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Systems Thinking as an Engineering Language

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Abstract Accelerated technological developments and the sharp rise in the complexity of systems have increased the importance of systems thinking - a field that deals with seeing the system as a whole and examining the processes that occur within it and its surrounding environment. Consequently, the more complex engineering systems become, the greater the need for systems engineers and managers with high levels of systems thinking - professionals capable of understanding the big picture, without having to break down the system into its separate components. The **research goal** of this study was to examine the degree of difference between the systems thinking capabilities of systems engineers and that of engineers from other fields. The study also explored the extent to which a correlation exists between the acquisition of engineering knowledge through practical work and systems thinking capabilities. Additionally, we examined the correlation between systems thinking capabilities and management capabilities. The study included quantitative and qualitative tools. The study population was comprised of 45 engineers from different fields, including systems engineers, software engineers, and mechanical engineers. The quantitative tool was a questionnaire that evaluated the engineers' systems thinking capability. The qualitative tool was comprised of semi-structured interviews conducted with different engineers from the systems engineering field, as well as engineers in managerial positions. Study findings revealed no significant differences between engineers' systems thinking capabilities and their engineering backgrounds. However, a significant difference was found between this capability and the engineers' current occupational fields. Engineers who deal with systems engineering were found to demonstrate a higher level of engineering systems thinking capability than engineers who deal with software, hardware, and sales. The results of the qualitative study show that systems engineers perceive systems thinking as a valuable tool that provides an overview of the entire project, helping to map the difficulties and risks likely to occur over time. Additionally, findings indicate that systems engineers demonstrate higher levels of creative thinking than engineers from other fields. The interviewees demonstrated how high systems thinking ability helps senior managers see the organization as a whole, manage employees, build long-term work programs, and adapt the company to future demands in the market.

Keywords Creative Thinking, Systems Engineering, Systems Thinking, Systems Thinking Skills

1. Introduction

According to Senge (1990) - Systems thinking is a field that deals with seeing the whole. Meaning, this is a field that perceives the system in its entirety, as well as the interaction among its different parts, and attempts to understand their inter-relationships and connections.

The study goal was to examine the extent to which a difference exists between the systems thinking capability of systems engineers and that of engineers from different backgrounds. The study also examined the extent to which a relationship exists between academic-practical engineering background and engineering systems thinking capability. Also, we examined the relationship between the engineer's systems thinking capability and managerial ability, as well as other advanced thinking skills.

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2. Research Questions

1. To what extent does engineering background influence systems thinking capability of engineers from different fields?
2. How is systems thinking perceived by engineers of different engineering fields?
3. To what extent does engineering background help resolve systems problems?
4. To what extent do differences exist between systems thinking of systems engineers to that of engineers from other fields?
5. To what extent do differences exist between creative thinking of systems engineers and that of engineers from other fields?
6. To what extent is there a correlation between engineering systems thinking and managerial ability among managers?

3. Literature Review

Systems thinking is more in demand than ever as we increasingly buckle under the burden of complexity and repercussions of the information explosion. Systems are becoming more and more divergent, complex, and dynamic.

Systems thinking is not a discipline with defines borders but rather comprises an interdisciplinary conceptual framework that can be adapted to an extensive range of areas. Several attempts to define systems thinking were made in areas in which it is used.

According to Forrester (1994), "systems thinking is coming to mean little more than thinking about systems, talking about systems, and acknowledging that systems are important. In other words, systems thinking implies a rather general and superficial awareness of systems" (p. 251). Nevertheless, in the past three decades, many explanations and definitions for this term have been offered.

Senge explained in his book *The Fifth Discipline: The Art and Practice of the Learning Organization* (1990) that systems thinking is "a discipline for seeing wholes. It is a framework for seeing interrelationships rather than things, for seeing patterns of change rather than static 'snapshots.' It is a set of general principles… It is also a set of specific tools and techniques" (p. 68). Several years later, Senge (1994) added that system thinking is "a way of thinking about, and a language for describing and understanding, the forces and interrelationships that shape the behavior of systems. This discipline helps us to see how to change systems more effectively and to act more in tune with the natural processes of the natural and economic world" (Senge et al., 1994, p. 6). Senge also described the method of breaking down a problem into components, apparently facilitating the handling of complex tasks and issues, but also often losing perception of the bigger picture.

Richmond (1994) suggested that systems thinking is "the art and science of making reliable inferences about behavior by developing an increasingly deep understanding of underlying structure" (p. 141). Subsequently, Richmond (2000) paraphrased the term *forest thinking* to clarify the concept of systems thinking, as a "view from 10,000 meters rather than focusing on local trees", and "considering how the system influences systems on the other side of the line and how these latter systems influence the former system" (p. 3). O'Connor and McDermott (1997) also argued that systems thinking means "seeing beyond what appear to be isolated and independent incidents to deeper patterns. You recognize connections between events, to better understand and influence them" (p. 7). Correspondingly, Gharajedaghi (1999) wrote that systems thinking is "the art of simplifying complexity. It is about seeing through chaos, managing interdependency, and understanding choice" (p. 283).

Sterman (2000) also considered systems thinking as a way of looking at systems, maintaining it constituted "the ability to see the world as a complex system, in which we understand that 'you can't just do one thing,' and that 'everything is connected to everything else'" (p. 4). However, in another context, Sterman saw systems thinking as the ability to act in a certain way: "…the art of systems thinking involves the ability to represent and assess dynamic complexity (e.g., behavior that arises from the interaction of a system's agents over time), both textually and graphically" (Sweeney & Sterman, 2000, p. 2). Hitchins (2007) has combined the systems perspective and the systems tools together: "…systems thinking is thinking, scientifically, about phenomena, events, situations, etc., from a system perspective, i.e., using systems methods, systems theory, and systems tools. Systems thinking, then, looks at wholes, and at parts of wholes in the context of their respective whole. It looks at wholes as open systems, interacting with other systems in their environment" (p. 17).

Squires and her colleagues (2011) claimed that systems thinking is the ability to think abstractly in order to: (1) incorporate multiple perspectives; (2) work within a space where the boundary or scope of problem or system may be "fuzzy"; (3) understand diverse operational contexts of the system; (4) identify inter- and intrarelationships and dependencies; (5) understand complex system behavior; and (6) most important of all, reliably predict the impact of change on the system.

Kapsali (2011) found that systems thinking methods provide the flexibility to manage innovativeness, complexity, and uncertainty in innovation projects more successfully.

The principles of systems thinking have evolved as a result of observing common holistic aspects of systems in diverse fields of endeavor. These principles are founded on an understanding that there are common relationships between systems in nature and in and amongst man-made systems that are useful to understand and exploit. Systems thinking, as an essential part of both systems science and systems engineering, is a major contributor in achieving a unification of disciplines in respect to systems (Lawson, 2010).

Monat and Gannon (2015a and b) concluded that Systems thinking is a perspective, a language, and a set of tools that can be used to address complex socio-economic issues. Specifically, Systems thinking is the opposite of linear thinking. It is a holistic approach to analysis that focuses on the way a system's constituent parts interrelate and how systems work over time and within the context of larger systems. Systems thinking recognizes that repeated events or patterns are derived from systemic structures which, in turn, are derived from mental models. It recognizes that behaviors derive from structure, it focuses on relationships rather than components, and it recognizes the principles of self-organization and emergence.

Systems thinking is the underpinning skill required for engaging in systems engineering. It is needed across the range of engineering disciplines. Systems thinking is radically different from the more common analytical or reductionist thinking typically employed by most engineers.

A general consensus exists among researchers regarding the importance of systems thinking as a tool to improve organizational performance. Despite this, its use is not developed enough in most organizations (Holmberg, 2000). The main reason for this is the limited number of tools existing in an organization that could increase the practical value of systems thinking. Neither has enough been done in the education system, in high schools and academic institutions, to examine the process by which this ability is acquired during the study period and to incorporate tools that could help in the development and evaluation of systems thinking (Kordova & Frank, 2010).

4. Systems Thinking Development

Relevant research literature also presents the ongoing argument on whether systems thinking ability is inherited (innate) or learned (acquired). For instance, Hitchins (2003) refers to systems thinking as an innate ability, stating that the human brain has the ability to see pattern-based similarities among disparate sets of information, which presumably emanate from its drive to reduce perceived entropy. Hitchins implied that some people are gifted in this respect. On the other hand, Davidz and Nightingale (2008) and Kasser (2011) found that systems thinking may be developed through experience, job rotation, education, and training. Well-designed and properly taught systems engineering courses may accelerate systems thinking development.

Haskins (2012) claimed that learned systems thinking is possible, but innate systems thinkers are more creative. Systems thinkers always begin by framing a situation within a context. They can find parallels between different contexts and apply prior experiences to new and unfamiliar situations.

Frank (2002; 2010) offered a course outline to develop systems thinking. In one of his studies, it was found that freshman engineering students may develop approaches and strategies related to systems thinking, though the extent of this development is individual. Frank (2010) found that systems thinking is most likely a combination of innate talent and acquired experience.

Frank and Kordova (2009) present an undergraduate course aimed at developing capacity for engineering systems thinking (CEST) through active learning in a project-based learning environment. Study findings showed that the final project contributed to the development of CEST among learners. Perhaps this is evidence that supports the notion that CEST may be improved and acquired through learning.

5. Methodology

The current study was based on a combination of quantitative and qualitative research methods. The study population included engineers from different fields, such as systems engineering, electronics engineering, software engineering and mechanical engineering.

The quantitative study included use of a questionnaire that examined systems thinking capability, distributed among 45 junior and senior engineers working in security companies and the high-tech industry. The qualitative study was based on seven semi-structured interviews with systems engineers and senior managers in the industry.

The questionnaire was based on several questionnaires and was comprised of 40 items. The subjects were asked to rank the extent to which they agreed or disagreed with the items on a scale of 1-5.

The interviews were based on a number of questions that examined the systems thinking aspect of managers in practice.

6. Validity and Reliability

Validity is the extent to which the tool represents the measured quantity. In this case, validity is the extent to which the questionnaire measures what it is supposed to measure. Two types of validity measures have been proposed to evaluate questionnaire validity: content validity and inter-judge validity.

The first type of validity was content validity, meaning the extent to which questionnaire items accurately represent the subject matter.

The questionnaire was comprised of items taken from three different questionnaires. Table 1 presents the source of each item of the questionnaire.

Table 1. Source of Questionnaire Items

Source	Item
Frank, M. (2010).	1,3,4,5,6,7,8,10,11,12,13, 14,15,20,23,26,34,36,39
Shaked, H., & Schechter, C. (2016).	2,16,17,18,19,21,24,25, 27,28,30,31,32,33,35,40
Davidz, H. L., & Nightingale, D. J. (2008).	9,22,29,33,37,38

The second type of validity was interjudge validity. The questionnaire was given to three experts from the field of systems thinking to assess the clarity and relevance of each questionnaire item for validity.

For each question, the judges were asked to provide a 1-5 score (Likert scale: 1 = not at all relevant to 5 = very relevant). The experts were also asked to comment on questionnaire content and structure. Following a review of answers and comments by the experts, several changes were made, including revisions related to the introduction and some of the questionnaire items.

Measurement reliability is represented in the extent to which it is accurate (Anastasi, 1988) and may be checked using several techniques. The first method in this study was interjudge reliability, whereby the questionnaire was sent to three experts from the field of systems thinking who were asked to evaluate item suitability and clarity.

For each question, the judges were asked to provide an answer ranging from 1-5 (Likert scale: 1 = not at all clear to 5 = very clear); a number of changes were made in the questionnaire in response to expert feedback, including revisions related to item formulation and version.

The second of the questionnaire's reliability tests was measured by calculating the Cronbach alpha coefficient. The result, as shown in Table 2 (0.954), was considerably higher than the minimum value stated as required in statistical literature.

This result shows that consistency exists in response to different questionnaire items.

Table 2. Cronbach's Alpha Coefficient

Reliability Statistics	
Cronbach's alpha	N of Items
.954	40

7. Data Analysis

Quantitative data analysis was performed using statistical software. Qualitatively, data from the interviews was recorded and summarized, after which a content analysis was performed on interviewee responses. Also, a triangulation process was carried out so that every finding presented here was found among three or more interviewees.

8. Study Findings

Findings of the Qualitative Study

As mentioned, the qualitative study was based on semi-structured interviews with systems engineers and senior managers in the industry. Interviews were recorded and summarized according to the main categories found among the different interviewee responses.

Interview Findings:

All findings presented here are based on a triangulation process, meaning they were found among three or more interviewees.

1. According to the findings, we can define *systems thinking* and its importance as follows: systems thinking helps professionals see the big picture, providing a broad perspective from different angles which perceives the system as a whole, with all its operations and complexities. This outlook allows for the accurate evaluation of project risks and dependencies by integrating technical and organizational knowledge, along with balancing financial considerations with client needs.
2. Regarding work experience gained from different projects: the majority of accumulated experience is in the areas of employee management and the ability to recruit workers to fulfill project goals, whilst meeting project targets and deadlines.

An additional aspect is *economic professionalization*, meaning improving evaluation of schedules and resources, and becoming better and more accurate over time. Moreover, all interviewees indicated that over time they gained professional experience as well as technical experience, which helped them in the future, mainly as managers.

3. Regarding the subject of *knowledge sharing*, most interviewees said they coped better when they shared professional knowledge with their colleagues. They stressed the importance of teamwork, stating that it provided inspiration and promoted creativity, bettering relations within the group, thus making it a faster and more efficient mode of work. Most respondents reported generally preferring teamwork, although some said that in certain situations (when time is not a factor and when relevant knowledge exists) they prefer to work alone, without being dependent on others, as this allows them professional freedom and enables them to overcome existing challenges.
4. Interviewees reported they were unfamiliar with special tools to encourage systems thinking and did not use them. Among all interviewees, brainstorming/staff meetings with the relevant technical people was the preferred way to solve problems during projects. Some interviewees said they send preliminary materials prior to meetings to facilitate productivity, as this allows people to come to the meeting armed with suggestions for possible solutions. Throughout meetings, the system is scrutinized "from above," then the particular details of various problems are discussed, questions are asked, and different ideas are proposed. These are also examined from several perspectives, with financial considerations, as well as relevant schedules and deadlines, all taken into account.
5. Interviewee responses indicate that engineering experience is considered of great importance from a professional viewpoint in relation to both theoretical and practical background. Most interviewees work in the engineering field in which they received their academic degree, and their theoretical foundation is well suited to their chosen areas of occupation. Furthermore, they mentioned that practical experience acquired while serving in junior positions as they progressed in their managerial careers allowed them to become familiar with all relevant aspects related to evaluating and managing projects.
6. The managerial involvement required during a project focuses mainly on managing employees and the budget (flow of funds) and adhering to project schedules and deadlines.
7. Regarding whether systems thinking can be learned, most interviewees stated that systems thinking should be part of formal engineering training. They also expressed the opinion that engineers fresh from their academic studies have a narrow perspective, and often fail to see the organizational, economic, and business aspects of a project, as they are overly focused on their own niche. They claim that this kind of training

(learning systems thinking) will encourage "out of the box" thinking and provide an opportunity to examine situations from different points of view. On the other hand, most interviewees said they doubted that a course or two given in the academic framework could really make a significant difference.

Findings of the Quantitative Study

The tool used in the quantitative study was a questionnaire that included items on systems thinking, and managerial skills.

Descriptive Statistics

The sample was comprised of 45 respondents from the 120 people given the questionnaire. Most of the respondents completed a degree in electrical engineering and electronics (64.4%); the rest completed their studies in other engineering tracks: software, mechanical, industrial engineering and management, and bio-medical.

Table 4 shows respondents' current fields of employment. The sample included 15 systems engineers (33.3%), 10 project managers (22.2%), 9 software engineers (20%), 5 hardware engineers (11.1%), and mechanical engineers/engineers who deal with sales (total: 13.4%).

Tables 5 and 6 present the A1-A4 variables, computed to perform the statistical analysis. The variables are management skills, systems thinking, creativity and academic and professional background. Each computed variable is the average of the results received from the relevant items (as illustrated in Table 5). The calculated average ranges from 1 to 5.

Table 3. Engineering Background of Respondents

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Electrical & Electronics Eng.	29	64.4	64.4	64.4
	Software	7	15.6	15.6	80.0
	Industrial Eng. & Management	3	6.7	6.7	86.7
	Mechanical Eng.	4	8.9	8.9	95.6
	Bio-Medical Eng.	2	4.4	4.4	100.0
	Total	45	100.0	100.0	

Table 4. Respondents' Distribution According to Job/Position

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Project Management	10	22.2	22.2	22.2
	Software	9	20.0	20.0	42.2
	Hardware	5	11.1	11.1	53.3
	Mechanical Eng.	3	6.7	6.7	60.0
	Systems Engineering	15	33.3	33.3	93.3
	Sales	3	6.7	6.7	100.0
	Total	45	100.0	100.0	

Table 5. Computed Variables

Computed variable	Items	Aspect
A1	2,18,20,21,22,25,36,37	Management skills
A2	1,3,5-7,10-14,19,23,24,26,21,30,33-35	Systems thinking
A3	4,8,9,27,29,31,38-40	Creativity
A4	15,16,17,28,32	Academic and professional background

Table 6. Average Scores of Computed Variables

	M	*SD*	N
A1	3.9500	.66058	45
A2	3.8123	.70036	45
A3	3.5160	.66293	45
A4	3.7511	.58799	45

Inferential Statistics

Research Question 1

To examine significant differences in systems thinking capability among groups with a different engineering background, a one-way ANOVA (analysis of variance) test was carried out. The independent variable was *engineering background,* and the dependent variable was *average responses to items examining systems thinking capability* (A2).

The results of the test are displayed in Tables 7 and 8.

The results of the ANOVA test indicated that no significant difference was found in engineers' systems thinking capability in relation to their engineering background (Sig = 0.296).

In contrast, a significant difference was found in engineers' systems thinking capability in relation to their different current job positions (Sig = o.ooo). The independent variable was *occupational field*, while the dependent variable was *average responses for statements examining the systems thinking capability* (A2). Results of the test are displayed in Tables 9-10 and in Figure 1.

Table 7. Descriptive Statistics of A2 Variable According to Engineering Background

	N	*M*	*SD*	*SE*	95% Confidence Interval for Mean		Min	Max
					Lower Bound	Upper Bound		
Electrical & Electronics Eng.	29	3.9540	.70961	.13177	3.6841	4.2239	2.50	5.00
Software	7	3.5556	.71650	.27081	2.8929	4.2182	2.78	4.89
Industrial Eng. & Management	3	3.8333	.89408	.51620	1.6123	6.0544	3.11	4.83
Mechanical Eng.	4	3.6111	.07857	.03928	3.4861	3.7361	3.56	3.72
Bio-Medical Eng.	2	3.0278	.58926	.41667	-2.2665	8.3220	2.61	3.44
Total	45	3.8123	.70036	.10440	3.6019	4.0228	2.50	5.00

Table 8. Results of ANOVA (A2 variable in relation to engineering background)

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2.438	4	.610	1.274	.296
Within Groups	19.144	40	.479		
Total	21.582	44			

Table 9. Descriptive Statistics of A2 Variable by Occupational Field

	N	*M*	*SD*	SE	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Project Management	10	3.9278	.63075	.19946	3.4766	4.3790	3.39	4.89
Software	9	3.2840	.43607	.14536	2.9488	3.6191	2.61	3.89
Hardware	5	3.2333	.49907	.22319	2.6137	3.8530	2.50	3.67
Mechanical Eng.	3	3.6296	.08486	.04900	3.4188	3.8404	3.56	3.72
Systems Engineering	15	4.4111	.53154	.13724	4.1168	4.7055	3.11	5.00
Sales	3	3.1667	.48113	.27778	1.9715	4.3618	2.61	3.44
Total	45	3.8123	.70036	.10440	3.6019	4.0228	2.50	5.00

Table 10. The results of the ANOVA (A2 variable by the occupational field)

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	11.051	5	2.210	8.185	.000
Within Groups	10.531	39	.270		
Total	21.582	44			

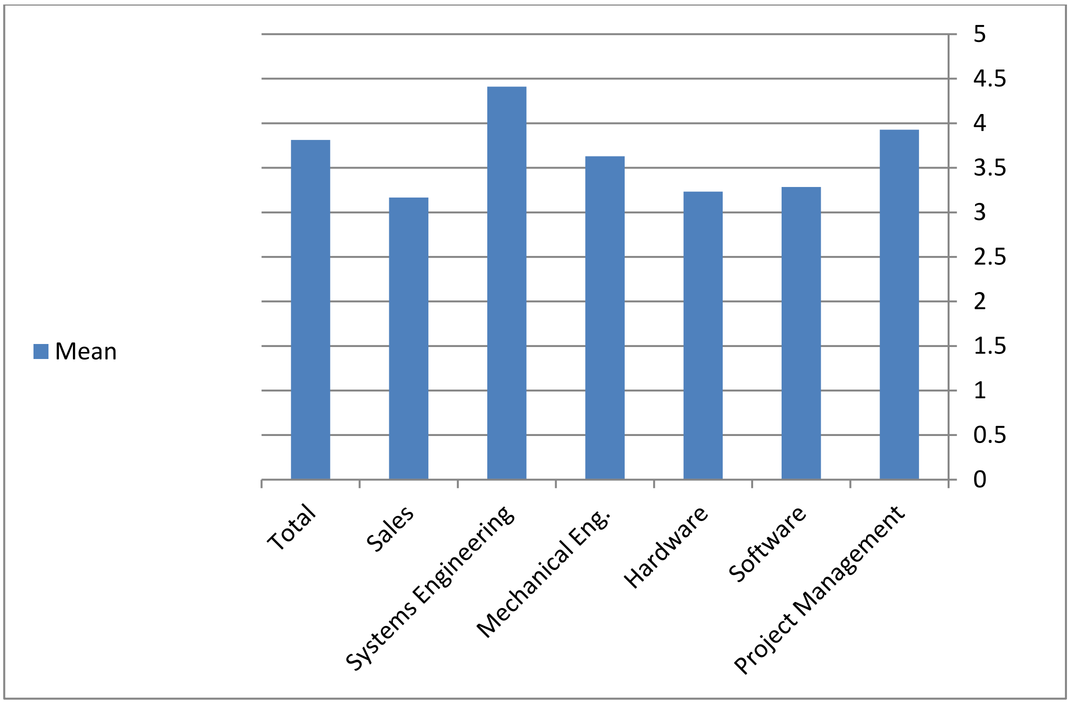

Figure 1. Average Score of Systems Thinking Capability (A2) by Occupational Field

As results of the one-way ANOVA tests describe only whether there is a difference among engineers' systems thinking capability in relation to the engineering field in which they currently work, but do not present the source of the difference, post-hoc Bonferroni and Tukey tests were also performed.

In the post-hoc Tukey test, a significant difference was found between systems thinking capability of engineers who work in systems engineering (average 4.41, s.d. 0.53) compared to that of software engineers (average 3.28, s.d. 0.44, $p<.001$), hardware engineers (average 3.23, s.d. 0.5, $p<.001$), and engineers working in sales (average 3.1667, s.d., 0.48, $p<.006$).

Significant changes were also found in the post-hoc Bonferroni test between systems thinking capability of engineers currently working in systems engineering and that of engineers working in the software, hardware, and mechanical engineering fields.

Research Question 4

The research question examined the extent to which differences exist between systems thinking capacity of systems engineers and that of engineers from other fields. The study hypothesis proposed that systems engineers have a higher level of systems thinking than engineers from other fields. The hypothesis was examined using an independent samples *t*-test between the average score of systems thinking capability (A2) of engineers from two groups: systems engineering and other engineering fields.

The results are presented in Tables 11 and 12.

Table 12 shows that Levene's Test for Equality of Variances is not significant (Sig = 0.624), so we used the *t*-test result reported on the first row. A significant different was found between systems thinking capability of systems engineers [M = 4.42, Sd.= 0.54] and that of engineers from other fields [M =3.52, Sd.= 0.58] [$t(43) = 5.066$ $p<.000$].

Research Question 5

The study question examined the extent to which differences exist in additional thinking skills, such as creative thinking. The study hypothesis proposed that systems engineers will demonstrate a higher level of additional advanced thinking skills compared to engineers from other fields. The hypothesis was examined using an independent samples *t*-test between the average score of creative thinking (variable A3) of two engineer groups: systems engineering and other engineering fields. The results are presented in Tables 13-14.

Table 14 shows that Levene's Test for Equality of Variances is not significant (Sig = 0.478), so we used the *t*-test result reported on the first row. A significant difference was found between the average score of creative thinking of systems engineers [M = 3.97, Sd. = 0.61] and that of engineers from other fields [M = 3.29, Sd. = 0.58] [$t(43) = 3.531$ $p<.001$].

Table 11. Average Score of Systems Thinking among Systems Engineers and Other Engineering Fields

Group Statistics

	System Eng. vs. all	N	*M*	*SD*	*SEM*
A2	1.00	15	4.4111	.53154	.13724
	.00	30	3.5130	.57415	.10482

Table 12. T- Test Results

		Levene's Test for Equality of Variances		*t*-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	*SED*	95% Confidence Interval of the Difference	
									Lower	Upper
A2	Equal variances assumed	.244	.624	5.066	43	.000	.89815	.17729	.54061	1.25568
	Equal variances not assumed			5.201	30.146	.000	.89815	.17270	.54553	1.25077

Table 13. Average Creative Thinking Scores among Systems Engineers and Other Engineering Fields

Group Statistics

	System Eng vs. all	N	*M*	*SD*	*SEM*
A3	1.00	15	3.9556	.61550	.15892
	.00	30	3.2963	.57796	.10552

Table 14. Results of t-test

Independent Samples Test

		Levene's Test for Equality of Variances		*t*-test for Equality of Means						
		F	Sig.	*t*	df	Sig. (2-tailed)	Mean Difference	*SED*	95% Confidence Interval of the Difference	
									Lower	Upper
A3	Equal variances assumed	.511	.478	3.531	43	.001	.65926	.18672	.28271	1.03581
	Equal variances not assumed			3.456	26.572	.002	.65926	.19076	.26755	1.05097

Research Question 6

To evaluate the extent to which a correlation exists between systems thinking capability and managerial skills among engineers, we examined the correlation between systems thinking capability (A2) and management skills (A1). The results are presented in Table 15.

Findings indicate a significant, strong, and positive correlation [r(45) = 0.836, p<.000] exists between systems thinking capability and management skills. Thus, we can conclude that the better one's systems thinking capability, the higher his/her managerial skills.

Table 15. Pearson Correlation - Systems Thinking Capability and Management Skills

Correlations

		A1	A2
A1	Pearson Correlation	1	0.836**
	Sig. (2-tailed)		.000
	N	45	45
A2	Pearson Correlation	0.836**	1
	Sig. (2-tailed)	.000	
	N	45	45

**. Correlation is significant at the 0.01 level (2-tailed).

9. Summary of Quantitative and Qualitative Findings

1. To what extent does engineering background affect the systems thinking capability of engineers from different fields?

The results indicated that no significant difference was found in systems thinking capability among reported respondent engineering background.

In contrast, upon examining systems thinking capability in relation to *engineers' current field of employment,* a significant difference was found between the groups. The post hoc tests revealed significant differences between systems thinking capability of systems engineers compared to this capacity among engineers in the fields of software, hardware, and sales.

2. How is systems thinking perceived by managers working in different engineering fields?

According to interview findings, systems thinking is perceived as an essential tool, enabling an overview of a project or system to map out the difficulties and risks that may arise over time. Systems thinking allows for responses in real time, in the most efficient manner possible, which leads to the desired outcome. The interviewees defined systems thinking as follows: the ability to see the big picture, a broad perspective, seeing the entire system from various angles, with all its operations and complexities. This type of perspective enables the assessment of project risks and dependencies. Systems thinking also integrates technical and organizational knowledge, as well as economic considerations, while also taking client needs into account.

In defining systems thinking, interviewees who were senior managers strongly emphasized the needs of both the client and the organization, as well as economic aspects of work; less senior interviewees focused on a more technical outlook, which examines the project or system and its current risks.

3. To what extent does engineering background help in solving systems-related problems?

According to interview findings, *engineering background* was of great importance from a professional perspective. Most interviewees work in the engineering field in which they received their academic degree; therefore, their theoretical foundation was well suited to their chosen areas of occupation.

The interviewees noted that *practical experience* was also of great importance, claiming it contributed to their general understanding and allowed them to correctly assess the meanings of engineering work when managing projects - from both an economic perspective and regarding the necessary resources needed to execute a task successfully.

Some of the interviewees claimed their engineering background provided an advantage in finding a solution to complex problems in certain circumstances. Combining a high technical ability with a comprehensive perspective made it possible to examine different solutions, understand the extent of their influence on system behavior, and identify various system interfaces. All of the above were perceived as advantageous when coping with organizational problems. On the managerial level, *engineering background* mainly influenced managers' technical abilities, providing excellent technical foundation and better assessment capabilities. Additionally, an extensive engineering background helped respondents come up with alternative ideas for the projects they were presented with. The interviewees also mentioned that as they climbed the managerial ladder, technical aspects of the job became less critical, and rich professional experience enabled the development of new abilities relevant to their managerial position.

Regarding problem coping, most of the engineers said they coped better when sharing professional knowledge with colleagues. They stressed the importance of teamwork, as it was inspirational, and improved creativity as well as work relations among team members. Teamwork was also perceived as a factor that facilitates speed and efficiency; respondents said that most of the time they would choose to work in a team.

4. To what extent do differences exist between the systems thinking capability of systems engineers and engineers from other fields?

Study findings support the hypothesis proposing that systems engineers have a higher level of systems thinking capability compared to engineers from other fields, as a significant difference was found in this capacity between systems thinking and other engineer groups.

5. To what extent do differences exist between creative thinking of systems engineers and that of engineers from other fields?

Qualitative study findings showed that systems thinking is perceived by interviewees as the ability to examine a problem from different points of view and create an original solution or diagnosis that satisfies all constraints. For example, this kind of thinking often provides an optimal solution that answers all the client's professional demands within budget limitations.

According to the interviewees, a *creative solution* is one that allows for the integration of existing and financially inexpensive systems, so that their integration creates one system with improved performance, higher systematic redundancy, availability, and competitiveness. Some interviewees mentioned *holistic thinking*. According to Kasser (2010), *holistic thinking* is defined as the integrations of analysis, systems thinking and critical thinking.

Kasser (2010) maintained that *analysis* is the examination of system details and components as parts of the whole (the system) and understanding their potential functions within the system. The interviewees claimed that during the brainstorming process, and also when trying to find a solution for a systems problem, they look at the problem from a bird's-eye view, while also addressing the system's small details. In their opinion, scrutinizing the small details of a system while still perceiving it as a whole is of paramount importance. The interviewees reported that when confronted with a problem, they first invest in self-thinking and traditional, initial planning. Next, they brainstorm with their team, during which they ask members questions and get additional ideas that aid them in the decision-making process. In the final stage, they carry out an assessment process, which combines a broad perspective and attention to small details. The interviewees said they utilized their engineering background and occupational experience accumulated over the years to create the most optimal system, from both a technical and economic perspective.

Quantitative study findings indicate a significant difference between average score of creative thinking of systems engineers to that of engineers from other fields.

6. To what extent is there a correlation between engineering systems thinking and managerial ability among managers?

Study findings show that higher level of systems thinking capability correlates to higher levels of managerial skills.

10. Discussion and Conclusions

The current study presents systems thinking aspects and an examination of correlations between systems thinking and other types of thinking, such as creative thinking and managerial skills. The study included a combination of quantitative and qualitative tools.

It is noteworthy that research results relied on respondent answers; however, no attempts were made to examine whether these capabilities actually exist in practice. Therefore, study findings relate only to perceived capability of systems thinking, as provided by interview and questionnaire findings. Evaluation of systems thinking capability in practice is likely to prove complicated, and there is a need for further research and future studies in this field.

According to Edson (2008), systems thinking may be perceived as an overview of the system, with the system constituting more than the sum of its parts, and the interactions among its interfaces influencing its operation. According to Wigal (2004), the goal of systems thinking is to translate the entire system into data, including its surrounding environment, goals, and ways in which those goals are supported by system components. Monat (2015) claims that systems thinking provides a great deal of power and value. It can be used to solve complex problems that are not solvable using conventional reductionist thinking, because it focuses on the relationships among system components, as well as on the components themselves; those relationships often dominate system performance.

Interview findings in this current study support this description, demonstrating that systems thinking is perceived as an essential tool, enabling engineers to see and examine each project or system from above and map potential risks and difficulties. This enables optimal and immediate responses, leading to desired outcomes.

The interviewees, all engineers from different fields, defined systems thinking similarly to examples found in research literature: as a framework, a broad perspective that perceives the system as a whole from different angles, including its various activities and components. According to the interviewees, systems thinking helps to assess project risks and dependencies, integrates technical and organizational knowledge, and balances economic considerations with client needs.

In addition, upon examining the senior managers' interview responses, it was found that a similarity exists between their implementation of systems thinking capabilities in the workplace and the following characteristics proposed by Frank (2000): **Seeing the whole, cause and result –** the understanding that every action may influence the whole. **Seeing the system from different points of view –** not just the engineering perspective. **Managerial capability –** from the organizational and economic perspectives and relying upon technology. **Implementing changes in the system –** the ability to predict and list the consequences of changes. **Problem solving –** the ability to weigh all alternative solutions and choose the optimal solution for each client. **The ability to acquire and utilize multidisciplinary and interdisciplinary knowledge –** identifying and implementing different disciplines and drawing conclusions using available information.

Analyzing system needs and the demands of the involved parties – the market demands together with the technological reality. These characteristics were mentioned in senior engineer/manager interview responses. They mentioned clients and their needs, the organization and its needs, and the financial aspect, which must also be an inseparable part of the engineer's decision-making process at every stage of the project. They also indicated the need to intelligently plan strategic projects, identify future market trends, and create a multiyear plan to satisfy changing client demands.

Most interviewees worked in the engineering field in which they received their academic degree, and their theoretical foundation was well suited to their chosen areas of occupation. The interviewees pointed out the importance of practical experience, saying it contributed to their ability to understand and correctly evaluate the meaning of engineering work whilst managing projects from both an economic perspective and as regards to mapping the necessary resources required to carry out tasks.

Some interviewees claimed their engineering background was an advantage in providing an overview and examining different interfaces entailed in projects. Regarding the managerial aspect, findings indicated *engineering background* mainly influenced managers' technical abilities, meaning managers with a technical background demonstrate better evaluation capabilities, as well as the ability to come up with alternative ideas for projects beyond those presented to him. Furthermore, study interviewees claimed that the higher you advance up the managerial ladder, the less important the job's technical aspects; managerial responsibilities necessarily entailed manage engineering disciplines other your own. They further maintained that engineering background and practical experience influenced their project management abilities. All of the above enabled managers to correctly assess the demands, costs, and repercussions of introducing engineering changes into the system and helped them stabilize economic aspects of the project.

The majority of interviewees reported they coped better with systems problems when sharing their professional knowledge with colleagues. They stressed the importance of teamwork, stating it provided an inspiring and creative dimension, improving relations within the work group, and generally streamlining and accelerating work. They also they generally prefer working in a team.

Frank (2006) presented the main characteristics of successful systems engineers, claiming that one of the crucial advanced thinking skills of successful systems engineers is *the ability to see and understand the system as a whole – without losing sight of the finer details*. Frank (2006) examined the cognitive characteristics, personal abilities, and behavioral characteristics in his investigation of the traits required of successful systems engineers. In the current study, we incorporated some of the statements used in Frank's (2010) questionnaire and found that a significant difference exists between the systems thinking capability of systems engineers and that of engineers from other fields. This study supports Frank's claim (2006) that systems engineers are imbued with different cognitive and personal characteristics than engineers in other fields, and from here stems their tendency towards systems thinking.

Current study findings regarding the existence of creative thinking skills among systems engineers were found to be in line with Kasser (2010), who presented thinking that combines analysis, systems thinking, and critical thinking. Kasser claimed *analysis* is accomplished by examining system details and components by understanding that they are part of the whole (the system) and recognizing their potential functions within it. This process was described similarly by most interviewees in the current study, who described the brainstorming process as a way to solve complex and multidimensional problems.

Interviewees added the imperative of examining the system's small details by looking at the system as a whole. This description illustrates Kasser's (2010) definition of analysis and systems thinking in practice. *Critical thinking* is a unique type of decisive attitude in which the thinker dictates criteria and standards for the activity of thinking and evaluates it accordingly. Interviewees described similar thinking processes when they invest an effort in independent thinking to solve system problems, after which they ask questions and offer ideas through brainstorming. An analysis of the interviews shows that interviewees implemented critical thinking when planning the system according to defined criteria. The use of engineering knowledge and professional experience helped create the optimal system from a technical and economic perspective. According to the definition that arises from these interviews, *systems thinking* is a framework of thought that simultaneously grasps client needs, professional requirements, available budget, and organizational needs. Current study findings show that systems engineers have the added advantages of holistic and creative thinking compared to engineers of other fields.

Frank's (2006) study findings showed that systems engineers with high systems thinking capabilities also demonstrate high managerial capabilities, such as the ability to be a team leader, plan and supervise work plans, define project boundaries, address non-engineering considerations, and display high interpersonal skills, an entrepreneurial sense and originality, as well as high learning ability.

In the quantitative part of the study, we examined the correlation between the capacity of systems thinking (A2) and management skills (A1). Quantitative outcomes study show that a positive significant and intense correlation exists between systems thinking capability and management skills [$r(45) = 0.836$, $p<.000$], thereby supporting results of previous studies.

Qualitative findings also demonstrated that systems engineers in senior managerial positions excel at managing employees, leading teams, showing initiation and organizational learning, and providing creative solutions for systems problems.

Engineers with particular personal characteristics can acquire or improve their systems thinking capability; this is a gradual, long-term process, achieved through proper training, by holding different job positions over various periods of time, and by building up a broad area of responsibility and expertise over time. Experiencing a wide array of relevant occupational positions means exposure to and becoming familiar with numerous systems and technologies. This leads to the acquisition of multidisciplinary experience, learning from the experience of others, and contact with engineers with systems thinking abilities.

As a continuation of the current study, it was decided to examine the extent to which it is possible to develop systems thinking capability through engaging a designated course, designed at presenting the foundations and necessary tools of systems thinking.

Summary

This study examined the systems thinking capability of engineers from different engineering backgrounds. The question of *how systems thinking is perceived* by these engineers was also examined, along with whether they use and are aided by this type of thinking at work. In addition, we focused on whether engineers with high systems thinking capability have other advanced thinking capabilities, such as creative thinking. In order to more closely examine systems thinking capability, its related perceptions and daily use as well as other thinking capabilities, we conducted a mixed methods study, including both a qualitative and a quantitative study.

The qualitative study included semi-structured interviews with systems engineers and senior managers/engineers from the industry. In the quantitative study, we used a questionnaire based on statements from previous studies on systems thinking; the statements in our questionnaire were congruent with the research questions. The questionnaire was distributed among different types of engineers in the high-tech industry and the security industry. The conclusions of the quantitative and qualitative studies were as follows: no significant difference was found between engineers' systems thinking capability in relation to their different engineering backgrounds. Contrastingly, a significant difference was found between engineers' systems thinking capability and their current occupational field. Study results reveal that systems engineers have higher systems thinking capability compared to that of engineers in the fields of software, hardware, and sales.

Next, we examined how systems thinking is perceived by engineers in different occupational fields. Most said they perceived systems thinking as an essential tool, helping them to comprehensively see and examine each project or system, map difficulties and risks likely to occur over time, and respond in real time in the best possible way, leading to the desired outcomes. Most engineers noted during interviews that professional experience was of great importance in the ability to manage systems and projects holistically.

Results of the quantitative study also indicated that a strong positive correlation exists between systems thinking capability and managerial skills. Further reinforcement of this finding is found in the interviews conducted with engineers who hold senior managerial positions, illustrating how systems thinking capability helps their general outlook, including dealing with the organization, managing employees, creating multiyear work plans, and adapting the organization to future client needs.

It is necessary to carry out additional research to further strengthen current study findings, including senior engineers and managers in general, and systems engineers in particular, all of whom deal with diverse projects in various industries. It is also noteworthy that the current study is based solely on respondent self-response statements; systems thinking *capability* in practice was not examined at all. To increase the validity of findings, other evaluation tools must be used, such as supervisor evaluation, colleague evaluation, and the analysis of engineers' problem-solving methods when coping with systems problems.

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