National Aeronautics and Space Administration

Modeling for Integrated Science Management and Resilient Systems Development

HRP Investigators' Workshop
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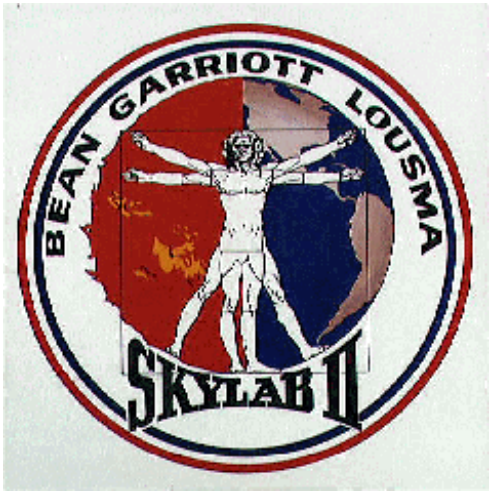
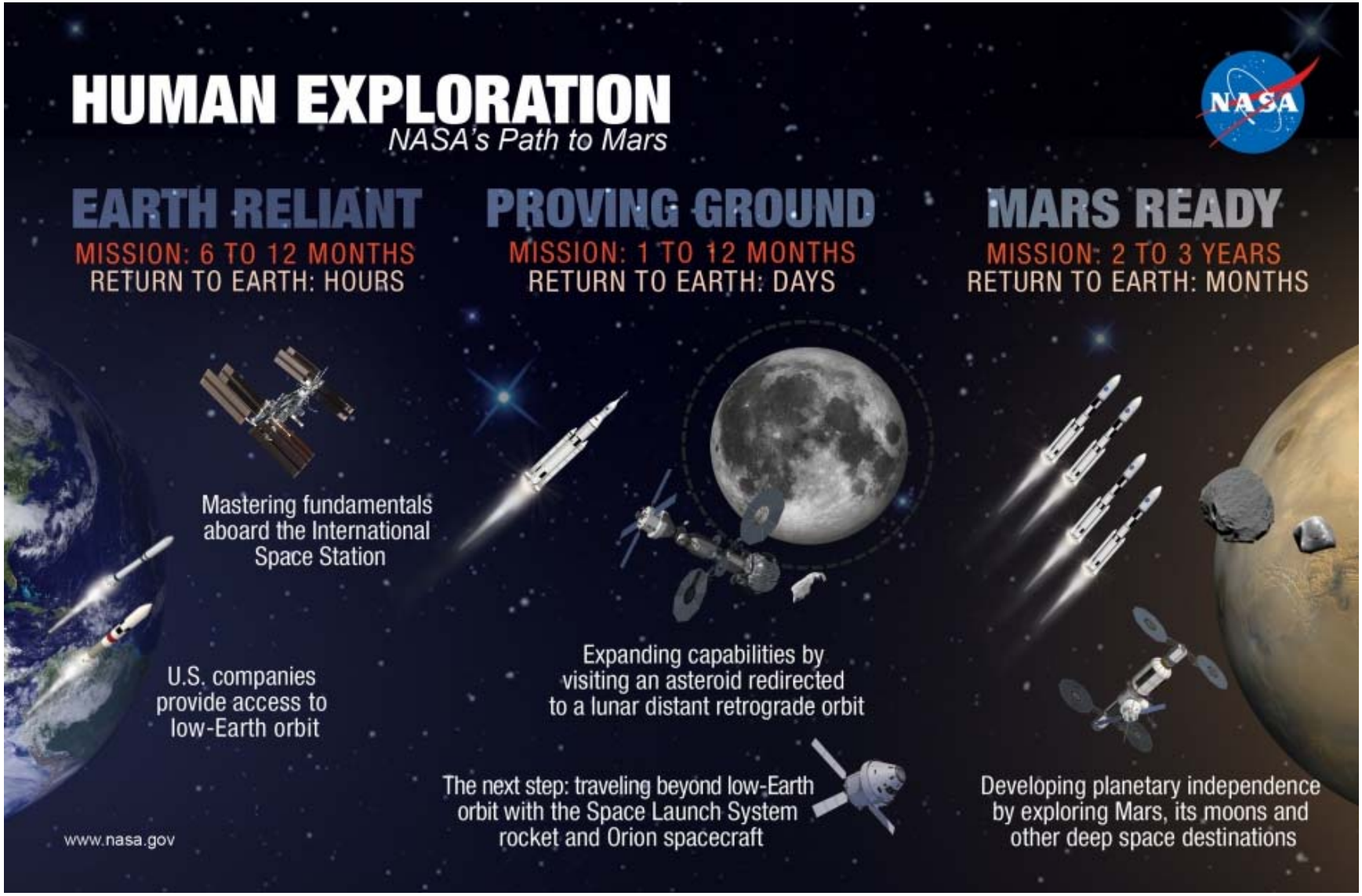
The Big Picture

- Need to better understand human adaptation to space
  - ✓ Provide better countermeasures
    - Integrated approaches to minimize mission resources (mass, power, crew time, etc.)
  - ✓ Provide tools for autonomy
    - Assess and maintain resilience – individual and team



Destination - MARS



Space Flight Affects Humans

- Affects most systems of the body
  - Sensorimotor, Cardiovascular, Muscle, Bone, Immune
- Different time courses and magnitudes
- Consequences for health *and* performance (physical *and* behavioral)
- Responses commonly explored individually
- Systems interact in ways we do not yet understand
- Adaptation to “space normal” occurs

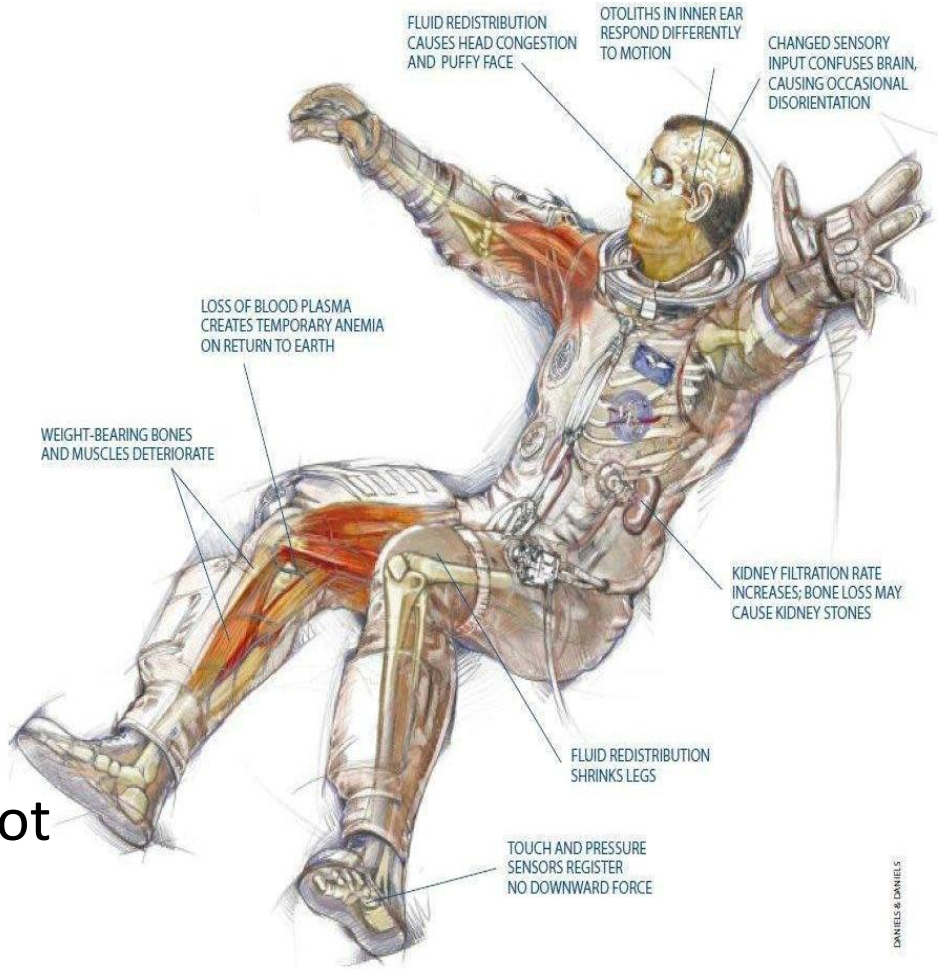


Image from: http://zerog2002.de/bodyreactions.html

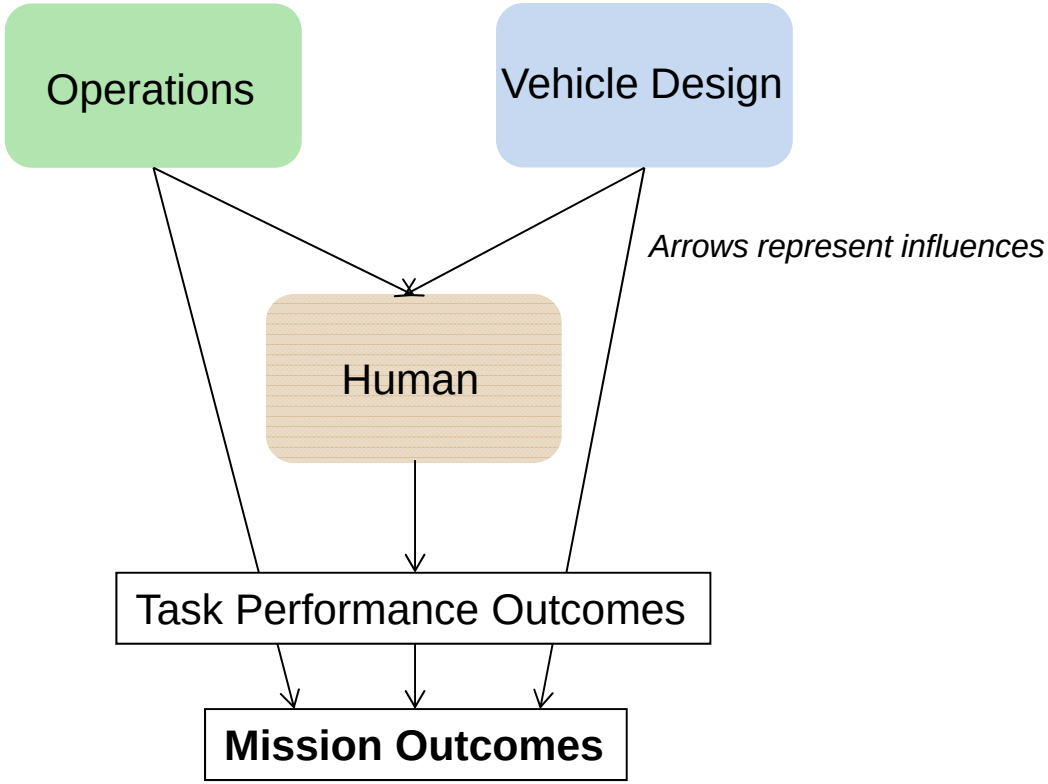
Need *integrated* understanding of how organism as a whole responds to spaceflight

Overview

- System-of-Systems Approach
- Complex Systems
- Networks to Model Systems
- Initial Applications Relevant to HRP Science Management
- Future Efforts

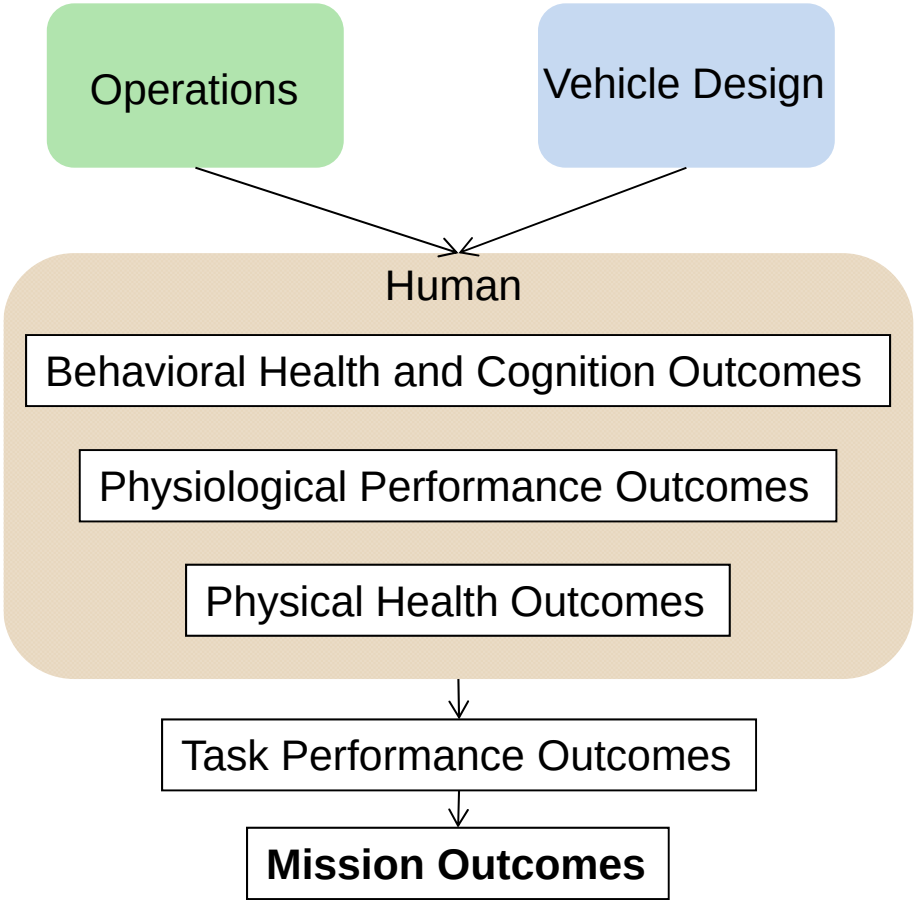
System-of-Systems Framework

- Common goals of safe, reliable, and productive human space flight
- Whether focus is on Operations, Vehicle Design or the Human System
- All interact as a system of systems



Outcomes within Human System

- In the Human System, HRP supports the protection of additional outcomes



Contributing Factor Map

Factors Influencing Human Health and Performance in Space

Socio-Technical Domain Key:

- Operations
- Vehicle Design
- Human

Task Planning and Scheduling | **Shift Scheduling** | **Mission Planning** | **Organizational Support**

Training Quality | **Crew Collaboration Quality**

Vehicle Physical Environment | **Vehicle Architecture** | **Habitability**

User Interfaces | **Quality of Procedures**

Time Context | **Task Familiarity** | **Work Load**

Behavioral Health Outcomes

Situational Awareness | **Cognitive Adaptations** | **Psychological Conditions**

Physiological Performance Outcomes

Physiological Adaptations

Physical Health Outcomes

Injury or Illness Conditions

Existing Physical Conditions

Above factors can influence task performance:

Task Performance Outcomes

OBSERVATION | INTERPRETATION | PLANNING | EXECUTION

Above factors and task performance can influence mission performance:

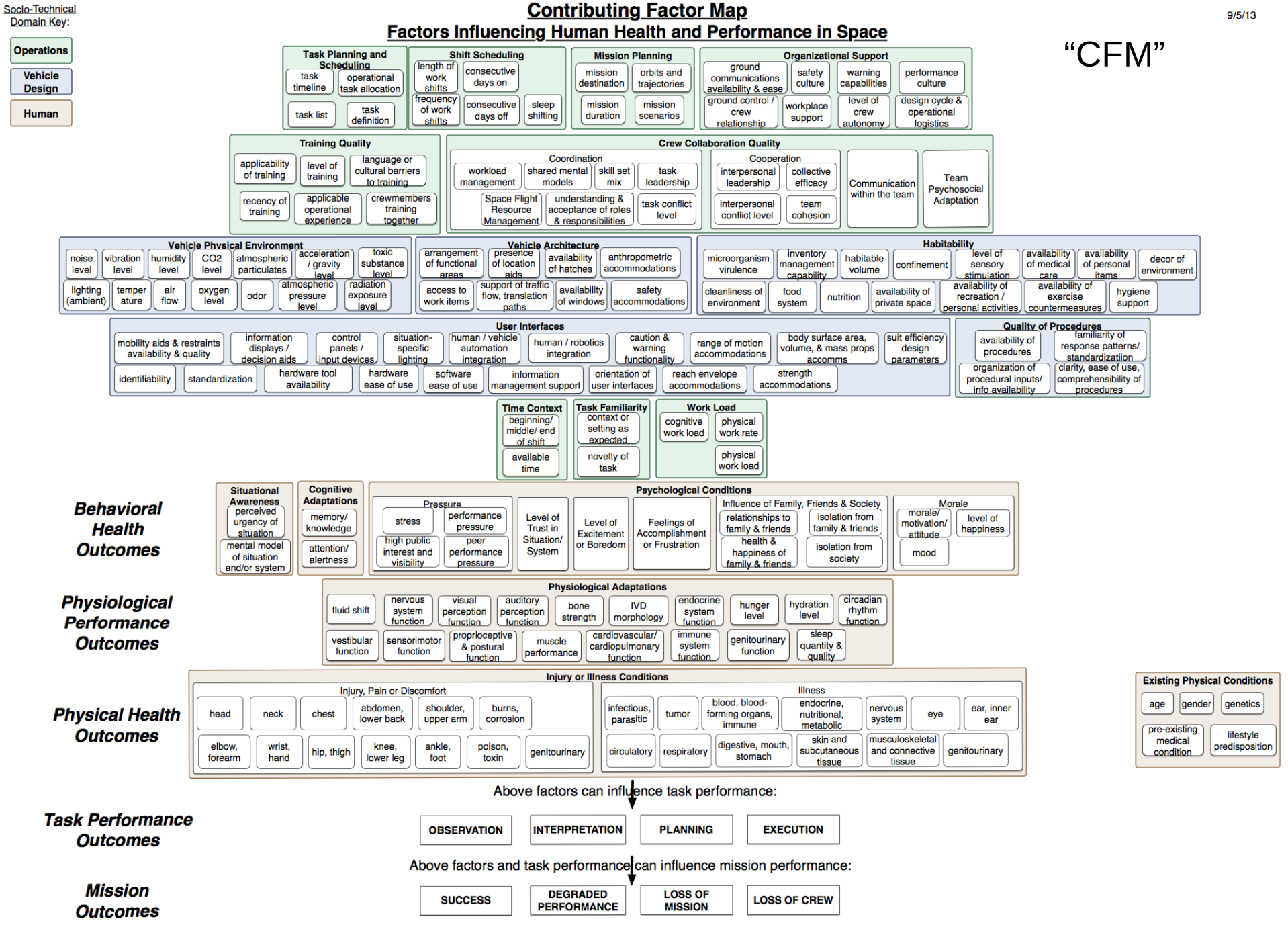
Mission Outcomes

SUCCESS | DEGRADED PERFORMANCE | LOSS OF MISSION | LOSS OF CREW

Adapted from Mindock, J., *Development and Application of Spaceflight Performance Shaping Factors for Human Reliability Analysis.* University of Colorado, Boulder, CO, 2012.

Contributing Factor Map
Factors Influencing Human Health and Performance in Space

"CFM"



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Complex Systems

What makes a system complex (not just complicated)?

- Many interacting objects or parts (e.g., factors from CFM)
- Whole > sum of its parts
  - Reductionist view not sufficient to capture system's behavior (e.g., weather systems, financial markets, Mars mission human/vehicle/ops system)
- Emergent behavior
  - Behavior or properties individual parts do not have
  - Fractals are an example of emergent output
- Resilience/adaptation capabilities
  - Certain aspects of the system can be altered without global effects
- Self-organizing
  - Parts not controlled by master controller
  - Parts compete for limited resources
- Behavior of parts affected by feedback – temporal and/or spatial
  - Feedback in time due to memory
  - Feedback in space due to **network** connections

References: Mitchell, M. *Complexity, A Guided Tour.* 2009.; Johnson, N. *Simply Complexity.* 2007.

Networks to Model Systems

- Why use networks to study Complex Systems?
  - Capture relationships between parts of system
  - Look at properties (e.g., structure) of networks for assessment, prediction, and possible prevention of unwanted outcomes
- Example network structure: Small World Networks
  - Shown to have increased speed of signal propagation

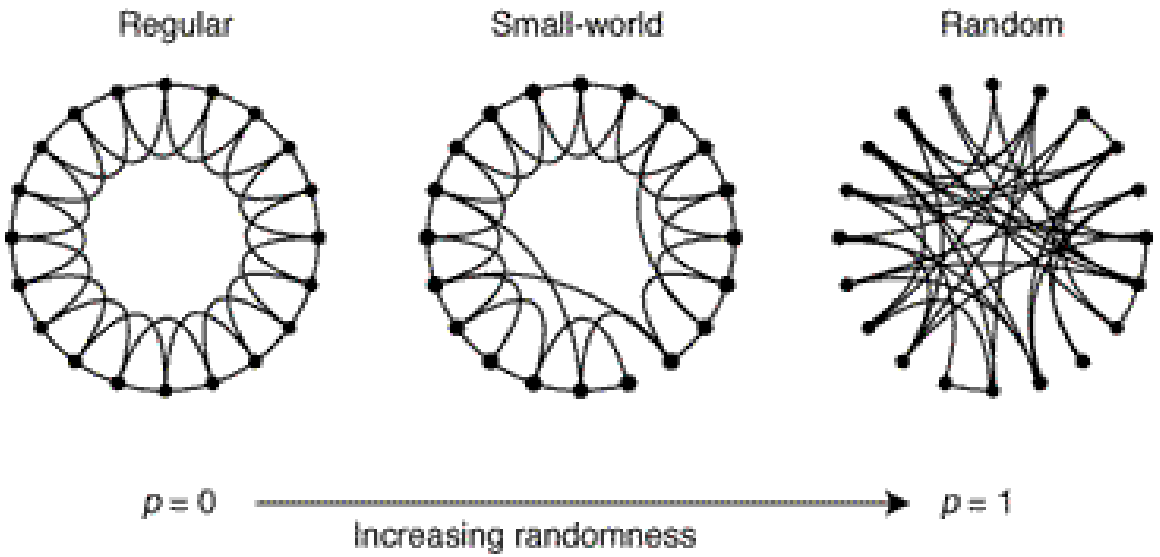


Fig. 1 from: Watts and Strogatz, "Collective dynamics of 'small-world' networks," *Nature*, vol. 393, p. 440-442, 4 June 1998.

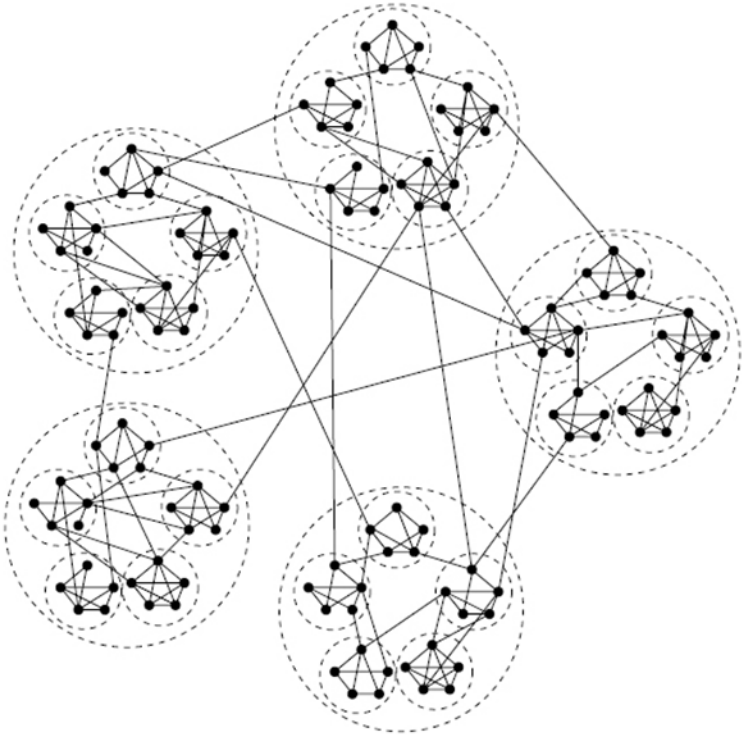
Our Network Applications

- We can model our complex system (with human, vehicle design, and operations aspects) as a network
- Use CFM as the system-of-systems framework of variables or parts
- Look at properties of networks modeling our complex system to determine if there are ***characteristics to enhance, such as connections to create or strengthen***
- Ties back to goal of providing better countermeasures based on ***integrated perspectives***

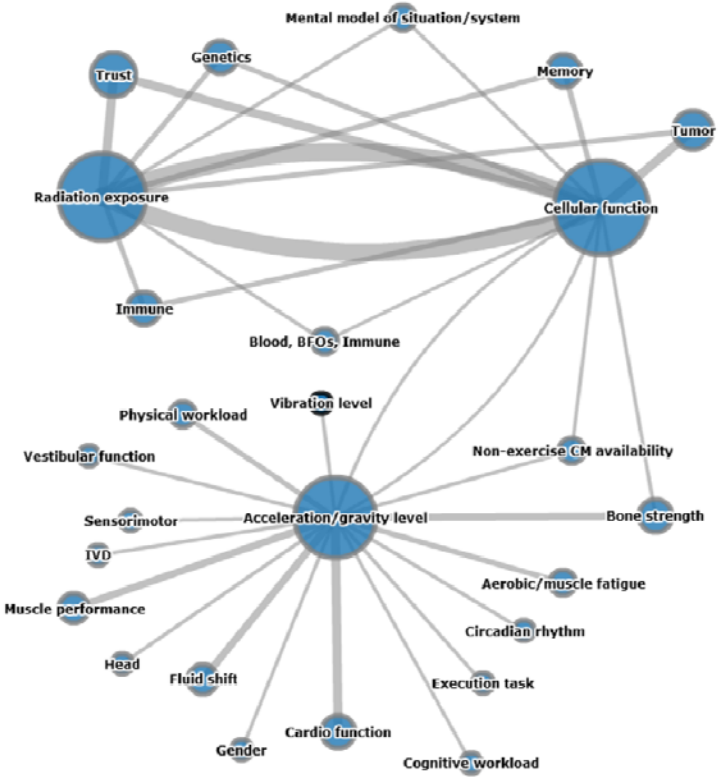
Initial Efforts

- Developing visualizations of linkages between topics covered by existing NASA Human Research Program work based on publication records

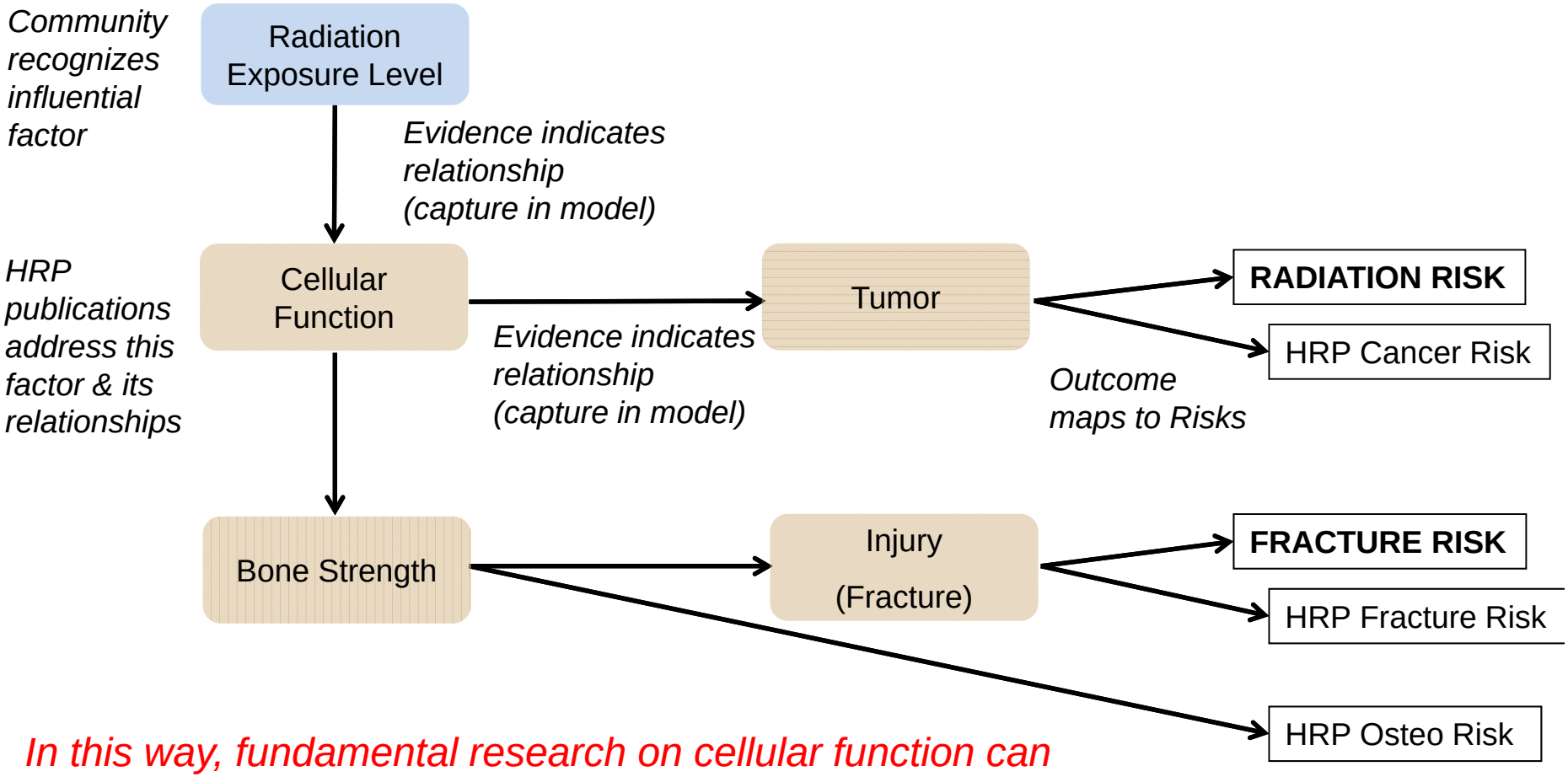
Small World Network conceptual example



Proof-of-concept network based on a subset of HRP publications



Future: Identify Influential Parts in Networks



- *In this way, fundamental research on cellular function can be shown to support multiple Risks.*
- *Additional **collaborative research** may be needed to address **important factors and relationships**.*

Future: Promote Resilience, Prevent Unwanted Outcomes

- Analyze behavior (resilience of system) when various nodes are removed or altered
- Potentially map time-series data to network representations
  - Compare “healthy” vs. “unhealthy” systems
  - Could enable monitoring to assess, predict, and prevent

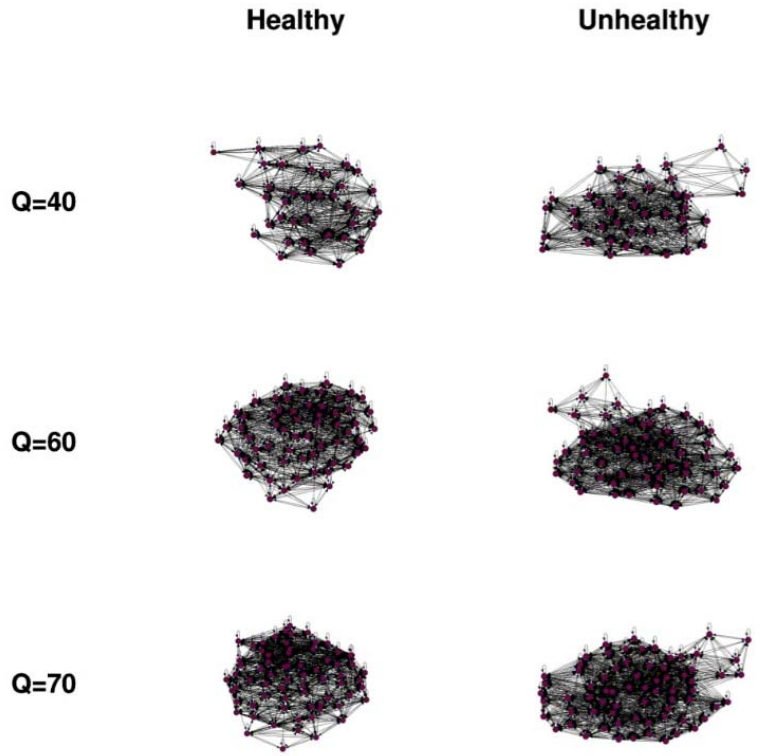


Figure 7 from: Campanharo, ASLO; Sirer, MI; Malmgren, RD; Ramos, FM; Amaral, LAN. *Duality between Time Series and Networks*, PLoS ONE, Aug. 2011.

Application of the proposed forward map to the heart rate time series using different number of quantiles. doi:10.1371/journal.pone.0023378.g007

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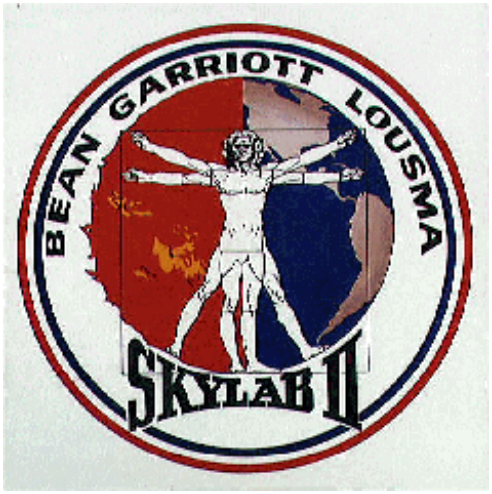
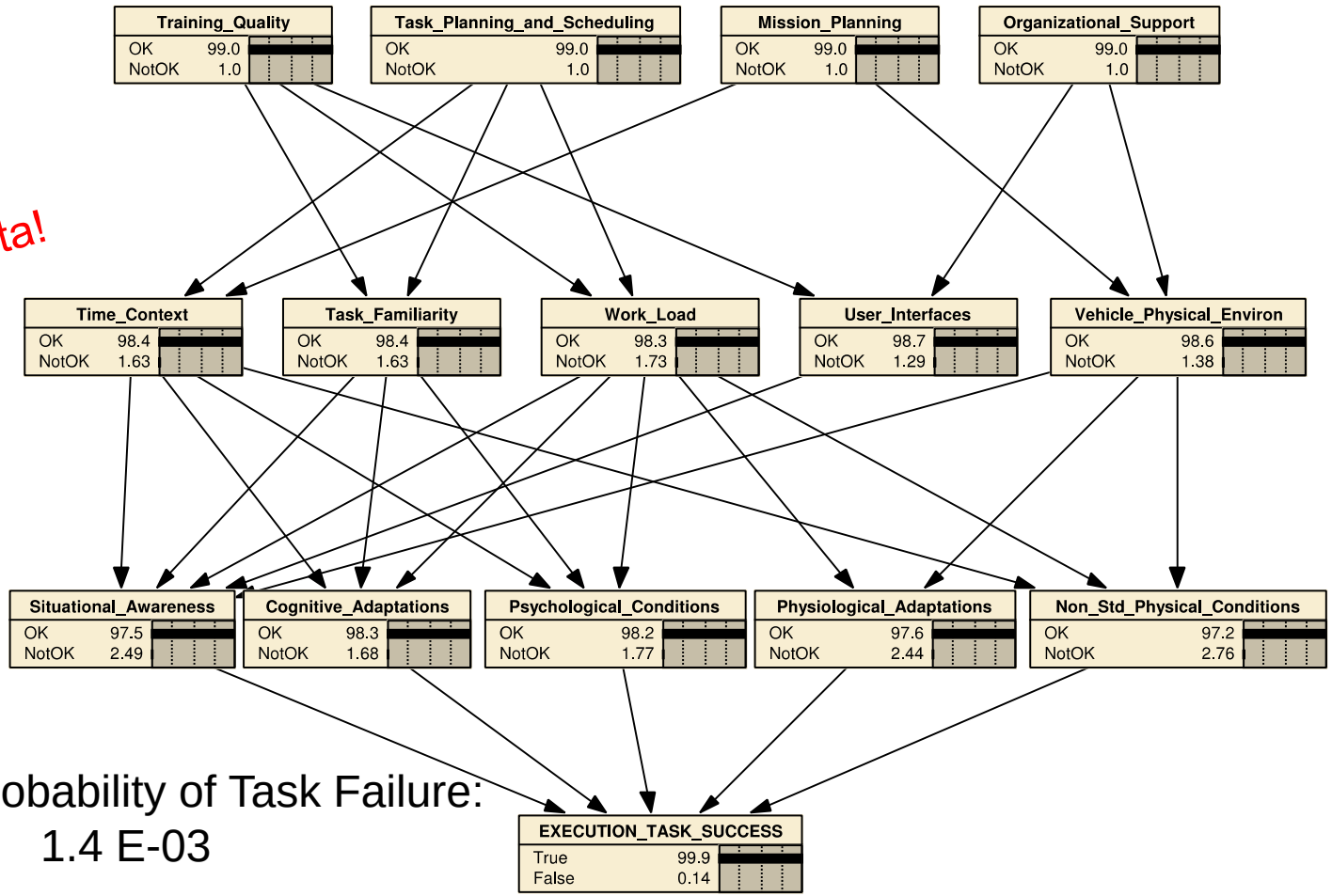


BACKUP

Conceptual Approaches - Networks

Sensitivity analysis on a Bayesian Network model such as this can be performed to identify areas of high influence.

Not real data!



Example Probability of Task Failure:
1.4 E-03

Diagram created with NETICA™ by Norsys.