Integrated Medical Model (IMM) 4.0 – Enhanced Functionalities

M. Young¹, A. B. Keenan¹, L. Saile¹, L. A. Boley¹, M. E. Walton¹, R. V. Shah², E. L. Kerstman², J. G. Myers³

¹Wyle Science, Technology and Engineering Group, Houston, TX; ²University of Texas Medical Medical Branch, Galveston, TX; ³Glenn Research Center, Cleveland, OH

www.nasa.gov
IMM v4.0 Overview

- Consider data for 100 medical conditions from the Integrated Medical Evidence Database (iMED)
- Simulate medical event occurrences over large number of missions via Monte Carlo methodology
- For each medical condition:
  - Incidence Rate
  - Time to occurrence
  - Best Case or Worst Case?
  - Treated or Untreated?
  - FI, duration, EVAC, LOCL

National Aeronautics and Space Administration
Incidence Rate (IR)

- Fixed, lognormal and gamma distributions defined in iMED
- Generate IR for each medical condition-crewmember combination
- Example: Sepsis

**Incidence:** Data category: Fixed  
Space Adaptation: No  
Incidence type: Rate  
**Model Data Path:** Incidence Rate: 0.0024  
**Distribution Data:** Incidence Distribution: Fixed  
Occurrence Distribution: Poisson  
**Characteristics Specific:** none
## Time to Occurrence

- Given IR and mission length, use exponential distribution to time-to-event(s) for generated IR
- **Example: Sepsis**
  - IR = 0.0024 (fixed) per person-year
  - Mission Length = 4383 hours (6 months)
  - 6 crew A-F

<table>
<thead>
<tr>
<th>Crew</th>
<th>Condition</th>
<th>Start Time</th>
<th>Worst case</th>
<th>Treated</th>
<th>CP1 FI (%)</th>
<th>CP1 DUR</th>
<th>CP2 FI (%)</th>
<th>CP2 DUR</th>
<th>CP3 FI (%)</th>
<th>CP3 DUR</th>
<th>EVAC</th>
<th>LOCL</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>Sepsis</td>
<td>1267</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>Sepsis</td>
<td>4012</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Incidence Rate** ➔ **Time to occurrence** ➔ **Best Case or Worst Case?** ➔ **Treated or Untreated?** ➔ **FI, duration, EVAC, LOCL**

National Aeronautics and Space Administration
Best Case or Worst Case?

- Worst case probability upper bound and lower bound defined in iMED
- $P_{\text{worst case}}$ drawn from uniform distribution
- Example: Sepsis
  \[
  W_{C_{\text{upper bound}}} = 0.38, \quad W_{C_{\text{lower bound}}} = 0.38 \quad \rightarrow \quad P_{\text{worst case}} = 0.38
  \]

<table>
<thead>
<tr>
<th>Crew</th>
<th>Condition</th>
<th>Start Time</th>
<th>Worst Case</th>
<th>Treated</th>
<th>CP1 FI (%)</th>
<th>CP1 DUR</th>
<th>CP2 FI (%)</th>
<th>CP2 DUR</th>
<th>CP3 FI (%)</th>
<th>CP3 DUR</th>
<th>EVAC</th>
<th>LOCL</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>Sepsis</td>
<td>1267</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>Sepsis</td>
<td>4012</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Treated or Untreated?

- Each medical condition has resources required to treat and possible alternatives defined in iMED.
- Examine contents of medical kit and determine whether sufficient resources exist to treat each medical event occurrence.
- Treatment order determined by start time of each medical event.
- For each occurrence, decrement contents of kit.
- Example: Sepsis

<table>
<thead>
<tr>
<th>Crew</th>
<th>Condition</th>
<th>Start Time</th>
<th>Worst Case</th>
<th>Treated</th>
<th>CP1 FI (%)</th>
<th>CP1 DUR</th>
<th>CP2 FI (%)</th>
<th>CP2 DUR</th>
<th>CP3 FI (%)</th>
<th>CP3 DUR</th>
<th>EVAC</th>
<th>LOCL</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>Sepsis</td>
<td>1267</td>
<td>0</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>Sepsis</td>
<td>4012</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Incidence Rate  ➔  Time to occurrence  ➔  Best Case or Worst Case?  ➔  Treated or Untreated?  ➔  FI, duration, EVAC, LOCL

National Aeronautics and Space Administration
Outcomes: Functional Impairment and Duration

Upper and lower bounds of beta pert distributions defined in iMED:

<table>
<thead>
<tr>
<th>Sepsis Outcomes</th>
<th>Clinical Phase 1</th>
<th>Clinical Phase 2</th>
<th>Clinical Phase 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>FI</td>
<td>Duration</td>
<td>FI</td>
</tr>
<tr>
<td>Treated, Best case</td>
<td>100</td>
<td>1</td>
<td>2-36</td>
</tr>
<tr>
<td>Treated, Worst case</td>
<td>100</td>
<td>1-2</td>
<td>16-58</td>
</tr>
<tr>
<td>Untreated, Best case</td>
<td>16-58</td>
<td>48-72</td>
<td>16-58</td>
</tr>
<tr>
<td>Untreated, Worst case</td>
<td>38-75</td>
<td>48-72</td>
<td>38-75</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Crew</th>
<th>Condition</th>
<th>Start Time</th>
<th>Worst Case</th>
<th>Treated</th>
<th>CP1 FI (%)</th>
<th>CP1 DUR</th>
<th>CP2 FI (%)</th>
<th>CP2 DUR</th>
<th>CP3 FI (%)</th>
<th>CP3 DUR</th>
<th>EVAC</th>
<th>LOCL</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>Sepsis</td>
<td>1267</td>
<td>0</td>
<td>1</td>
<td>100</td>
<td>1</td>
<td>12</td>
<td>97</td>
<td>0</td>
<td>3010</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>C</td>
<td>Sepsis</td>
<td>4012</td>
<td>1</td>
<td>1</td>
<td>100</td>
<td>1.4</td>
<td>28</td>
<td>64</td>
<td>100</td>
<td>305.6</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

Incidence Rate → Time to occurrence → Best Case or Worst Case? → Treated or Untreated? → FI, duration, EVAC, LOCL

National Aeronautics and Space Administration
Summarizing Results

• Probability of evacuation (pEVAC)
  • Proportion of simulated missions with one or more evacuations
  • Confidence limits are estimated with bootstrap resampling
• Probability of loss of crew life (pLOCL)
  • Proportion of simulated missions with one or more loss of crew life
  • Confidence limits are estimated with bootstrap resampling
• Crew Health Index (CHI)
  • Proportion of mission time not lost to medical events

\[
1 - \frac{\sum QTL}{L \cdot n} = CHI
\]

Where n= # crew, L = mission length, QTL=quality time lost; is a function of functional impairment and duration
Timeline

**IMM v3.0:**
All medical events occur at beginning of mission

**Limitations:**
- Overestimation of quality time lost due to CP3 functional impairment
- Must impose artificial order of treatment

**IMM v4.0:**
- Generate time-to-event for each medical event
- Crewmember cannot have medical events following EVAC or LOCL

**Impacts:**
- Probability of LOCL and EVAC
- CHI
- Resource utilization

National Aeronautics and Space Administration
Partial Treatment

**IMM v3.0:**
If single resource is not available (e.g. one pill), medical event goes entirely untreated, untreated outcomes used

*Limitations:*
Overestimate negative impact of medical events

**IMM v4.0:**
- Introduce continuum between distributions defined for treated and untreated scenarios
- New distributions defined by proportion of resources available
Alternative Treatment

**IMM v3.0:**
Only primary resources designated for each medical condition may be used to treat

**IMM v4.0:**
Alternative resources are designated in iMED and may be used for treatment

*Limitations:*
Does not reflect real-world system.
Mars (6 crew, 2.5 years)
Total Medical Events

National Aeronautics and Space Administration
Mars (6 crew, 2.5 years)
Crew Health Index

IMM version/
functionality

v3 – IMM version 3.0
v4.T – IMM with timeline only
v4.TPT – IMM with timeline and partial treatment
v.4.0 – IMM version 4.0 (timeline + partial treatment + alternative treatment)
Mars (6 crew, 2.5 years) Evacuations

National Aeronautics and Space Administration
Mars (6 crew, 2.5 years)
Loss of Crew Life

![Bar chart showing the number of LOCLs for different Mars missions.]

- v3: 95,167 trials
- v4.T: 96,571 trials
- v4.TPT: 97,728 trials
- v4.0: 97,787 trials

# of LOCLs
- 2
- 1
- 0

National Aeronautics and Space Administration
ISS (6 crew, 6 months)
Total Medical Events

IMM version/functionality

v3 – IMM version 3.0
v4.T – IMM with timeline only
v4.TPT – IMM with timeline and partial treatment
v4.0 – IMM version 4.0 (timeline + partial treatment + alternative treatment)
ISS (6 crew, 6 months)
Crew Health Index

IMM version/functionality
- v3 – IMM version 3.0
- v4.T – IMM with timeline only
- v4.TPT – IMM with timeline and partial treatment
- v4.0 – IMM version 4.0 (timeline + partial treatment + alternative treatment)
ISS (6 crew, 6 months)
Evacuations
ISS (6 crew, 6 months)
Loss of Crew Life
Conclusions

- Total Medical Events
  - Decrease because no events may occur following loss of crew life or evacuation

- Crew Health Index
  - Increase due to:
    - More medical events being treated due to partial treatment and alternative treatment functionalities
    - Timelined medical events causing duration of lingering functional impairment to be shortened

- Probabilities of Evacuation and Loss of Crew Life
  - Decrease due to due to partial treatment and alternative treatment functionalities
Questions?