SYSTEMS ARE CHANGING. WHAT ABOUT METRICS?

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Outline

- Human Centered Principles
- Human Capability
- Complex Systems
- Human Roles
- Metrics

Human Centered Principles

1. System demands are compatible with human capabilities and limitations

e.g. compliance with design standards, levels of force required, visibility, workload, minimizes probability of error

2. System enables utilization of human capabilities in non-routine and unpredicted situations

Makes use of unique human capabilities

Humans are more than just error generators

3. System can tolerate and recover from faults/failures/incorrect actions

Unanticipated actions can be detected, reversed or tolerated

Cognitive Processes

- Two systems
  - Fast
  - Slow
- Divisions of labor between the two systems
  - minimizes effort, and
  - optimizes performance

Suggested Reading: Daniel Kahneman (2011).
Thinking Fast and Slow.
NY: Farrar, Straus, & Giroux.

System Two (Slow)

- Allocates attention for effortful mental work
  - Focus on voice of a particular person in a crowd
  - Memorize a phone number
  - Search memory to identify a surprising a sound
  - Compute 14 * 78
  - Fill out a tax form
  - Deliberate decision making
  - Monitor and control Thinking Fast System

"When we think of ourselves, we identify with System 2, the conscious, reasoning self… Although System 2 believes itself to be where the action is, the automatic System 1 is the hero of the book". Kahneman, 2011

System One (Fast)

- Operates automatically and quickly
- Learns from both correct and incorrect responses
  - Orients to the source of a sudden sound
  - Detects hostility in a voice
  - Detects that one object is closer than another
  - Steers a car on an empty road
  - Understands simple sentences
  - Answers simple questions, e.g. 2 + 2 =
  - Avoids losses
  - Identifies causal connections between events
  - Recognizes patterns

"The situation has provided a cue; this cue has given the expert access to information stored in memory, and the information provides the answer. Intuition is nothing more and nothing less than recognition". Simon, 1992

Humans Will Adapt

- Find New Ways To Solve Problems
- Humans Can Cope with Uncertainty
- But at what cost?

- These characteristics are something we rely on
  - As individuals
  - As designers

- It is this creativity that adds reliability to complex systems

Complexity

1. Complexity arises in any system in which many agents interact and adapt to one another and their environments. - Santa Fe Institute

2. …comprised of a (usually large) number of (usually strongly) interacting entities, processes, or agents, the understanding of which requires the development, or the use of, new scientific tools, nonlinear models, out-of equilibrium descriptions and computer simulations."

   - Advances in Complex Systems Journal

3. "A system that can be analyzed into many components having relatively many relations among them, so that the behavior of each component depends on the behavior of others." - Herbert Simon

4. "…involves numerous interacting agents whose aggregate behaviors are to be understood. Such aggregate activity is nonlinear, hence it cannot simply be derived from summation of individual components behavior." - Jerome Singer

Characteristics

Complex systems Often display or contain (at some level)…

- A number of strongly coupled components or nested systems of systems, or networks
- Emergent behavior
- Sudden transitions or tipping-points
- Large events or Cascading Failures
- Limited predictability
- Evolutionary dynamics and or Self-organization
- a memory (e.g., attractors)
- Nonlinearity (part of Def.)
- Positive or Negative feedback loops
- Dynamic Complexity
- Fundamental Uncertainty

Off-nominal events can have their antecedents in unrecognized faults that have existed in the systems from design, emerge, or have been added over the life cycle

Autonomy Paradox

Dr. Blackhurst, AF HSI Chief Scientist

- The very systems designed to reduce the need for human operators require more manpower to support them.
- Growing body of experience shows that autonomous systems have not actually solve any given problem, but merely change its nature.
- Key characteristics of autonomous systems
  - Self-sufficiency—to take care of itself
  - Self-directedness—the ability to act without outside control
  - Ability to understand intent
- Design parameters of an interdependent human-machine system look very different than a machine designed to maximize autonomy
- The side effect has been to reduce autonomy, creativity and reactivity of human operators and make systems increasing brittle outside the boundaries of the normal operating envelope.

Humans Roles in Complex Systems

- Usually described as "Supervisory"
- Responsible for success of the mission
- Respond effectively to all off-nominal events

- Provide resilience
  - Anticipate
  - Monitor
  - Respond
  - Learn

What is happening today?

Human Intervention x Outcome Contingency Table

Outcome

Attributed to Human Intervention

	Not Accident	Accident	
No			
Yes			
		388	244,000,000

World-wide jet data from 2007 – 2016: 244 million departures, 388 accidents

Data and Assumptions

Jet data from 2007-2016: 244,000,000 departures 388 accidents (Boeing, 2016)

Assume 80% of accidents due to human error

Assume humans must intervene on 20% of normal flights (PARC/CAST)

Human Intervention x Outcome Contingency Table

Outcome

Attributed to Human Intervention	Not Accident	Accident
No		
Yes	20%	80%

80% of aviation accidents due, at least in part, to human error Shappell & Wiegmann, 1996

Aircraft malfunctions noted as threats and mitigated by pilots on 20% of normal flights (PARC/CAST, 2013)

Data and Assumptions

Jet data from 2007-2016: 244,000,000 departures 388 accidents (Boeing, 2016)

Assume 80% of accidents due to human error

Assume humans must intervene on 20% of normal flights (PARC/CAST)

Human Intervention x Outcome Contingency Table

Outcome

Attributed to Human Intervention	Not Accident	Accident	
No	195,199,690	78	195,199,768
Yes	48,799,922	310	48,800,232
	243,999,612	388	244,000,000

Investigated

Poorly understood

Data and Assumptions

Jet data from 2007-2016: 244,000,000 departures 388 accidents (Boeing, 2016)

Assume 80% of accidents due to human error

Assume humans must intervene on 20% of normal flights (PARC/CAST)

Air Transat Flight 236, Azores Islands

❖ About 4 hours into the flight, crew looked at a secondary display to check engine status.

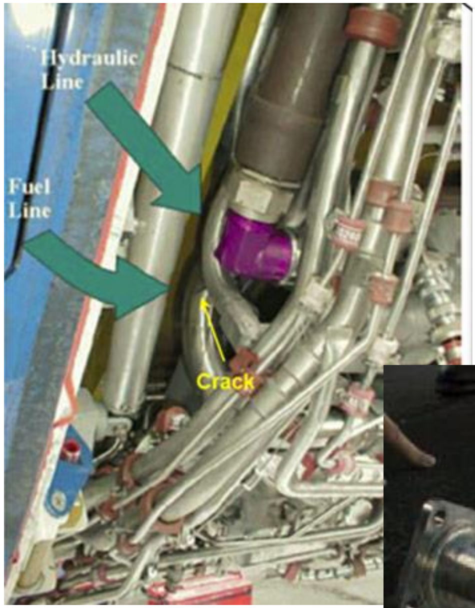
	Left Engine	Right Engine
Oil temp (°C)	110	65
Oil pressure (psi)	80	150
Oil quantity (L)	18.2	14.5

❖ 30 minutes later a fuel imbalance warning

❖ Engine displays showed normal fuel-flow as fuel enters engine

❖ Incident was a fuel leak caused by incorrect part being installed in hydraulics system.

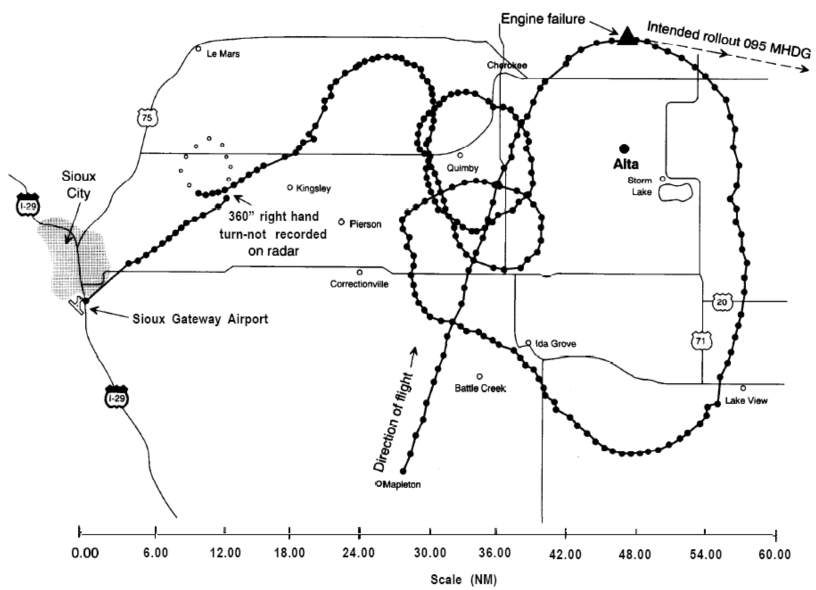
❖ The on-board computer now checks all fuel levels against the flight plan, and provides a warning if fuel is decreasing faster than expected



http://lessonslearned.faa.gov/ll_main.cfm?TabID=4&LLID=73&LLTypeID=2

United Airlines Flight 232

- Fan disk in engine failed and disintegrated
- Pieces penetrated the aircraft's tail
- Punctured all three hydraulic systems
- There were no procedures for landing without hydraulics



- 185 passengers and crew survived

https://www.ntsb.gov/investigations/AccidentReports/Reports/AAR-90-06.pdf

US Airways Flight 1549

On January 15, 2009, as U.S. Airways Flight 1549 climbed to cruising altitude after a take off from LaGuardia airport, the aircraft encountered a flock of migratory geese.
At 3,200 feet, both aircraft engines, operating at 80% fan speed, sucked several geese through their inlets.
At least one goose impacted and destroyed each engine's core, abruptly terminating engine capability to generate useable thrust.

The Captain immediately assumed control and activated the auxiliary power unit (APU).
The First Officer started the Dual Engine Failure Checklist, attempting to relight the engines.
Air Traffic Control (ATC) began relaying instructions for landing at LaGuardia or Teterboro airports, but the captain saw the Hudson river as the only viable landing option.
The aircraft entered alpha-protection mode at 150 feet and skidded onto the water 3 minutes after the birdstrike.

External pressure from the impact tore the rear fuselage apart, and water gushed through the opening, rendering rear exits and slide/rafts useless.
With only the forward emergency slide/rafts available, passengers were forced to evacuate onto the airplane wings.

Rescue vehicles arrived within 5 minutes of the ditching, and the last passengers were rescued 20 minutes later.

Humans enable system resilience

- Humans are flexible, creative, and adaptable.
- We have a vast set of skills acquired over a lifetime of trial and error.
- We successfully live and adjust to the ever changing, complex natural and social environments.
- We successfully work and adapt to complex engineered environments and technologies.
- Human performance needs to be understood in these contexts, with the understanding that new environments and new missions may require novel approaches to support human performance.

Time to Complete Tasks Standard

- **5.2.1 Time and Performance [V2 5005]**

  Effective task performance includes timeliness and accuracy: the task is to be performed successfully within an appropriate time frame to meet mission objectives.

  The ability to perform tasks in a timely and accurate manner **shall** be accommodated in the design of all system elements that interface with the crew for all levels of crew capability and all levels of task demands.

- Can be operationally critical
  - Initiate an abort
  - Change from automation to manual functions
  - Complete all steps required by system in time
- Difficult to write requirements and verifications prior to task analyses/designs

Information Standard

- **5.2.2 Situational Awareness [V2 5006]**

  SA refers to the process and outcome of understanding the current context and environment, evaluating that situation with respect to current goals, and projecting how that situation will evolve in the future.

  Systems **shall** be designed such that the SA necessary for efficient and effective task performance is provided and can be maintained for all levels of crew capability and all levels of task demands.

- Can be operationally critical

- Difficult to write requirements and verifications prior to task analyses/designs

Human-in-the-loop Testing and Metrics

- Often focuses on nominal operations
- Off-nominal tests are for events documented in checklists

- Metrics
  - Workload
  - Time to complete tasks
  - Errors
  - Situational Awareness
  - Satisfaction

Number of Events N Needed to Obtain Reliable Estimates of Human Error Probabilities when 0 errors occur

	Confidence level	
P_E	P_C = 80%	95%
0.1	16	30
0.01	160	300
0.001	1,600	3,000
0.0001	16,000	30,000
0.00001	160,000	300,000

Number of Events Needed to Obtain Reliable Estimates of Human Error Probabilities when 1 error occurs

	Confidence level	
Human error probability	80%	95%
0.1	29	46
0.01	300	475
0.001	3,000	4,750
0.0001	30,000	47,500
0.00001	300,000	475,000

System Level Metrics--What will be needed?

- Complex systems will require new approaches
  - From Modeling the systems
  - To Enabling mission resilience
- New interdependencies among operational elements will reduce resilience of the overall system and cause system performance to degrade precipitously.
- Future complex systems require humans and machines to work together in ways that have not been identified.
- Understanding human capability and designing missions to take advantage of it, remains critical
- Existing testing methods do not scale to these new challenges.
- Integrated Human-System V&V methods, tools, human-system models and system level performance measures for complex designs and emerging operations.