21st ANNUAL INCOSE INTERNATIONAL SYMPOSIUM

Engineering Systems Thinking and Project Success

Moti Frank – HIT, Holon Institute of Technology, Israel
Arik Sadeh – HIT, Holon Institute of Technology, Israel
Sharon Ashkenazi – IMI, Israel Military Industries

Introduction: The Problem

- According to the Standish Group Report (2009), 68% of all projects failed:

  - 44% of the projects were late, over planned budget, and/or had less than the required features and functions.

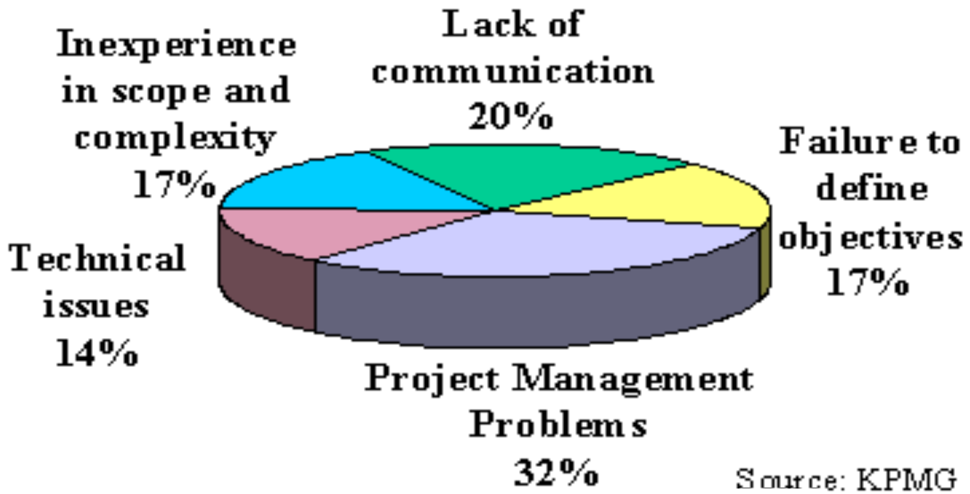
  - 24 % were cancelled prior to completion or delivered and never used.

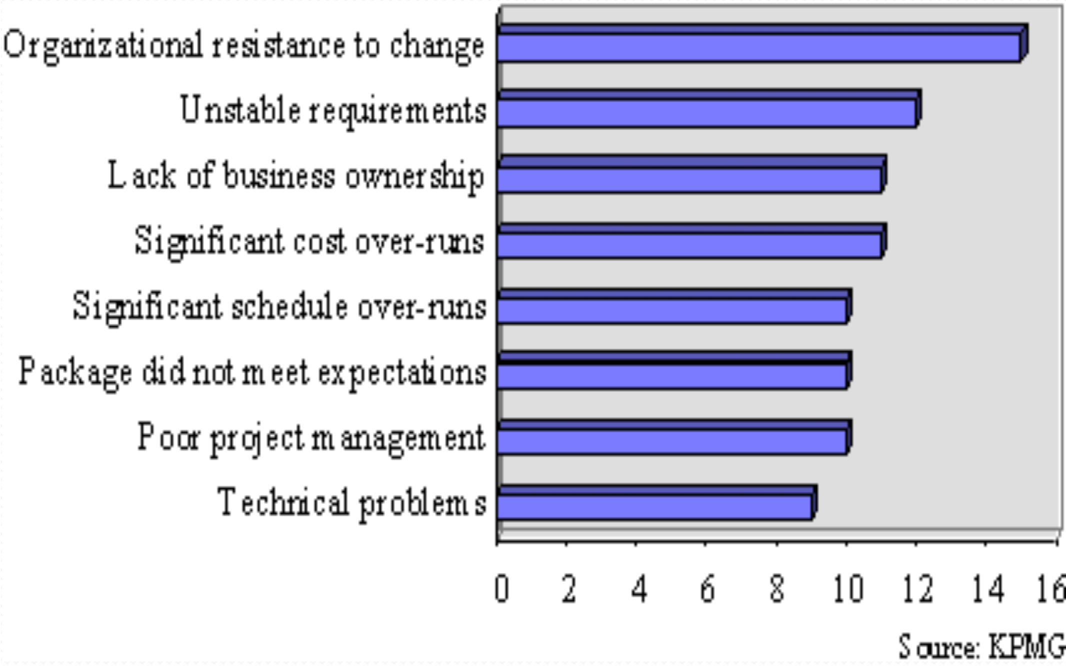
Note: There was some increase in project success rate in 2010.

How Come?

- The systems engineering and project management bodies of knowledge have experienced rapid growth in recent years.
- A huge number of scholarly books and papers have been published, many tools are offered by various vendors, and an impressive number of conferences related to PM and SE are held every year.
- Yet, despite the vast amount of literature available, about two-thirds of all projects still fail.

Why Projects Fail?





What causes projects to fail?

- In a survey conducted among 256 UK companies:
  - 32 percent - poor project management
  - 20 percent - lack of communication
  - 17 percent - failure to properly define objectives and requirements
  - 17 percent - unfamiliar project scope or complexity
  - 14 percent - inability to cope with new technology
- According to another survey:
  - The main reasons for project failure were incorrect requirements, insufficient planning, poor risk mitigation, and use of incorrect technical solutions.
- Another study: the top five reasons for IT project failure were lack of user support and involvement, lack of properly defined project scope, lack of executive management support and commitment, imprecisely defined objectives, and poor project management and leadership.

What causes projects to fail?

- We focus here on another reason:

Lack of engineers with a high capacity for engineering systems thinking (CEST)

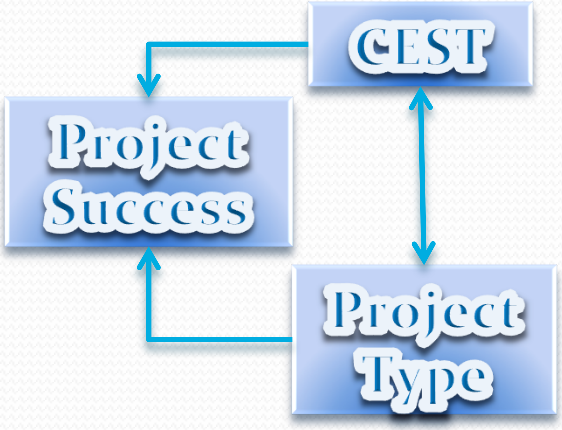
"**Systems Thinking** is what makes Systems Engineering different from other kinds of engineering" . "**Systems Thinking** is the underpinning skill required to do Systems Engineering" (Beasley & Partridge, 2011; and many others).

The Goal of the Study

The study aimed at exploring the relationship between (1) systems engineers' capacity for engineering systems thinking (CEST), (2) project success and (3) project type.

Let me now explain what do I mean by:

- CEST
- Project success
- Project type



The study aimed at exploring the relationship between (1**) systems engineers' capacity for engineering systems thinking (CEST)**, (2) project success and (3) project type.

1. CEST

Engineering Systems Thinking

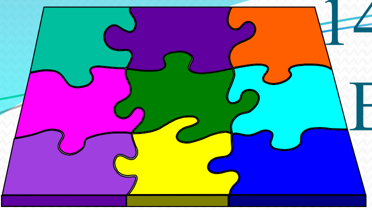
- *Systems thinking* is a discipline for seeing wholes (Senge, 1994).
- Systems thinking means different things to different people.
- *Engineering Systems Thinking* is a major high-order thinking skill that enables individuals to successfully perform systems engineering tasks.
- To successfully perform systems engineering roles, systems engineers need a systems view or a high **C**apacity for **E**ngineering **S**ystems **T**hinking (CEST).
- It was found that this ability is a consistent personality trait, and that it can be used to distinguish between individual engineers.

Competencies of Successful Systems Engineers

- A prior study has identified 83 competencies of successful systems engineers (Frank, 2002).

- Later, the 83 competencies have been aggregated into 35 competencies of successful systems engineers (Frank, 2006).

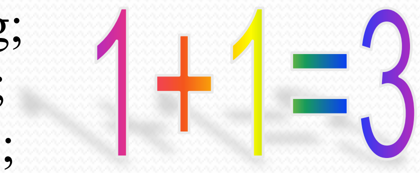
- They have been classified as follows:
  - **14 cognitive competencies**
  - 11 abilities/skills
  - 7 individual traits (behavioral competencies)
  - 3 dealing with multidisciplinary knowledge and experience

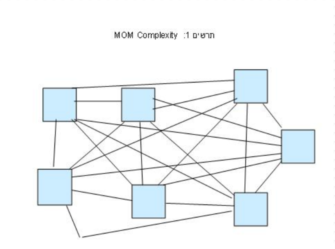


14 Cognitive Competencies of Successful Systems Engineers: All are Related to **Systems Thinking**

Successful systems engineers:

1. understand the whole system and see the big picture;
2. understand interconnections; closed-loop thinking;
3. understand system synergy (emergent properties);
4. understand the system from multiple perspectives;
5. think creatively;
6. understand systems without getting stuck on details; tolerance for ambiguity and uncertainty;
7. understand the implications of proposed change;
8. understand a new system/concept immediately upon presentation;
9. understand analogies and parallelism between systems;
10. understand limits to growth;
11. ask good (the right) questions;
12. (are) innovators, originators, promoters, initiators, curious.
13. are able to define boundaries;
14. are able to take into consideration non-engineering factors.



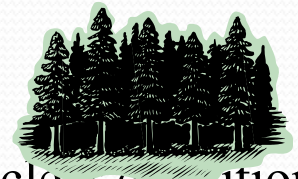


Example: No. 6

- <u>Understanding Systems without Getting Stuck on Details; Forest Thinking</u>
  - Able to conceptually and functionally understand the system, even without first understanding all its details.
  - avoid getting snagged by the details.
  - Able to understand the whole/overall picture and continue to act without understanding fully all of the system's details.
  - Not knowing all the details does not disturb them or hinder their efforts to solve a systems problem.

.

- Tolerance for Ambiguity and Uncertainty



  - Feel comfortable with ambiguity and working in unclear conditions and in an uncertain environment.

Assessing Systems Thinking in Engineers

Assessing CEST (Capacity for Engineering Systems Thinking)

- There is no known way for directly measuring the Systems Thinking skill of individuals.

- The will/desire and the interest to be a systems engineer (to be involved in systems projects) mainly means the will and interest to deal with positions that require engineering systems thinking.

- One of the seven behavioral competencies/traits of successful systems engineers is the will/desire to deal with systems (to be involved in systems projects).

- Thus, the will/desire to be involved in positions that require engineering systems thinking predicts success in systems engineering positions.

- Interest inventory is a very common tool which is frequently used to help people choose a profession, and as a selection tool (to determine whether a certain individual is suitable for a certain role) in the recruiting process.

- Frank (2010) introduced an interest inventory for assessing engineers' interest regarding systems engineering positions and the results of three studies aimed at examining its reliability and validity.

Assessing Systems Thinking in Engineers (Cont.)

- The *content validity* of the interest inventory was achieved by basing its items on the findings of the study mentioned above (the study in which 35 competencies of successful systems engineers have been found).

- *Contrasted Groups Validity - S*ystems engineers achieved significantly higher scores than domain engineers.

- *The concurrent validity* was obtained by comparing the inventory scores with the assessment of the employees' senior supervisor. The supervisor was asked to assess the CEST of each engineer on a scale of 1 = very low to 7 = very high. A significant high positive correlation between the participants' interest inventory scores and the appraisal of their supervisor has been found.

The study aimed at exploring the relationship between (1) systems engineers' capacity for engineering systems thinking (CEST), (2) **project success** and (3) project type.

2. Project Success

Project Success

- The literature traditionally use time, budget, and performance as the main indicators of project success.
- More elements to the assessment of project success found such as:
  - Stakeholders' satisfaction.
  - Efficiency of the implementation process.
  - Personal growth.
  - Business and financial performance.
  - The creation of new opportunities.
  - (and many more …).

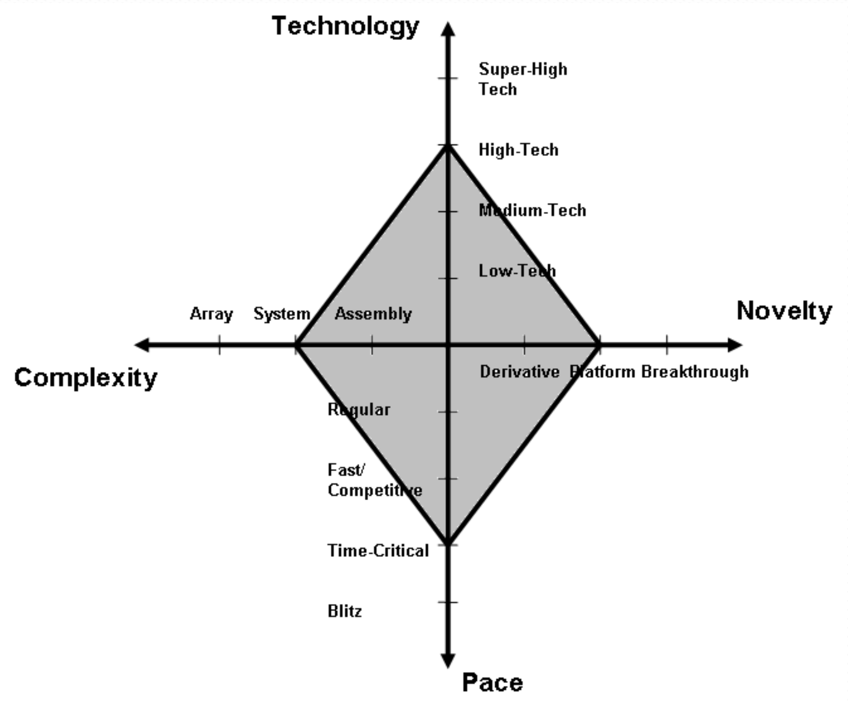
Project Success

- In this study we used the following five measures:
  - Meeting planning goals (project efficiency)
  - Customer benefits (success from the customer's point of view)
  - Benefits to the developing organization
  - Benefit to the community and national infrastructure
  - Benefit to the project team

The study aimed at exploring the relationship between (1) systems engineers' capacity for engineering systems thinking (CEST), (2) project success and (3) **project type**.

3. Project Type

Project Types



- Shenhar and Dvir (2007) identified four dimensions to distinguish among projects: **N**ovelty, **T**echnology/uncertainty, **C**omplexity, **P**ace (NTCP model).
- NTCP model can guide project managers and systems engineers in selecting their project handling style.

METHOD

Method (1 of 4): The Tool

A self report questionnaire comprised of three parts :

- Assessing CEST
  - The tool presented earlier.
- Assessing project success
  - Measured along the 5 dimensions presented earlier.
- Identifying project type
  - The items in this part were based on the NTCP model.

Method (2 of 4): The Participants

- ***Population*** - all senior systems engineers employed in the 'high-tech – electronics – systems' industry in Israel.
- ***Sampling frame*** - all senior systems engineers employed in the sixteen largest 'high-tech – electronics – systems' companies in Israel.
- ***Sample*** – 114 senior systems engineers who were randomly selected from the sampling frame (sampling error 9.18%, $p \leq 0.05$).
  - About 40% of the survey's participants were from the defense industry.

Method (3 of 4): The Projects

The projects can be classified, according to the NTCP model, as follows:

- **Novelty**: 54 subjects were engaged in 'platform' projects, 30 in 'derivative' projects and 30 in 'breakthrough' projects.
- **Technology**: 11 subjects were engaged in 'super-high-tech' projects, 65 in 'high-tech' projects, 26 in 'medium-tech' projects and 12 in 'low-tech' projects.
- **Complexity**: 44 subjects were engaged in 'array' projects, 60 in 'system' projects and 10 in 'assembly' projects.
- **Pace:** 3 subjects were engaged in 'blitz' projects, 23 in 'time-critical' projects, 41 in ‘fast-competitive' projects and 47 in 'regular' projects.

- The duration of the projects: 6 months – 3 years.
- The budget: $200K – 200M (average – $28.7M).

Method (4 of 4): The Procedure

Two stages:

- Pilot survey - 36 senior systems engineers participated.
- Main survey.

- The findings of the pilot study were used to revise and improve the questionnaire.
- Confidentiality at all stages was promised and enforced.

Engineering Systems Thinking: Correlation with Project Success

Main Results (slide 1 of 4)
CEST Scores

CEST Group	Mean	N	Std. Deviation
1 (Low CEST)	46.94	9	9.745
2 (Medium CEST)	72.28	45	4.909
3 (High CEST)	84.67	60	5.094
Total	76.80	114	11.902

Main Results (slide 2 of 4)

Correlations between the subjects' CEST and the projects' five success criteria

	Efficiency	Custor	Team	Business	Future	PR_Succ
Pearson Correlation	**.249(**)**	.065	.050	**.338(**)**	**.305(**)**	**.310(**)**
Sig. (2-tailed)	.008	.503	.601	.000	.001	.001
N	114	109	114	105	114	114

The findings indicate that there is a ***positive significant correlation*** between subjects' CEST and project success in four dimensions

Main Results (Slide 3 of 4)

- An ANOVA test was performed to examine whether the project type (according to the NTCP model) is a moderator variable that affects the correlation between the subjects' CEST and project success.

- In order to test whether there is a specific dimension (novelty, technology, complexity and pace) that affects the correlation between the subjects' CEST and project success, four two-way ANOVA tests were performed – one test for each dimension.

Main Results (Slide 4 of 4)

- It was found that the variable 'novelty' does significantly affect the correlation between the subjects' CEST and project success.
- Post-Hoc tests revealed that the more innovative the project, the higher the correlation between the subjects' CEST and project success.
- In other words, successful systems engineers (systems engineers with high CEST) are needed mostly in platform projects (projects that produce a new generation of products) and breakthrough projects (radical innovative projects).

Discussion (slide 1 of 3)

- The findings of this study clearly show that there is a significant correlation between CEST and project success.
- The extent of the project's novelty (derivative, platform or breakthrough) is a moderator variable that affects this correlation.
- The more innovative the project is, the higher the correlation between the subjects' CEST and project success.

Discussion (slide 2 of 3)

- However, the findings of the current study show that the coefficient of determination, R^2, is relatively low.
- This means that the prediction of project success can be only minimally based on CEST.
- Only a low percent of the variation in project success can be explained by CEST. The remaining percentage should be explained by other variables.
- Of course, this finding makes sense, as many other variables might explain project success.

Discussion (slide 3 of 3)

- In any case, a significant correlation between CEST and project success does exist.
- Because correlation is *necessary* for causation, it is clear beyond all doubt that organizations should select engineers who possess a high capacity for engineering systems thinking.

Thank You!