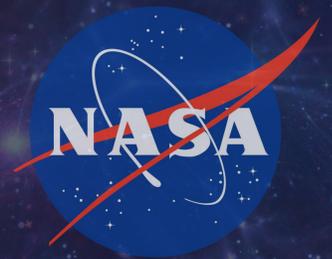# POTENTIAL OF CENTRALITY MEASURES TO REVEAL IMPORTANT NODES IN CAUSAL NETWORKS

Robert J. Reynolds[1], Mary Van Baalen[2], Dan Buckland[2,3]

[1]KBR, Inc. Houston TX 77058 (robert.j.reynolds-2@nasa.gov), [2]NASA Johnson Space Center (dan.buckland@nasa.gov, mary.vanbaalen-1@nasa.gov), [3]Duke University School of Medicine

Background

The National Aeronautics and Space Administration (NASA) maintains a set of **causal diagrams** as part of the process of continuous risk management of the human system risks of spaceflight. These diagrams provide a knowledge graph structure that enables clear communication regarding the sequence of **events that lead from the hazards of spaceflight to seven pre-defined Mission-Level Outcomes (MLO)**. These diagrams also offer the ability to **select and evaluate potential risk mitigation targets** in terms of their direct and indirect effects on the causal system. One such method of evaluation is through the **analysis of the network structure via metrics known as centrality measures**. These measures, when interpreted judiciously, can provide insight into the **role and influence of individual nodes in a causal network**, and thus reveal the **optimal places to intervene** to reduce the risk of specific outcomes.

Conclusions

- **Network Insight:**
  - The MegaDAG can be disrupted if a deliberate, planned strategy is pursued
- **Centrality measure insights:**
  - **Degree centrality** is useful as an indicator of how easily a node's influence may be modulated, as well as providing information about how to pursue risk reduction
  - **Directed closeness** is a bad measure for this context as it only considers unidirectional paths; **Total Closeness** is best
  - **Alpha/Katz** is naturally highest in the outcomes; Alpha on a reversed network would be better, as it would find influential causes
- **Nodal insights:**
  - **Individual Readiness** is perhaps the single most important node in the MegaDAG, but also one of the most difficult to mitigate
  - **Individual Factors** has the single most direct effects, but will also be difficult to mitigate as it is really a collection of factors with few causes
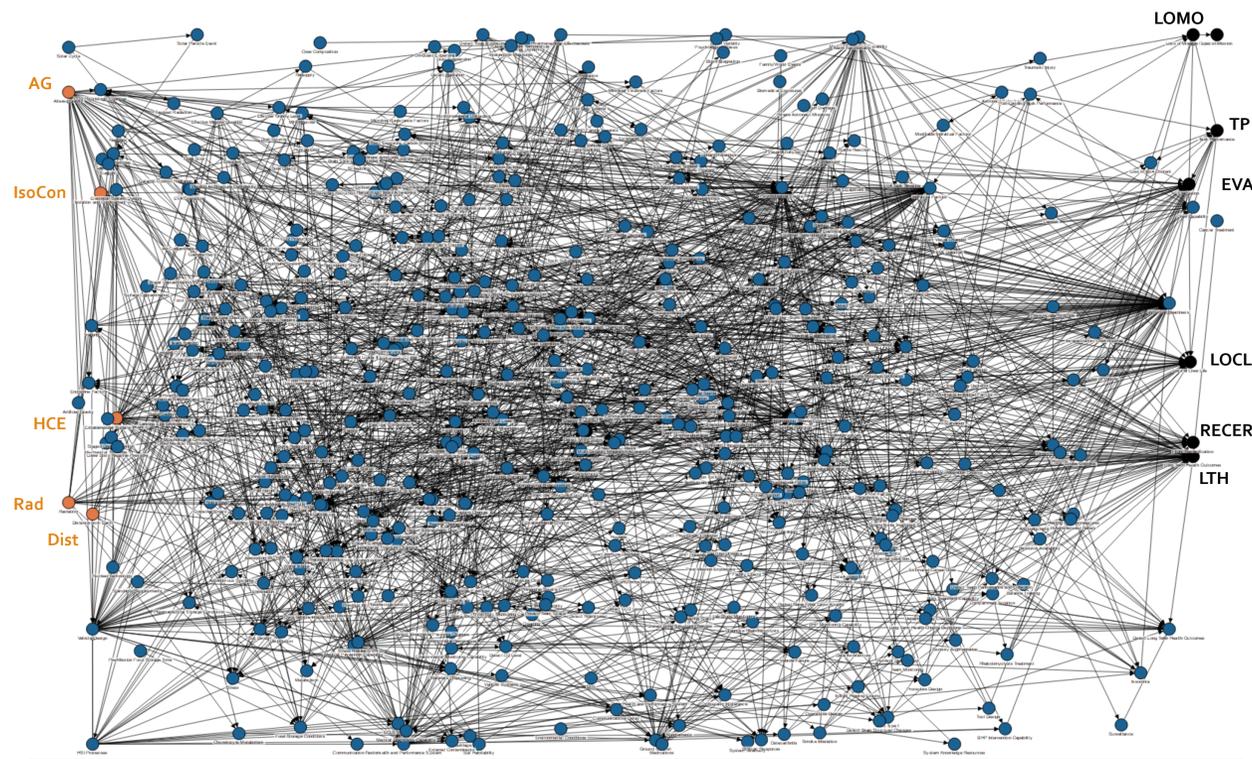

Figure 1: The HSRB Composite Risk Network ("MegaDAG")

Methods

- **Centrality:**
  - Based purely on the **structure** of the network
  - Attempts to **quantify "importance"** of a node based on its **relationships to other nodes**
  - Here each connection is treated as equal, but could be weighted by nodal metadata
- **Measures**
  - **Degree** (in, out, total) are the number of connections
  - **Betweenness** shows which nodes bridge network segments
  - **Total Closeness** identifies nodes spatially central
  - **Outbound Closeness** uses only outbound connections, i.e., considers effects, not causes for each node
  - **Alpha/Katz** indexes which nodes have broad influences
- **Network vulnerability to disruption:**
  - Assessing the distribution of degree centrality relates if it follows a **power law**, which provides information on which strategies will work to remediate risk in the network

Results

Table 1: Summary statistics for centrality measures in the MegaDAG network

Centrality Measure	Min	1st Quartile	Median	Mean	3rd Quartile	Max	Top node
In degree	0	1	2	4	4	88	Individual Readiness
Out degree	0	1	2	4	4	63	Individual Factors
Total degree	1	3	5	7	8	95	Individual Readiness
Between	0.0	8.0	48.0	299.7	278.8	6421.9	Individual Readiness
Out-bound closeness	0.0006	0.0014	0.0064	0.0321	0.0125	1.0000	Long Term Health Outcomes
Total closeness	0.0004	0.0006	0.0007	0.0007	0.0008	0.0010	Individual Readiness
Alpha/Katz	1.0	5.0	19.4	1168.8	156.3	53272.8	Loss of Mission Objectives

Degree centralities (in, out, total) all show evidence of following a power law distribution

Outbound closeness favors nodes toward the end of the network; Total closeness nodes toward the true center

Alpha/Katz centrality is highest at the end of the network

Individual Readiness has many causes, making it the single most proximally connected node in the MegaDAG

Individual Readiness is central to the network: it is on average closest to all nodes and acts as a connector for sections of the network

Table 2: Top-ranking nodes in centrality measures in the MegaDAG network

Node	No. top rankings	Centralities
Individual Factors	1	Out degree
Individual Readiness	4	{In degree, total degree, betweenness, total closeness}
Long Term Health Outcomes	1	Out closeness
Loss of Mission Objectives	1	Alpha/Katz

Individual Factors has many immediate effects, but only the Astronaut Selection and Training nodes are causes, highlighting the impact of individual variation on risk

This collection of measures, considered together, shows the central, highly-influential role of Individual Readiness, as it dominates degree and connectedness

https://www.nasa.gov/hhp/hsrb