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# Application of Case Studies to Engineering Management and Systems Engineering Education

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## Abstract and Introduction

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- ▶ Lacking **systemic perspective** complex systems often fail
- ▶ Imperative to **educate and train technical leaders** in this
- ▶ Advocate **case studies** for effective learning
- ▶ **People** in complex system is paradigm shift of mind set
- ▶ Political, operational, economic, psychological, and philosophic **perspectives trump technology**
- ▶ Complex systems cry for **information sharing, self-organization, and collaboration** as well as competition
- ▶ It is about **questions**, not answers
- ▶ We must **nurture children's profound understanding of complexity** to improve quality and sustainability of life

## Useful Notions to Keep in Mind (1/2)

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- ▶ Reductionist techniques do not work in complex systems
- ▶ One is not in control, can only influence stakeholders, and cannot accurately predict or pre-specify
- ▶ Focus on improved capabilities, not requirements
- ▶ Pursue opportunities while mitigating risk
- ▶ Embrace systems thinking concepts (Jackson)
  - ▶ Strategic Assumptions Surface Testing
    - ▶ Establish certainty/importance of key stakeholders
  - ▶ Soft Systems Methodology
    - ▶ Add perspectives of faith, love, justice, social intercourse, feeling, and sensory perception

## Useful Notions to Keep in Mind (2/2)

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- ▶ Systems thinking concepts (concluded)
  - ▶ Critical Systems **Heuristics**
    - ▶ Attack pre-supposed judgments and tease-out marginalized groups
  - ▶ Post-modern Systems Thinking
    - ▶ **Address** inter-group conflict and **enhance** deliberation, debate, and decision
  - ▶ Total Systems Intervention
    - ▶ Focus on technical, **organizational**, and **procedural** aspects, not functional
- ▶ **Tell stories** utilizing engineering **case studies**
- ▶ Make **nonlinear thinking** part of engineering education

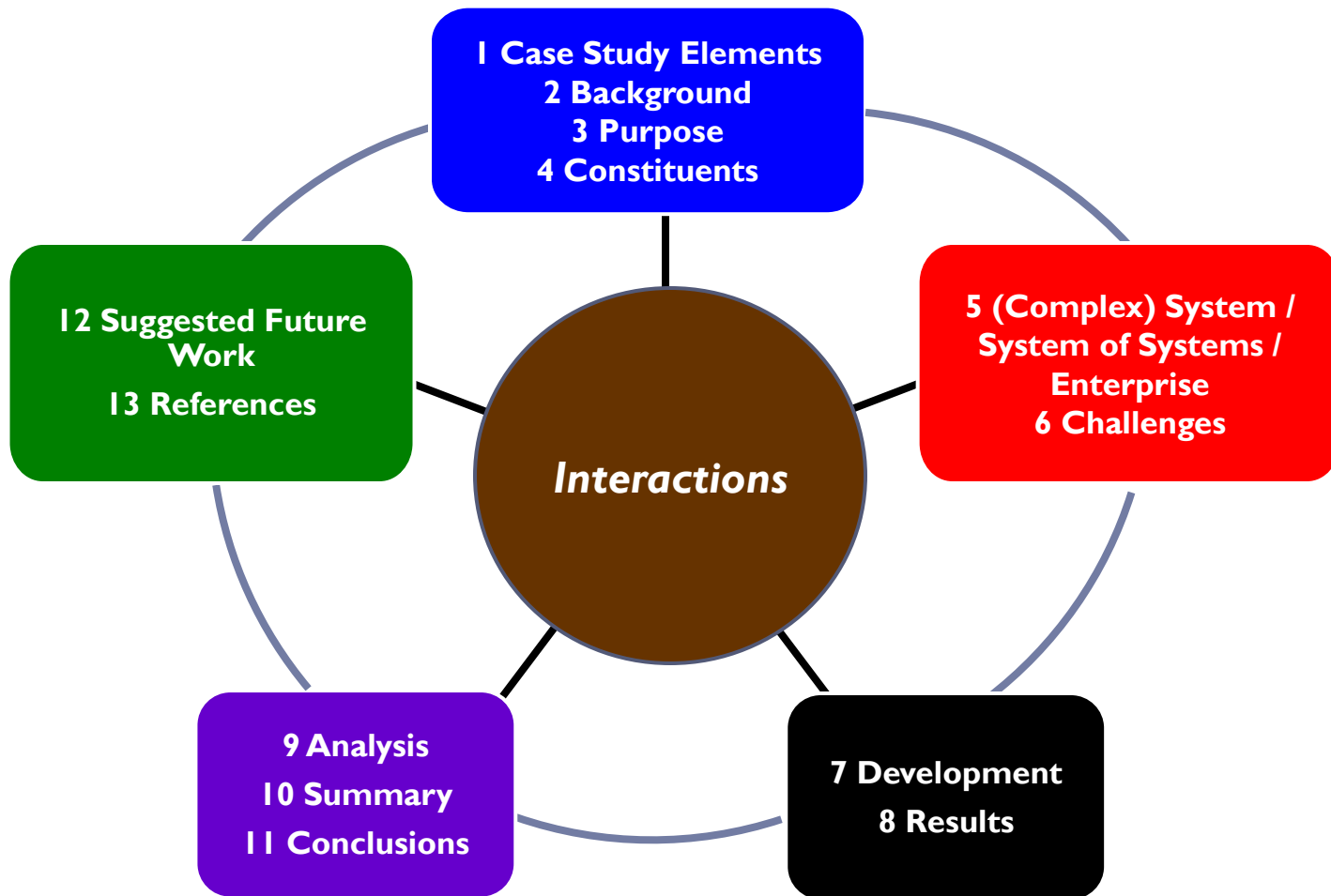
# Sources of Case Studies for Benefiting Engineering Management Education

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- ▶ Massachusetts Institute of Technology (M.I.T.)
  - ▶ Engineering Systems Division (ESD)
    - ▶ Systems Engineering Advancement Research Initiative (SEARI)
  - ▶ Lean Advancement Initiative (LAI)
  - ▶ System Design and Management (SDM) masters program
- ▶ Stevens Institute of Technology (Stevens)
- ▶ Other Universities
  - ▶ University of Vermont (UVM)
  - ▶ University of Virginia
  - ▶ Old Dominion University
  - ▶ University of Texas
  - ▶ University of Southern California's (USC's) Viterbi School of Engineering
  - ▶ University of Illinois (U of I)
- ▶ Announcing **new book** (present authors are co-editors), *Case Studies in System of Systems, Enterprises, and Complex Systems Engineering*, to be published in **2013** by Taylor & Francis/CRC Press.

# Relationships Among Case Study Sections

(Figure 1)



# Principal Objectives of Case Study Sections

(Table 1)

Index	Main Section of Case Study	This Section's Principal Case Study Objective	Color*
1	<b>Case Study Elements</b>	Provide enough concise information to enable a researcher/practitioner or general reader to decide whether this case study is of particular interest.	Blue
2	<b>Background</b>	Further define the case study, especially for those that are not yet sure if it is relevant to their interests.	Blue
3	<b>Purpose</b>	Capture the impetus behind and specific reasons for the case study, and show some of the passion that drove or is driving this transformation.	Blue
4	<b>Constituents</b>	Characterize people and institutions interacting in the case study, and illuminate their motivations, e.g., what incentives drove or drive them?	Blue
5	<b>(Complex) System / System of Systems / Enterprise</b>	Provide a clear and complete but focused description of the subject complex system, system of systems, or enterprise.	Red
6	<b>Challenges</b>	Highlight the principal aspirations and difficulties.	Red
7	<b>Development</b>	Show just how transformational change can occur.	Black
8	<b>Results</b>	Answer the "So what?" questions.	Black
9	<b>Analysis</b>	Provide suggestions to others in how to interpret results of their system transformation and what it all means.	Violet
10	<b>Summary</b>	Complement mainly the Case Study Elements, Background, and Purpose sections, especially for those that only want to skim the case study and not delve into the details.	Violet
11	<b>Conclusions</b>	Whet a reader's appetite to revisit the case study body for more detail.	Violet
12	<b>Suggestions for Future Work</b>	Motivate additional effort to further understand complex systems and advance complex systems engineering.	Green
13	<b>References</b>	Lend credibility to the case study and highlight relevant literature from related bodies of knowledge.	Green

## Case Study Outline (1/7)

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- ▶ 1. Case Study Elements – **bulletized** executive summary for **sorting** and understanding
  - ▶ Essence – what about?
  - ▶ Relevance – why it matters?
  - ▶ Domain – academia, commerce, government, and/or industry?
  - ▶ Country – most involved
  - ▶ Constituency – who cares?
  - ▶ Insights – takeaways?
- ▶ 2. Background
  - ▶ Context – how case study arose and why?
  - ▶ Definitions – any unfamiliar terminology
  - ▶ Theories – research and supporting literature
  - ▶ **Principles** – guidance and existing practices
  - ▶ Characterizations – system type, maturity, environment, and/or activities
  - ▶ Descriptions – before and after, high-level diagrams, and/or performance graphs



## Case Study Outline (2/7)

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- ▶ 3. Purpose
  - ▶ History – how case study came about
  - ▶ Situation – then current
  - ▶ Problems – shortfalls
  - ▶ Mission and Capabilities – vision, goals, and objectives
  - ▶ Transformation – need and/or reason for
- ▶ 4. Constituents – good place for **stories**
  - ▶ Sponsor – who paid?
  - ▶ Customer – who needed system?
  - ▶ Stakeholders – who cared?

## Case Study Outline (3/7)

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- ▶ 5. (Complex) System/System of Systems/Enterprise
  - ▶ Environment – external influence and **energy/information flows**
  - ▶ Scope – size, and span of control/influence
  - ▶ Structure – architecture and **interrelationships**
  - ▶ Boundaries – how defined?
  - ▶ Relationships – and degree of **self-organization**
  - ▶ Factors – and their impacts
  - ▶ Constraints – and their effects
- ▶ 6. Challenges – **what kept stakeholders awake at night?**
  - ▶ Anticipated – were any missed?
  - ▶ Actual – what was unexpected?

## Case Study Outline (4/7)

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- ▶ 7. Development – how was transformation accomplished, and what **non-traditional processes** of interest applied?
  - ▶ Program Management
    - ▶ Planning
      - Contingences
      - Information Management
        - **Sharing**
        - **Security**
      - Strategy
      - Resources
        - **Roles**
        - Budget
        - Funding – **rewards for results?**
      - Schedule – expected disruptions?
      - Users/Operators – **involvement up-front?**

## Case Study Outline (5/7)

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- ▶ 7. Development (concluded)
  - ▶ Systems Engineering
    - ▶ Architecture – **relatively stable** guide to system development
    - ▶ Alternatives – nurture two or three just in case
    - ▶ Opportunities – be open to change but **balance** with risk mitigation
    - ▶ Approach – emphasize **interoperability**, test early and often, and plan for fielding, sustainment, and retirement
  - ▶ Change Management – if present, how instituted and successful?  
To what degree were these aspects addressed?
    - ▶ **Politics**
    - ▶ Operations
    - ▶ Economics
    - ▶ Technology

## Case Study Outline (6/7)

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### ▶ 8. Results – so what happened?

Emergent **surprises**, major improvements, **added capabilities**, user or operator satisfactions, set-backs, shortfalls, and **unintended consequences**

- ▶ Transformation accomplished – functions, services, etc.
- ▶ Final descriptions – block diagram and/or performance graph

### ▶ 9. Analysis – answers to “why” questions

- ▶ Findings – key tasks, events, delays, and methods
- ▶ Lessons – **what worked or did not work?** Future impacts?
- ▶ Practices – which will **benefit others?**
- ▶ Prospects – replication likelihood? Necessary conditions and proposed actions?

## Case Study Outline (7/7)

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- ▶ 10. Summary – concise overview of problem, solution, approach, results, and subsequent events
- ▶ 11. Conclusions – most important nuggets; **elevator speech**
- ▶ 12. Suggested Future Work
  - ▶ Research
  - ▶ Practices/Processes
  - ▶ **Precepts/Principles**
  - ▶ Continued Improvements
  - ▶ Questions for Discussion
- ▶ 13. Useful References/Bibliography/End Notes

## Conclusion

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- ▶ **Case studies are powerful** for furthering effective systems engineering practices to address
  - ▶ **Complex problems** facing humanity and global community continue to **abound and intensify**, e.g.,
  - ▶ **Sustainability** of Earth's resources in face of **unlimited material growth and overpopulation**
- ▶ **We must**
  - ▶ Advance our understanding of complex systems and application of complex systems engineering principles
  - ▶ **Concentrate on education and motivation** of technical leaders
  - ▶ Encourage broader views engaging philosophy, psychology, sociology, economics, politics, and change management

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## Appendix A (Definitions)

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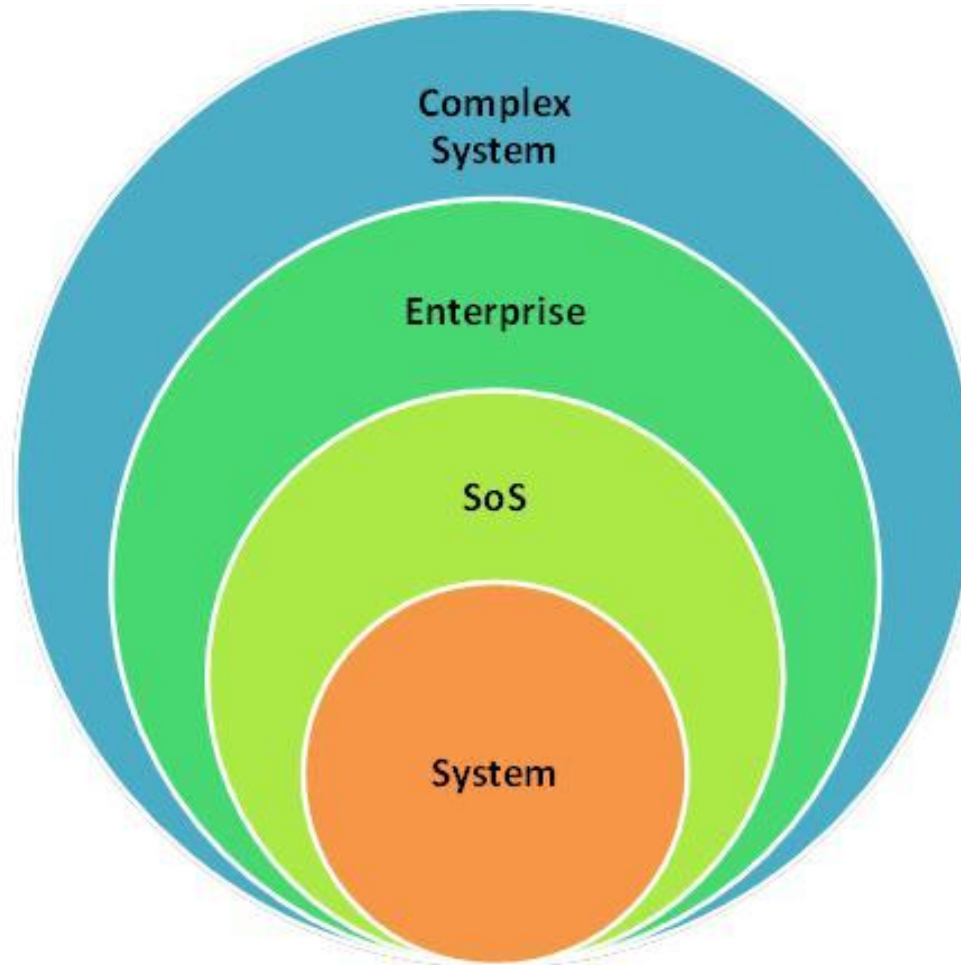


Figure AI.Venn Relationships Among System Types<sup>23</sup>

# Appendix B (Detailed Case Study Outline) (1/6)

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- ▶ **1. Case Study Elements** (bulletized, for sorting purposes)
  - ▶ Fundamental Essence (briefly, what's this about?)
  - ▶ Topical Relevance (briefly, why does this matter?)
  - ▶ Domain(s) (choose one)
    - ▶ Academia
    - ▶ Commerce
    - ▶ Government
    - ▶ Industry
    - ▶ Other (specify)
  - ▶ Country of Focus (country most involved)
  - ▶ Interested Constituency (who cared or cares?)
  - ▶ Primary Insights (takeaways)
- ▶ **Key Words** (alphabetized, separated by commas)
- ▶ **Abstract** (no more than 200 words)
- ▶ **[Glossary** (abbreviations and acronyms, alphabetized)]
- ▶ **2. Background**
  - ▶ Context (how did this arise, and why?)
  - ▶ Relevant Definitions (define unfamiliar terms)
  - ▶ Pertaining Theories (theoretical knowledge applied)
    - ▶ [Literature Overview]
    - ▶ Research Nuggets (past and present)
  - ▶ [Existing Practices (extant methods, available tools, and/or proven processes)]
  - ▶ Guiding Principles (applicable principles, precepts, and/or tenets)

## Appendix B (Detailed Case Study Outline) (2/6)

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- ▶ Characterizations
  - ▶ Type of System (refer to Fig. A1 of Appendix A)
  - ▶ System Maturity (legacy, upgrade, or new)
  - ▶ Environment
  - ▶ Systems Engineering Activities (before and after)
- ▶ “As Is” System Description (before)
  - ▶ High-Level Diagram
  - ▶ [Performance Graphs]
- ▶ “To Be” System Description (after)
  - ▶ High-Level Diagram
  - ▶ [Performance Graphs]
- ▶ **3. Purpose**
  - ▶ History (describe previous situation and evolution)
  - ▶ Then Current Situation
  - ▶ Known Problem(s)
  - ▶ Mission and Desired or Expected Capabilities
    - ▶ [Vision
    - ▶ Goals
    - ▶ Objectives]
  - ▶ Transformation Needed and Why
- ▶ **4. Constituents** (their identification, objectives, and status)
  - ▶ Sponsor
  - ▶ Customer
  - ▶ Other Stakeholders

# Appendix B (Detailed Case Study Outline) (3/6)

- ▶ **5. (Complex) System/System of Systems/Enterprise** (refer to Appendix A for some definitions) (describe each of the following items in sufficient detail)
  - ▶ Environment
  - ▶ Scope
  - ▶ Structure
  - ▶ Boundaries
  - ▶ Internal Relationships
  - ▶ External Factors
  - ▶ Constraints
  - ▶ Other Descriptors
- ▶ **6. Challenges** (what kept people awake at night?)
  - ▶ Anticipated
  - ▶ Actual
- ▶ **7. Development** (emphasize non-conventional aspects)
  - ▶ Program Management
    - ▶ Planning
    - ▶ Contingencies
    - ▶ Information Management
      - ▶ Sharing
      - ▶ Security
    - ▶ Strategy
    - ▶ Resources
      - ▶ Staffing
      - ▶ Roles
    - ▶ Budget
    - ▶ Schedule
    - ▶ User/Operator Involvement
    - ▶ [Processes Instantiated]

# Appendix B (Detailed Case Study Outline) (4/6)

Systems Engineering (in narrow sense)

- ▶ Architecture
- ▶ Alternatives Analysis
  - ▶ System Approaches
  - ▶ Description
  - ▶ Technology
    - ▶ [Technology Readiness]
    - ▶ Technologies Selected
- ▶ Opportunity and Risk Management
- ▶ Selected Approach
  - ▶ Design
  - ▶ Implementation
  - ▶ Integration
  - ▶ Testing
  - ▶ Fielding
  - ▶ [Sustainment]
  - ▶ [Retirement]
- ▶ Change Management (how implemented and integrated?)
  - ▶ [Philosophy]
  - ▶ [Policy]
  - ▶ Politics
  - ▶ [Organization]
  - ▶ Operations
  - ▶ Economics
  - ▶ Technologies

# Appendix B (Detailed Case Study Outline) (5/6)

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## ▶ 8. Results

- ▶ Transformation Accomplished
  - ▶ Functions
  - ▶ Services
  - ▶ Other Assets or Capabilities
- ▶ Final System Description
  - ▶ High-Level Diagram
  - ▶ [Performance Graphs]

## ▶ 9. Analysis

- ▶ Analytical Findings
  - ▶ Activities (key tasks and their interactions)
  - ▶ Time Frame/Line
    - ▶ [Sequence of Events]
    - ▶ Significant Delays Incurred and Why
  - ▶ Methods Employed (and their efficacies)
- ▶ Lessons Learned
  - ▶ How Were Biggest Challenges Met?
  - ▶ What Worked and Why?
  - ▶ What Did Not Work and Why?
  - ▶ What Should Have Been Done Differently?
  - ▶ To What Extent Were Lessons Applied to Subsequent Programs/Projects?
- ▶ Best Practices (what would be recommended to others?)
- ▶ Replication Prospects (how practical might this case study become?)
  - ▶ Necessary Conditions
  - ▶ Proposed Action Steps



## Appendix B (Detailed Case Study Outline) (6/6)

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- ▶ **I 0. Summary** (provide concise overview of what happened after the fact)
- ▶ **[Epilogue]** [what significant events have occurred since?]
- ▶ **I 1. Conclusions** (construct an elevator speech)
- ▶ **I 2. Suggested Future Work**
  - ▶ Further Questions for Discussion
  - ▶ Additional Research
- ▶ **[End Notes]**
- ▶ **I 3. References** ([primary and secondary] using IEEE format)
- ▶ **[Appendices]**
- ▶ **[Index]**