Fundamentals of Systems Engineering

Session 1
Systems Engineering Overview
Stakeholder Analysis
This class is an introduction to the **Fundamentals of Systems Engineering**, a “door opener” to this important and evolving field

- Ideal for graduate students (1st, 2nd year of masters program)
  - Some advanced undergraduates or returning professionals can also benefit

- Taught in format of a SPOC (Small Private Online Course)
  - All lectures are recorded and available online on webex

- At MIT: **16.842**, 6 units, taught in 9-057 and webex format
  - Serves as a core class in the Department of Aeronautics and Astronautics for students interested in the ‘systems tracks’ and doctoral qualifying exams

- At EPFL: **ENG-421**, 5 ECTS credits, taught in ODY-10020 and webex
  - Serves as one of the core classes in the new Minor in Systems Engineering
Agenda for Today

- Introductions
  - Personal Introductions
  - Course Introduction, incl. Learning Objectives

- Systems Engineering (SE) Overview
  - A bit of history
  - The “V”-Model
  - SE Standards and Handbooks
  - Challenges of current practice

- Stakeholder Analysis
  - Identifying Stakeholders
  - CONOPS
  - Stakeholder Value Network (SVN) Analysis

- Assignment A1
  - 2016 Cansat Competition, Team Formation etc…
Personal Intro

- Olivier de Weck
  - Dipl. Ing. Industrial Engineering – ETH Zurich 1992
  - 1993-1997 Engineering Program Manager Swiss F/A-18 Project, RUAG (formerly F+W Emmen)
  - Liaison Engineer at McDonnell Douglas, St. Louis
  - S.M.’ 99 Ph.D.’ 01 Aerospace Systems – MIT
  - Visiting Researcher at NASA Goddard Spaceflight Center
  - Professor – dual appointment Department of Aeronautics and Astronautics and Institute for Data, Systems, and Society (IDSS)
  - Adjunct Professor at EPFL, since 2012
  - Editor-in-Chief Journal Systems Engineering (since 2013)
  - MIT Strategic Engineering Research Group:
    - http://strategic.mit.edu
A Transatlantic Journey ...

1993

1997

MIT Cambridge

NASA Goddard SFC

JPL Pasadena

Boeing St. Louis

NASA JSC Houston

NASA KSC Florida

ETH Zurich

RUAG Aerospace

Fribourg

EPFL Lausanne

Zermatt

What’s wrong with this picture?
F/A-18 Complex System Change

F/A-18 System Level Drawing

- Fuselage Stiffened
- Flight control software changed
- Gross takeoff weight increased
- Center of gravity shifted
- Manufacturing processes changed

Image by MIT OpenCourseWare.
F/A-18 Center Barrel Section
Lessons Learned from Swiss F/A-18 Program

- High-performance aircraft are very complex internally ... propulsion, avionics, structures ...

- Changing requirements can have ripple effects because everything is tightly coupled
  - It is difficult to predict the totality of system interactions ahead of time

- The “whole” system is much more than the air vehicle: logistics, training, incl. simulators etc..

- People matter a lot: contracts, culture, incentives ....
And who are you ...?

- **Briefly introduce yourself**
  - Name
  - Department or Lab Affiliation
  - Any prior experience with Systems Engineering?
  - Name **one** thing you want to learn in this class

- Try to keep it to 30 seconds or less
Motivation for this class

- Aerospace Systems deliver important functions to society ... air transportation, defense, sensing, exploration ...
- Complex “machines” with thousands of unique parts and potentially millions of interactions
  - Many aerospace systems require 6+ levels of decomposition to arrive at indivisible parts that cannot be taken “a-part”
- Humans play an important role as designers, operators, beneficiaries, maintainers ....
- Best Practices have emerged since the 1960’s and are continuously evolving ... documented in standards/handbooks
- Limitations of “traditional” SE
  - System safety ... recent SpaceX Falcon 9 launch failure
  - Typical program cost and schedule overruns ... Boeing Dreamliner 787 delays ...
- Systems Engineering is also penetrating in other industries
  - Automobiles, Software, Medical Devices ....
Example: FLIR System for Aircraft

FLIR = Forward Looking Infrared

The FLIR System AN/AAQ-22 Star SAFIRE electro-optical/infrared sensor has been designed to provide full digital high-definition (1280x720) video compliant with US and NATO specifications.
Why do we need system decomposition?
Concept Question 1

- How many levels of decomposition (depth of drawing tree) do we need to describe the car shown in the previous picture?
  - 1
  - 2
  - 3
  - 4
  - 5
  - 6
  - >6

- This question does not make sense to me
## System Complexity

Assume 7-tree [Miller 1956]

http://www.musanim.com/miller1956/

### How many levels in drawing tree?

\[
\text{#levels} = \left\lfloor \frac{\log(#\ parts)}{\log(7)} \right\rfloor
\]

<table>
<thead>
<tr>
<th>Item</th>
<th>Parts</th>
<th>Levels</th>
<th>Complexity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Screwdriver (B&amp;D)</td>
<td>3</td>
<td>1</td>
<td>simple</td>
</tr>
<tr>
<td>Roller Blades (Bauer)</td>
<td>30</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Inkjet Printer (HP)</td>
<td>300</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Copy Machine (Xerox)</td>
<td>2,000</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Automobile (GM)</td>
<td>10,000</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Airliner (Boeing)</td>
<td>100,000</td>
<td>6</td>
<td>complex</td>
</tr>
</tbody>
</table>

Learning Objectives

Participants in this class will be able to ...

- SE1: Describe the most important Systems Engineering standards and best practices as well as newly emerging approaches[1]
- SE2: Structure the key steps in the systems engineering process starting with stakeholder analysis and ending with transitioning systems to operations
- SE3: Analyze the important role of humans as beneficiaries, designers, operators and maintainers of aerospace and other systems
- SE4: Characterize the limitations of the way that current systems engineering is practiced in terms of dealing with complexity, lifecycle uncertainty and other factors
- SE5: Apply some of the fundamental methods and tools of systems engineering to a ‘simple’ cyber-electro-mechanical system as a stepping stone to more complex and real world projects

[1] Our main “textbook” for the class will be the NASA Systems Engineering Handbook, NASA/TP-2007-6105, Rev 1. All participants will receive a copy of the handbook.

Note: This class is not an explicit preparation for CSEP Certification
• “Bible” for Systems Engineering at NASA

• Makes The Bridge From “Typical” Guidance Back To NASA Systems Engineering Process (NPR 7123.1)
  – Guidance From Practitioners
    • Written by practitioners for practitioners
  – “How” Vs “What”

• Updates The Guidance from SP-6105 (basic)
  – Updates The Practice/Methodology from 1995

• Provides Top-level Guidance for Systems Engineering Best Practices; It Is Not Intended In Any Way To Be A Directive

• Adds Additional Special Topics
  – Tools
  – NEPA
  – Human Factors
Class Format – 5 major elements

Lectures
- 12 Lectures total (2h each)
- Follow roughly the “V-Model”

Assignments
- Team-based (5 people)
- 5 Assignments total (~ 2 weeks duration for each)
- Create a “PDR”-Level Design

Design Competition
- Top 3 Teams at each school will qualify for the 2016 Cansat Competition

Readings
- Pre-Readings based on sections of NASA SE Handbook, see syllabus for details
- Post-Readings are 1-2 journal or conference papers on topic
- Expect to read about 30-40 pages per week

Exams
- Online Quiz
- Oral Exam (20’ per student)
  - Based on 2-page reflective memo
Grading Scheme

- Group Assignments A1-A4 (total of 4) 50%
  - 12.5% each
- Group Assignment A5 (PDR presentation) 20%
- Online Quiz 10%
- Oral Exam (incl. 2-page reflective memo) 10%
- Active Class Participation* 10%
- Total 100%

*Measured based on concepts question responses, class attendance and in-class contributions.
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  - A bit of history
  - The “V”-Model
  - SE Standards and Handbooks
  - Challenges of current practice

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- Assignment A1
  - 2016 Cansat Competition, Team Formation etc…
A bit of SE History

- Systems Engineering has been informally practiced since antiquity
  - Great Wall of China, Egyptian Pyramids, Roman Aqueducts
  - Mainly a “workforce” problem to build large infrastructures

- The term “Systems Engineering” can be traced back to Bell Labs (1940s)
  - [https://en.wikipedia.org/wiki/Bell_Labs](https://en.wikipedia.org/wiki/Bell_Labs)
  - Beginning of new methods to better handle complexity

- Formal Systems Engineering really started after WWII
  - 1950’s and 1960s: Cold War, Apollo Lunar Program, ICBMs etc…
  - Complex Engineering Systems: Air Traffic Control, High Speed Rail, Nuclear ..
  - Mainly (paper) document-based: requirements, specifications, test plans etc…

- Early Pioneers
  - Arthur D. Hall, Kelly Johnson, Simon Ramo, Eberhard Rechtin, Andrew Sage, Margaret Hamilton, and others

- 1995 Founding of International Council for Systems Engineering (INCOSE)

- Since ~2000: Development of new Model-Based-Systems-Engineering (MBSE). Need to accelerate SE and better handle complexity
How would you define Systems Engineering?

- **Turn to your neighbor** and discuss for about **5 minutes**:
  - What is your definition of Systems Engineering?
  - Can you agree amongst yourselves?
  - What are the key elements of a definition?

- We will sample after about 5 minutes!
Some Definitions of SE

- "System engineering is a robust approach to the design, creation, and operation of systems. In simple terms, the approach consists of identification and quantification of system goals, creation of alternative system design concepts, performance of design trades, selection and implementation of the best design, verification that the design is properly built and integrated, and post-implementation assessment of how well the system meets (or met) the goals."— NASA Systems Engineering Handbook, 1995.

- "An interdisciplinary approach and means to enable the realization of successful systems”— INCOSE handbook, 2004

- More recently the scope of SE has broadened:
  - Design of Enterprises, Infrastructure Networks etc…
The famous “V-Model” of Systems Engineering

16.842/ENG-421 Fundamentals of Systems Engineering

1. Stakeholder Analysis
2. Requirements Definition
3. System Modeling Languages - MBSE
4. System Architecture Concept Generation
5. Tradespace Exploration Concept Selection
6. Design Definition Multidisciplinary Optimization
7. Verification and Validation
8. System Integration Interface Management
9. Commissioning Operations
10. Lifecycle Management
11. PFR
12. FRR
12. Prototyping Manufacturing

“V-Model”

Numbers indicate the session # in this class

*optional
## NASA Program & Project Lifecycle

<table>
<thead>
<tr>
<th>NASA Life Cycle Phases</th>
<th>FORMULATION</th>
<th>Approval for Implementation</th>
<th>IMPLEMENTATION</th>
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<td><strong>Project Life Cycle Phases</strong></td>
<td>Pre-Phase A: Concept Studies</td>
<td>Phase A: Concept &amp; Technology Development</td>
<td>Phase B: Preliminary Design &amp; Technology Completion</td>
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<td><strong>Launch Readiness Reviews</strong></td>
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<tr>
<td><strong>Supporting Reviews</strong></td>
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</tbody>
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### ACRONYMS
- **ASP**—Acquisition Strategy Planning Meeting
- **ASM**—Acquisition Strategy Meeting
- **CDR**—Critical Design Review
- **CERR**—Critical Events Readiness Review
- **DR**—Decommissioning Review
- **FAD**—Formulation Authorization Document
- **FRR**—Flight Readiness Review
- **KDP**—Key Decision Point
- **LRR**—Launch Readiness Review
- **MCR**—Mission Concept Review
- **MDR**—Mission Definition Review
- **NAR**—Non-Advocate Review
- **ORR**—Operational Readiness Review
- **PFR**—Post-Flight Assessment Review
- **PLAR**—Post-Launch Assessment Review
- **PNAR**—Preliminary Non-Advocate Review
- **PRR**—Production Readiness Review
- **SAR**—System Acceptance Review
- **SDR**—System Definition Review
- **SIR**—System Integration Review
- **SMSR**—Safety and Mission Success Review
- **SRB**—System Review Board
- **LRR (LV)**—Launch Readiness Review (Launch Vehicle)
- **FRR (LV)**—Flight Readiness Review (Launch Vehicle)
- **PLAR SAR**—Post-Launch Assessment Review—System Acceptance Review
- **SMSR, LRR (LV), FRR (LV)**—Safety and Mission Success Review—Launch Readiness Review (Launch Vehicle)—Flight Readiness Review (Launch Vehicle)

### Footnotes
1. Flexibility is allowed in the timing, number, and content of reviews as long as the equivalent information is provided at each KDP and the approach is fully documented in the Project Plan. These reviews are conducted by the project for the independent SRB. See Section 2.5 and Table 2-6.
2. PRR needed for multiple (≥4) system copies. Timing is notional.
3. CERRs are established at the discretion of Program Offices.
4. For robotic missions, the SRR and the MDR may be combined.
5. The ASP and ASM are Agency reviews, not life-cycle reviews.
6. Includes recertification, as required.
7. Project Plans are baselined at KDP C and are reviewed and updated as required, to ensure project content, cost, and budget remain consistent.
SE Standards and Handbooks

- **Systems Engineering Standards**


- **Selected Conference and Journal Articles (in “Readings” folder)**
  - Explore beyond traditional SE
  - Somewhat MIT-centric

These are suggestions based on my best knowledge/experience. Feel free to make additional suggestions as the literature in SE is growing fast.
The NASA Systems Engineering “Engine”

System Design Processes
- Requirements Definition Processes
  1. Stakeholder Expectations Definition
  2. Technical Requirements Definition
- Technical Solution Definition Processes
  3. Logical Decomposition
  4. Design Solution Definition

Requirements Flow Down from Level above

Requirements Flow Down to Level below

Technical Management Processes
- Technical Planning Process
- Technical Control Processes
  11. Requirements Management
  12. Interface Management
  13. Technical Risk Management
  14. Configuration Management
  15. Technical Data Management
- Technical Assessment Process
  16. Technical Assessment
- Technical Decision Analysis Process
  17. Decision Analysis

Product Realization Processes
- Product Transition Process
  9. Product Transition
- Evaluation Processes
  7. Product Verification
  8. Product Validation
- Design Realization Processes
  5. Product Implementation
  6. Product Integration

Realized Products to Level above

Realized Products from Level below

System Design Processes applied to each WBS Model down and across system structure

Product Realization Processes applied to each product up and across system structure
Gentry Lee’s Critical Behavioral Characteristics of a Good Systems Engineer

- Intellectually Curious – ability and desire to learn new things
- Ability to make system-wide connections
- Comfortable with uncertainty and unknowns
- Proper Paranoia – expect the best, but plan for the worst
- Strong team member and leader
- Self Confidence and Decisiveness – short of arrogance
- Appreciation for Process – rigor and knowing when to stop
- Exceptional Two-way Communicator
- Diverse Technical Skills – ability to apply sound technical judgment
- Ability to See the Big Picture – yet get into the details
- Comfortable with change
Challenges of current practice ...

- NASA and other formal Systems Engineering processes are very helpful and valuable, but ...
  - Assume mostly “clean sheet” design, but many real projects are modifications of previous systems
    - How to do “redesign”, use legacy or COTS components etc...?
  - Assume that system/mission requirements and stakeholder needs are known and stable over time, but in reality they change with new administrations
    - Impact of externalities (e.g. policy) is underrepresented
  - Effect of design iterations and rework on budgets and project outcomes is more important than the linear “waterfall” or “stagegate” process suggests
    - See recent NRC Study on Cost and Schedule Growth in NASA’s Earth and Space Science Missions in which I participated (see next chart).
- Etc...etc..
Ranking of 40 NASA science missions in terms of absolute cost growth in excess of reserves

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12. Prototyping Manufacturing

*optional

Numbers indicate the session # in this class
Concept Question 2

- Before rushing to propose or design something we need to spend considerable amount of time **engaging with stakeholders**, Why?

- Pick what you think is the most important reason
  - Because they have the funds
  - Because we need to understand their needs first
  - Who is my competition?
  - Need to understand regulations and laws
  - Other

- Answer Concept Question 2 (see supplemental files)
NASA view of stakeholder process
Stakeholder Expectations Definition Process
Who is a Stakeholder?

- A group or an individual who is **affected by** or is in some way **accountable** for the outcome of an undertaking

Stakeholders can be classified as:

- **Customers** – An organization or individual that has **requested** a product and will **receive** the product to be delivered. Examples:
  - An end user of the product
  - The acquiring agent for the end user
  - The requestor of the work product from a technical effort

- **Other interested parties** who provide broad overarching **constraints** within which the customers’ needs must be achieved, or who **have influence** on success of the system. Examples:
  - Those affected by the resulting product
  - Those affected by the manner in which the product is realized or used
  - Those who have a responsibility for providing life-cycle support services (e.g. design, manufacturing, operations, maintenance)
## Examples of Stakeholders

<table>
<thead>
<tr>
<th>Relative to Org</th>
<th>Stakeholder</th>
<th>Typical Expectations</th>
</tr>
</thead>
<tbody>
<tr>
<td>External</td>
<td>Customer</td>
<td>Expected level of product quality, delivered on time, affordable, life cycle support &amp; services</td>
</tr>
<tr>
<td></td>
<td>Subcontractors/vendors</td>
<td>Well defined requirements</td>
</tr>
<tr>
<td></td>
<td>Local, State, National Public</td>
<td>Products must not contaminate the environment</td>
</tr>
<tr>
<td>Internal</td>
<td>Org Management</td>
<td>Internal Commitments met (cost, schedule), good status provided, compliance with org policies, directives and procedures</td>
</tr>
<tr>
<td></td>
<td>PM</td>
<td>Expected technical work products delivered on time and can be used for decision making</td>
</tr>
<tr>
<td></td>
<td>Technical Team members</td>
<td>clear tasks, job security, rewards, teamwork</td>
</tr>
<tr>
<td></td>
<td>Functional Organizations (e.g., test)</td>
<td>Test support products available, clear test requirements, recognition for project help</td>
</tr>
</tbody>
</table>
Concept of Operations (CONOPS)

- One of the major outputs for capturing stakeholder expectations is the Concept of Operations or “ConOps”.
- The ConOps is an important component in capturing expectations, forming requirements and developing the architecture of a project or system.
- Should be addressed early in the project.
- Thinking through the ConOps and use cases often reveals requirements and functions that might be otherwise overlooked.
Example CONOPS: Lunar Design Reference Mission

- **LLO 100 km (54nm)**
- **Altair performs LOI 1,000 m/s (3,281 ft/s) (Propellant load for 950 m/s)**
- **Orion TLI control mass 20,185 kg (44,500 lbm)**
- **ERD up to 241 km (130nm), minimum 222 km, LEO attitude = Gravity gradient**
- **Ares-I Delivered mass 23.6 t (52,070 lbm) 4 days LEO loiter**

Image by MIT OpenCourseWare.
Relationships among the upstream System Design Processes
Stakeholder Expectations Definition - Best Practice Process Flow Diagram

**Input**
- From Project
  - Initial customer expectations
- From Design Solution Definition (recursive loop) and Requirements Management and Interface Management processes
  - Other stakeholder expectations
  - Customer flowdown requirements

**Activities**
- Establish list of stakeholders
- Elicit stakeholder expectations
- Establish operations concept and support strategies
- Define stakeholder expectations in acceptable statements
- Analyze expectation statements for measures of effectiveness
- Validate that defined expectation statements reflect bidirectional traceability
- Obtain stakeholder commitments to the validated set of expectations
- Baseline stakeholder expectations

**Output**
- To Technical Requirements Definition and Management processes
  - Validated stakeholder expectations
- To Technical Requirements Definition and Configuration Management processes
  - Operations concept
- Enabling product support strategies
- To Technical Requirements Definition and Technical Data Management processes
  - Measures of effectiveness
What are the Benefits of the Stakeholder Expectations Process?

- Build a system that meets customers’ expectations
  - Operators requirements
  - Support from Congress and Public
- Build a system that can be tested, operated and maintained
- Ensure Stakeholder commitments are obtained and realized.
Stakeholder Value Network (SVN) Modeling

Most stakeholder models only focus on a single focal organization and Ignore the indirect relationships amongst other stakeholders. This Can lead to project failures if not recognized. Stakeholder Value Network (SVN) models attempt to capture these 2\textsuperscript{nd} order effects and value loops.

Based on the PhD Thesis of Dr. Wen Feng

Introduction: “Hub-and-Spoke” Model and Value Network

“Hub-and-Spoke” Stakeholder Model (Adapted from Donaldson and Preston, 1995)

Stakeholder Value Network (Feng, Cameron, and Crawley, 2008)

Figure 3 in Wen Feng; Edward F. Crawley; Olivier de Weck; Rene Keller; Bob Robinson. :Dependency structure matrix modelling forstakeholder value networks". Proceedings of the 12thInternational DSM Conference, Cambridge, UK, 22.-23.07. 3-16.DSM 2010. CC by-nc-sa 3.0.
Motivation

- **Indirect Relationships:**
  - Understand the impact of both direct and indirect relationships between stakeholders on the success of large projects.

- **Strategies with Reduced Complexity:**
  - Apply such an understanding to inform decisions on stakeholder management strategies in a positive way and with reduced complexity.

- **Communication Platform:**
  - Build a common platform for engineering, external affairs, and management within a project to consistently communicate important information about stakeholders.
SVN Methodology

**Inputs/Outputs**
- Stakeholders and Their Roles, Objectives, and Needs
- Qualitative Model of Stakeholder Value Network
- Quantitative Model of Stakeholder Value Network
- The Solution Space of Value Paths between Any Two Stakeholders
- Important Paths/Outputs/Stakeholders/Flows

**Steps**
- **Step 1: Mapping**
- **Step 2: Quantifying**
- **Step 3: Searching**
- **Step 4: Analyzing**

**Techniques**
- Document Survey, Stakeholder Interview, and Network Visualization
- Questionnaire for Value Flow Scoring (Intensity, Importance, and Timing)
- Object-Process Network (OPN) or Matrix Multiplication
- Network Measurements Definition and Network Statistics Construction
BP Whiting Refinery Modernization Project

- Whiting Refinery: located in northwest Indiana, with more than 100-year history;
- Modernization Project: 2007-2012, $3.8 billion, + 1.7-million-gallon gasoline/day;
- Stakeholder Support: new water permits for increased discharge of ammonia and suspended solids, issued by Indiana Department of Environmental Management (IDEM) and EPA;
- Stakeholder Opposition: an unanticipated firestorm of protest from Public Media (Chicago Tribune, Chicago Sun-Times, etc.) and Local Public (in Illinois), concerning water permitting;
- BP finally promised to keep the lower discharge limits
- Managers’ initial Mental Model for Stakeholder Importance: Indiana State Government (IDEM) and U.S. Federal Government (EPA) are the most important stakeholders.
BP Whiting Refinery Modernization Project (WRMP)
Issue 1: Local Economic Stimulation
– Issue Map
### Issue 1: Local Economic Stimulation – 6 Stakeholders and 26 Value Flows

<table>
<thead>
<tr>
<th>To Stakeholder</th>
<th>Value Flow</th>
<th>From Stakeholder</th>
<th>Questionnaire Ranking</th>
<th>WVFO (BP-Centered)</th>
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<tbody>
<tr>
<td>BP</td>
<td>Equipment and Service</td>
<td>Contractors/Suppliers/Third Parties</td>
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<td></td>
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<td>Local Public</td>
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<td>Public Media</td>
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<td>Economic Stimulation</td>
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<td>Indiana State Gov</td>
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**Issue 1: Local Economic Stimulation**

– *Stakeholder Balance*

**Definition 1:** Blue Bars represents the total transaction value from BP to Stakeholders, while Red Bar represents the total transaction value from Stakeholders to BP;

**Definition 2:** The Left Graph shows the value of Direct transactions between BP and Stakeholders in the Hub-and-Spoke model, while the Right Graph shows the value of both Direct and Indirect transactions between BP and Stakeholders in the Stakeholder Value Network model;

**Implication 1:** For a specific balance where Blue Bar is longer than Red Bar, BP is more powerful than the Stakeholder because BP provides more value to the Stakeholder than the Stakeholder provides to BP, vice versa;

**Implication 2:** From the Hub-and-Spoke model to the Network model, the scale of transaction value generally becomes much larger because of the inclusion of Indirect transactions;

**Implication 3:** All the Stakeholder Balance comparisons are under a specific Issue (Local Economic Stimulation, General Economic Performance, Local Environmental Protection, or National Energy Security) and based on a specific model (Hub-and-Spoke or Network).
Stakeholders and Their Roles, Objectives, and Needs

Qualitative Model of Stakeholder Value Network

Quantitative Model of Stakeholder Value Network

The Solution Space of Value Paths between Any Two Stakeholders

Important Paths/Outputs/Stakeholders/Flows

Step 1: Mapping

Document Survey, Stakeholder Interview, and Network Visualization

Step 2: Quantifying

Questionnaire for Value Flow Scoring (Intensity, Importance, and Timing)

Step 3: Searching

Object-Process Network (OPN) or Matrix Multiplication

Step 4: Analyzing

Network Measurements Definition and Network Statistics Construction
BP Whiting Case: Insight – Important Stakeholders

- Weighted Stakeholder Occurrence (WSO) =

- **WSO** identifies the most important stakeholders who have the most effect on BP’s project.

- **Comparison 1 (with BP Managers’ initial Mental Model):** Public Media (pm) and Local Public (lp) are the two most important stakeholders for BP, which have been confirmed by the later facts but ignored in managers’ mental model at the beginning.

- **Comparison 2 (with the “Hub-and-Spoke” Model):** the Value Network model is closer to the later facts on important stakeholders, through considering the indirect stakeholder relationships.
BP Whiting Case: Insight—Important Value Flows

- Weighted Value Flow Occurrence (WVFO) = \[
\frac{\text{Score Sum of the Value Paths Containing a Specific Value Flow}}{\text{Sum (Score Sum of the Value Paths Containing a Specific Value Flow)}}
\]

- WVFO (and WSO) can be used as the guidance to build a smaller Stakeholder Value Network consisting of the **most important value flows** (between the most important stakeholders) to **reduce network complexity**.
Conclusions Stakeholder Value Networks (SVN)

- **Framework**: to understand the qualitative/quantitative impacts of indirect relationships between stakeholders on the success of large projects;

- **Reduced Complexity**: highlighting the important stakeholders (WSO) and the important value flows (WVFO), which can be used to construct a smaller model for more detailed analysis;

- **Strategic Insights**: identifying the critical value paths to engage stakeholders and prioritizing the high-leverage project outputs to allocate resources;

- **Transparent, Collaborative, and Alive Platform**: for different teams in a project (and for different stakeholders) to share important knowledge that is otherwise difficult to express or communicate.
Agenda for Today

- **Introductions**
  - Personal Introductions
  - Course Introduction, incl. Learning Objectives

- **Systems Engineering (SE) Overview**
  - A bit of history
  - The “V”-Model
  - SE Standards and Handbooks
  - Challenges of current practice

- **Stakeholder Analysis**
  - Identifying Stakeholders
  - CONOPS
  - Stakeholder Value Network (SVN) Analysis

- **Assignment A1**
  - 2016 CanSat Competition, Team Formation etc…
## Assignments in this class

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<td>A2 (group)</td>
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<tr>
<td>Oral Exam (individual)</td>
<td>20’ Oral Exam with Instructor 2-page reflective memorandum</td>
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2016 CanSat competition overview

- **Design-build-fly** competition, provides teams with opportunity to experience the design lifecycle of an aerospace system
  - Competition reflects typical aerospace program on a small scale
  - Competition includes all aspects of an aerospace program from preliminary design review (PDR) to post-mission review

- Competition organized by American Astronautical Society (AAS) and American Institute of Aeronautics and Astronautics (AIAA) in Burkett, Texas

- In this class:
  - Students form teams of 5
  - Over the course of the semester, teams prepare the [PDR-level design](#)
  - Internal PDR will be conducted to determine teams ranking
  - Top 3 teams from MIT and EPFL (6 teams in total) can apply to the competition
CanSat mission overview

- Mission simulates a sensor payload travelling through a planetary atmosphere, sampling it during flight.

- Overall CanSat system has 2 components:
  - **Glider:**
    - Samples air temperature and pressure at 1Hz and transmits it to the ground station.
    - Records and transmit glider position and velocity data.
    - Takes pictures when requested by ground.
  - **Re-entry container:**
    - Protects the glider during the rocket deployment phase.
    - Provides stable, less forceful release environment.

- Mission requirements given in the competition guide, uploaded on Stellar.
The payload and nose cone section are separated from the rocket. During this process, the shock chord between them pulls the rocket parachute from the rocket.

1. CanSat rests on its parachute. The nose cone parachute rests on the bottom of the CanSat.

2. When the front section tips over, the nose cone falls off and the CanSat is released from the payload section. CanSat’s parachute now inflates over it.

3. CanSat parachute

4. The CanSat, nose cone and rocket descend under parachutes.
Additional details

- Teams shall be formed among students from the same school
  - Five students per team
  - Let your TA know if you need help with team formation
  - Mixed teams (MIT/EPFL) require instructor permission

- CanSat competition registration deadline
  - Registration fee $100 sponsored by Prof. de Weck
  - CanSat building costs – max $1000, need to be fundraised by student teams participating in the competition (after this class)

- Class will have an internal PDR
  - Will provide team rankings before the competition registration deadline
PDR package contents

- PDR is a “multi-disciplined technical review to ensure that the system under review can proceed into detailed design and can meet the stated performance requirements within cost (program budget), schedule (program schedule), risk and other system constraints”

- CanSat teams shall demonstrate:
  - Understanding of the CanSat mission requirements
  - Allocation and derivation of system and subsystem requirements
  - Definition of CanSat concept of operations (CONOPS)
  - Overview of preliminary design that meets requirements
  - Results of, or identification of, necessary trades to support preliminary design
  - Results of, or identification of, necessary prototyping or testing efforts necessary to support of finalize the preliminary design
  - Preliminary budget
  - Detailed development schedule
Assignment A1 Summary

- Assigned in Session 1
- Due 2 weeks from Session 1
- Four parts:
  - 1. Team Formation – Teams of ideally 5 students (20%)
    - Teams members should be from one school, MIT or EPFL; mixed teams require permission but are not impossible
  - 2. SE Definitions (20%)
  - 3. Stakeholder Analysis (30%)
  - 4. Refined CONOPS for CanSat 2015 (30%)
- Assignment is worth 12.5% (1/8) of your grade
- One writeup per team needs to be sent as “A1_Team#_2015.pdf”
Session 1 Summary

- Aerospace vehicles and other systems are becoming more complex and need at least 3-4 layers of decomposition ("magic" number 7)

- "V"-Model of Systems Engineering is the classic approach
  - Start with Stakeholder Analysis all the way to operations and Lifecycle Management
  - Importance of stage gates (‘milestones’): SRR, PDR, CDR, FRR, PFR

- Several standards exists that codify how SE should be done (NASA, INCOSE, ISO ...)

- Systems Engineering is far from perfect today
  - Latest trend is Model-Based Systems Engineering (MBSE), accidents and overruns still happen

- Stakeholder Analysis is always the first step
  - Identify who are the key stakeholders
  - Determine their needs and CONOPS
  - Stakeholder Value Network (SVN) analysis allows ranking stakeholders, value flows and provides a quantitative basis for stakeholder management

- Next Friday: Session 2 Requirements Definition