *Complexity* is calculated for each respondent, as expressed in Equation (1). As a result, each respondent receives an aggregate score for each ST dimension, which ranges from 0% to 100%. The scores of each ST dimension indicates the skill/preference toward that dimension. In other words, if a respondent has a score of 83.3% in complexity dimension, s/he is more comfortable working with multidimensional problems and limited system understanding than a respondent with a score of 16.7% in the same dimension (Exhibit 1, first row, provides a definition of the *level of complexity* dimension). The descriptive statistics for the observed dependent and independent variables are presented in Exhibit 7.

$$\text{Level of } \textit{Complexity} = (\text{Sum of more systemic answers}/6)*100 \qquad (1)$$

Exhibit 7. Descriptive Statistics for the Observed Dependent and Independent Variables.

Variable Type	Dimension	Engineering Managers (percentage)	Systems Engineers (percentage)
		Mean (*SD*)	Mean (*SD*)
Latent Dependent Variable (ST Skills Preferences)	Interaction	60.6 (27.5)	61.2 (27.1)
	Independence	48.5 (24.8)	49.6 (28.0)
	Change	50.2 (18.8)	48.7 (20.3)
	Uncertainty	40.2 (22.3)	30.8 (23.1)
	Complexity	57.2 (24.6)	55.8 (25.4)
	Sys. Worldview	47.5 (28.5)	50.0 (27.6)
	Flexibility	57.6 (27.7)	55.0 (31.6)
Latent Independent Variable (Personality Traits)	Extraversion (E)	49.3 (28.7)	53.9 (25.9)
	Intuition (N)	30.7 (22.8)	28.7 (22.1)
	Feeling (F)	41.2 (26.6)	36.5 (23.4)
	Perceiving (P)	22.6 (18.6)	23.0 (19.7)

Latent Independent Variable

To assess practitioners' "Personality Traits (PTs)," the study utilized the MBTI instrument with its four dimensions 1) level of *Extraversion* (E), 2) level of *Intuition* (N), 3) level of *Feeling* (F), and 4) level of *Perceiving* (P). These four dimensions, which are condensed into one latent variable called "Personality Traits (PTs)," are used as a personality indicator for the study's population.

The same scoring (ST scoring) system is performed to find the score for each of the four MBTI dimensions. The three MBTI dimensions, *Intuition-Sensing, Feeling-Thinking, and Perceiving-Judging* have 20 binary questions each, and *Extraversion-Introversion* dimension has ten binary questions. The binary MBTI questions are coded in a way to make aggregate accuracy score for each dimension (for example, more *Intuitive* answer coded one while more *Sensing* answer coded zero in *Intuition-Sensing* dimension). Then, the aggregate score was converted to a percentage score. Since the score in each MBTI dimension is a continuum, each dimension was named as one extreme for simplification. As an example, the score of the *Intuition-Sensing* dimension is named "level of *Intuition,*" which contains information of both extremes of *Intuition* and *Sensing*. For instance, an individual with a 75% score in the *Intuition* dimension (which is equal to a score of 25% in *Sensing* dimension) indicates that he has a more intuitive preference than sensing preference. Therefore, an aggregate score in each of the four MBTI dimensions (ranging from 0% to 100%) is given to each respondent.

$$\text{Level of } \textit{Intuition} = (\text{Sum of intuitive answers}/20)*100 \qquad (2)$$

Moderator Variables

Three moderator variables were utilized to investigate their interactional effects on the relationship between practitioners' PTs and the level of ST skills preferences. It was hypothesized that these three moderator variables might magnify or weaken the relationship that exists between practitioners' PTs and the level of ST skills preferences. The first moderator, the education level of practitioners, was coded 1 through 4 with one having other degrees such as high school diploma, associate degree, and some college credits, two as having a bachelor degree, three having a master's degree, and four having a doctorate level of education. The higher value of the first moderator represents practitioners with a higher level of education. The second moderator, the current occupation type of practitioners, was a binary variable and coded as one for engineering managers and zero for systems engineers. The higher value of the second moderator toward one represents practitioners with engineering managerial occupations and the lower value toward zero represents practitioners with systems engineering positions. The third moderator, practitioners' managerial experience, was evaluated based on the number of years a manager had been in a managerial position throughout his/her career. The managerial experience was an ordinal observed variable distinguished by five categories including five years and below (coded 1), six to 10 years (coded 2), 11 to 15 years (coded 3), 16 to 20 years (coded 4), and 21 years and above of managerial experience (coded 5). The higher value of the third moderator indicates practitioners with more managerial experience.

Control Variable

Work experience was chosen as a control variable for the third moderator variable (that is, managerial experience). The work experience was evaluated based on the number of years a manager had been in the current occupation. We were interested in investigating the moderation effect of practitioners' managerial experience, with the exclusion of their work experience, on the relationship between their PTs and ST skills preferences. Work experience was an ordinal observed variable which was distinguished by five categories (same as managerial experience categories) including five years and below of work experience (coded1), six to ten years (coded 2), 11 to 15 years (coded 3), 16 to 20 years (coded 4), and 21 years and above (coded 5).

As shown in the "*Hypotheses Development and the Proposed Theoretical Model*" section, there is much research that used demographic variables such as educational level, occupation type, managerial experience, and work experience in the context of both ST and PTs literatures. For instance, a study showed that there are some relationships between the ST skills of managers and their amount of experience (Nagahi et al., 2019). Additionally, Furnham and Stringfield (1993) reported a relationship between the managerial experience of managers and their PTs. Since there are studies in each of ST and PTs literatures suggesting managerial experience can be an impacting factor of ST and also PTs, we assumed managerial experience might influence the main relationship of the current study, which is the relationship between practitioners' ST and Pts. The same assumptions have been made for education level, occupation type, and work experience. In other words, we found these demographic variables influential in both ST and personality literatures, which potentially moderate the relationship between practitioners' ST skills and PTs.

Limitation

The managerial and work experience variables might be subjective due to their definitions, and consequently, the results associated with (H_4) should be interpreted cautiously; and for future research, it is beneficial to add the managers' level in the organization (e.g., CEO, middle manager and so on) as a moderator variable. Therefore, a new hypothesis can be written as practitioners' managerial level in the organization (e.g., CEO, middle manager, and so on) strengthens/weakens the relationship between personality traits (PTs) and their ST skills preferences. In addition to the current study variables, more comprehensive research might be needed to identify and utilize other control and impacting variables such as the level and position of managers in the organization related to ST skills preferences and PTs in the domain of complex systems. Other potential demographic variables such as gender, race, age, and others can be added to the proposed theoretical model to investigate their hypothetical impact on the main relationship of the study. These are some limitations of the current study, which can be investigated in future studies.

Construct Validity of the Theoretical Model

Before interpreting the results of the study, the proposed theoretical model needs to be validated through the establishment of construct validity. As mentioned, the proposed theoretical model, which consists of different variables related to practitioners' sample including the PTs (latent independent variable), ST skills preferences (latent dependent variable), three moderators and one control variable (that is the education level, the current occupation type, the managerial experience, and work experience) shows the structural relationship among all the study's variables through the regression and measurement weights. Two confidence intervals of 99 and 95 percent associated with *p*-values of less than 0.001 and 0.05 were used to determine significance in this study.

The construct validity of the theoretical model is obtained through the investigation of model fit indices, as shown in Exhibit 8. The fit indices values indicated that the proposed theoretical model obtained the construct validity and measures what it is intended to measure; consequently, it is deemed valid to test the study's hypotheses. The reliability of the theoretical model was obtained through composite reliability. Both latent variables— PTs and ST skills preferences—achieved desirable composite reliability of 0.7 in the proposed model (Bagozzi & Yi, 1988). The construct validity and composite reliability were conducted 1) to show that the proposed theoretical model was able to measure what it is intended to measure (i.e., the proposed model fits the data), 2) to show that the associated results of the model can be generalizable, and 3) to test the study hypotheses.

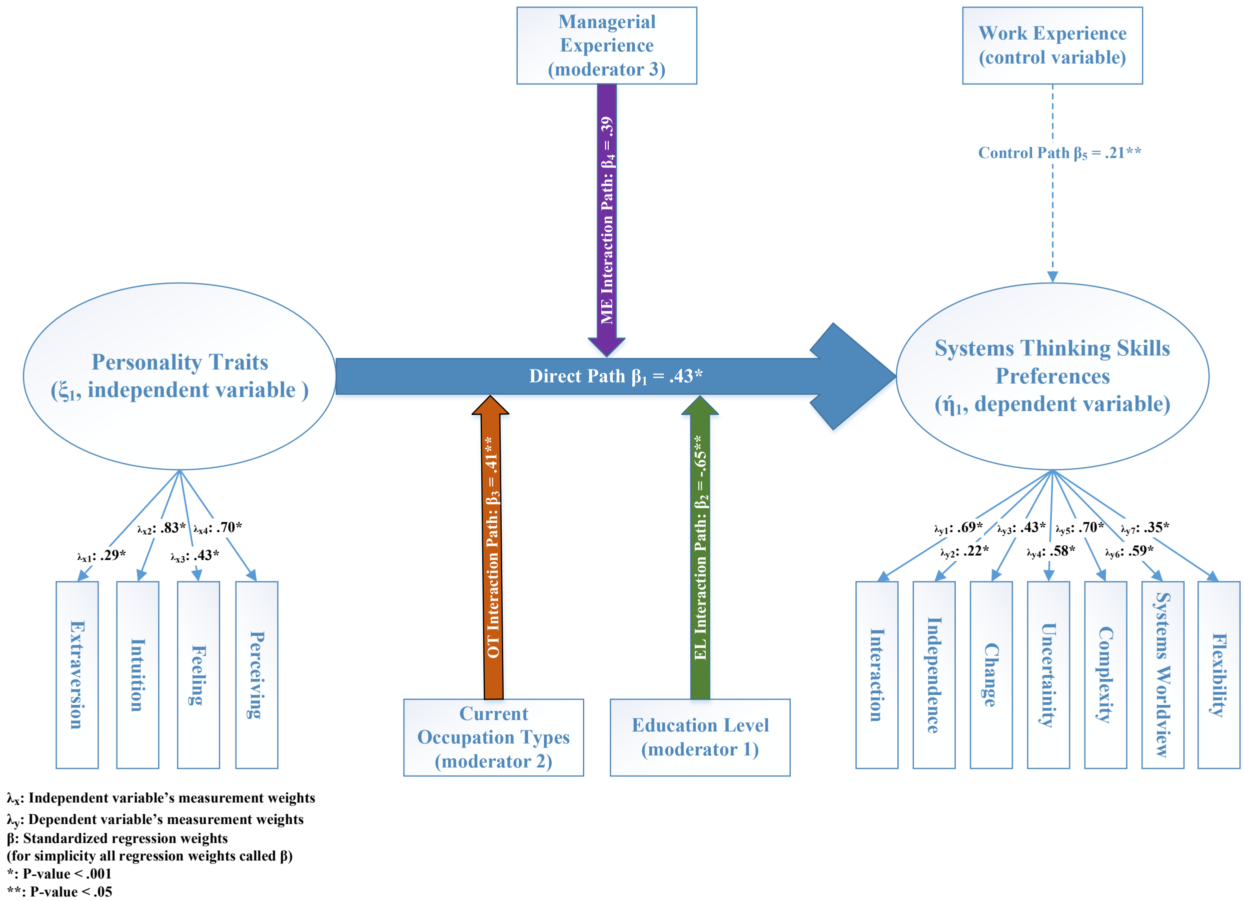
Exhibit 8. The Construct Validity for the Proposed Theoretical model

Name of category	**Name of index**	**Literature**	**Threshold**	**The proposed model**
Absolute fit	χ^2/DF	(Hair et al., 2009)	<3.0 Good; 3.0 to 5.0 sometimes permissible	1.80 [χ^2(df) = 184.9(103)]
	RMSEA;	(Byrne, 2010)	RMSEA < 0.08	0.063; CI [0.048, 0.077]
	RMSEA 95% CI	(Meyers et al., 2005)	<.08 good fit; .08 to .1 moderate fit; > .1 poor fit	
	SRMR	(Hair et al. , 2009)	SRMR<0.09 is acceptable	0.072
Incremental fit	CFI	(Bentler, 1990), (Hatcher, 1994)	CFI > 0.90	0.97
	IFI	(Meyers et al., 2005)	IFI > 0.90	0.97
Parsimonious fit	PNFI	(Meyers et al., 2005)	PNFI > 0.5	0.62

Hypotheses Testing and Results

To test the study hypotheses, the proposed theoretical model was tested through structural equation modeling using AMOS software version 24.0. The standardized solution for the theoretical model consists of the full structural model and is used to assess all the relationships among the study's variables (see Exhibit 9).

Exhibit 9. The Full Structural Model Analysis of the Proposed Theoretical Model



The Main Relationship Test (H_1)

As seen in Exhibit 9, practitioners with high scores on the PTs dimensions of *Extraversion* (E), Intuition (N), *Feeling* (F), and *Perceiving* (P) also have high scores in the 7-dimensions of ST skills preferences namely, levels of *Complexity*, *Independence*, *Interaction*, *Change*, *Uncertainty*, *Systems Worldview*, and *Flexibility*. For example, a practitioner with a high score in the *Intuition* dimension indicates his/her clear preference toward *Intuition* compared to *Sensing*, and a practitioner with a high score in the *Complexity* dimension indicates his/her clear skill preference toward *Complexity* compared to *Simplicity* (see Exhibit 9). The Practitioners with low scores on the PTs dimensions are associated with low scores on the 7-dimensions of ST skills preferences.

Since the *Interaction, Uncertainty, Complexity*, and *Systems worldview* dimensions explain most of the variance in the ST skills preferences latent variable. These four dimensions are considered to be the most critical dimensions in measuring the overall systemic skills preferences of practitioners. Similarly, *Intuition* (I) and *Perception* (P) have the highest factor loading in measuring the independent variable, PTs. In other words, practitioners with high *Intuition* and *Perceiving* characteristics have a high tendency toward working in systems that are more interactional, uncertain, large scale, and complex. This finding is consistent with other studies such as Linder and Frakes' study (2011), which showed intuitive and perceiving respondents inclined to engage in systems thinking practices. Additionally, Krumwiede and Lavelle, (2000) which showed that *Intuition* is the MBTI dimension most applicable in explaining the performance of successful total quality managers.

Since the relationship between the PTs and the ST skills preferences latent variables is significant with p-value < 0.001 (t-value = 4.75) and standardized regression weight of $\beta_1 = +0.43$ (with the standard error of 0.09), H_1 of the study is supported. This indicates that the PTs of practitioners have a positive relationship with their ST skills preferences. In other words, practitioners' PTs affect their ST skills preferences in solving complex system problems.

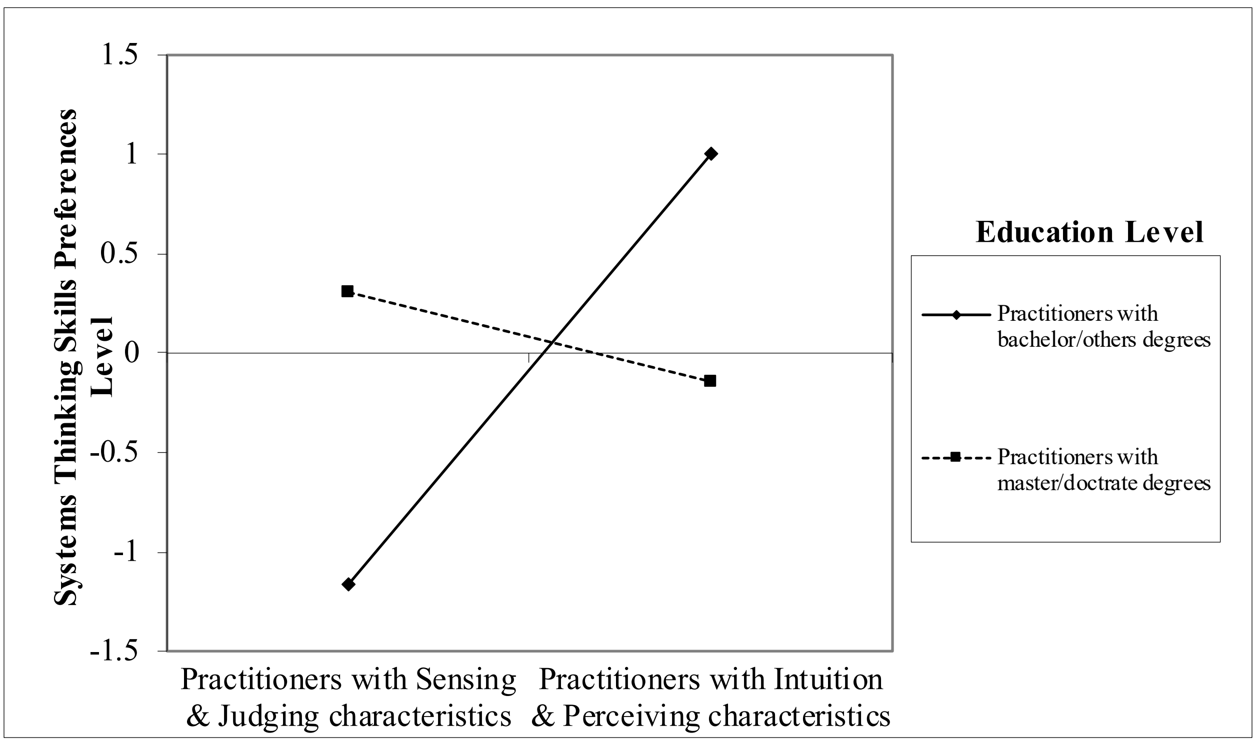
Moderation Test (H_2, H_3, and H_4)

The moderation tests were performed to explain "how" the primary relationship between the independent and dependent variables exists. To test moderation in the proposed theoretical model, the Bootstrap method is performed (Bollen & Stine, 1990; Shrout & Bolger, 2002). The Bootstrap (resampling) technique was used to ensure that the assumption of normality is maintained in the proposed model. The Bootstrap was placed on 5000 samples with a 95 percent bias-corrected confidence interval. All p values are < .05 unless otherwise noted.

As mentioned in the study variables section, three moderation variables are utilized to test their interaction effects on the relationship between practitioners' PTs and ST skills preferences. The three moderation variables are the education level, the current occupation type, and the managerial experience of practitioners. The moderation tests are conducted and interpreted according to the guidance provided in the literature, specifically the studies from Aiken and West (1991) and Dawson (2014). The standardized regression weights are used to plot and interpret the interactional effects. In other words, the independent and dependent variables have a mean of zero and *SD* of one in all interaction plots. As a result, +1 *SD* of ST skills preferences indicates that individuals have more systemic preferences than -1 *SD* of ST skills preferences. Similarly, +1*SD* of PTs indicates individuals with *Intuition* and *Perceiving* characteristics, while *-1SD* of PTs shows individuals with *Sensing* and *Judging* characteristics.

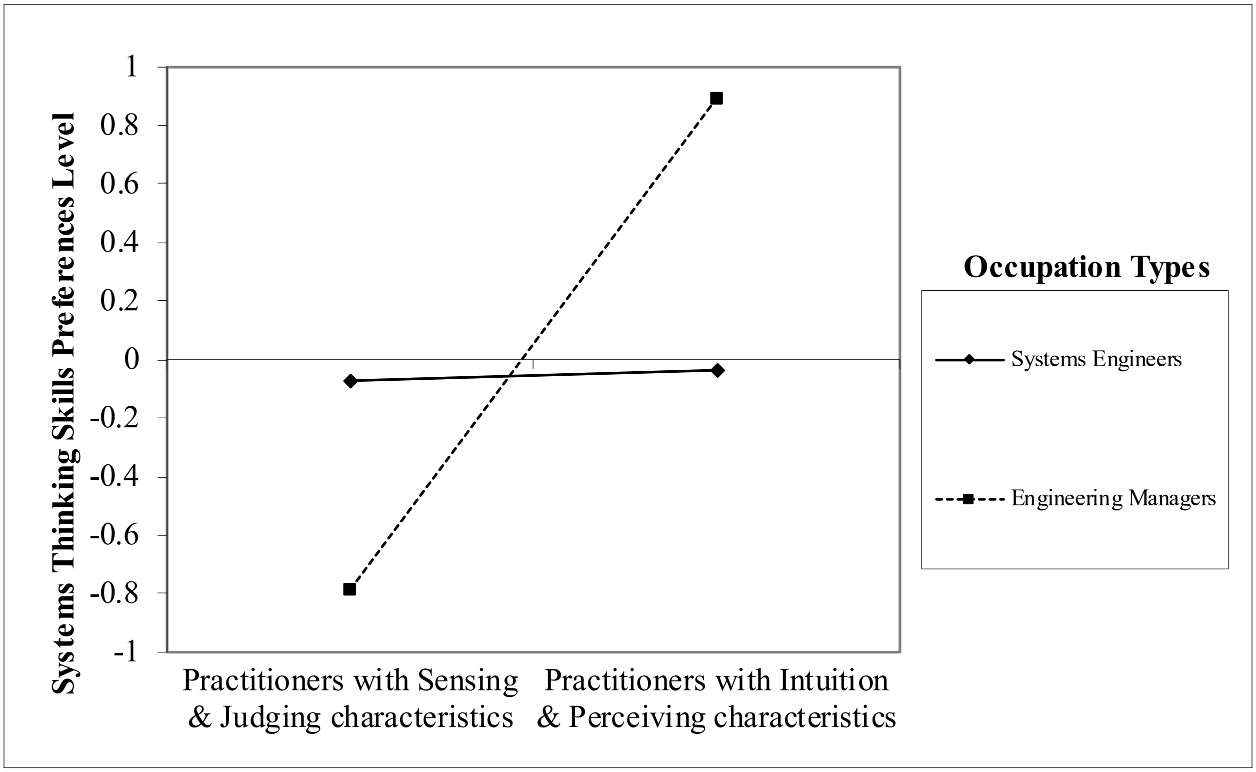
The interaction effect of the first moderator, the practitioners' education levels, was tested to determine the relationship between PTs and ST skills preferences (H_2). The interaction effect with β_2 = -0.65 was found to be significant (*t*-value = -2.41 and *p*-value = .016), indicating the presence of a moderation. Therefore, the second hypothesis (H_2) was supported. This result indicates that practitioners' education levels weaken the positive relationship between PTs and ST skills preferences. Exhibit 10 shows the first moderator interactions plotted at +/- 1 *SD* of ST skills preferences level (that is, practitioners with more or less systemic preferences).

Exhibit 10. The Interaction Effect of Practitioners' Education Level as a Moderator on the Relationship between PTs and ST Skills Preferences



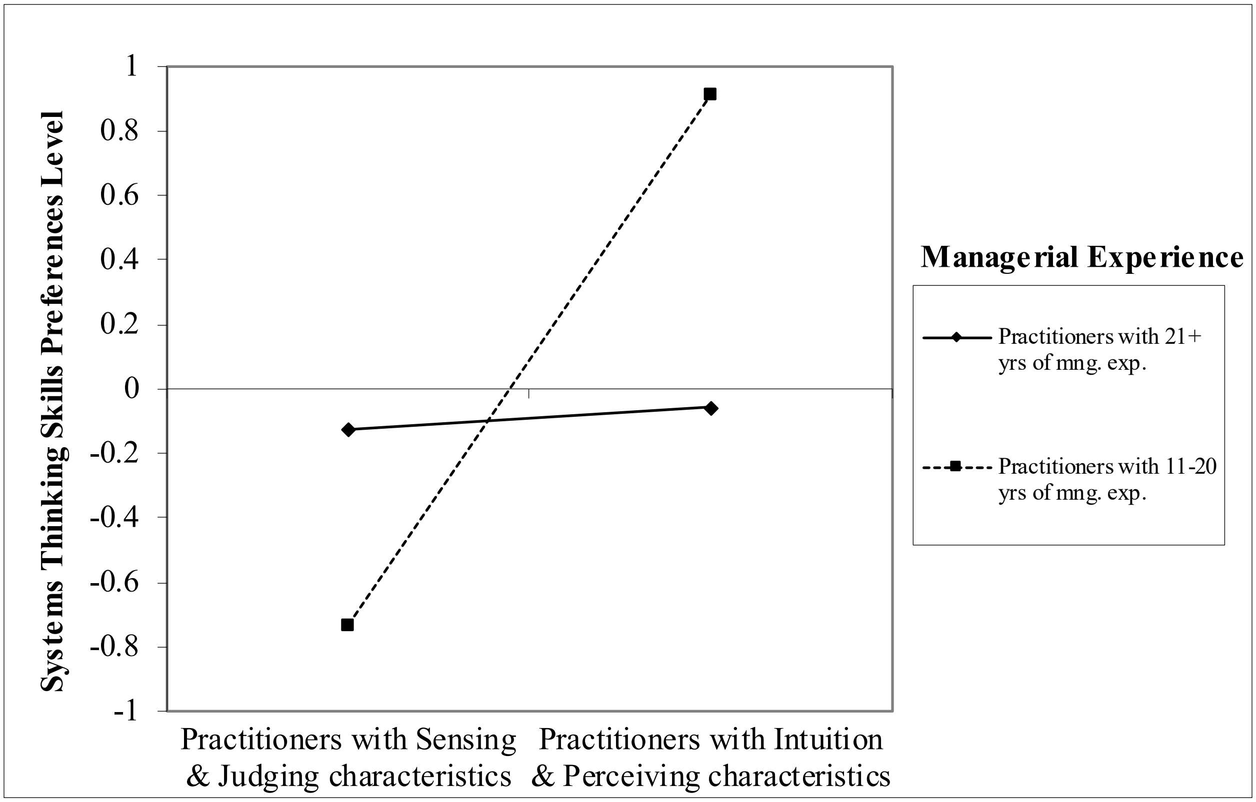
The interaction effect of the second moderator, the practitioners' current occupation type, was tested to determine the relationship between PTs and ST skills preferences. Results indicated a significant interaction effect of practitioners' PTs on their ST skills preferences for the second moderator, β_3 = 0.41 (*t*-value = 2.06 and *p*-value = .040). As a result, the third hypothesis (H_3) of the study was supported. Practitioners' current occupation type strengthens the positive relationship between PTs and ST skills preferences. Exhibit 11 shows the second moderator interactions plotted at +/- 1 *SD* of the ST skills preferences level.

Exhibit 11. The Interaction Effect of Practitioners' Current Occupation Type as a Moderator on the Relationship between PPs and ST Skills Preferences



It was hypothesized (H_4) that practitioners' managerial experience, controlled by their work experience, moderates the relationship between PTs and ST skills preferences. The interaction effect of the managerial experience was not significant at a 95 percent confidence interval ($\beta_4 = 0.39$, *t*-value = 1.57, and *p*-value = .117), and therefore, the fourth hypothesis of this study was not supported. Although we know the interaction effect of managerial experience on the relationship between PTs and ST skills preferences is not significant, based on a study by Brambor, Clark, and Golder (2006), we interpreted the result of this interaction and suggested that there may be a "weak moderation effect." Practitioners' managerial experiences strengthen the positive relationship between PTs and ST skills preferences. Exhibit 12 presents the third moderator (that is, managerial experience) interactions plotted at +/- 1 *SD* of ST skills preferences level.

Exhibit 12. The Interaction Effect of Practitioners' Managerial Experience as a Moderator on the Relationship between PTs and ST Skills Preferences



Discussion and Implications for the Engineering Management Domain

This discussion is based on an analysis of the testing of the four hypotheses.

Contribution and validity of H_1: Based on testing, the first hypothesis was supported. Numerous studies have shown that systems thinking promotes better management of problems in the complex systems' domain (Checkland, 1999; Flood & Carson, 2013; Keating et al., 2003; Steward, 1981). In the literature, no studies are investigating the impact of systems engineers and engineering managers' PTs on ST skills preferences when education level, current occupation type, and managerial experience are added as moderator variables. Understanding the connection between PTs and ST skills preferences can help engineering managers and systems engineers match the practitioners' skills preferences with the requirements of the work environment. The contribution of the first hypothesis is consistent with other studies such as Linder and Frakes (2011), which showed there is a correlation between respondents' PTs and their preferences for using systems thinking practices. Balkis and Isiker (2005) who found a close positive relationship between different thinking styles and the personalities of university students. Davidz and

Nightingale (2008) also showed that participants' personality characteristics positively affect the development of systemic thinking.

Implications of H_1 for academics and practitioners: The positive relationship between PTs and ST skills preferences indicates that engineering managers and systems engineers who scored toward high-level of *Intuition* and *Perceiving* personality traits scored toward the *Complexity*, *Interaction*, *Uncertainty*, and *Systems worldview* dimensions. This implies that perceiving and intuitive engineering managers and systems engineers are more comfortable in dealing with complex systems problems where complexity, uncertainty, and interaction are the main characteristics. This result is consistent with Linder and Frakes's (2011) study that found intuitive and (to a lesser extent) perceiving respondents have more tendency toward systems thinking practices than respondents with other PTs.

Based on the structural model analysis for this study sample, *Complexity* (λ_{y5} = 0.70), *Interaction* (λ_{y1} = 0.69), *Systems Worldview* (λ_{y6} = 0.59), and *Uncertainty* (λ_{y4} = 0.58) are the ST dimensions most correlated with the *Intuition* (λ_{x2} = 0.83) and *Perceiving* (λ_{x4} = 0.70) PTs. The main implications drawn from the results are that perceiving and intuitive engineering managers or systems engineers 1) are more comfortable working in multidimensional problems, 2) tend to accept working solutions (good enough) instead of optimal solutions, 3) enjoy working on problems that have not only technological issues but also inherent human/social, organizational/managerial, and political/policy dimensions, 4) prefer to work on solving problems within a team, 5) are less interested in identifying cause-effect paradigms, and 6) focus more on the whole system in solving problems and formulate a problem by looking at the big picture to understand the overall interaction. Based on H_1, we conclude that practitioners with *Intuition* and *Perceiving* PTs tend to be more systemic.

It is important to clarify that the ST skills preferences cannot be treated and classified as the same category as personality traits. There is a difference between skill and trait. Personality is a trait-based variable, which is a relatively stable and enduring individual difference in personality. On the other hand, ST is a more skill-based variable, which is an individual difference in specific patterns of activity during work striving and can be taught and manipulated easier than a trait. According to the interactionist perspective, skills are affected by traits and task/environment conditions (Kanfer and Heggestad, 1997). It means you can earn better systemic skills if you work on it. On the other hand, it might not be possible that a skill-based variable such as ST skill preferences influence a trait-based variable like personality traits.

Contribution and validity of H_2: Based on the research analysis, H_2 is supported. The education level of practitioners moderates the relationship between their PTs and ST skills preferences. The first moderation test showed that engineering managers and systems engineers who hold a bachelor or other degrees and have more tendency toward *Intuition* and *Perceiving* characteristics lean more toward systemic paradigms than practitioners with *Sensing* and *Judging* traits and the same level of education (Exhibit 10). Practitioners who hold graduate degrees and have more tendency toward *Intuition* and *Perceiving* traits tend to be less systemic than those who hold a graduate degree and have *Sensing* and *Judging* traits.

Implications of H_2 for academics and practitioners: The level of systems skills preferences among practitioners with bachelor/other degrees are highly sensitive to their personality traits; i.e., Intuitive and Perceiving practitioners with bachelor/other degrees are much more likely to be systemic thinkers than Sensing and Judging practitioners with bachelor/other degrees. Additionally, the level of system skills preferences found among practitioners who have graduate degrees is less sensitive to their personality traits.

Contribution and validity of H_3: According to the analysis, H_3 is also supported. The current occupation type of practitioners serves as a moderator for the relationship between their PTs and ST skills preferences. The second moderation test showed that the levels of engineering managers' ST skills preferences are sensitive to their personality traits. On the other hand, the levels of systems engineers' ST skills preferences are less sensitive to their PTs (see Exhibit 11). Results showed that engineering managers with a tendency more towards *Intuition* and *Perceiving* characteristics lean toward holistic paradigms than engineering managers who have more preferences toward *Sensing* and *Judging* characteristics. A range of studies found that the thought process, leadership, and performance of engineering managers differ depending on the manager's PTs (Cable & Judge, 2003; Tetlock et al., 1993; Williams, 2004; Zhao & Seibert, 2006).

Implications of H_3 for academics and practitioners: The main implication for practitioners is that with the presence of the second moderation, the systems engineers' PTs, have little impact on their level of ST skills preferences, but it is not the case for engineering managers. This means that engineering managers with Intuitive and Perceiving traits are potentially more comfortable working in systems that are complex and large. Sensing and Judging engineering managers prefer to work with simple small-scale complex systems problems.

Contribution and validity of H_4: Based on the analysis, H_4 is not supported. Although practitioners' managerial experience may play an insignificant role in the relationship between PTs and ST skills preferences, the associated results were interpreted as having a "weak moderation effect." For more details about the "weak moderation effect," readers can refer to the work of Brambor et al. (2006).

The result of the last moderation test found that a practitioner with 11-20 years of managerial experience and a preference toward *Intuition* and *Perceiving* traits is much more inclined toward systemic paradigms than a practitioner with similar experience and a *Sensing* and *Judging* PTs. This is consistent with Porter (2008), who stated that managerial experience affects the level of managers' systems skills capabilities concerning corporate social responsibility issues. Additionally, Nagahi et al. (2019) showed that managers with more experience possess relatively more ST skills than their counterparts. Bureš and Čech (2007) also emphasized the effect of managerial experience on teaching and understanding systems thinking concepts.

Implications for the Education and Policy Domains

Quenk (2009) defines intuitive individuals as concentrating more on perceiving patterns and interrelationships. Intuitive individuals have five dominant characteristics including 1) focus on the abstract meaning of ideas, 2) imaginative in engaging in a new experience and solving problems, 3) enjoy conceptual knowledge and complexity, 4) trust theoretical patterns and interrelationships, and 5) value originality and uniqueness (Quenk, 2009). Quenk (2009) also describes perceiving people as inclined toward flexibility resulted in dealing with the outer world. Perceiving people have five major features: 1) flexible approach in dealing with both the expected and unexpected events as occurring, 2) prefer flexible plans and freedom to choose, 3) gather ideas and materials following specific deadlines, 4) unmotivated by routines, and 5) comfortable dealing with emergent behavior regardless of detailed plans.

Our finding is consistent with Quenk's study, where the Level of *Complexity*, level of *Interaction*, level of *Systems Worldview*, and level of *Uncertainty* are highly correlated with the *Intuition* and *Perceiving* dimensions of PTs. This would inform practitioners that individuals with a more intuitive and perceiving personality have more systemic skills. Consequently, practitioners can train individuals to become more systems thinkers by focusing on the mentioned personality features in the *Intuition and Perceiving* dimension. These features are permissible to train students in the K-12 education system, and work-training environment to enhance the possibility of equipping the current, future systems engineers and engineering managers with a high level of systemic thinking. Identifying the connection between PTs and ST skills can provide direct utility for practitioners and enhance the system's performance by fitting individuals' skillset and personality with their job requirements in a timely fashion. This would reduce the burden of long training costs and prepare companies to provide the relevant needed training for their employees based on their skillset and personality types.

Additionally, the improvement of ST skills and certain personality traits can be supported through engineering curriculums across colleges, and determine which majors produce more systems thinker students than others. In order to improve these skills, the curriculum should be revised to design more courses that are relevant to solving complex system problems (Assaraf & Orion, 2005; Frank, 2001; Sweeny & Sterman, 2000). This will enhance critical thinking power and provide new viewpoints and ways of thinking to understand and solve complex system problems. Redesigning the educational curriculum in such a way would foster students' formation of holistic thinking along with their personality traits. Moreover, identifying more systemic thinking based on personality profiles can help students in understanding the influence of the level of ST and personality traits with respect to taking actions and making decisions in complex system problem domains.

If complex system problems cannot be solved using traditional engineering methods, then there is a need to use more systemic approaches. Research shows that socio-technical system problems require more systems thinkers since these problems contain technical, culture, policy, and social components (Boardman & Sauser, 2006; DeLaurentis, 2005; Jaradat et al., 2018). Managing and engineering socio-technical systems require a cadre of individuals who are capable of taking a more holistic approach. Examples of these approaches include *big picture analysis*, *understanding the interrelationships of a robust casual chain of the events*, *consideration of integration within system of systems*, and *chaos management*.

Big picture analysis would enable systems engineers and engineering managers to better understand the whole aspect of a complex system problem. The focus on much detail might hinder the process of achieving acceptable solutions, and it is more likely to yield to type III errors—solving the wrong problems precisely (Mitroff, 1998).

Understanding the interrelationships of a robust casual chain of the events is necessary for systems engineers and engineering managers because a simple linear cause-effect paradigm is not sufficient to understand the connectivity and interaction of large-scale complex system problems. It is not feasible to achieve a full understanding of complex systems using the simple one-cause one-effect approach. The ST-based paradigm is much more consistent with the working environment of systems engineers and engineering managers.

Consideration of integration within system of systems allows practitioners to not only plan based on the requirements of the individual systems, such as different sections and departments within an organization, but also consider the requirements of the organization as the whole unit. This creates better management and planning for a system of systems based on holistic systemic approaches.

Chaos management equips systems engineers and engineering managers against the emergent behavior of complex systems, especially in the phase of operations. Such emergent behaviors are unintended and problematic, which exposes the entire system in a higher degree of risk and danger. Consequently, systems engineers and engineering managers should have more flexible and resilient plans to adapt to these unpredictable and unexpected problems of complex systems. A holistic systemic approach can help practitioners to more effectively deal with the unintended and unpredictable challenges of complex systems domain.

The ST skills preferences profiles generated using the ST skills instrument are not meant to place judgment on a practitioner's capabilities. In other words, there are no good or bad profiles, and both holistic and reductionist thinkers might be needed in the work environment. Depending on the specific scenario and environment, more systemic thinkers may be appropriate (such as managerial positions), while in other situations (such as specific engineering or data analytic positions), reductionist thinkers may be more suitable to handle the challenges. For a better work environment, it is better to match the level of ST skills/preferences of individuals with their level of environmental complexity.

Future Studies

There is a lack of studies that investigates the relationship between practitioners' personality traits and the level of ST in the field of systems engineering. As a result, future studies are needed to test the consistency and generalizability of the findings of the current study with the findings of future similar studies. Since the sample of this study was limited to engineering managers and systems engineers, other samples from different populations of interest, including non-engineering managers and non-system engineers, can be investigated in future studies to test the effects of PTs on ST skills preferences across different categories. Data from that study could then be used in another study comparing the results of different sample studies.

Although the "MBTI instrument" adopted by Keirsey and Bates (1984) is used as the PTs indicator in the current study, the Five-Factor Model (FFM) is another widely used personality indication tool popular in academic research (Furnham, 1996). Future studies could use the NEO-PI Five-Factor Model (FFM) and proactive personality instruments as the PTs predictor, and their results could be compared with the results of this study, which used the "MBTI instrument." Classification of the proposed model with respect to PTs and ST skills preferences classes (both PTs and ST skills preferences are latent variables) using Bayesian latent class analysis (BLCA) can be performed in future studies. Moreover, we should emphasize that we found evidence of construct validity for the proposed theoretical model of this study, which means our proposed model can measure what it was intended to measure; however, for the final construct validation of a theoretical model, more studies are needed to test the validity and reliability of the proposed model with different populations of interest during different periods of time.

In this study, the instrument data was used as a quantitative approach. However, according to Cresswell and Cresswell (2018), in addition to the close-ended survey, several data collection strategies can be used to analyze data including, census data, interviews (for example, researching about feeling, experience, or behaviors of LGBTQ students' peers in the classroom), observations, documents, records, observational checklists (researching about academic/instructional behaviors of students in the classroom), and other methods. These data collection strategies can be used, in future studies, as supporting methods to provide more insights about the study findings. Finally, no causality should be inferred from the study results.

In our long-term ST research, a methodology called ST-Cap Method has been designed and utilized. The ST-Cap Method is exemplary of an ST approach that guides identification, assessment, and development of ST for individuals and organizations. The ST-Cap Method is conducted in six steps. The primary goal is to determine the degree of ST that exists in an organization and the congruence of that capability to that which is demanded. For example, in a job with routine, linear, technical, and focused scoped condition, a reductionist practitioner might be needed rather than a holistic thinker. For clarification, the mentioned sentence is modified in the revised version. The long-term ST research (ST-CAP method) will:

1. Assess individuals' level of systems thinking skills across different domains,
2. Assess the level of environmental complexity of an organization,
3. Match between individuals' systems thinking skills/preferences and environmental complexity,
4. Assess the actual behavior based on the systems thinking skills,
5. Investigate if there is a relationship between individuals' ST skills/preferences and the actual ST performance,
6. Identify the gaps between an individual's ST skills and employers' ST needs.
7. Suggest changes in policy, education, curriculum, and others based on the gap analysis

The current research, presented in this paper, mainly related to the first step of the long-term ST research. Moreover, the other steps are conducting or will be conducting in future studies.

References

Abbas, M., Sajid, S., & Mumtaz, S. (2018). Personal and Contextual Antecedents of Knowledge Sharing and Innovative Performance among Engineers. Engineering Management Journal, 1-11.

Ackoff, R. L. (1971). Towards a system of systems concepts. *Management Science*, Vol. 17, No. 11, pp. 661–672.

Ackoff, R. L. (1994). Systems thinking and thinking systems. *System Dynamics Review*, *10*(2-3), 175-188.

Ackoff, R. L. (1995). 'Whole-ing' the Parts and Righting the Wrongs. *Systems Research*, Vol. 12, No 1, pp. 43-46.

Aiken, L. S., & West, S. G. (1991). *Multiple regression: Testing and interpreting interactions.* Newbury Park, London, Sage.

Appelbaum, S. H. (1997). Socio-technical systems theory: an intervention strategy for organizational development. *Management decision*, *35*(6), 452-463.

Assaraf, O. B. Z., & Orion, N. (2005). Development of system thinking skills in the context of earth system education. *Journal of Research in Science Teaching*, 42(5), 518–560. https://doi.org/10.1002/tea.20061

Balkis, M., & Isiker, G. B. (2005). The Relationship Between Thinking Styles and PTs. *Social Behavior and Personality: An International Journal*, 33(3), 283–294. https://doi.org/10.2224/sbp.2005.33.3.283

Bawden, R. J., Macadam, R. D., Packham, R. J., & Valentine, I. (1984). Systems thinking and practices in the education of agriculturalists. *Agricultural Systems*, 13(4), 205–225. https://doi.org/10.1016/0308-521X(84)90074-X

Bentler, P. (1990). Comparative fit indices in structural models. *Psychological Bulletin*, 107(2), 238–246. https://doi.org/res

Betts, F. (1992). How systems thinking applies to education. *Educational Leadership*, 50(3), 38–41.

Boardman, J., & Sauser, B. (2006). System of Systems-the meaning off of. In System of Systems Engineering, 2006 IEEE/SMC International Conference on (pp. 6-pp). IEEE.

Bagozzi, R. P. & Yi, Y. (1988). On the Evaluation of Structural Equation Models. *Journal of the Academy of Marketing Science*, 16(1), 74-94.

Bollen, K. A., & Stine, R. (1990). Direct and indirect effects: Classical and bootstrap estimates of variability. *Sociological Methodology*, 20, 115–140.

Bradley, J. H., & Hebert, F. J. (1997). The effect of PT on team performance. *Journal of Management Development*, 16(5), 337–353. https://doi.org/10.1108/02621719710174525

Brambor, T., Clark, W. R., & Golder, M. (2006). Understanding interaction models: Improving empirical analyses. *Political Analysis*, 14(1), 63–82. https://doi.org/10.1093/pan/mpi014

Brown, K. W., & Moskowitz, D. S. (1998): Dynamic stability: The rhythms of our daily lives. *Journal of Personality*, 66, 105–134.

Buffinton, K. W., Jablokow, K. W., & Martin, K. A. (2002). Project team dynamics and cognitive style. *Engineering Management Journal*, 14(3), 25-33.

Bureš, V., & Čech, P. (2007). Complexity of ambient intelligence in managerial work. ITiCSE 2007: 12th Annual Conference on Innovation and Technology in Computer Science Education - Inclusive Education in Computer Science, 325. https://doi.org/10.1145/1268784.1268892

Byrne, B. M. (2010). *Structural equation modeling with AMOS: Basic concepts, applications, and programming*. Routledge (Vol. 22). https://doi.org/10.4324/9781410600219

Cable, D. M., & Judge, T. A. (2003). Managers' upward influence tactic strategies: The role of manager personality and supervisor leadership style. *Journal of Organizational Behavior*, 24(2), 197–214. https://doi.org/10.1002/job.183

Checkland, P. (1981). *Systems thinking, systems practice*.

Checkland, P. (1999). *Systems Thinking, Systems Practice*, John Wiley & Sons, New York.

Churchman, C. W. (1968). *The Systems Approach*. Dell Publishing, New York.

Churchman, C. W. (1971). *The Design of Inquiring Systems*. Basic Books, New York.

Churchman, C. W. (1979). *The systems approach and its enemies*. Basic Books.

Clegg, C. W. (2000). Sociotechnical principles for system design. *Applied Ergonomics*, *31*(5), 463-477.

Dawson, J. F. (2014). Moderation in management research: What, why, when and how. *Journal of Business and Psychology, 29, 1-19.*

Davidz, H. L., & Nightingale, D. J. (2008). Enabling systems thinking to accelerate the development of senior systems engineers. *Systems Engineering*, 11(1), 1-14.

DeLaurentis, D. (2005). Understanding transportation as a system-of-systems design problem. In 43rd AIAA Aerospace Sciences Meeting and Exhibit (p. 123).

Deming, W. E. (1982). *Out of the crisis*. Cambridge, MA: MIT Center for Advanced Educational Services.

Drucker, P. (1954). *The Practice of Management*. New York: Harper.

Drucker, P. (2012a). *Management*. Routledge.

Drucker, P. (2012b). *Managing in the next society*. Routledge.

Dolansky, M.A., & Moore, S. M. (2013). Quality and Safety Education for Nurses (QSEN)_ The Key is Systems Thinking. OJIN: The Online Journal of Issues in Nursing, 18(3), 1–12. https://doi.org/10.3912/OJIN.Vol18No03Man01

Dragoni, L., Oh, I. S., Vankatwyk, P., & Tesluk, P. E. (2011). Developing Executive Leaders: The Relative Contribution Of Cognitive Ability, Personality, And The Accumulation Of Work Experience In Predicting Strategic Thinking Competency. *Personnel Psychology*, 64(4), 829–864. https://doi.org/10.1111/j.1744-6570.2011.01229.x

Eisner, H. (2008). *Essentials of project and systems engineering management*. John Wiley & Sons.

Eppinger, S. D. (1991). Model-based approaches to managing concurrent engineering. *Journal of Engineering Design*, 2(4), 283–290. https://doi.org/10.1080/09544829108901686

Flood, R. L., & Carson, E. R. (2013). *Dealing with complexity: an introduction to the theory and application of systems science.* Springer Science & Business Media.

Frank, M. (2001). Engineering of complex systems for the future. *Engineering Management Journal*, 13(2), 25-32.

Frank, M. (2006). Knowledge, abilities, cognitive characteristics and behavioral competences of engineers with high capacity for engineering systems thinking (CEST). *Systems Engineering*, *9*(2), 91-103.

Frank, M., & Elata, D. (2005). Developing the capacity for engineering systems thinking (CEST) of freshman engineering students. *Systems Engineering*, *8*(2), 187-195.

Frank, M., & Kordova, S. (2009, April). Developing the capacity for engineering systems thinking (CEST) of senior engineering management students: Learning in a project-based learning (PBL) environment. In *Proceedings of the 7th Annual Conference on Systems Engineering Research*.

Freeman, J. B., Dale, R., & Farmer, T. A. (2011). Hand in motion reveals mind in motion. *Frontiers in Psychology*, 2, article 59.

Furnham, A. (1996). The big five versus the big four: The relationship between the Myers-Briggs Type Indicator (MBTI) and NEO-PI five-factor model of personality. *Personality and Individual Differences*, 21(2), 303–307. https://doi.org/10.1016/0191-8869(96)00033-5

Furnham, A., & Stringfield, P. (1993). Personality and work performance: Myers-Briggs type indicator correlates of managerial performance in two cultures. *Personality and Individual Differences*, 14(1), 145–153. https://doi.org/10.1016/0191-8869(93)90184-5

Gorod, A., Sauser, B., & Boardman, J. (2008). System-of-systems engineering management: A review of modern history and a path forward. *IEEE Systems Journal*, 2(4), 484-499.

Hair, J. F., Black, W. C., Babin, B. J., & Anderson, R. E. (2009). *Multivariate Data Analysis: A Global Perspective* (7th ed.). Upper Saddle River: Prentice Hall.

Hatcher, L. (1994). *A Step-by-Step Approach to Using the SAS System for Factor Analysis and Structural Equation Modeling*. Cary: SAS Institute.

Hossain, N. U. I., Jaradat, R. M., Hamilton, M. A., Keating, C. B., & Goerger, S. R. (2019a). A Historical Perspective on Development of Systems Engineering Discipline: A Review and Analysis. *Journal of Systems Science and Systems Engineering*, 1-35.

Hossain, N. U. I., Nagahi, M., Jaradat, R., & Keating, C. (2019b). Development of a new Instrument to Assess the Performance of Systems Engineers. In *Proceedings of the International Conference on Industrial Engineering and Operations Management*, Toronto, Canada, October 23-25, 2019.

.

Jaradat, R. M. (2015). Complex system governance requires systems thinking - how to find systems thinkers. *International Journal of System of Systems Engineering*, 6(1/2), 53. https://doi.org/10.1504/IJSSE.2015.068813

Jaradat, R. M., Keating, C. B., & Bradley, J. M. (2018). Individual capacity and organizational competency for systems thinking. *IEEE Systems Journal*, 12(2), 1203-1210.

Jaradat, R., Stirgus, E., Goerger, S. R., Buchanan, R. K., Ibne Hossain, N. U., Ma, J., & Burch, R. (2019). Assessment of Workforce Systems Preferences/Skills Based on Employment Domain. Engineering Management Journal, 1-13. DOI: 10.1080/10429247.2019.1672407

Kanfer, R., & Heggestad, E. D. (1997). Motivational traits and skills: A person-centered approach to work motivation. *Research in Organizational Behavior, vol 19*, 1-56.

Keating, C. B. (2008). Emergence in system of systems. *System of systems engineering: Innovations for the 21st century*, 169-190.

Katina, P. F., Keating, C. B., & Jaradat, R. M. (2014). System requirements engineering in complex situations. *Requirements Engineering*, 19(1), 45-62.

Keating, C., Rogers, R., Unal, R., Dryer, D., Sousa-Poza, A., Safford, R., Peterson, W., & Rabadi, G. (2003). System of systems engineering. *Engineering Management Journal*, 15(3), 36-45.

Keirsey, D., & Bates, M. M. (1984). *Please understand me.* Prometheus Nemesis.

Krumwiede, D. W., & Lavelle, J. P. (2000). The effect of top-manager personality on a total quality management environment. *Engineering Management Journal*, 12(2), 9-14.

Lawrence, JM., Hossain, N. U. I., Nagahi, M., & Jaradat, R. (2019). Impact of a Cloud-Based Applied Supply Chain Network Simulation Tool on Developing Systems Thinking Skills of Undergraduate Students. In *Proceedings of the International Conference on Industrial Engineering and Operations Management*, Toronto, Canada, October 23-25, 2019.

Linder, N. & Frakes, J. (2011). *A new path to understanding systems thinking.* The systems thinker. Retrieved from: https://thesystemsthinker.com/%EF%BB%BFa-new-path-to-understanding-systems-thinking/

McCaulley, M. H. (1990). *The Myers-Briggs Type Indicator and leadership*. Leadership Library of America.

Meyers, L. A., Pourbohloul, B., Newman, M. E. J., Skowronski, D. M., & Brunham, R. C. (2005). Network theory and SARS: Predicting outbreak diversity. *Journal of Theoretical Biology*, 232(1), 71–81. https://doi.org/10.1016/j.jtbi.2004.07.026

Mitroff, I. (1998). *Smart thinking for crazy times*, San Francisco, CA: Berrett-Koehler Publisher Inc.

Mumford, M. D., Zaccaro, S. J., Harding, F. D., Jacobs, T. O., & Fleishman, E. A. (2000). Leadership skills for a changing world: Solving complex social problems. *The Leadership Quarterly*, 11(1), 11-35.

Myers, I. B. (1962) *The Myers-Briggs Type Indicator: Manual*, Consulting Psychologists Press, Palo Alto, CA.

Myers, I. B. & McCaulley, M. H. (1985) *Manual: A Guide to the Development and Use of the Myers- Briggs Type Indicator*, Consulting Psychologists Press, Palo Alto, CA.

Nagahi, M., Hossain, N. U. I., Jaradat, R. & Grogan, S., (2019). Moderation effect of managerial experience on the level of systems-thinking skills. In proceeding of the 13th Annual IEEE International Systems Conference.

Porter, T. B. (2008). Managerial Applications of Corporate Social Responsibility and Systems Thinking for Achieving Sustainability Outcomes. *Systems Research and Behavioral Science*, 25(3), 397–411. https://doi.org/10.1002/sres

Quenk, N. L. (2009). *Essentials of Myers-Briggs type indicator assessment* (Vol. 66). John Wiley & Sons.

Richmond, B. (1993). Systems thinking: critical thinking skills for the 1990s and beyond. *System Dynamics Review* (Wiley), 9(2), 113–133. https://doi.org/10.1002/sdr.4260090203

Schmidt, R. C., & Richardson, M. J. (2008). Dynamics of interpersonal coordination. In A. Fuchs & V. Jirsa (Eds.), Coordination: Neural, behavioural and social dynamics (pp. 281–308). Heidelberg: Springer-Verlag.

Schneider, B., Smith, D. B., Taylor, S., & Fleenor, J. (1998). Personality and organizations: A test of the homogeneity of personality hypothesis. *Journal of Applied Psychology*, 83(3), 462–470. https://doi.org/10.1037/0021-9010.83.3.462

Schuldberg, D., & Gottlieb, J. (2002). Dynamics and correlates of microscopic changes in affect. *Nonlinear Dynamics, Psychology and Life Sciences*, 6, 231–257.

Senge, P. M. (1991). The fifth discipline, the art and practice of the learning organization. *Performance+ Instruction*, *30*(5), 37-37.

Senge, P. M. (2004). The leader's new work: Building learning organizations. *How Organizations Learn: Managing the search for knowledge*, 462-486.

Shrout, P. E., & Bolger, N. (2002). Mediation in experimental and nonexperimental studies: New procedures and recommendations. *Psychological Methods*, 7, 422–445.

Soleimani, N., Nagahi, M., Nagahisarchoghaei, M., & Jaradat, R. M. (2018). The Relationship between Personality Types and the Cognitive-Metacognitive Strategies.

Spivey, M. J. (2007). *The continuity of mind*. Oxford: Oxford University Press.

Steward, D. V. (1981). The design structure system: A method for managing the design of complex systems. *IEEE Transactions on Engineering Management*, EM-28(3), 71–74. https://doi.org/10.1109/TEM.1981.6448589

Stirgus, E., Nagahi, M., Ma, J., Jaradat, R., Strawderman, L., & Eakin, D., (2019). Determinants of systems thinking in college engineering students: research initiation. In *proceeding of the 126th Annual Conference & Exposition American Society for Engineering Education.*

Sweeney, L. B., & Sterman, J. D. (2000). Bathtub dynamics: initial results of a systems thinking inventory. *System Dynamics Review*, *16*(4), 249-286.

Tetlock, P. E., Peterson, R. S., & Berry, J. M. (1993). Flattering and unflattering personality portraits of integratively simple and complex managers. *Journal of Personality and Social Psychology*, 64(3), 500–511. https://doi.org/10.1037/0022-3514.64.3.500

Toshima, Y. (1993). Standardization of an integrated aptitude test for system engineers: Intellectual abilities and personality factors. *Japanese Psychological Research*, 35(4), 182–192.

Tucker, J. & Kroeger, O. (2010). Optimizing Myers-Briggs type indicator training: practical applications. Software Technology Support Center, pp. 22-25.

Vallacher, R. R., Read, S. J., & Nowak, A. (2002). The dynamical perspective in personality and social psychology. *Personality and Social Psychology Review*, 6, 264–273.

Warren, W. H. (2006). The dynamics of perception and action. *Psychological Review*, 113, 358–389.

Wasson, C. S. (2015). *System engineering analysis, design, and development: Concepts, principles, and practices*. John Wiley & Sons.

Wideman, R. M. (1998). Dominant personality traits suited to running projects successfully (and what type are you?). In Project Management Institute Seminar/Symposium, Long Beach, CA.

Williams, S. D. (2004). Personality, attitude, and leader influences on divergent thinking and creativity in organizations. *European Journal of Innovation Management*, 7(3), 187–204. https://doi.org/10.1108/14601060410549883

Williamson, J. M., Lounsbury, J. W., & Han, L. D. (2013). Key personality traits of engineers for innovation and technology development. *Journal of Engineering and Technology Management* - JET-M, 30(2), 157–168. https://doi.org/10.1016/j.jengtecman.2013.01.003

Zhang, L. F. (2000). Are Thinking Styles and PTs Related? *Educational Psychology*, 20(3), 271–283. https://doi.org/10.1080/713663742

Zhang, L. F. (2001). Thinking styles and PTs revisited. *Personality and Individual Differences*, 31(6), 883–894. https://doi.org/10.1016/S0191-8869(00)00189-6

Zhang, L. F. (2002). Measuring thinking styles in addition to measuring personality traits? *Personality and Individual Differences*, 33(3), 445–458. https://doi.org/10.1016/S0191-8869(01)00166-0

Zhao, H., & Seibert, S. E. (2006). The big five personality dimensions and entrepreneurial status: A meta-analytical review. *Journal of Applied Psychology*, 91(2), 259–271. https://doi.org/10.1037/0021-9010.91.2.259

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14. ABSTRACT
In this study, we used a structural equation modeling method to investigate the relationship between systems engineers and engineering managers' Systems-Thinking (ST) skills preferences and their Personality Traits (PTs) in the domain of complex system problems. As organizations operate in more and more turbulent and complex environments, it has become increasingly important to assess the ST skills preferences and PTs of engineers. The current literature lacks studies related to the impact of systems engineers and engineering managers' PTs on their ST skills preferences, and this study aims to address this gap. A total of 99 engineering managers and 104 systems engineers provided the data to test four hypotheses posed in this study. The results show that the PTs of systems engineers and engineering managers have a positive impact on their level of ST skills preferences and that the education level, the current occupation type, and the managerial experience of the systems engineers and engineering managers moderate the main relationship in the study.

15. SUBJECT TERMS
Systems-Thinking Skills Preferences, Myers-Briggs Type Indicator (MBTI), Complex Systems, Moderation Model, Structural Equation Modeling

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