Risk Mapping and Interaction Approach: A Special Session for HSRB Risk Custodians

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HRP IWS

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Session Objective and Outline

To discuss how to strategically update the Human System Risk process to highlight and flush out the linkages between risks, contributing factors, and countermeasures in a useful way

1. Erik – Overview and Needs
2. Rob – Visualization, DAGs and Networks
3. Q&A

Definitions

Here are some definitions:

- **Risk** – the probability (likelihood) and magnitude (consequence) of a loss, disaster, or undesirable event

  Mathematically this looks like: $Expected\ Loss = \sum_i P_i * C_i$

- **Risk Management** – the identification, assessment, and prioritization of risks followed by coordinated and economical application of resources to minimize, monitor, and control the probability and/or impact of unfortunate events

- **Human System Risk** – a recognized and tracked potential NASA flight-crew health or performance risk that has a defined **consequence** and associated **likelihood** supported by **evidence** which applies to a particular **DRM**.

Other 'risks' that the agency holds – programmatic and institutional risks - are outside the scope of this discussion.

A basic fact

No one is satisfied with the way we are handling risks.

Dissatisfaction with the Risk Approach

- Archiving in Powerpoint is inappropriate.
- We fail to consider the known and suspected links between risks.
- We have a rudimentary prioritization system.
- We don’t leverage our knowledge as well as we could to improve decisions.
- We don’t leverage software to manage our data and knowledge.

Problems

HSRB has the responsibility to set Human System Risk Posture and recommend targets for risk mitigation efforts.

- **Problem 1** – We need to inform Risk Posture based on an understanding of the effects of and linkages between contributing factors and countermeasures. *At this time, those are only written out on a set of Powerpoint slides.*

- **Problem 2** – We need to inform Risk Posture based on operational endpoints. *When we approach risks in a silo, we often fail to identify 'how much' they contribute to the operational endpoints of interest.*

- **Problem 3** – We need to have a transparent and repeatable method to prioritize Risks on the basis of DRMs and known or suspected Risk-Risk interactions. *At this time, we prioritize based on what is red.*

Problems *(cont'd)*

- **Problem 4** – We need to succinctly communicate our understanding of the Risk Posture crews face. *If we get too granular in our visualization or communication, we fail in communicating.*

- **Problem 5** – We need to improve our decision velocity. *We don't leverage software to track, catalog, and inform decisions.*

- **Problem 6 –** Money is always a problem. *There has historically been a lack of funding for HMTA work*

- **Problem 7 –** We are not writing down what we know. *There is lack of organization to leverage critical SME inputs*

What can we do?

There are a number of ways we are trying to improve our systems:

- ✓ Updating the HSRB Risk Management Plan – clearly define DRMs, 5x5 Risk Matrix, Levels of Evidence guidance, Risk Objectives Hierarchy, Risk Prioritization Principles
- ✓ Articulate clear expectations for what is likely to improve risk color
- ✓ Asking risk stakeholders to bring forward their deliverables and risk mitigation plans
- ✓ Explore Software tools for categorizing, relating, mapping and visualizing risks (Architex)

- ❖ Drawing, tracking, and using the links between risks and risk factors that we know or think we know?

History

There have been attempts to set up communication and visual tools and framework to understand risk relationships

- Risk Management Analysis Tool (RMAT)

Database format to understand Human System Risks and compare standards, requirements, mitigation strategies, etc. against known mission architectures and resources.

Sample RMAT for EVA Risk (2013)

Adobe Acrobat Document

Human Systems RMAT

Record Entered: 2010-09-20 14:22 PDT
Last Modified: 2013-02-28 09:33:07 PST

Record 42 (MRL-8a) — DRAFT
Risk of Compromised EVA Performance Due to Inadequate EVA Suit Systems

1. Basic Information

Reporter:	Michelle Edwards (medwards@wylehou.com)
Custodian:	Steven Patrick Chappell (steven.p.chappell@nasa.gov)
CC:	elkin.romero-1@nasa.gov, steven.p.chappell@nasa.gov
Risk Statement:	Given that past Extra Vehicular Activity (EVA) Suit Systems have presented signficant limitations and challenges for suited crewmembers, there is a possibility that new suit designs and EVA systems could limit crew efficiency in performing mission objectives, resulting in increased timelines.
Context:	Performance of space flight EVA consists of placing a human in a micro-environment which must provide all the life support, nutrition, hydration, waste, and consumables management functions of an actual space vehicle, while allowing crewmembers to perform as close as possible to the 1-g shirt-sleeved environment. Improperly designed EVA suits and systems can result in the inability of the crew to perform as expected, and can cause acute and long-term adverse impacts to crew health or mission objectives.
IRMA Cross-Reference:	No information listed.
Mission Applicability:	Asteroid, Lunar Sortie, Lunar Outpost, Mars
Operational Phase:	Transit, Surface Operations/On Orbit
Verification Status:	Verified
Adverse Event:	Exhaustion/fatigue, poor EVA work efficiency, inability to complete mission objectives
Relevance to Exploration Medical Condition List:	No information listed.
Level of Evidence:	Case Study, Spaceflight Incident, Terrestrial Data
Explanation of the Level of Evidence:	Historically, there have been very few incidents of EVA termination and most have been due to mechanical issues rather than human performance. But the operational concepts of Exploration indicate that there will be significantly more EVAs during Exploration class missions and these will be to unknown destinations, with unknown suit designs to do unknown tasks. It is likely that the frequency and intensity of EVA will increase and the per EVA duration will decrease.

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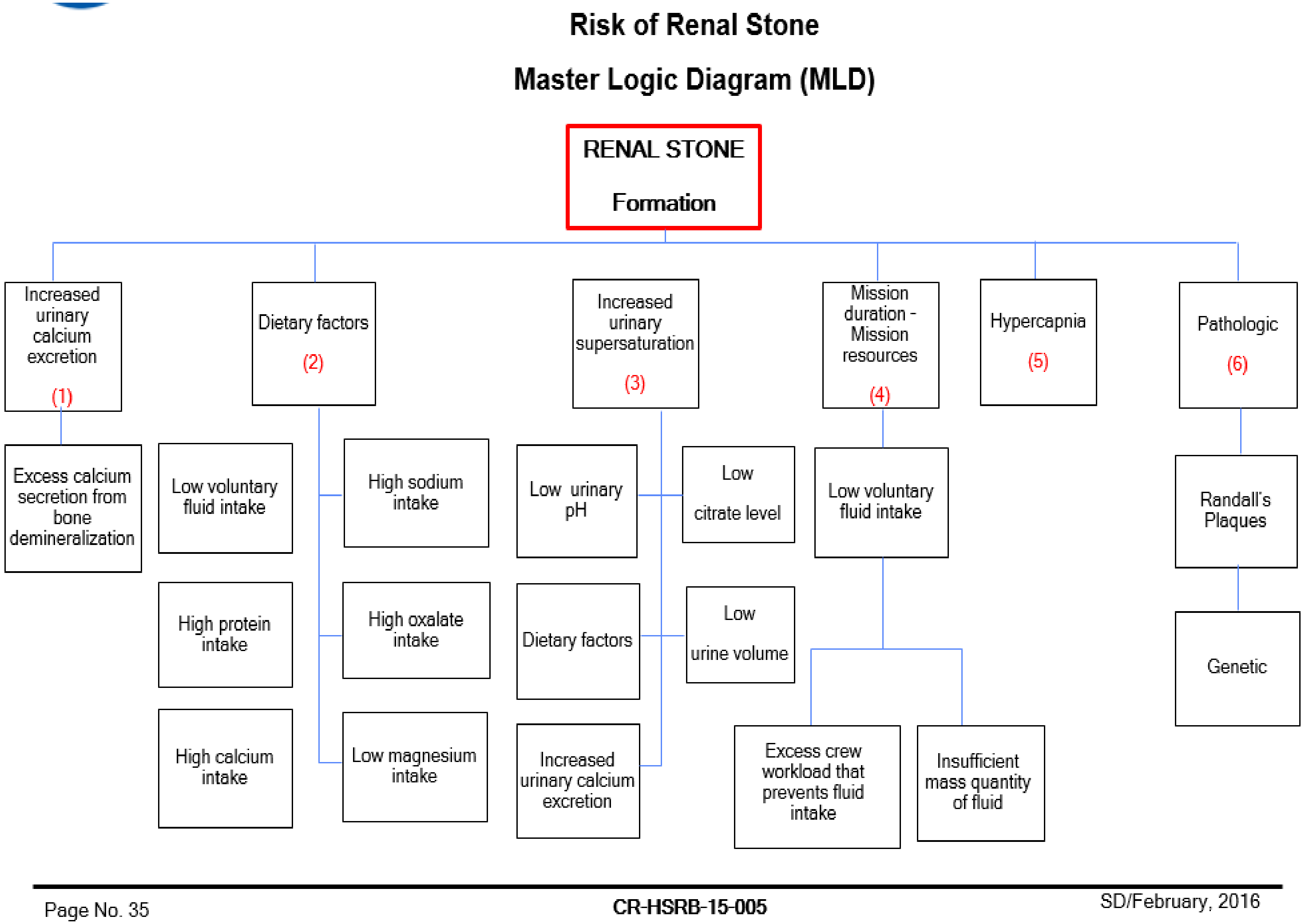
History *(cont'd)*

❖ Master Logic Diagram (MLD)

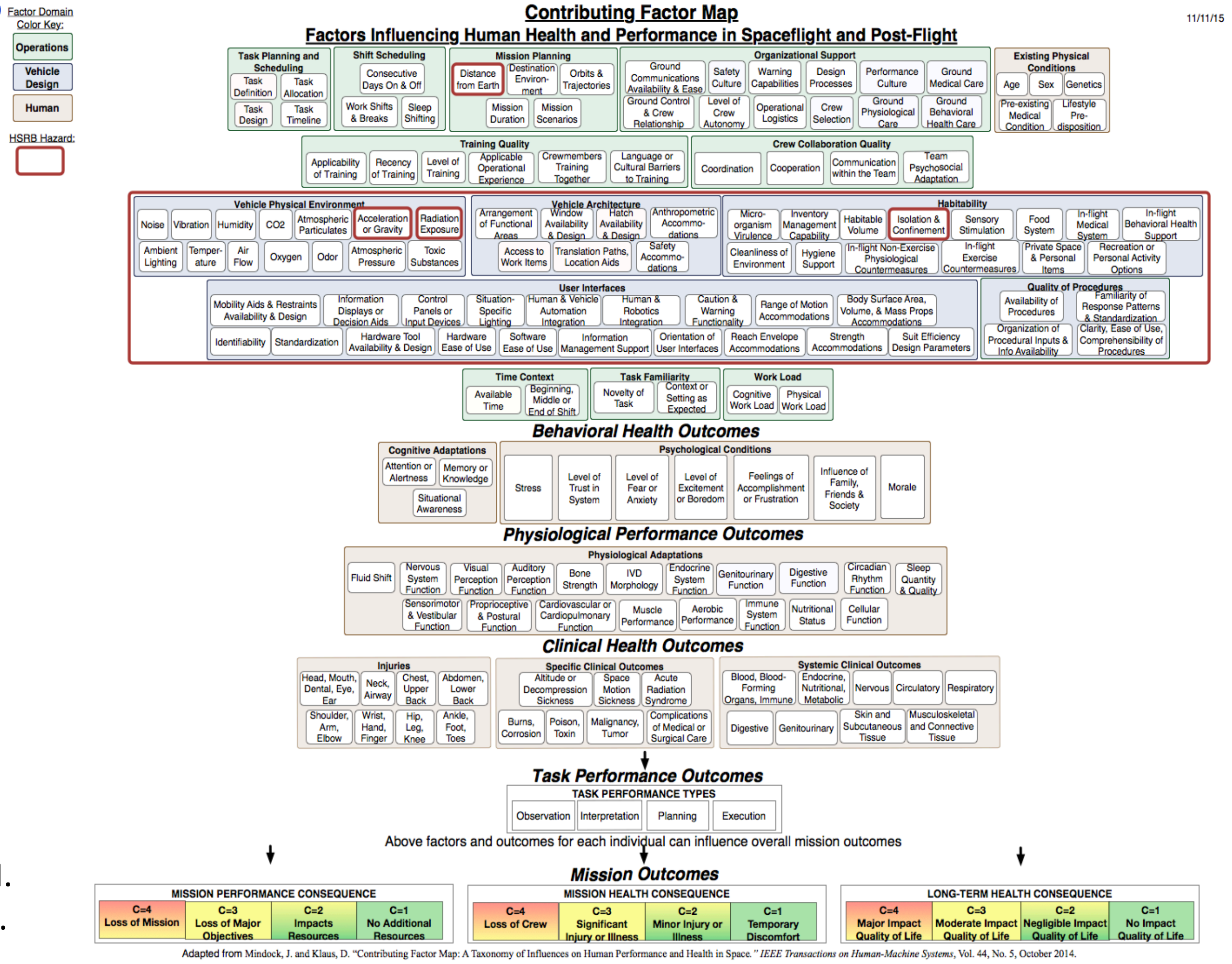
Visual tool showing hierarchy of contributing factors



History *(cont'd)*

- Contributing Factor Map (CFM) - HRP

Visual representation of a taxonomy of terminology of factors influencing human health and performance in spaceflight.



Mindock J, Lumpkins S, Anton W, Havenhill M, Shelhamer M, Canga M. Integrating spaceflight human system risk research. Acta Astronautica. 2017 Oct 1;139:306-12.

We continue to try…

- Identifying the links between risks is an ongoing activity both from the bottom up…

frontiers in Psychology

REVIEW
published: 21 November 2019
doi: 10.3389/fpsyg.2019.02571

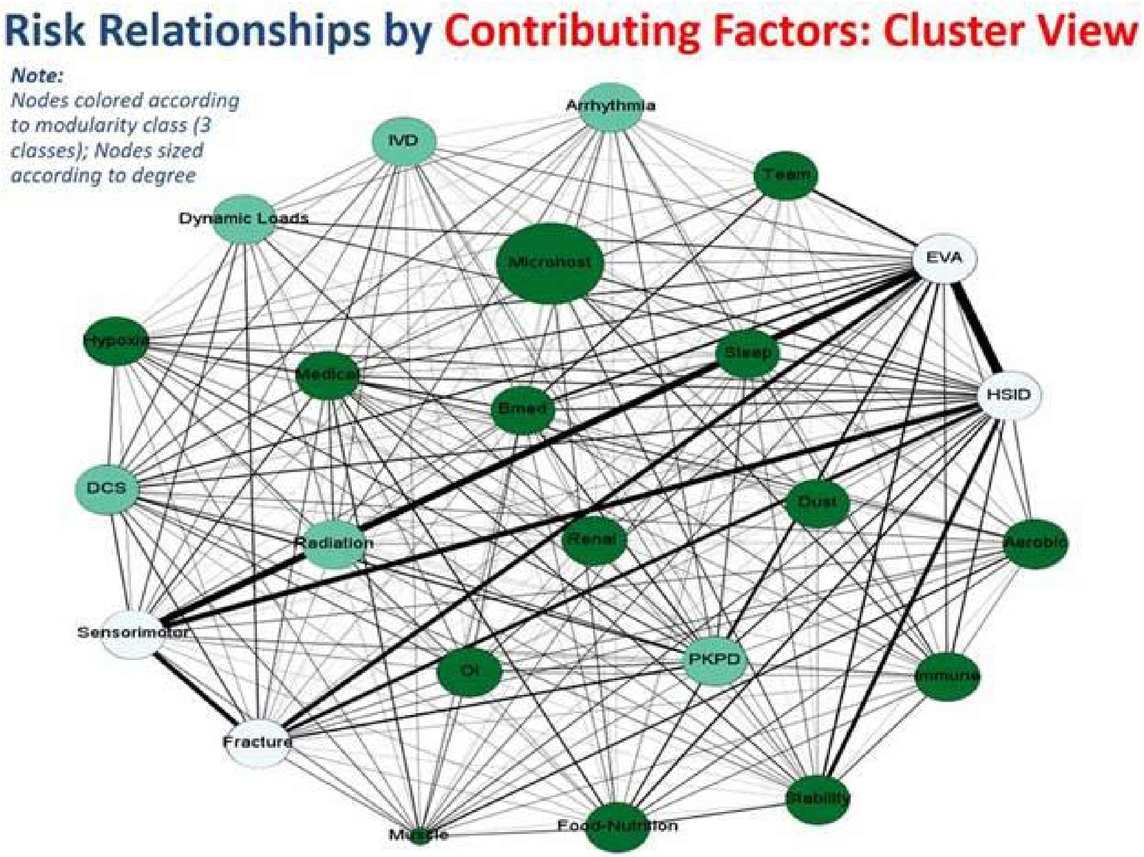
Check for updates

The Behavioral Biology of Teams: Multidisciplinary Contributions to Social Dynamics in Isolated, Confined, and Extreme Environments

*Lauren Blackwell Landon[1], Grace L. Douglas[2], Meghan E. Downs[3], Maya R. Greene[4], Alexandra M. Whitmire[5], Sara R. Zwart[6] and Pete Roma[1]**

And try…

- ❖ Identifying the links between risks is an ongoing activity from the top down…



Notional only

Not for decision making

Why haven't these efforts been enough?

- When they come in one giant pre-formed package people want to know if the whole thing is right (*how do we validate, the SME's don't have bandwidth for that?*)

- When they come from the bottom up, people want to know why it is missing this piece or that piece (*throws out useful information because it isn't the whole picture yet*)

- Both of these approaches can have too much granularity (*the message gets lost in the details*)

- Are we even asking the right question?

What is the question we are asking?

- What are the risks our crews face in a given mission type?

- How can we make **the mission** less risky?

Risk Summary

Information

Risk Title: Risk of Renal Stone Formation

Risk Statement: Given changes in urinary biochemistry during space flight, there is a possibility that symptomatic renal stones may form, resulting in urinary calculi or urolithiasis, renal colic (pain), nausea, vomiting, hematuria, infection, hydronephrosis.

Primary Hazard: Altered gravity (μ-gravity - excess calcium excretion, low urine volume, urinary supersaturation)

Secondary Hazard: Hostile/closed environment (spacecraft design - limited H_2O resource)

Countermeasure:
Prevention: Screening, Crew Education, Diet (includes H2O), K-Cit/ bisphosphonates, exercise
Treatment: Return to Earth

Contributing Factors: Increased Urinary Calcium Excretion (bone loss/calcium excretion), Decreased Urine Volume , Increased Urinary Supersaturation, Dietary Factors (Decreased fluid intake, Increased Na^+ Intake, etc., reference MLD), Mission Duration - Mission Resources, Hypercapnia.

State of Knowledge: All DRMs: Concern with post mission occurrence of renal stones; (36 post mission renal stone events). Risk mitigation strategies are well-defined although the ability to treat a renal stone during exploration missions is not yet available. Potential use of in-flight ultrasound for diagnosis and treatment . Identification of Randall's plaques as a predictor of stone formation represents a new area for research and clinical use. Ground bedrest & immobilization studies indicate that exercise is a good CM to lower urinary Ca++ and that exercise also increases sweating providing an alternate route for Ca++ release; therefore, exercise should be counted as a valid/current countermeasure.

DRM Categories	Mission Duration	LxC OPS	Risk Disposition	LxC LTH	Risk Disposition
Low Earth Orbit	6 Months	2 x 3	Accepted	3 x 3	Accepted
	1 Year	2 x 3	Accepted	3 x 3	Accepted
Deep Space Sortie	1 Month	2 x 3	Accepted	3 x 3	Accepted
Lunar Visit/ Habitation	1 Year	2 x 3	Accepted	3 x 3	Accepted
Deep Space Journey/Hab	1 Year	2 x 4	Requires Mitigation	3 x 4	Requires Mitigation
Planetary	3 Years	2 x 4	Requires Mitigation	3 x 4	Requires Mitigation

L x C Driver: OPS Likelihood all DRMs: < 1% likelihood of renal stone formation in mission due to existing countermeasures (per IMM 0.37% astronaut population incidence rate) and Planetary (per IMM 0.43% incidence). **Consequence: all except Planetary:** Potential incapacitation, significant impact in performance, possible loss of mission objectives due to evacuation of multiple crewmembers. **Consequence LEO, Sortie, Lunar:** Significant injury that may affect personal safety (capability of return to Earth for treatment). **DS Journey & Planetary:** Death or permanent disabling injury due to inability to provide in-mission and/or return to Earth for treatment. **LTH Likelihood All DRMs**: Based on post mission occurrence of renal stones; (36 renal stone events in 22 crewmembers). **LTH Consequence: LEO, Sortie, and Lunar:** Return to near baseline requires medical intervention with known treatments. **DS Journey & Planetary:** Stone event in mission and inability for immediate return for treatment, unknown and improbable return to baseline;

Risk Disposition Rationale: OPS/LTH Accepted for LEO, Sortie and Lunar as missions may be aborted for treatment on Earth. Requires Mitigation for DS Journey and Planetary missions as inflight treatments are not yet available and missions cannot be aborted for immediate treatment to Earth. Prevention of event through preflight screening and hydration education. Provide adequate in-flight resources (water, bone CM) to minimize risk. Define medical requirements to diagnose, monitor and treat an in-flight event.

(*) Risk Custodian: R. Pietrzyk

Why do we have these?

❖**Contributing Factor** - an operational, design, or human-system variable that is likely to ***worsen*** **Human System Risks**. This is something that happens.

NOTE – a Human System Risk may be a contributing factor to other Human System Risks.

❖**Countermeasure** - any action, hardware/software, or capability provided pre-, in-, or post-mission that serves to ***reduce*** risk within the **Risk Impact Categories**. These are things we do.

Most of us are just making a laundry list of semi-relevant information when we capture these for the Risk Summary Slide

Risk Title: Risk of Performance Decrement and Crew Illness Due to Inadequate Food and Nutrition

Risk Statement: Given that there is a constrained ability to supply adequate food in spaceflight missions, there is a possibility that inadequate nutrition will result in performance decrement, crew illness, and long term health effects.

Primary Hazard: Distance from earth

Secondary Hazard(s): Isolation, Radiation

Contributing Factors: Mission design; changing nutritional requirements over long duration missions; food safety; food acceptability; nutritional stability of food; compromised storage, packaging, or handling of food; radiation; immune system function during spaceflight; spaceflight microbial environment; vehicle design for food storage/mass/volume.

Countermeasure:
Monitoring: *dietary intake, track medical conditions and performance metrics*
Prevention: validated nutrition requirements and acceptability standards, pre-packaged balanced/optimized food with stable nutrition, processing and packaging standards, microbial standard
Intervention: *dietary prescription*

State of Knowledge: Much is known about the basic nutrition required to maintain performance and health during spaceflight. Nutrition Stand, 3001, Section 4.2.7 Permissible Outcome Limit. Standards/controls exist to maintain food safety during spaceflight. Adequate nutrition and safe food have been demonstrated for 6 month missions and limited 1 year missions that have resupply. Optimizing food/nutrient intake will likely benefit multiple systems, will drive nutrient requirement definitions, and food provisions. Providing a five year shelf life for safe pre-packaged food with appropriate nutrition content, acceptability, and variety are a challenge. Some CMs being investigated are: Bioregenerative supplementation and alternative processing, packaging, and storage. Potential health impacts include 1) reductions in crew performance (loss of endurance, cognition); 2) crew illness (loss of bone and muscle mass, immune function, cardiovascular performance, gastrointestinal function, severe dehydration, nausea, diarrhea, endocrine function, ocular, psychological health, and the ability to mitigate oxidative damage); 3) long term health effects (cancer, bone, cardio, etc.), 4) interactions with other systems/countermeasures (e.g., drug/nutrient interactions, environment influences on oxidative stress, exercise-induced alterations in energy reqs.)

L x C Drivers:
OPS Likelihood
<30 days: ≤0.1% probability of inadequate nutrition due to short duration of mission. **Likelihood All DRMs except <30 days:** Likelihood ≥1%. Although adequate nutrition/safe food has been demonstrated in 6m missions, evidence also indicates that 34% of crews lose 5 to 10% of body weight and that 2% of the crewmembers lose >10% during those missions. Additionally, due to meal item selection ability, some crew data indicate nutrient content with at least one data point out of normal range (pre/in/post). This incidence is compounded for **Lunar 30 days to 1 year and Planetary:** Due to duration of mission, prepositioning, and lack of resupply (instability of food nutrition and acceptability), high likelihood of inadequate nutrition and/or illness.
OPS Consequence All cases where food is prepositioned beyond best if used by date: Risk of decrements to health and performance due to inadequate nutrition. **Consequence Planetary, and Lunar:** Significant and severe consequence (respectively) of inadequate nutrition and illness due to prepositioning and lack of resupply, unpredicted changes in nutritional needs, increased radiation exposure, and BHP.
LTH Likelihood DRMs with resupply, no prepositioning: Low and medium probability of experiencing vitamin deficiencies post-flight - expected to return to baseline within 3 months with limited intervention. **Likelihood LEO 1y, Lunar, and Planetary:** ≥1% probability of nutritional deficiencies post-flight from these longer missions lacking food resupply (effects may become evident with unpredicted changes in nutritional needs). **Planetary:** High likelihood of not meeting standard due to lack of resupply.
LTH Consequence DRMs with resupply, no prepositioning : Return to baseline within 3 months. **Lunar 30 days to 1 year**: Return to baseline within 1y as mission conditions (closed food system, unpredicted changes in nutritional needs, radiation, and BHP) may exacerbate post-flight recovery. **Planetary**: May have long term effects (unknown & improbable return to baseline) on multiple systems, especially with no resupply, unpredicted changes in nutritional needs, increases in radiation, along with BHP.

DRM Categories	Mission Type and Duration	LxC OPS	Risk Disposition	LxC LTH	Risk Disposition
Low Earth Orbit	Short (<30 days)	3x1	Accepted/ Optimize	2x1	Accepted
	Long (30 days to 1 year)	3x1	Accepted/ Optimize	3x1	Accepted
Lunar Orbital	Short (<30 days)	3x1	Accepted/ Optimize	3x1	Accepted/ Optimize
	Long (30 days to 1 year)	3x3		3x2	
Lunar Orbital + Surface	Short (<30 days)	3x1	Accepted/ Optimize	3x1	Accepted/ Optimize
	Long (30 days to 1 year)	3x3		3x2	
Mars	Preparatory (<365 days)	3x4	Requires Mitigation	3x4	Requires Mitigation
	Planetary (365 days to 3 years)	3x4	Requires Mitigation	3x4	Requires Mitigation

Risk Disposition Rationale per DRM: For all missions except Lunar 30 days to 1 year (assuming food is prepositioned, no resupply), and Planetary, the risk is accepted but validation of requirements is needed, and optimization of food system is desired. **For Planetary**: Validation of requirements is needed, and optimization of food system is needed. Mitigation is required to provide a food system that can maintain nutritious, safe food for five years promotes health within resource restrictions (reduced mass/volume).

Risk Custodian Team: G. Douglas, S. Smith, B. Chamberlain, J. Maners

Decreased Food Acceptability

(Contributing Factor)

Refrigeration

(Preventive Countermeasure)

Food and Nutrition Risk

Anticholinergic medications

(Contributing Factor)

Urinary Retention

Risk

Catheterization

(Intervention Countermeasure)

Decreased Hydration Status → Renal Stone Risk

(Contributing Factor)

Decreased Hydration Status → MRM Formation → Renal Stone Risk

(Contributing Factor) (Contributing Factor)

Water Intake Tracking

(Monitoring)

Ultrasound → Prevention Countermeasure?

(Monitoring)

Seeking Causality

- Directed Acyclic Graphs - DAGs
- Eventually targeting a Bayesian Network

It’s a good time…

…to try something new!

- The organizational structure for Human System Risk is being redefined and funded now.
- The maturity of techniques and data management systems and increasing complexity of missions demand a new approach.
- Status quo means we keep working in Powerpoint alone and don’t have the ability to link risk information in a meaningful way

What is our target?

- ❖ We are going to try to build the network from the ground up with an end goal of creating the larger picture of Risk – eventually.
  - Use DAGs to link contributing factors and countermeasures to the risk scenarios and incorporate into the workflow for risk updates.
  - The DAGs produced will be formally approved as part of Risk Updates and used to feed the larger network.

- ❖ This is not a project. This is a process change.
  - Continuously update the network over time based on what we learn
  - This is a framework, identifying what we don't know is GOOD
  - We know that we will get it wrong. Early. More than once. That is okay. We will figure it out.
  - We will learn and improve the network, and over time create a network with a sufficient level of fidelity to improve our risk management.

What's next after IWS?

- Risk Custodian Teams will be asked to bring a draft DAG for their risk to their orientation sessions as their risks stand up (we expect the first few to be a mess).

- Additional meetings with Erik and Rob will be scheduled based on the maturity of each Risk DAG.

- A slide will be added to any risk update package that includes a final DAG for Board approval in the larger package.

- The HSRB Risk Management Office will work from these DAGS to inform the larger network.

Turning over to Rob…

- Today is all about first steps*:* We will provide a clear set of deliverables and expectations in the Orientation Sessions we have for each risk going forward. Do not freak out.

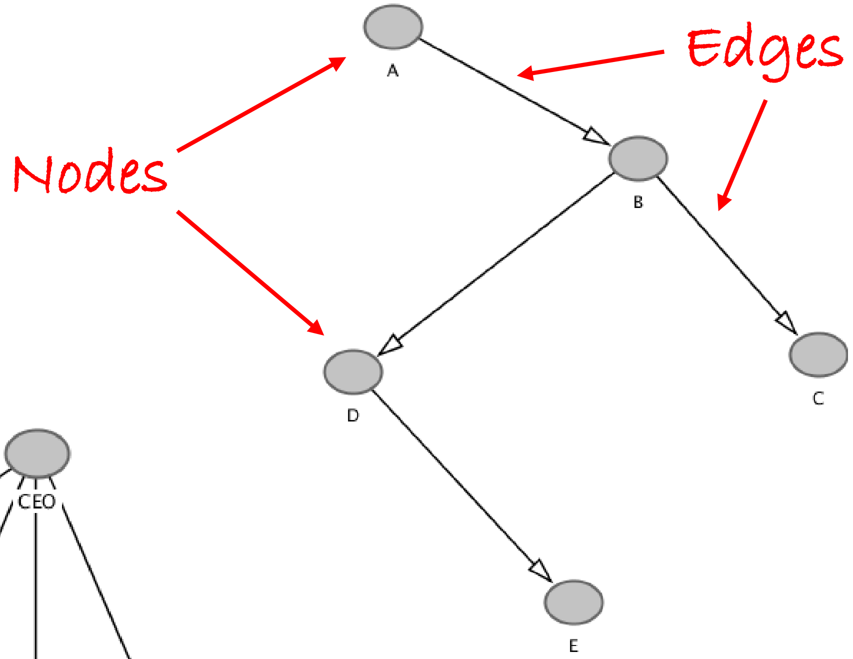
- Walk-through example

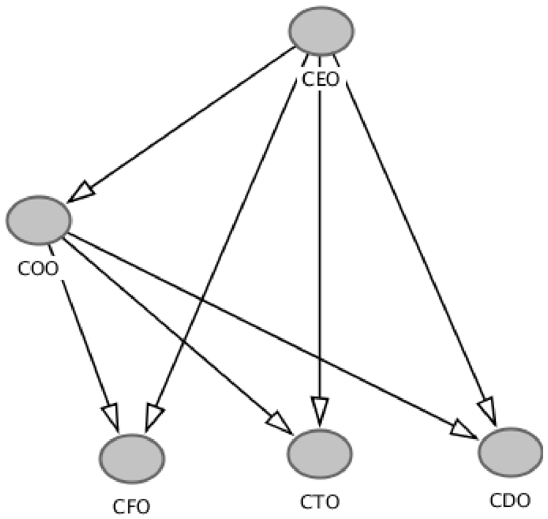
- Q&A Time

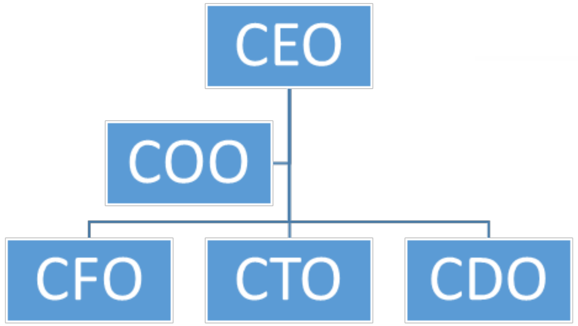
HSRB Key Questions

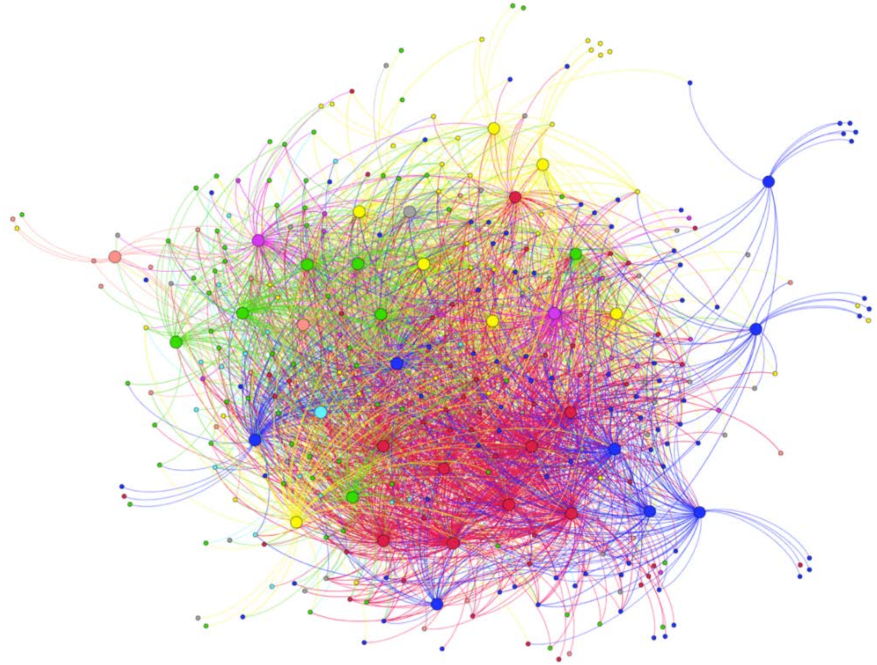
- ❖ How do we represent and keep track of all "contributing factor" relationships and risk-risk interactions in a way that is accessible and comprehendible?
- ❖ Given no risk can ever be brought to zero, how will we objectively determine which ones to buy-down or accept?
- ❖ For any exposure-outcome combination, is it better to try to *prevent the exposure* (preventive countermeasures) or is it better to try to *reduce the magnitude of the consequence* (intervention countermeasures)?
- ❖ How can we know (and express) our total probability (at a high level) of a particular outcome/consequence from all sources?

Graphs



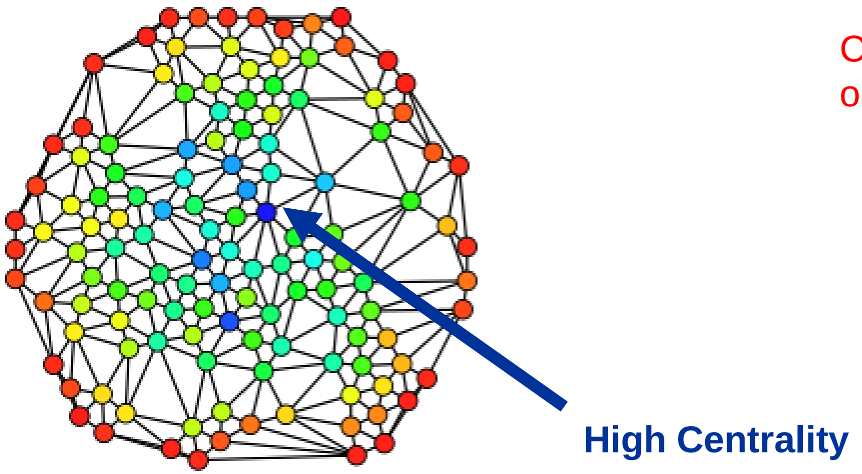


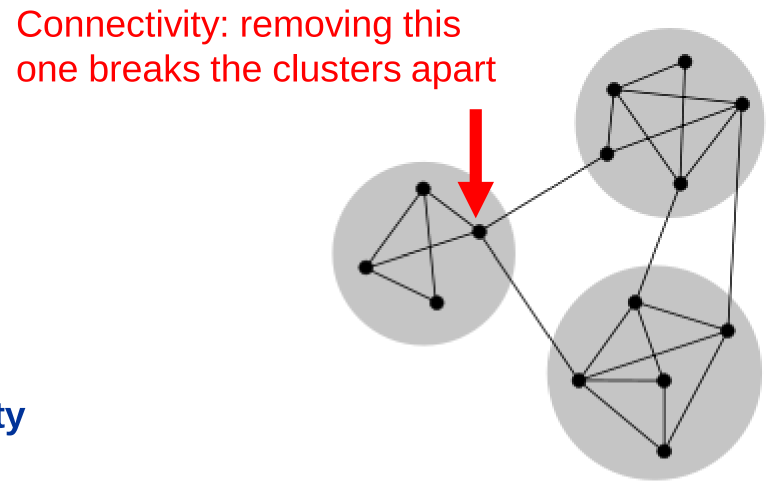




Benefits of graph structure

- ❖Independencies: nodes that are independent of one another given graph
- ❖Centrality: most “important” or “influential” nodes in a network
- ❖Connectivity: measure of network complexity; minimum number of links that must be broken to disconnect network components

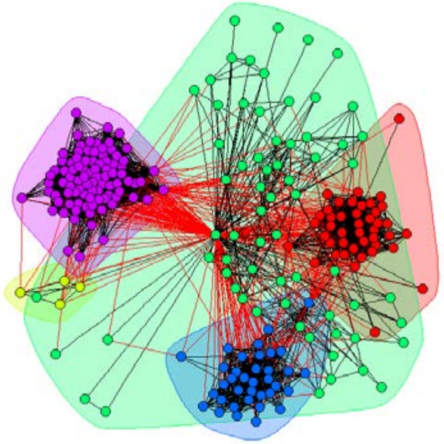


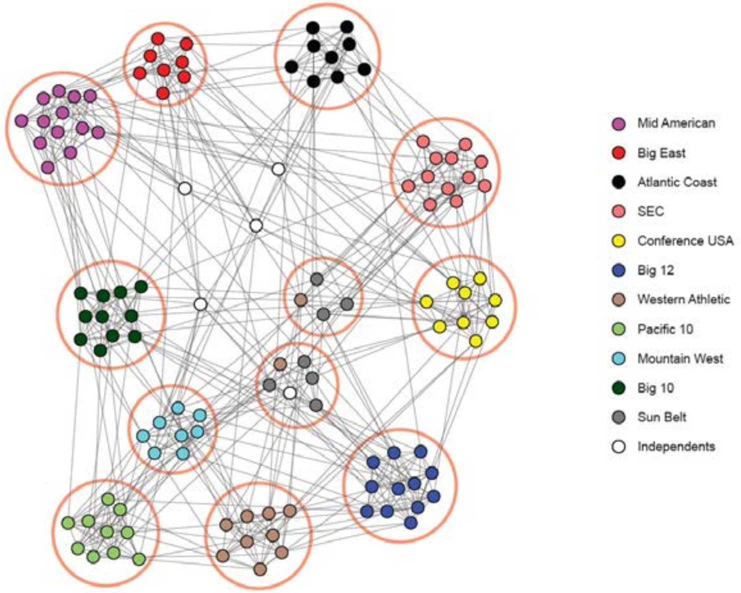


Benefits of graph structures

❖Community detection

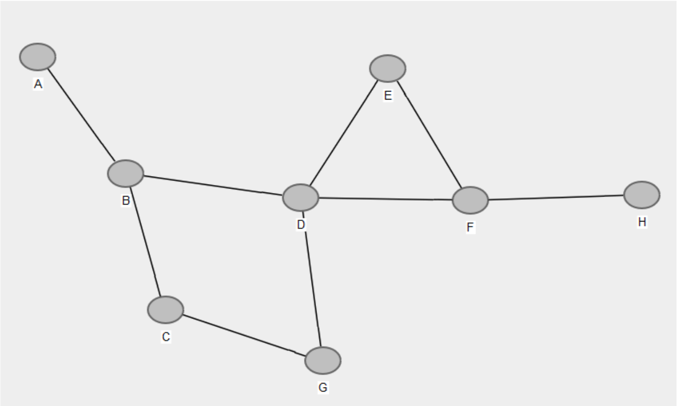
- Nodes that are closer to each other than any others - analogous to cluster analysis
- Communities can be discrete or overlapping



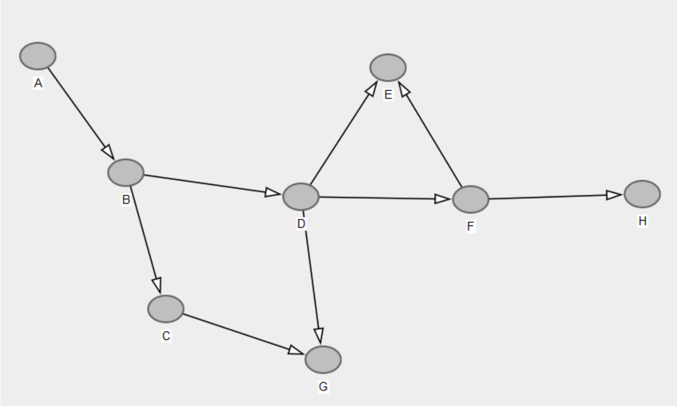


Directed Acyclic Graphs (DAGs)

- Specific type of graph
  - Directed: single-headed arrows show direction of relationship
  - Acyclic: no ‘cycles’ (feedback loops); relationship goes one way and there are no directed paths back to a node once we’ve left it
- DAGs are used to represent causality in a network graph format, i.e. a causal relationships are the basis for connection between nodes

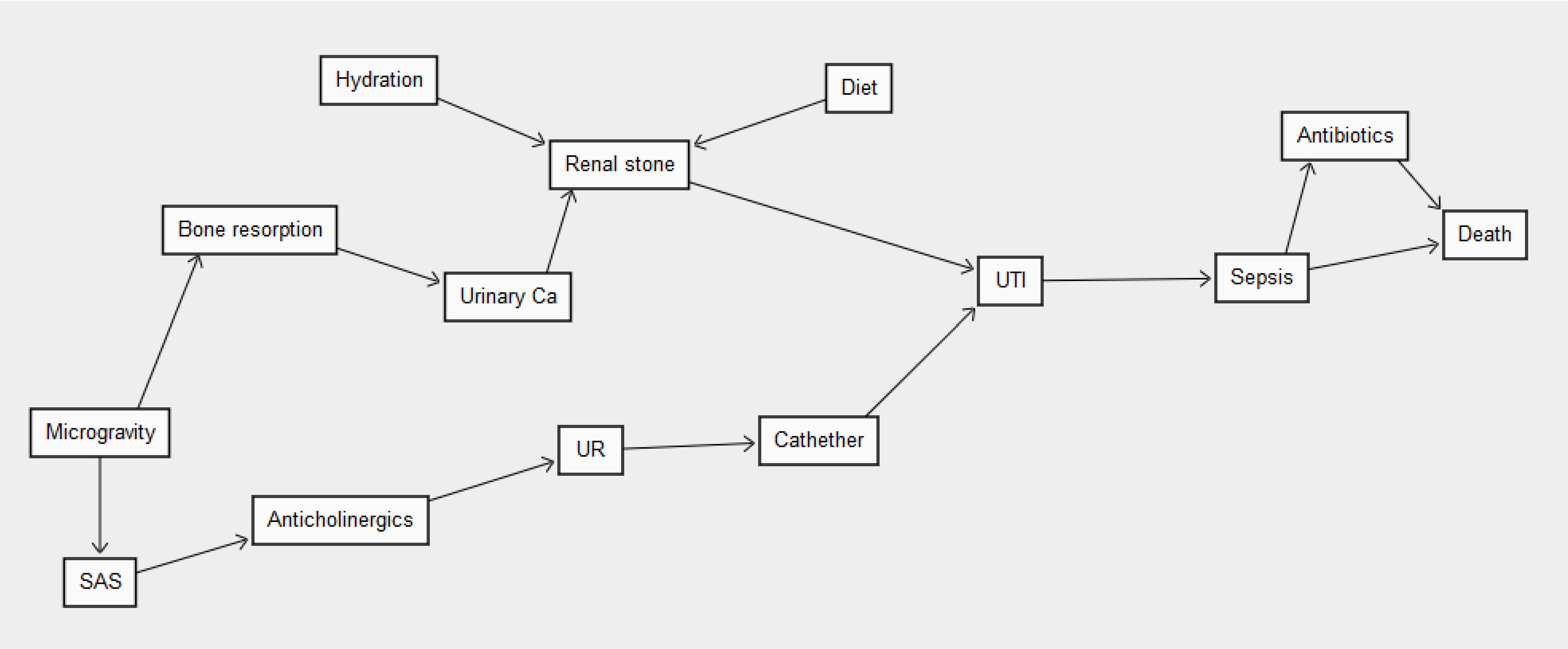


General network representation



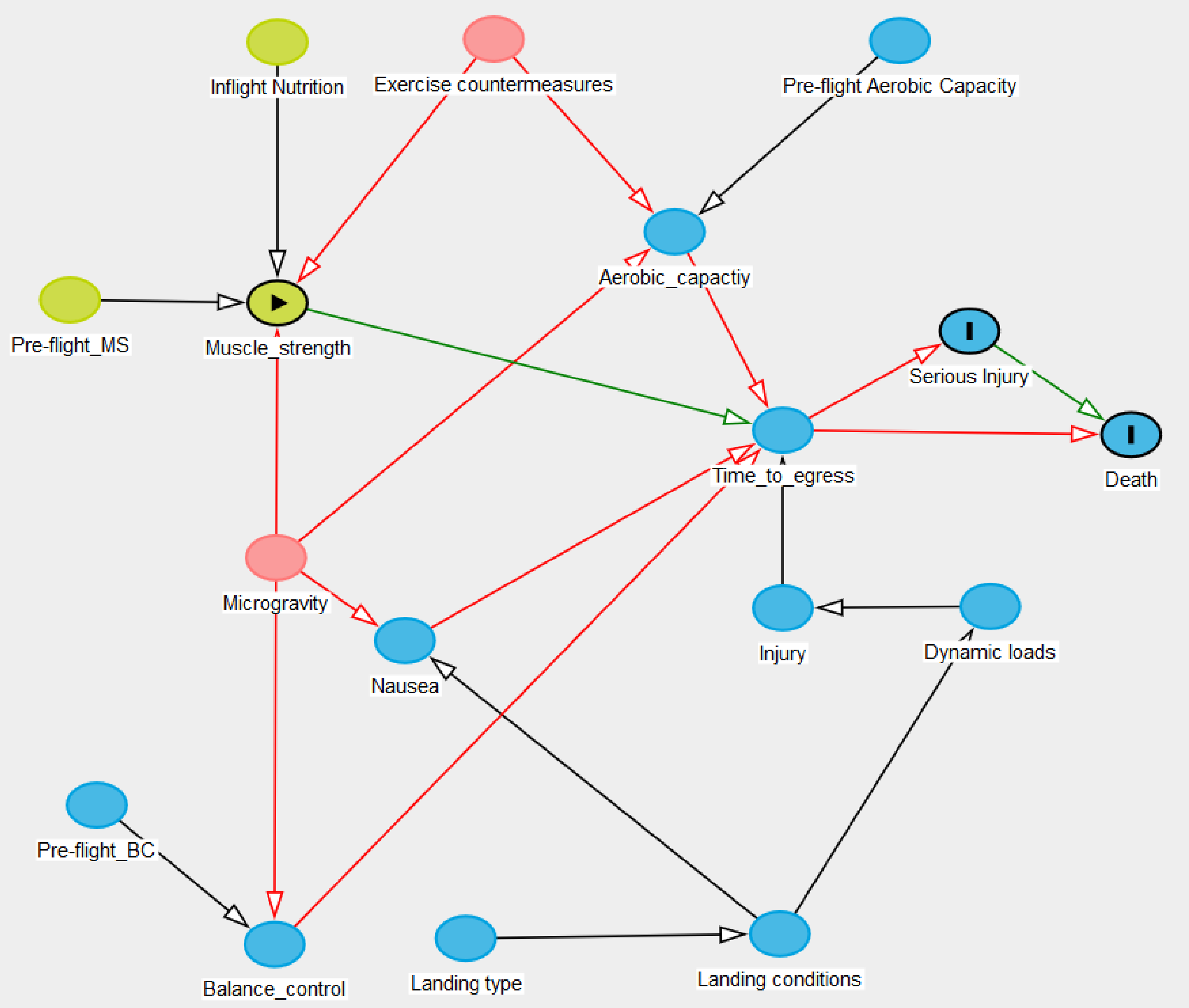
DAG

Example DAG: UTI



Novel question: How does use of anticholinergics modify our total probability of death from sepsis after UTI?

Example DAG: Crew Egress Example

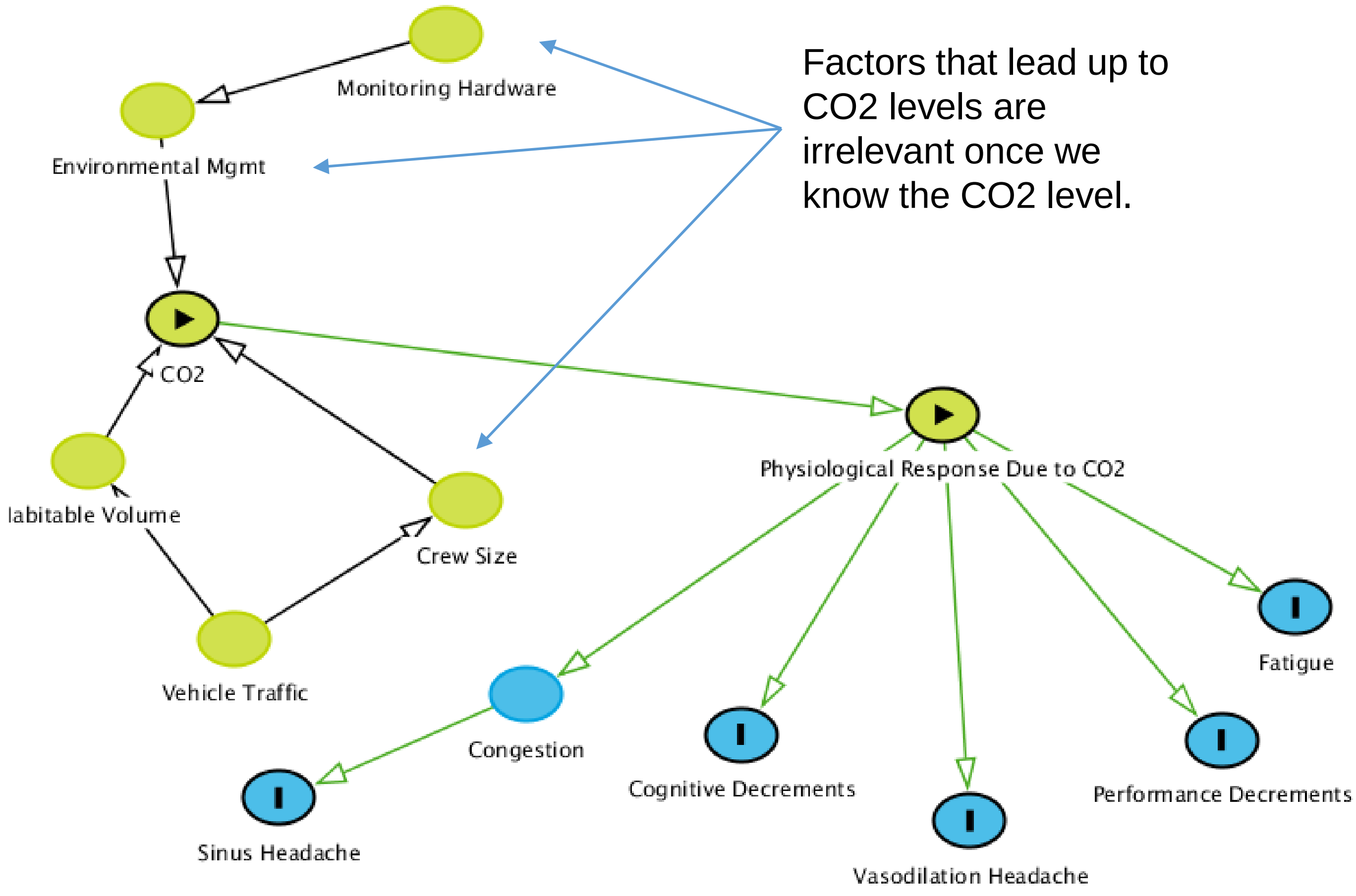


How does muscle strength modify the total probability of Serious Injury and Death upon crew egress from a water-landing capsule?

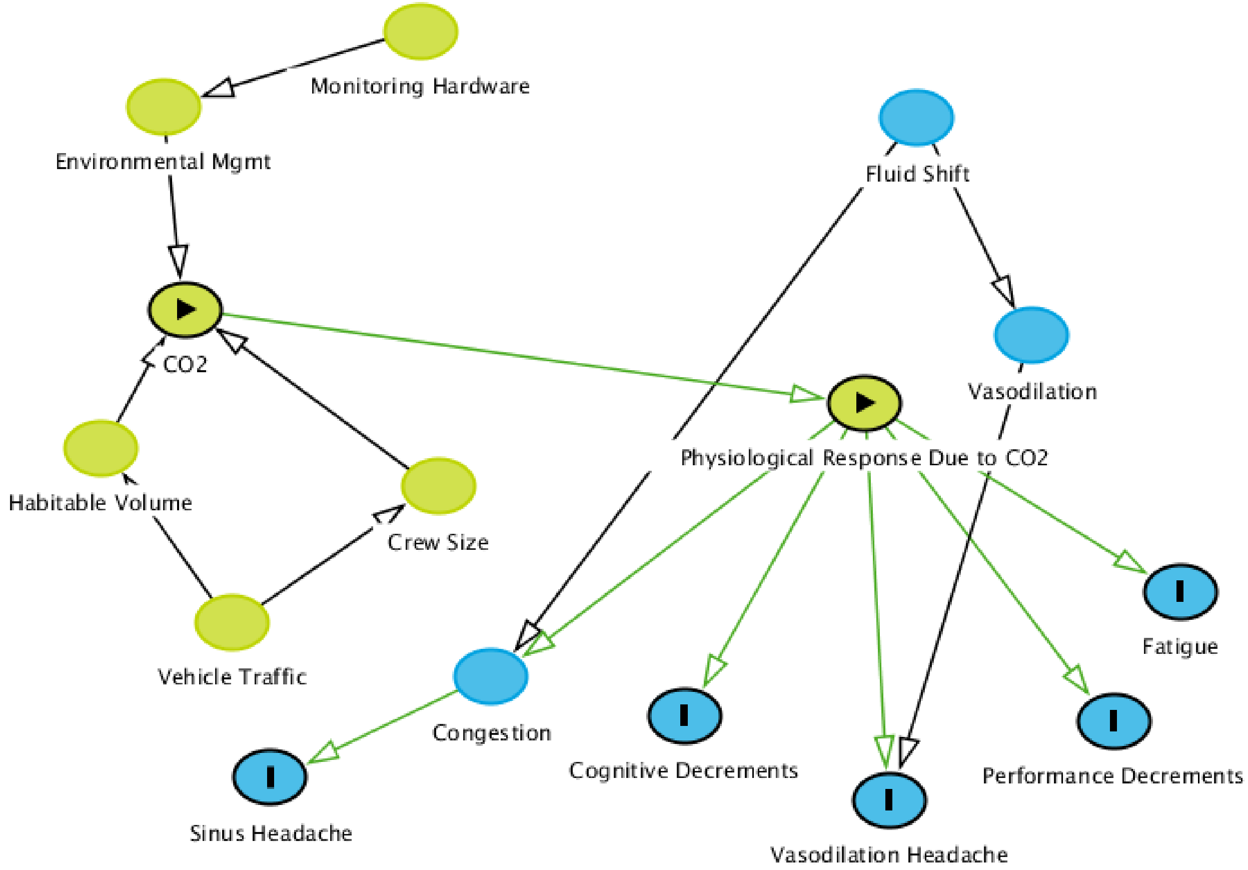
This graph implies the following:

- If we fail to account for in-flight exercise (Exercise countermeasures), we will get a biased answer;
- If we fail to account for the source of diminished physical capability, we will get a biased answer.

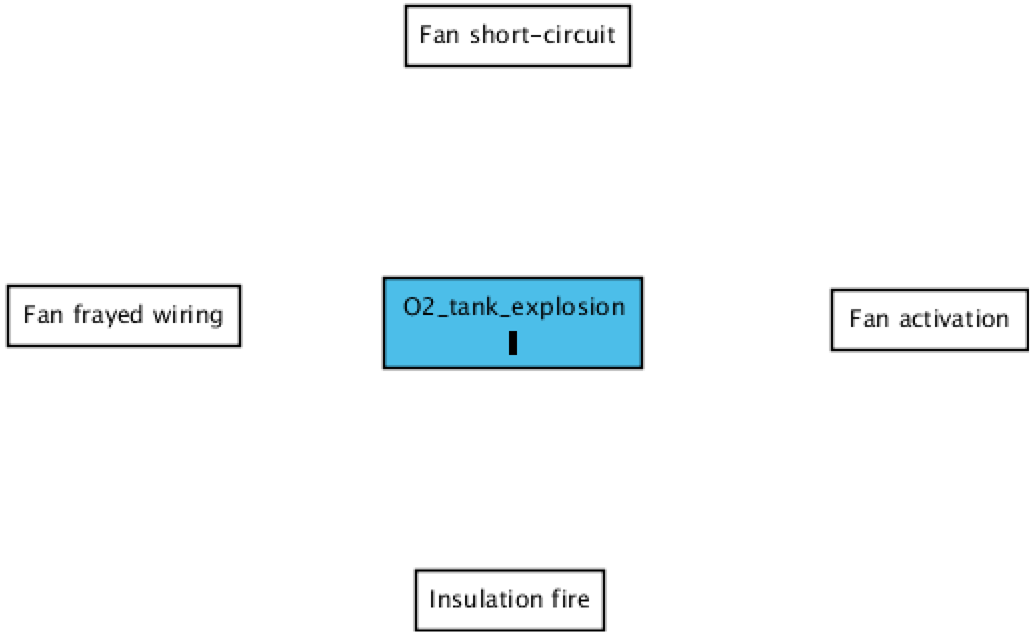
Example DAG: Elevated CO_2 exposure



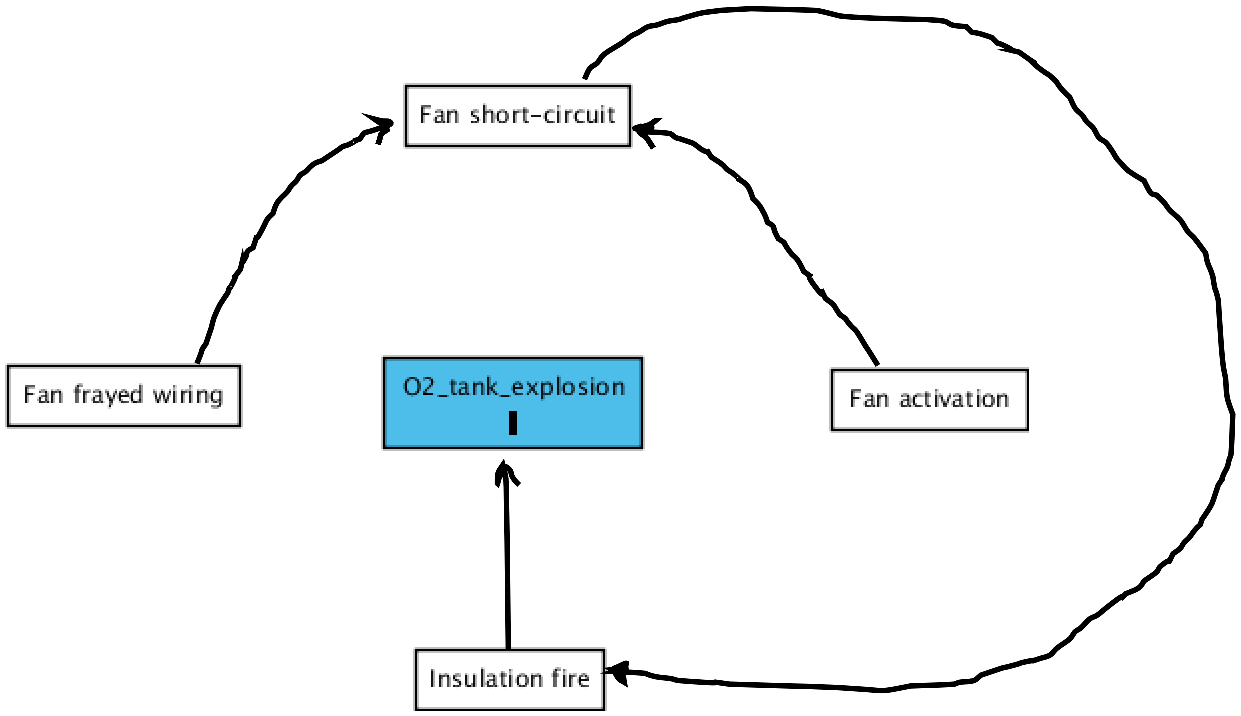
Factors that lead up to CO2 levels are irrelevant once we know the CO2 level.


Monitoring Hardware
Environmental Mgmt
Fluid Shift
CO2
Vasodilation
Physiological Response Due to CO2
Habitable Volume
Crew Size
Fatigue
Vehicle Traffic
Congestion
Cognitive Decrements
Performance Decrements
Sinus Headache
Vasodilation Headache

DAG example: Apollo 13

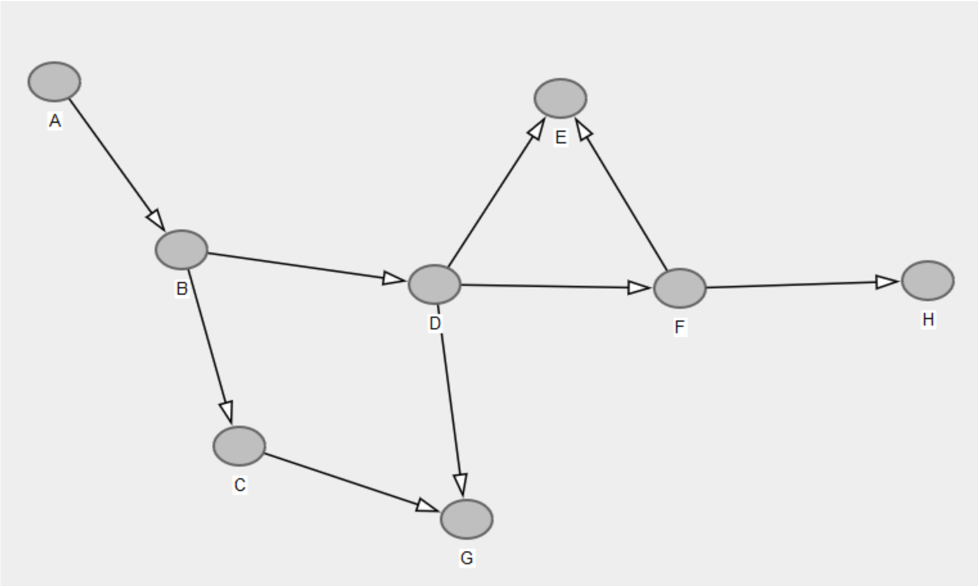


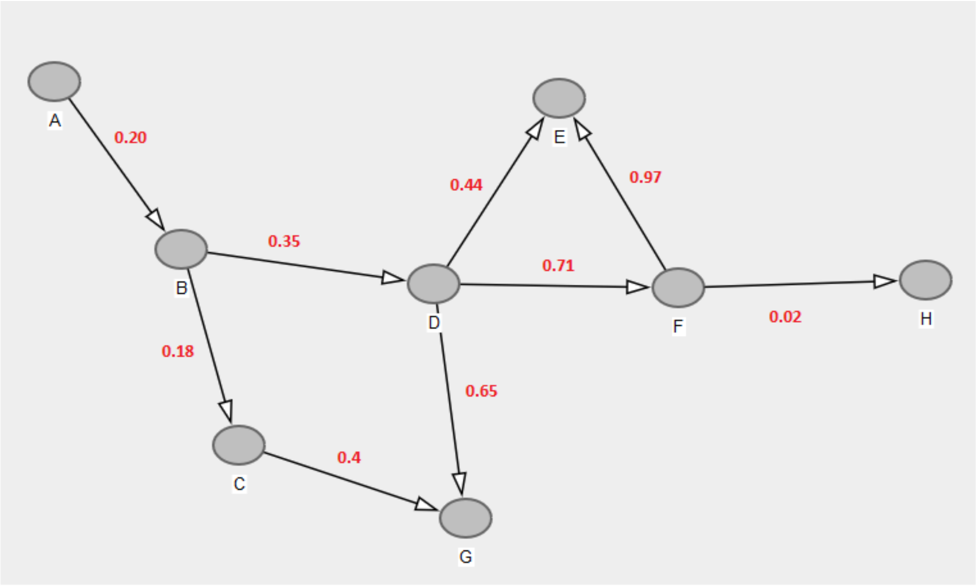
Apollo 13: one possible version



Bayesian Networks

- ❖ Bayesian Networks are DAGs combined with joint probability distributions
- ❖ Allows for straight-forward computation of probability of events under “what-if” scenarios





DAG

Bayesian Network

HSRB Key Questions

Question	Potential Strategy
How do we represent and keep track of all "contributing factor" relationships and risk-risk interactions in a way that is accessible and comprehendible?	Nodes & edges in DAG; Implied structural independencies; Communities/clustering
Given no risk can ever be brought to zero, how will we objectively determine which ones to buy-down or accept?	Centrality measures; Changes in Connectivity with mitigation; Changes in total probabilities by outcome
For any exposure-outcome combination, is it better to try to *prevent the exposure* (preventive countermeasures) or is it better to try to *reduce the magnitude of the consequence* (intervention countermeasures)?	Compare P(exposure) vs. P(outcome|exposure)
How can we know (and express) our total probability (at a high level) of a particular outcome/consequence from all sources?	Bayesian Network

What this process provides

Early on:

- A common view of our risks that we can all work off of together to generate hypotheses and break down silos
- Network metrics that allow us to prioritize exposures and outcomes as targets for research

As the network matures:

- A way to find the best mitigation strategy for a given risk based on the probabilities of exposure and outcome
- Ability to quantify total probability in outcome categories (e.g. “total probability of loss of crew on a Mars exploration mission”)

Always:

- Good understanding of the gaps in our knowledge

What this process <u>cannot</u> provide

1. An immediate answer to all our unknowns
2. The “Right” answer in the face of uncertain data
3. Value judgments about acceptable levels of probability for various outcomes
4. A replacement for the expert judgement of the risk custodial teams and element scientists. Instead, this is designed to *capture and represent* all expert knowledge, and make it *accessible* to all

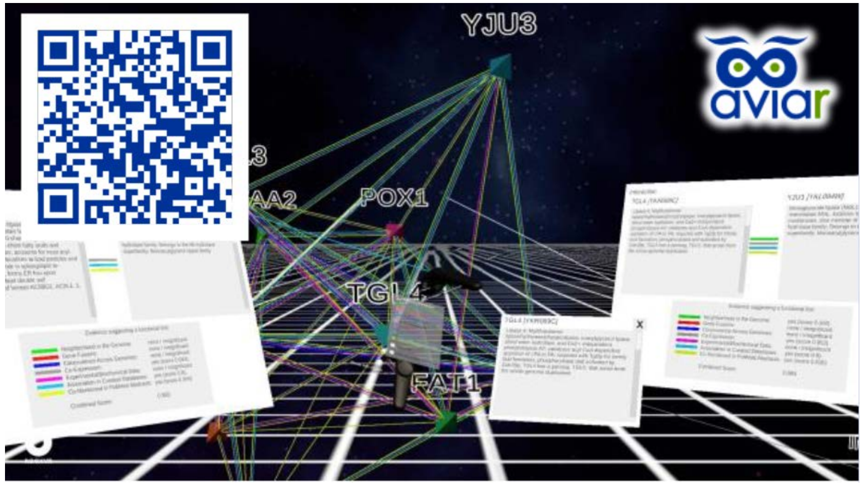
Visualizing complex networks

❖Complex network maps are best represented in 3 dimensions

❖Visualizing them in 3D is best done in a VR environment

❖We are working on a 3D network map visualization in VR: VIDRA (Virtual Reality / Data Science Risk Assessment & Analysis)

❖A live demo of this project is here today – feel free try it out!



Backup Slides

FAQ

- **I already have a good understanding of my risk and what needs to be done with it. Why do I need to do this?**

This effort will (1) enable new ways to measure risk importance; (2) make it far easier to understand contributing factors, risk-risk interactions and countermeasures; and (3) make it easier to communicate risk to other risk custodial groups, programs, and the Agency in general.

- **My DAG will be very complex. How do I know I've got it right?**

We will most likely not get it "right." The value of attempting to represent the cause-effect network is that it will help us think clearly about relationships between exposures and outcomes. This will in turn give us hypotheses to test, which will allow us to continually refine the network.

- **We'll never have all the data we need to find all the probabilities for a Bayesian Network. How can we use it without that?**

Depending on the independencies inherent in the network structure and the things we're willing to assume, we may not need all the data for all of our queries to the network.

- **How is this different than MEDPRAT?**

MEDPRAT is a general, complex simulation tool that uses Markov Chain Monte Carlo (MCMC) methods. Our network will be a tool for understanding risk interplay, and MEDPRAT may in fact help inform some risk estimates in our network, and our network may feed MEDPRAT exposure-outcome links.

- **Am I expected to know how to draw a DAG correctly on my own?**

Drawing DAGs is surprisingly easy. However, the Epidemiologists, Biostatisticians, and the HHPD Data Scientist will be available to support groups in drawing their initial DAG. Epidemiologists are trained in DAG interpretation, construction, and independency analysis, and will provide ongoing support.

FAQ

❖**Is there a way to use data to demonstrate the truth of a DAG?**

No, we can never prove that a DAG is true. However, there are ways to use data to demonstrate that parts of a DAG are false.

❖I think my risk has factors that could have double-headed arrows. How do we represent that if arrows are unidirectional?

Events that happen simultaneously cannot be each others' causes, so one or the other must always come first. To represent this in a DAG we need to explicitly add in time frames, and there are various straightforward methods to do that.