Optimizing Medical Kits for Space Flight

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Introduction

- Space is an inherently hostile environment
- Altered incidence, mitigation and recovery from adverse medical events
- Medical system
  - Physical limitations
  - Limited resupply

Optimization Goal

• Optimize medical kit using IMM results
  • Specific mission profile

• Two scenarios
  1) Best outcome given resource constraints
  2) Minimize resources given desired outcome(s)

IMM Outcomes

- Crew Health Index (CHI)
- Probability of evacuation
- Probability of loss of crew life
- Resources utilization
- Combined metric
Resource Constraints

• Multiple constraints on medical resources
  • Mass
  • Volume
  • Cost
  • Packaging
  • Bandwidth
  • Power
  • Etc.
Consider Scenario 1

• Best outcome given resource constraints
  • Define resource requirements
    • Maximum mass
    • Maximum volume
  
• Decide which outcome(s) are of interest
  • Maximize CHI
  • Minimize Pr(evacuation)

• Fill medical kit with the most efficient set of medical resources
Optimization Scenario 1

• Maximize outcome(s) of interest subject to resource constraints

- Run Simulation (~50 thousand trials)
- Identify least influential resource
- Remove one unit
- Check constraints
- Calculate Outcome(s)
- Determine “maximum” medical kit

Determine “maximum” medical kit
Are Constraints Satisfied?

- Identify least influential resource
- Remove one unit
- Check constraints
- Calculate Outcome(s)
- Add Resources Back?
- Satisfied?
  - Yes
  - No
  - Yes
  - No
  - STOP
  - No
Additional Considerations

• Essential vs. Nonessential
  • Nonessential resources will be removed first
  • Band-aids, thermometer, etc.

• Consumable vs. Nonconsumables
  • Number of units
  • Frequency of use

• Tie breakers
  • Mass
  • Volume
  • Cost
  • Etc.
Results

• Maximize CHI

• Mission Length
  • 24 days

• Number of crew members
  • 4 (2M, 2F)

• Resource constraints
  • 4.3 kg
  • 6421.7 cm³

http://www.nasa.gov/multimedia/imagegallery/iotd.html#
Results (24 days, 4 crew)

- Resource constraints
  - 4.3 kg
  - 6421.7 cm³

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Minimum</th>
<th>Optimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass (kg)</td>
<td>0</td>
<td>3.42</td>
<td>67.3</td>
</tr>
<tr>
<td>Volume (cm³)</td>
<td>0</td>
<td>6421.7</td>
<td>191434</td>
</tr>
<tr>
<td>Mean CHI (SD)</td>
<td>15.2 (12.3)</td>
<td>94.3 (4.9)</td>
<td>94.9 (3.9)</td>
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<tr>
<td>Median CHI</td>
<td>13.5</td>
<td>96.3</td>
<td>96.4</td>
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</table>
CHI Distribution by Medical Kit
Optimization Scenario 2

• Minimize resources subject to constraints on the outcome(s)
  • Define outcome requirements
    • \( \Pr(\text{evac}) \leq 10\% \)
    • \( \text{CHI} \geq 90\% \)

• Identify the medical kit
Optimization Scenario 2

- Minimize resources subject to constraints on the outcome(s)

1. Randomly select combinations of events to treat
2. Calculate mass, volume, etc.
3. Check constraints
4. Identify all combinations of medical conditions

Run Simulation (~50 thousand trials)

Repeat many times.
Lowest mass and volume wins!
Results

• Minimize Mass and Volume

• Mission Length
  • 24 days

• Number of crew members
  • 4 (3M, 1F)

• Evacuation constraints
  • \( \Pr(\text{Evacuation}) < 2\% \)

http://www.nasa.gov/multimedia/imagegallery/iotd.html#
Results (24 days, 4 crew)

• Evacuation constraints
  • $\text{Pr (Evacuation)} < 2\%$

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<tr>
<td>Mass (kg)</td>
<td>0</td>
<td>38.66</td>
<td>81.86</td>
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<tr>
<td>Volume (cm$^3$)</td>
<td>0</td>
<td>94,527.73</td>
<td>201,669.01</td>
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<tr>
<td>Mean CHI (SD)</td>
<td>78.27(8.52)</td>
<td>91.38 (3.74)</td>
<td>95.21 (2.35)</td>
</tr>
<tr>
<td>Evacuation Probability</td>
<td>16.01%</td>
<td>1.94%</td>
<td>0.37%</td>
</tr>
</tbody>
</table>
Additional Considerations

- Goal is to minimize resources
- Some conditions will not satisfy outcome constraints even if treated
- Resources are used to treat medical events
  - Not primary prevention
Flexibility

• Resource inclusion and exclusion criteria
  • Flight surgeons

• Personal medical kits

• Customized metrics
  • Outcomes
Conclusions

• Trade-off
  • Occurrence
  • Impact
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