Integrated Medical Model (IMM) 4.0 – Enhanced Functionalities

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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
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>
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<tr>
<td>C</td>
<td>Sepsis</td>
<td>4012</td>
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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
  \[ WC_{\text{upper bound}} = 0.38, \ WC_{\text{lower bound}} = 0.38 \Rightarrow P_{\text{worst case}} = 0.38 \]

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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

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Incidence Rate → Time to occurrence → Best Case or Worst Case? → Treated or Untreated? → FI, duration, EVAC, LOCL
## 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>
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<tbody>
<tr>
<td></td>
<td>FI</td>
<td>Duration</td>
<td>FI</td>
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<tr>
<td>Treated, Best case</td>
<td>100</td>
<td>1</td>
<td>2-36</td>
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<tr>
<td>Treated, Worst case</td>
<td>100</td>
<td>1-2</td>
<td>16-58</td>
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<tr>
<td>Untreated, Best case</td>
<td>16-58</td>
<td>48-72</td>
<td>16-58</td>
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<tr>
<td>Untreated, Worst case</td>
<td>38-75</td>
<td>48-72</td>
<td>38-75</td>
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</tbody>
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### Crew Data

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<td>1267</td>
<td>0</td>
<td>1</td>
<td>100</td>
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<td>12</td>
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<td>64</td>
<td>100</td>
<td>305.6</td>
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<td>0</td>
</tr>
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**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

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

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
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

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![Graph showing probability density vs. functional impairment for treated and untreated scenarios.](image1)

![Graph showing probability density vs. functional impairment for various proportions of resources available.](image2)
Alternative Treatment

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

Limitations:
Does not reflect real-world system.

IMM v4.0:
Alternative resources are designated in iMED and may be used for treatment
Mars (6 crew, 2.5 years)
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)
Mars (6 crew, 2.5 years)
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Mars (6 crew, 2.5 years)
Evacuations

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

# of LOCLs

% Trials

v3 95167
v4.T 96571
v4.TPT 97728
v4.0 97787

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

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ISS (6 crew, 6 months)

Evacuations

% Trials

# of EVACs

0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

v3 82763
v4.T 85819
v4.TPT 94056
v4.0 94503

National Aeronautics and Space Administration
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?