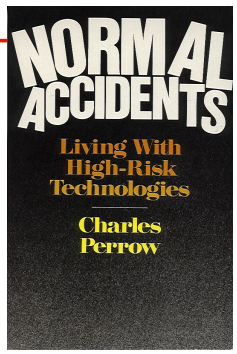
Vicente's Human-tech solution

1. We must address both parts, Human and tech
2. We must focus on the interactions
3. Human comes first
4. Human nature is the key constraint
5. Human-tech renders the hi-tech/low-tech contrast irrelevant

Vicente's three-fold problem (HF pg 33)

Complex hard technology
Unhelpful soft technology
And it's getting worse

Complexity, Coupling, and Catastrophe



Perrow's Predictions (1984)

Before 1984	Since 1984
Three Mile Island	Chernobyl
Petrochemical	Bhopal
Teneriffe, etc.	Singapore 006, etc.
Torrey Canyon	Exxon Valdez, etc.
Gemini, Apollo 13	Challenger, Columbia
HMS Canberra	Vincennes, Gulf War, Iraq, Afghanistan…

System elements

Part (a single component)	Tank insulation, leading edge wing panel
Unit (a functionally related collection of parts)	External tank, wing
Subsystems (an array of units)	Fuel system, heat protection system
System	Space shuttle

Incident

Damage limited to parts or a unit, whether the failure disrupts the system or not.
There are many more incidents than accidents.

Examples:
- Heart attack
- Engine failure
- Flat tire
- QB hurt

Accident

A failure in a subsystem or the system as a whole, that damages more than one unit and in doing so disrupts the on-going or future output of the system.

- Car crash
- Players strike

Component Failure Accident

One or more component failures (part, unit, or subsystem) that are linked in an anticipated sequence.

1. Fuel tank leak
2. Fuel pump runs dry
3. Carburetor fails to mix fuel and air
4. Engine stops
5. Power steering fails

System (Normal) Accident

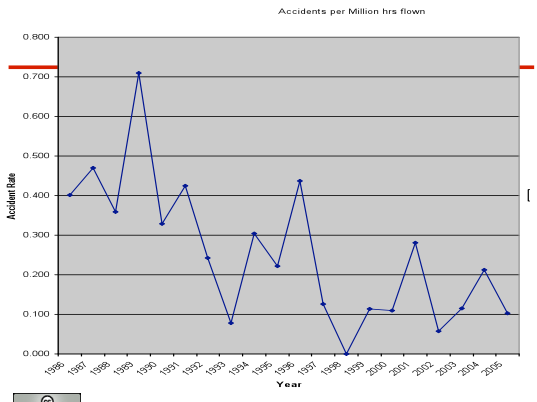
An accident involving unanticipated interactions among multiple failures.

Victims

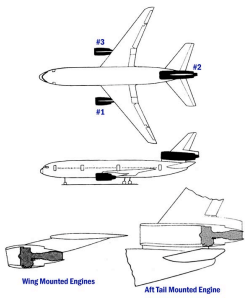
First party (operators)
Second party (non-operating system personnel or system users)
Third party (innocent bystanders)
Fourth party (fetuses and future generations)

Complex Systems

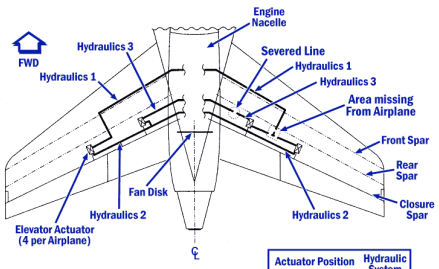
Proximity of components	DC10 #2 engine and hydraulics
Common-mode connections	Heat exchangers
Interconnected sub-systems	Maneuvering and radar "seeing"
Limited Substitutions	
Feedback loops	Fires, PIO
Multiple and interacting controls	Helicopters, global economic system
Indirect information	Radar, spacecraft telemetry, battlefield intel
Limited Understanding	Environment,



Proximity of components (United Airlines 232, July 1989)



Proximity of Components



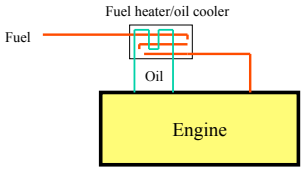
Actuator Position	Hydraulic System
RH Inbd Elev	1 & 3
LH Inbd Elev	2 & 3
RH Outbd Elev	1 & 2
LH Outbd Elev	1 & 2

Not to Scale

Complex Systems

- Proximity of components
- Common-mode connections
- Interconnected sub-systems
- Limited Substitutions
- Feedback loops
- Multiple and interacting controls
- Indirect information
- Limited Understanding
- DC10 #2 engine and hydraulics
- Heat exchangers
- Maneuvering and radar "seeing"
- Fires, PIO
- Helicopters
- Radar, spacecraft telemetry, battlefield intel
- Environment,

Common-mode connections



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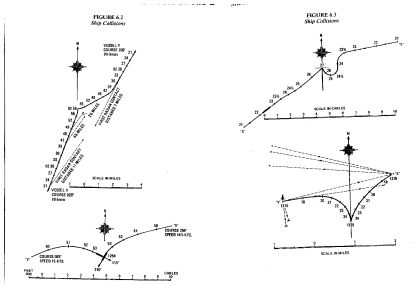
Ship surface radar displays

Radar Assisted Collisions



Complex Systems

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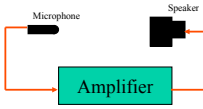
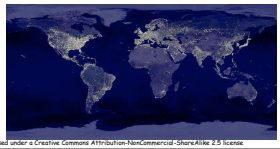
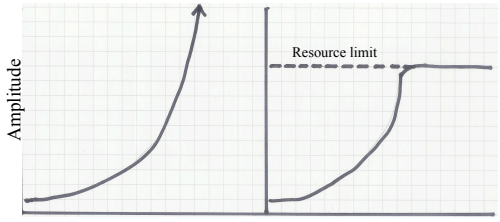
Some Positive Feedback loops



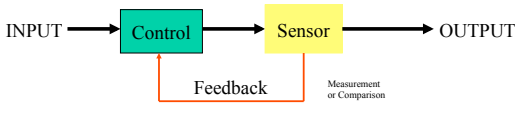
- Fires
- Washboard roads
- Structure of the universe
- Coral branching
- Cities



Response characteristics of positive feedback loops

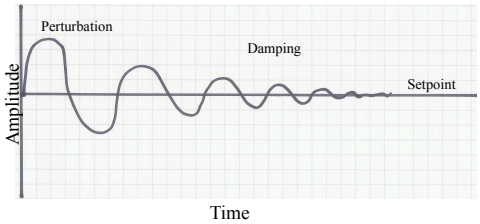


Typical Negative Feedback loop

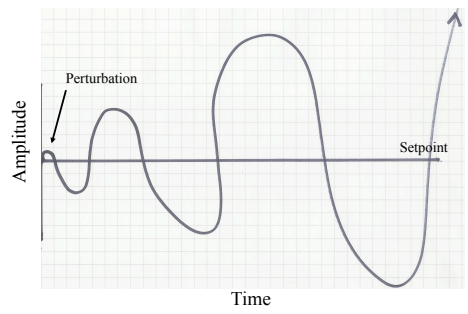


Thermostat
Homeostasis in the human body
Airliner yaw damper

The desired response characteristic of a negative feedback loop

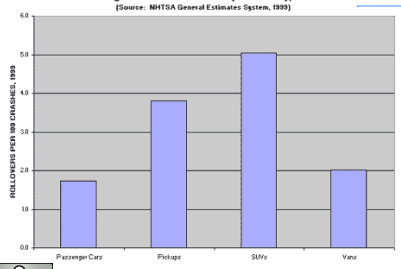


The response characteristic of a negative feedback system with gain too high

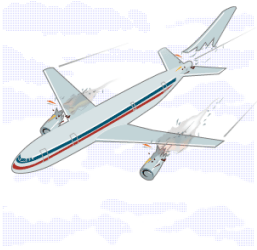


SUV Rollovers

Figure 4. Rollover Rate by Vehicle Type
(Source: NHTSA General Estimates System, 1999)



A300 Rudder Control with Pilot Induced Oscillation



Feedback loops produce non-linear response characteristics.

Complex Systems

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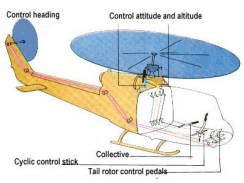
Feedback loops	Fires, PIO
Multiple and interacting controls	Helicopters, economic systems
Indirect information	Radar, spacecraft telemetry, battlefield intel
Limited Understanding	Environment,

Multiple interacting controls



Economic controls
- Tax rates
- Interest rates
- Money supply
- Wage caps
- Etc....

Complex Systems

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Feedback loops	Fires, PIO
Multiple and interacting controls	Helicopters, social systems
Indirect information	Radar, spacecraft telemetry, battlefield intel
Limited Understanding	Environment,

Indirect information

Complex Systems

Proximity of components	DC10 #2 engine and hydraulics
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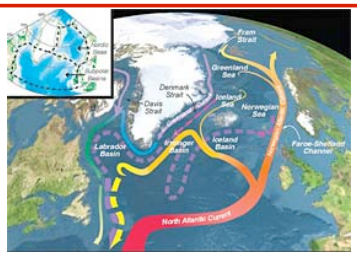
Limited Substitutions	
Feedback loops	Fires, PIO
Multiple and interacting controls	Helicopters, social systems
Indirect information	Radar, spacecraft telemetry, battlefield intel
Limited Understanding	Environment, politics, …

Limited understanding



A map of Nordic seas and subpolar basins shows the circulation of surface currents (solid curves) and deep currents (dashed curves) that form a portion of the Atlantic Meridional Overturning Circulation. Much like a conveyor belt, the climate-regulating ocean pattern transports warm surface waters toward the north and cool, deep waters toward the south.

Illustration by Jack Cook, Woods Hole Oceanographic Institution

Linear Systems

Spatial segregation
Dedicated connections (not common-mode)
Segregated sub-systems
Easy Substitutions
Few feedback loops
Single purpose controls
Direct information
Extensive understanding

Cognitive consequences of the properties of Complex Systems

Proximity of components	Unexpected interactions
Common-mode connections	Unexpected interactions
Interconnected sub-systems	Unexpected interactions
Limited Substitutions	Small space of solutions
Feedback loops	Non-linear behavior
Multiple and interacting controls	Unexpected interactions
Indirect information	Unexpected interactions
Limited Understanding	Limited Understanding

Specialization and knowledge

"Specialized personnel tend not to bridge the wide range of possible interactions…"
Does anyone know how the system works?
Is there any one person who can understand the complex interactions of the entire system.

Tight Coupling

Delays in processing not possible
Invariant sequences
Unifinality (only one way to do the job)
Little slack
Buffers designed-in
Substitutions designed-in

Loose Coupling

Processing delays possible
Order of sequences can be changed
Alternative methods available
Slack in resources
Buffers and redundancies fortuitously available
Substitution fortuitously available

Progress and complexity

In the interest of efficiency, scientific management eliminates redundancy, buffers, delays and slack.
In tightly coupled systems, effects propagate quickly.
Automation reduces delays, flexibility, slack, and understanding.
Automation increases complexity.

The "invisible hand" of progress produces more complex, more tightly coupled systems.

Fundamental tradeoffs

Speed/accuracy
Speed/safety (highway speed limits)
Productivity/safety (production pressure)
Efficiency/robustness (tight coupling)
Complexity/understanding