SYSTEMS ENGINEERING RESEARCH CENTER

STEVENS INSTITUTE of TECHNOLOGY THE INNOVATION UNIVERSITY

Sandia National Laboratories

A Predictive Analysis Framework for Six Degrees of Freedom Vibration Qualification

Sponsor: DASD(SE)

By

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FHI 360 CONFERENCE CENTER

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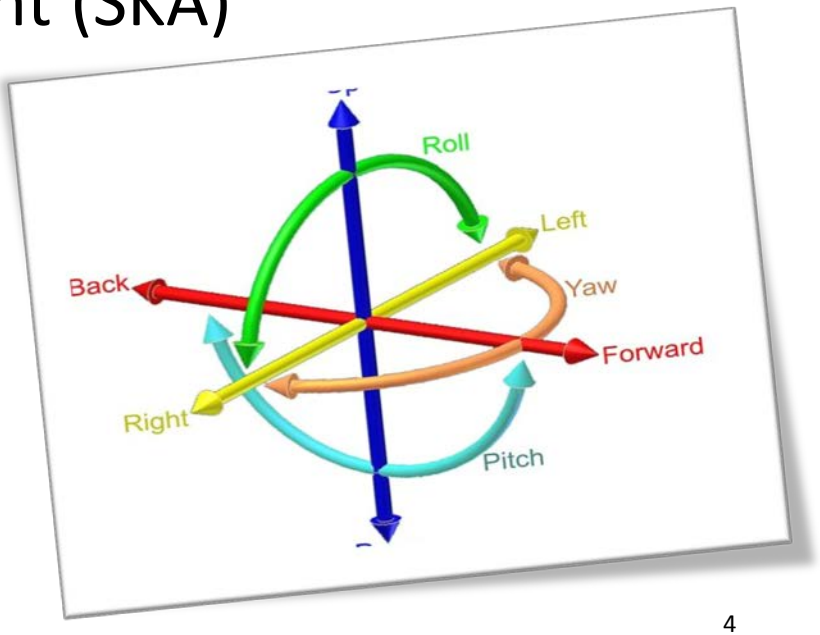
Outline

- Definitions
- Problem Statement
- Results
  - Building the BN Model
  - Validation
- Conclusion/Recommendations

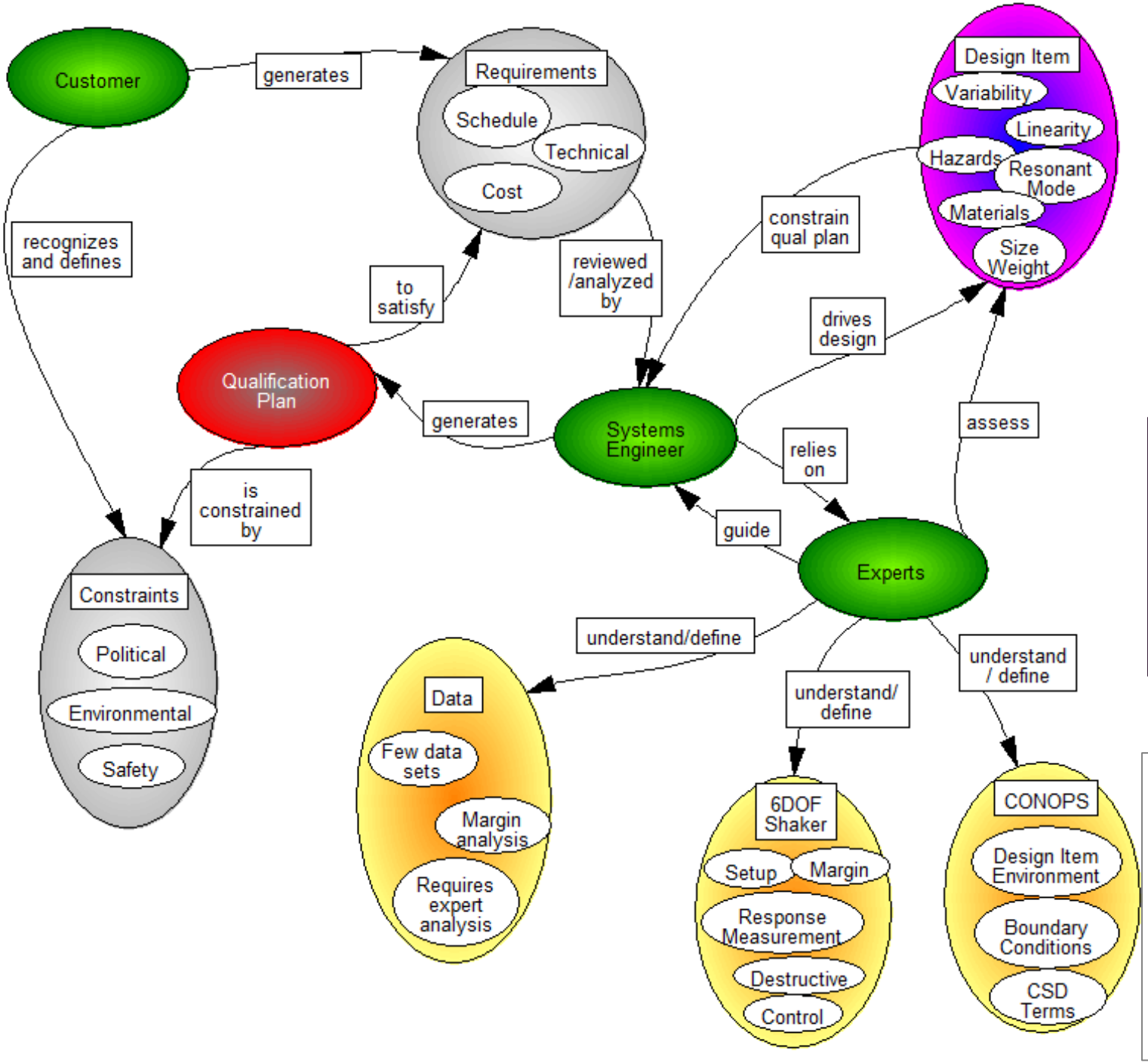
Definitions

Definitions

- Qualification
- Six Degrees of Freedom (6DOF)/ Single Degree of Freedom
- Bayesian Network Model
- Structural Knowledge Assessment (SKA)



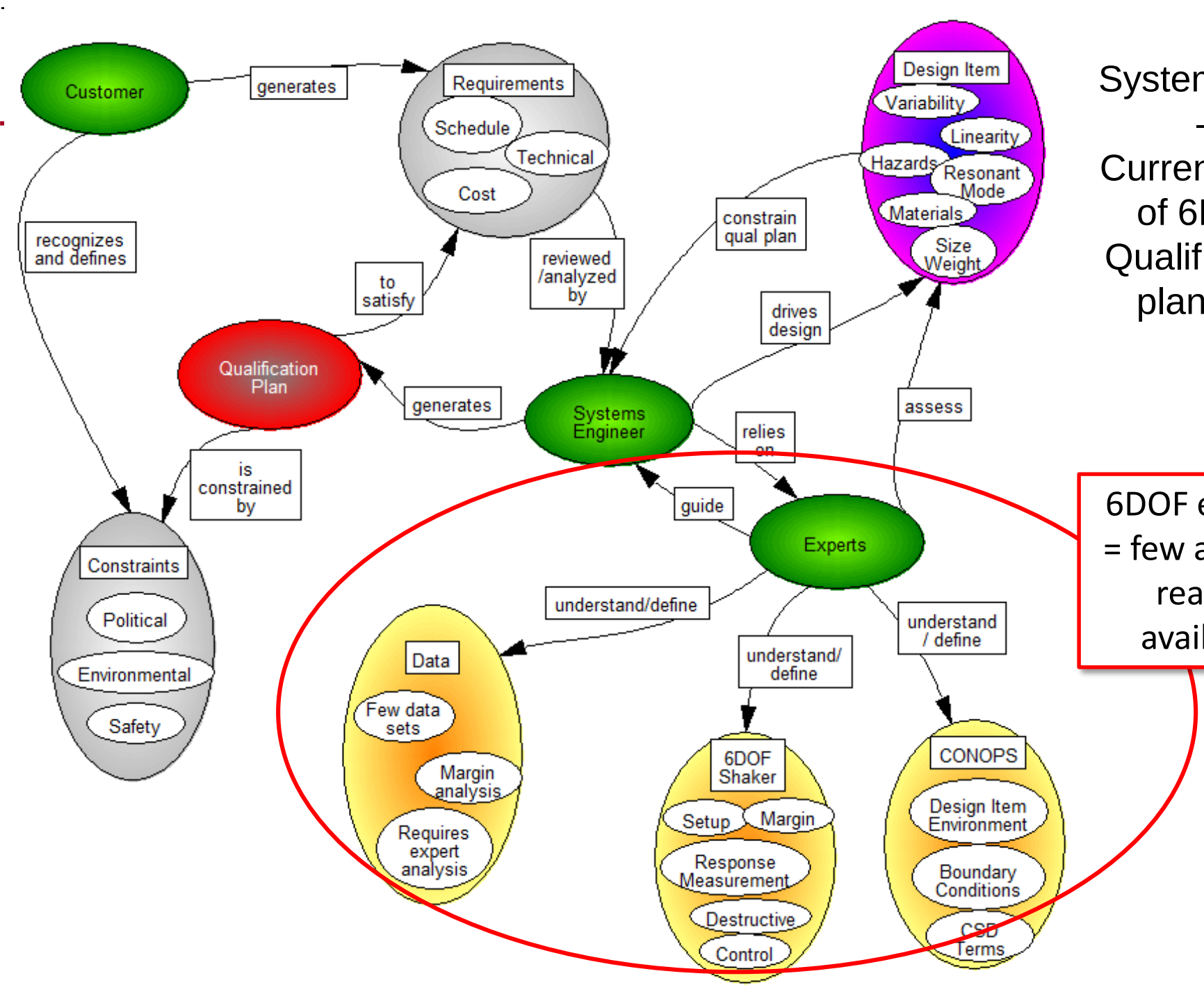
Problem Statement



Systemigram – Current state of 6DOF Qualification planning

6DOF vibration - many benefits but very complex

Causal technical factors must be considered (expert required)



Systemigram – Current state of 6DOF Qualification planning

6DOF experts = few and not readily available

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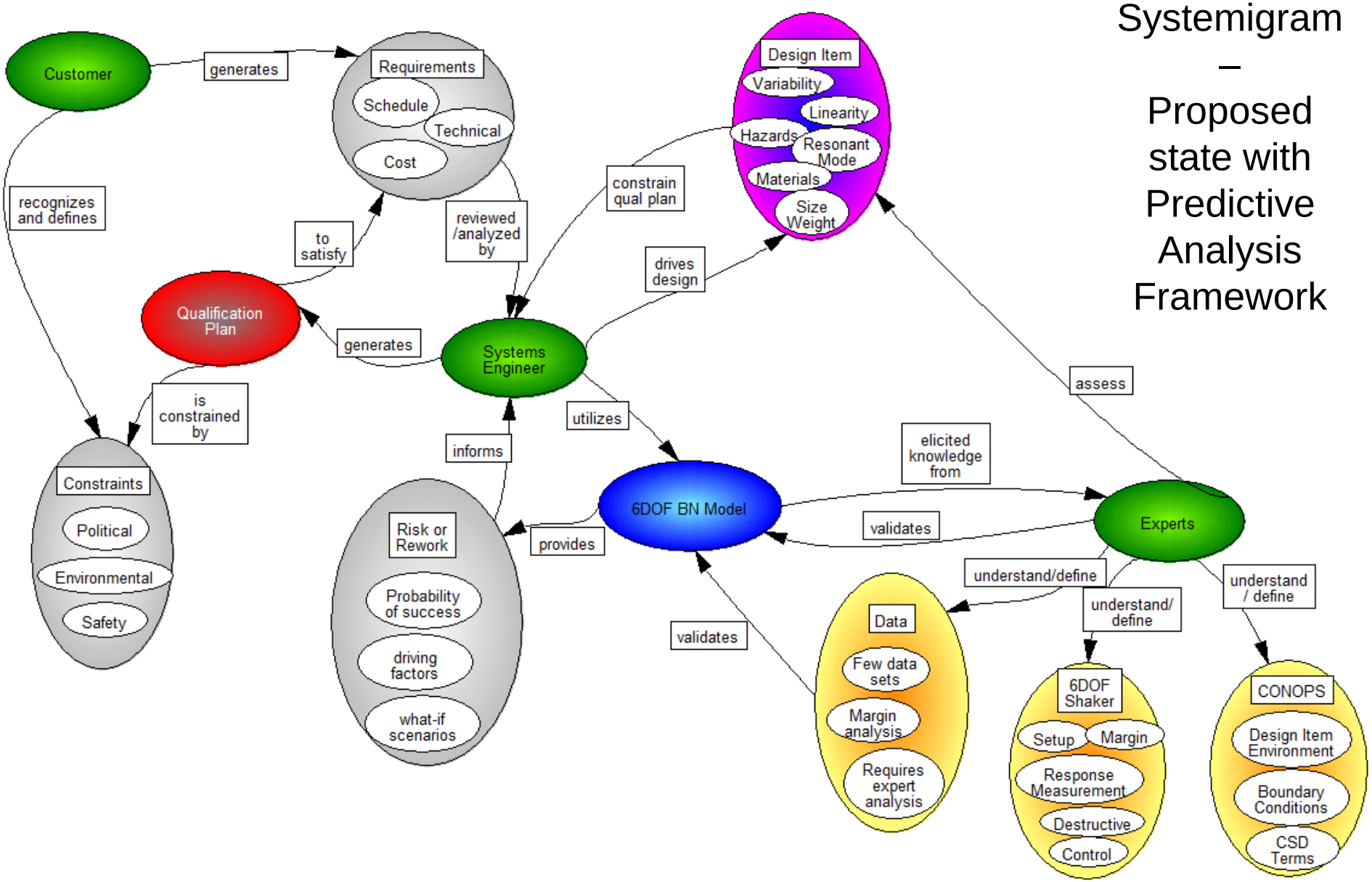
Systemigram – Proposed state with Predictive Analysis Framework



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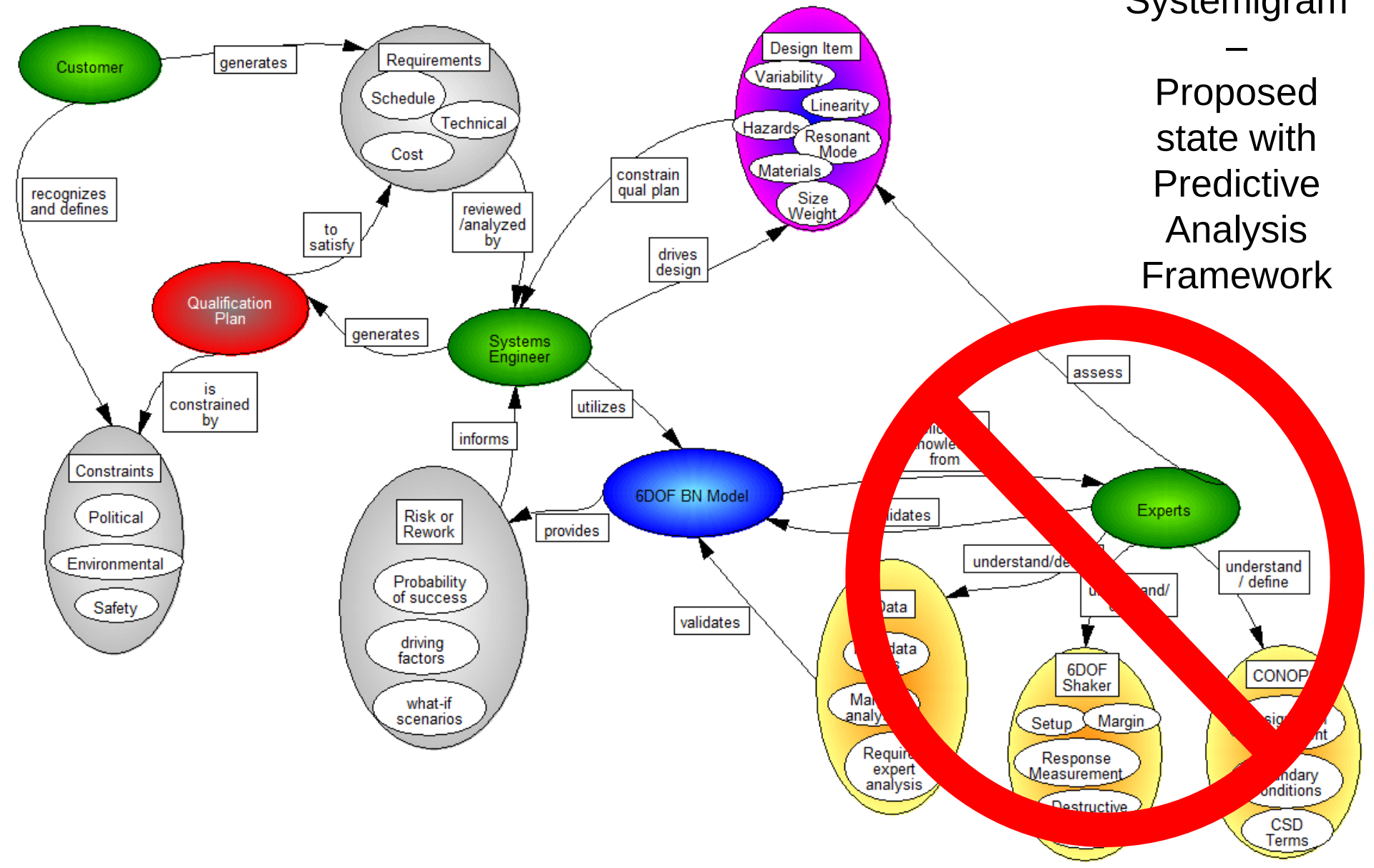
Systemigram – Proposed state with Predictive Analysis Framework



Problem Statement

- What?
  - Incorporate technical factors into decision space
  - Extremely limited data / reliance on experts
- Why? (GAPS)
  - Systems engineers are required to make decisions about complex subjects[1]
  - Experts and/or data may not be available
  - Existing qualification decision models focus on cost, schedule, risk and quality only[2]
- How?
  - Use a Bayesian Network model
  - Capture the technical factors and expert knowledge
  - Understand the risk of using 6DOF tests for qualification

Results – Building the BN Model

Building the BN Model

- Build BN Model - Critical Effort

1. Identify Causal Factors
   - Literature review, screening experiment
2. Identify Relationships
   - Based on expert input
   - Novel approach – Structural Knowledge Assessment[3]
3. Identify Factor Probability Distributions
   - Based on expert input
   - Modified Sheffield Elicitation Framework (SHELF)[4]

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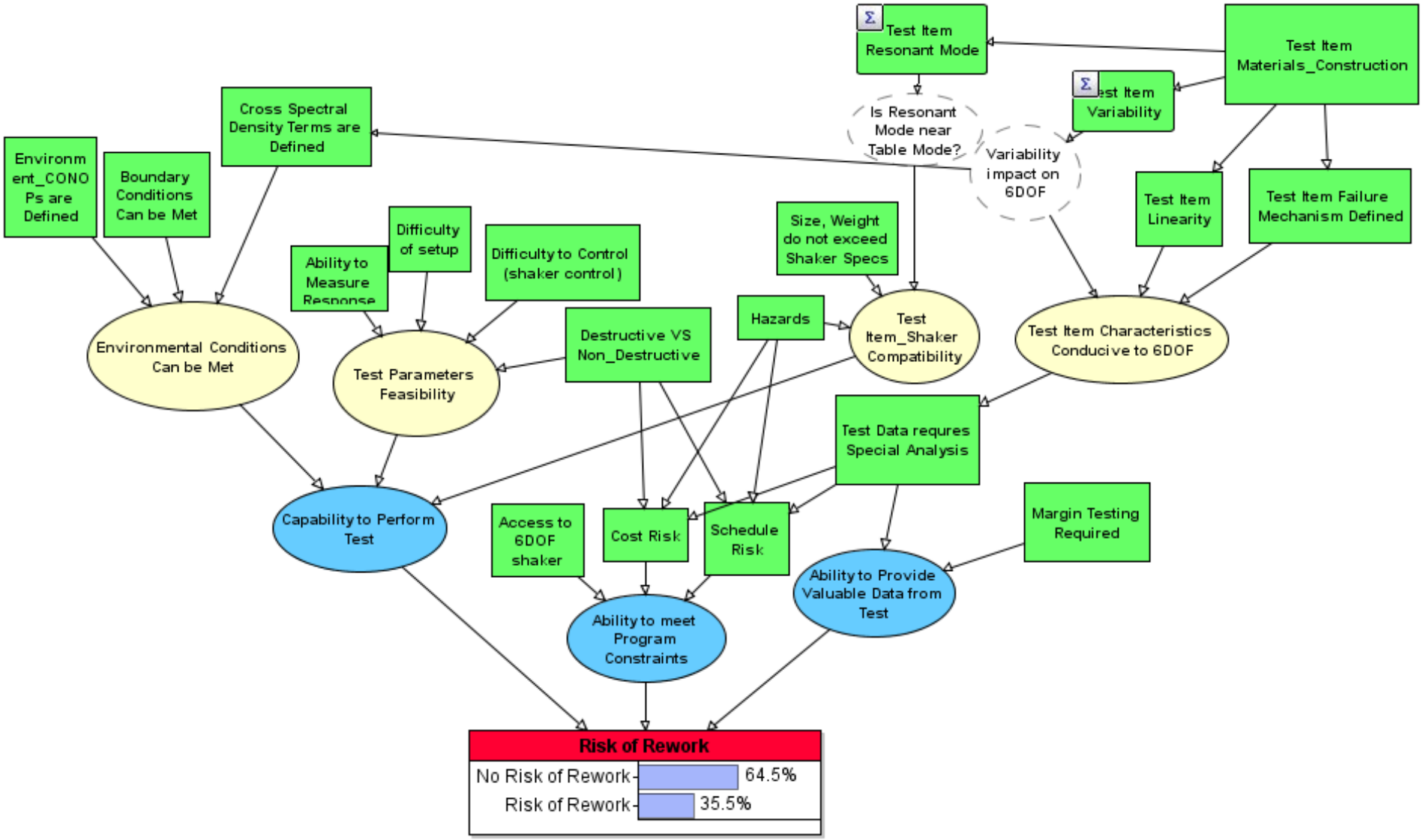

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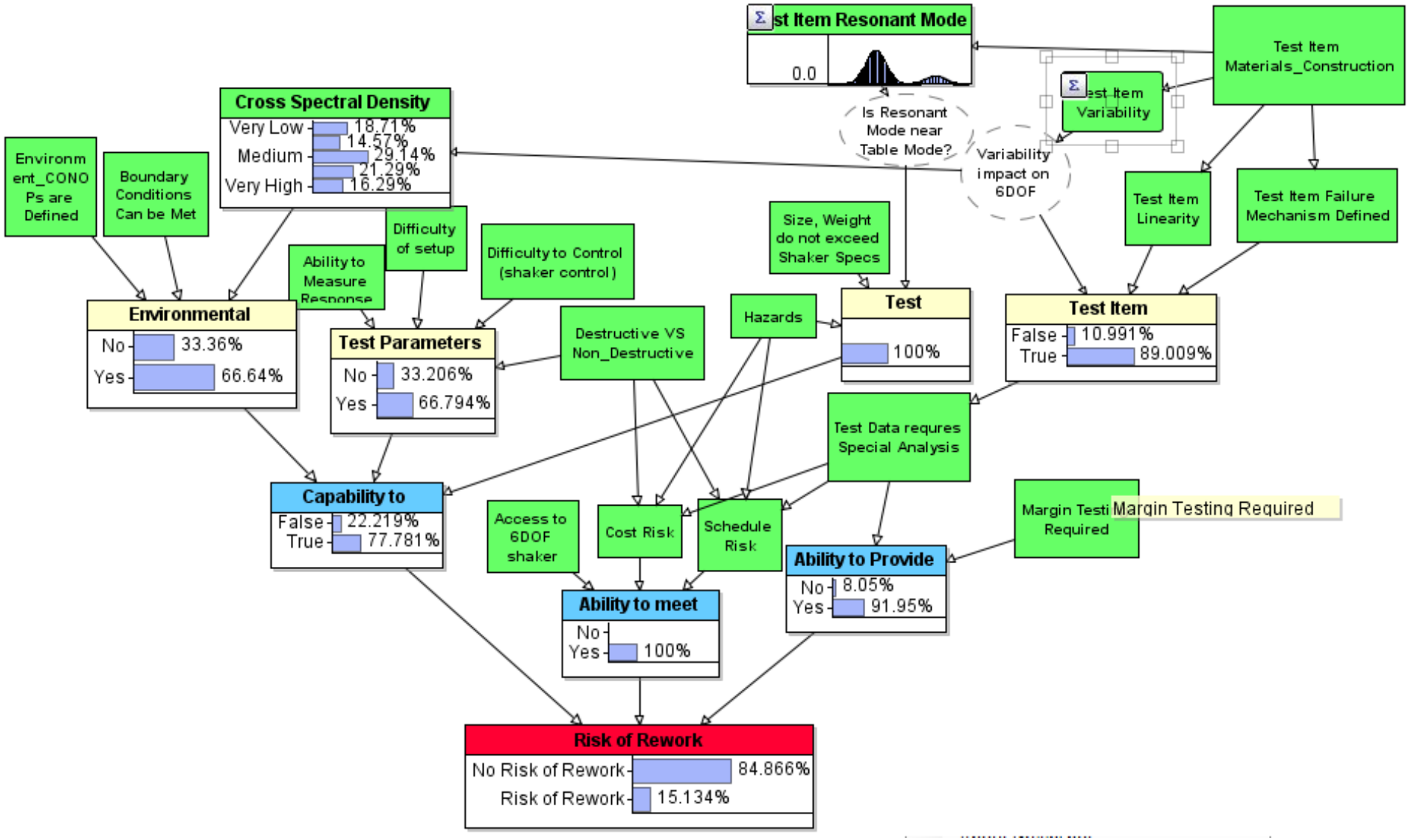
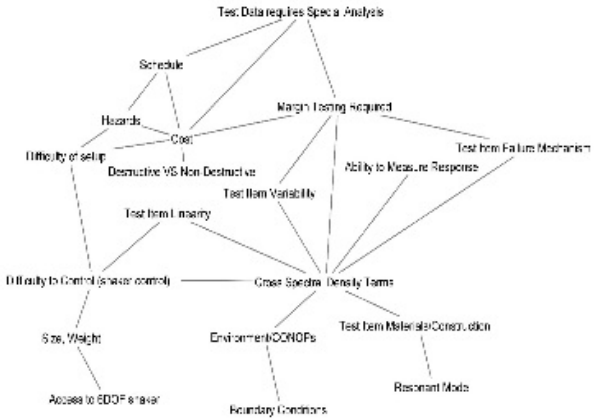
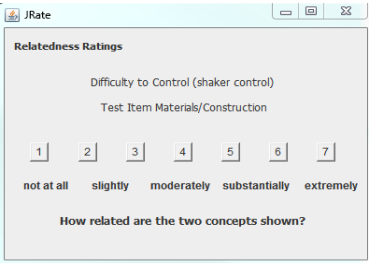

st Item Resonant Mode
0.0
Test Item Materials_Construction
est Item Variability
Is Resonant Mode near Table Mode?
Variability impact on 6DOF
Cross Spectral Density
Very Low 18.71%
14.57%
Medium 29.14%
21.29%
Very High 16.29%
Environm ent_CONO Ps are Defined
Boundary Conditions Can be Met
Difficulty of setup
Ability to Measure Response
Difficulty to Control (shaker control)
Size, Weight do not exceed Shaker Specs
Test Item Linearity
Test Item Failure Mechanism Defined
Environmental
No 33.36%
Yes 66.64%
Test Parameters
No 33.206%
Yes 66.794%
Destructive VS Non_Destructive
Hazards
Test
100%
Test Item
False 10.991%
True 89.009%
Test Data requres Special Analysis
Capability to
False 22.219%
True 77.781%
Access to 6DOF shaker
Cost Risk
Schedule Risk
Margin Testi
Required
Margin Testing Required
Ability to Provide
No 8.05%
Yes 91.95%
Ability to meet
No
Yes 100%
Risk of Rework
No Risk of Rework 84.866%
Risk of Rework 15.134%

Structural Knowledge Assessment

- All possible relationships between factors is a large list
- Need:
  - Unbiased assessment of relationships
  - Strength of relationships
  - Determine whether the relationship is a driver



- SKA was modified to derive BN model relationships
  - Used in education, medical and cognitive science fields
  - Represents the structural properties of domain-specific knowledge
  - Factors presented in pairs to expert who rates based on the strength of the relationship
  - Pathfinder algorithm: derives a network from proximities for pairs of factors



Structural Knowledge Assessment (SKA) used to elicit relationships from experts

Sheffield Elicitation Framework

- Prior elicitation: discretization and parameterization
  - Elicit priors from experts in an unbiased manner
  - Quantitative and qualitative data
  - Probability of an event AND
  - Probability of the probability (uncertainty)
- SHELF method - objectively elicit priors from experts and incorporate data in the process
  - Multi-step process
  - Provides 'evidence dossiers'
  - Requires working meetings with the experts
- Roulette and Quartiles methods
  - Clear definition of factors defined in advance
  - Assign probability distributions
  - I modified to support qualitative data

Structural Knowledge Assessment (SKA) used to elicit relationships from experts

Results - Validation

Iterative Validation Approach

1. Verification of the model – Tolerance, deterministic, structured walk-thru, built-in tools with BN software
2. Validation of factors – screening experiment, peer review with industry working group
3. Validation of relationships and probability distributions – multiple expert peer review with SKA and SHELF, convergent and concurrent validity with other BN models
4. Validation of model performance – prediction metric 98.3%
5. Validation of model performance with historical test data - historical prediction metric 83.3%
6. Validation test cases – two test cases, 8 teams total, examine the effectiveness of the model to aid decision AND assess *learning* through the use of the model - validation case study metric 100%

- Demonstrated the model is effective as a decision aid in planning 6DOF qualification
- Demonstrated the model is effective in teaching key technical concepts

Conclusions

Conclusions

- **Effective decision aid** that could significantly **reduce the cost of rework** in vibration qualification efforts.
- Expand into other areas of Systems Engineering – Method to **capture expert knowledge** in a **predictive framework** to **guide system decisions** when the experts are not available.
  - Technical factors included
- **Ideas/Methods** to **help develop** BN Models – **Expert elicitation**
  - Use of the Structural Knowledge Assessment to elicit SME input on relationships between factors in an unbiased manner.
  - Customized SHELF framework for expert elicitation of quantitative and qualitative factor probabilities
- Method to **accelerate learning** relative to the causal information in the model

Questions?

Thank you!

Recommendations

- Use BN Models for critical systems engineering problems requiring assessment of technical factors
- Use BN Models for high risk programs where changes are expected
- Use BN Models to capture expert knowledge
- Use BN Models to accelerate learning
- Make sure the definitions and assumptions for the model are understood

References

1. INCOSE. Systems Engineering Handbook. Kreuger, M., Walden, D., Hamelin, D. (Editors). International Council on Systems Engineering, San Diego, V.3.2.2., 2011.

2. Rizzo, D., Blackburn, M. Use of Bayesian networks for qualification planning: a predictive analysis framework for a technically complex systems engineering problem. Procedia Computer Science, 61, 2015, 133-140.

3. Stevenson, J., Shah, S., Bish, J. Use of Structural Assessment of Knowledge for Outcome Assessment in the Neuroscience Classroom. The Journal of Undergraduate Neuroscience Education 15 (1) 2016, A38-A43.

4. Oakley J. E. and O'Hagan, A. SHELF: the Sheffield Elicitation Framework (version 3.0). School of Mathematics and Statistics, University of Sheffield, UK , 2016.