When Systems Engineering Fails —— Toward Complex Systems Engineering

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Overview

- Large Engineer Projects
- Complex system and innovation
  - Simplification
  - Evolution
    - Enlightened evolutionary engineering
    - Application to air traffic control
- Conclusion

Large Engineering Projects

Many large engineering projects follow example of Manhattan Project and Space Program

Assumptions for large projects

- New Technology
- New technology to be used is well understood

Many projects today focus on replacing older technology systems

Large Engineering Projects

Reality of most large engineering projects

- Failed or Abandoned
- Over budget and over time
- Reduced functionality

Failed FAA Advanced Automation System

- Meant to automate many processes in managing flights, replacing systems from the 50s
- Tried replacing all at once, went poorly
- Air Traffic Controllers could opt out due to safety

Large Engineering Projects

Project Statistics:

- Less than 20% on-time, on-budget, and on-function
- 50% were "challenged", budget and time required almost doubled
- 30% were "impaired" in that they did not finish

Large Engineering Projects

System Function – Responsible Organization	Years of Work (outcome)	Approx. Cost M=Million, B=Billion
Vehicle Registration, Drivers license – Calif. DMV [3,10,23,24,39,40]	1987-1994 (scrapped)	$44M
Automated reservations, ticketing, flight schedul-ing, fuel delivery, kitchens and general administration – United Air Lines [27]	Late 1960s–Early 1970s (scrapped)	$50M
State wide Automated Child Support System (SACSS) – California [12,37]	1991-1997 (scrapped)	$110M
Hotel reservations and flights – Hilton, Marriott, Budget, American Airlines [26]	1988-1992 (scrapped)	$125M
Advanced Logistics System – Air Force [38]	1968-1975 (scrapped)	$250M
Taurus Share trading system – British Stock Exchange [16]	1990-1993 (scrapped)	$100–$600M
IRS Tax Systems Modern-ization projects [34]	1989-1997 (scrapped)	$4B
FAA Advanced Automation System [35]	**1982-1994 (scrapped)**	**$3–$6B**
London Ambulance Service Computer Aided Dispatch System [30]	1991-1992 (scrapped)	$2.5M, 20 lives

Large Engineering Projects

- Problems with modern projects is massive inherent complexity
  - Characteristic of large systems with many interdependent parts
- Existing methods for dealing with complexity
  - Modularity - Separation into parts
  - Abstraction - simplifies description, but this assumes interdependence from other parts
  - Hierarchy - Use of modularity and abstraction to make a simple model, often leads to oversimplified or incorrect view of the system
- Two responses for why it is so difficult
  - Law of Requisite Variety- relates system complexity to task complexity
  - Second - for all practical purposes adequate testing of complex engineering projects is impossible

Large Engineering Projects

- Two solutions
  - Limiting complexity - ability to do this is limited
  - Evolutionary Process - Much more achievable with incremental change
- Evolutionary Process
  - Smaller changes over time
  - Parallel changes across the different parts of the system
  - Testing is done in the field, learning from direct feedback
  - Avoids design being determined by a single person

Enlightened Evolutionary Engineering

Basic concept: create an environment that allows innovation and evolutionary changes

- Task to be performed should be analogous to resources in biology
- Individual parts of the system should be analogous to various organisms that involved evolutionary process
- Changes in individual parts happened by introducing alternative components
- Changes are part of dynamics of the system
- It's possible for conventional engineering of equipment or software components to occur
- The focus is to change small part rather than change the system as a whole
- Increment of components involves in change in one part not in every part of the system
- Even when the same component exists in many parts of the system, changes are not imposed on all of these parts at the same time.
- …

Enlightened Evolutionary Engineering

Difference between evolutionary engineering and conventional one:

- Involve in multiple variant of human, equipment, software in parallel

The process of overall changes consisting innovation usually occurs in several stage:

1. New components are introduced, which won't affect other components because they run in parallel
2. The new components are more effective
3. Keep the old system as long as they are needed and eventually discard "naturally"

Enlightened Evolutionary Engineering

As part of the result from previous slides:

- Conventional engineering is not replace, but is placed within a larger context of an evolutionary process
- Conventional engineering provides direct feedback on effectiveness

Something to notice:

- After some time of selection and completion, a single dominant type will inhibit innovation (“founder effect” in biology and monopolization in economics)
- Balance is needed between promoting the propagation and adoption of improved systems and inhibiting propagation in order to allow sufficient time for testing

Application to air traffic control

Major topic: How can we introduce changes in what an air traffic controller is doing without grave risks to people in airplane?

The changes are slow because extensive tests are needed

Example of existing process of innovation in the air traffic control system: training of new air traffic controllers: when train a new controller, a second controller(supervisor) exists, who supervise trainees but also prevent accident happening

This “double trainer” system is analogous to double set of chromosomes that exist in humans and animals

Conclusion

The complexity of large engineering has led to abandonment of many expensive projects. Thus, complex system development requires evolutionary strategy. This stratgy should rapid change to ensure robustness and safety.

Constraints and dependencies will increase the complexity, they should only be imposed when necessary.

Security is also needed

Questions?

FAQ:

Q: Why this concept seems very “common sense” in the “modern” view:

A: This paper is published in 2003, which is 20 years ago