Verification, Validation and Credibility of the NASA Integrated Medical Model Sleep Disruption-Medical Intervention Forecasting Tool Exploration Medicine Capabilities Project Human Research Program

J.G. Myers¹, J.E. Brooker¹, B.E. Lewandowski¹, S.R. Hursh³, M.M. Mallis³, J.L. Caldwell², M.E. Walton⁴

1. NASA Glenn Research Center, 21000 Brookpark Rd., Cleveland, OH 44135, jerry.g.myers@nasa.gov
2. Air Force Research Laboratory, Wright-Patterson AFB, OH 45433
3. Institutes for Behavior Resources, Inc., 2104 Maryland Avenue, Baltimore, MD 21218
4. Wyle Integrated Science and Engineering, Houston TX 77058
Focus on the future, Informed with the past

- Questions for NASA Human Research Program
  - How do we best inform decision makers and mission planners on what is needed to allow humans to visit Moon, Mars, and other celestial bodies?
  - How do we optimize medical needs for astronauts with limited Mass, Volume and Power?
Integrated Medical Model (IMM)

"The most important questions of life are indeed, for the most part, really only problems of probability." ~Pierre Simon Laplace

Potential Medical Condition

Evaluate with IMM

- Integrate best available evidence to quantify the probability and consequences of medical risks
- Identify medical resources and inform operational decisions which optimize health and mission success
- "Data hungry" process

Likelihood of occurrence, probable severity of occurrence, and optimization of treatment and resources.

www.nasa.gov
Houston, we have a problem

- Forecasting rare medical events confounded by space travel
  - Insufficient data
    - Few or no occurrences
  - No clear correlation to terrestrial analog
  - Multiple influencing conditions
    - Mission details
    - Vehicle limitations (environment)
    - Physiological adaptations
    - Interaction of the contributing factors

- How do we verify and validate?
  - When we are data "starved"
It's Really About Model Credibility!
Achieving a high level of belief or trust in the model

- NASA-STD-7009
  - Standard for Models and Simulations (M&S)
- M&S Development
  - Verification
  - Validation
- M&S Operations
  - Input Pedigree
  - Results Uncertainty
  - Results Robustness
- Supporting Evidence
  - Use History
  - M&S Management
  - People Qualifications

Human research program:
- a) Scoring subject to SME review
- b) Results used to balance project derived evidence
## Facts are Stubborn Things
### Credibility Levels of Evidence

<table>
<thead>
<tr>
<th>Level</th>
<th>Verification</th>
<th>Validation</th>
<th>Input Pedigree</th>
<th>Results Uncertainty</th>
<th>Results Robustness</th>
<th>Use History</th>
<th>M&amp;S Management</th>
<th>People Qualifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Numerical errors small for all important features.</td>
<td>Results agree with real-world data.</td>
<td>Input data agree with real-world data.</td>
<td>Non-deterministic &amp; numerical analysis.</td>
<td>Sensitivity known for most parameters; key sensitivities identified.</td>
<td>De facto standard.</td>
<td>Continual process improvement.</td>
<td>Extensive experience in and use of recommended practices for this particular M&amp;S.</td>
</tr>
<tr>
<td>3</td>
<td>Formal numerical error estimation.</td>
<td>Results agree with experimental data for problems of interest.</td>
<td>Input data agree with experimental data for problems of interest.</td>
<td>Non-deterministic analysis.</td>
<td>Sensitivity known for many parameters.</td>
<td>Previous predictions were later validated by mission data.</td>
<td>Predictable process.</td>
<td>Advanced degree or extensive M&amp;S experience, and recommended practice knowledge.</td>
</tr>
<tr>
<td>2</td>
<td>Unit and regression testing of key features.</td>
<td>Results agree with experimental data or other M&amp;S on unit problems.</td>
<td>Input data traceable to formal documentation.</td>
<td>Deterministic analysis or expert opinion.</td>
<td>Sensitivity known for a few parameters.</td>
<td>Used before for critical decisions.</td>
<td>Established process.</td>
<td>Formal M&amp;S training and experience, and recommended practice training.</td>
</tr>
</tbody>
</table>

**Climb the Ladder**

www.nasa.gov
Sleep Disruption- Medical Intervention Forecasting (SDMIF) Tool

- Predict the sleep inducing medication use during a space mission
  - Resulting from circadian rhythm disruption, insomnia, and environmental disruptions

Probability Distribution of Taking a Sleep Aid on a Simulated ISS Increment (180 days, nominal sleep/wake opportunities, 5000 iterations)

The sleep quality factor (SQF) is a measure of the number of 5-minute interruptions per hour of sleep period time (SPPT) and is defined as the ratio of total sleep time (TST) to SPPT. The SQF modulates the sleep recovery (SR) calculation within SAFTE by uniformly scaling each minute of the SR thereby controlling the benefit of sleep recovery.
SDMIF: Verification and Validation

- Limited space flight data most likely used in the development of the model
- Verification exercises
  - Fixed and Extreme value testing of all PDFs
  - Estimates of numerical error
- Validation of individual components
  - Validate conceptual structure by SME review
    - Schedulers verify mission schedule component
    - Medical Ops validate the diagnosis component
- Validation of Module Performance
  - Face validation as V&V tool
    - Turing or Schruben tests with operational and flight medical experts
  - Direct comparison to observed incidence
    - Historical testing – Select data used for validation
    - Prospective validation – Future missions observations
Model Data, Robustness and Uncertainty

- **Model Data**
  - Desired: Assure data are appropriate for the intended model use
  - Achieved: Highest quality of the data correlated to the scenario

- **Model Robustness**
  - Desired: percentage of the contribution of an independent variable to the variation of the outcome
  - Achieved: Rank order correlation sensitivity analysis

- **Model Uncertainty**
  - Desired: magnitude and confidence of estimate
  - Achieved: quantified based on non-deterministic analysis
Use History, Management and Qualifications

• Use History
  – Desired: Model use extended to address similar questions
  – Achieved:
    • Similar outputs to other tools in limited scenarios
    • When Model is used to inform real world decisions

• Management: Continuous Improvement
  – Desired and Achieved: Document all activity, management processes and decisions affecting code development, input changes, and V&V efforts.

• Qualifications
  – Desired: Staff can interpret and use the results
  – Achieved: Development staff maintains expertise levels required to develop, maintain, update and operate the model environment.
Implementation in Global IMM

• Implementation requires that modules
  - Undergo subject matter review
    • SDMIF – Conceptual model, Input data, validation process reviewed by National Space Biomedical Research Institute
  - Undergo integration team review
    • IMM team review of module performance and evidence
      - Credibility MUST be at least that of the rest of the IMM
  - New IMM model undergoes V&V and credibility assessment

• All evidence meticulously documented
  - "We can lick gravity, but sometimes the paperwork is overwhelming." ~Wernher von Braun
Let's Review

- Models related to medical events used to inform Space Flight Operations and Planning
  - Must exhibit a high level of *Credibility* for the intended use
  - Must have their *Credibility* assessed over multiple factors
- Chief factor is an acceptable V&V process
  - Complicated by limited in-flight data
  - Relies on systematic use of SME’s and Face Validation to balance limits in direct comparative evidence
Acknowledgements

- The IMM and SDMIF is funded by the NASA Human Research Program, which is managed at the Johnson Space Center.

- Special Thanks
  - IMM development team at Wyle ISGE
    - Many are probably in the audience – *Thanks Guys!*
  - David Baumann (JSC) and DeVon Griffin (GRC)
    - NASA ExMC Project Managers
  - Lauren Leveton – BHP Lead NASA-JSC
  - Daniel Mollicone – Pulsar Informatics Inc. (SME Review)
  - Laura Barger – NSBRI (SME Review)
  - Gary Beven – JSC medical Operations (SME Review)
  - Host of other players