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

Calculate Outcome(s)

Remove one unit

Check constraints

Determine “maximum” medical kit
Are Constraints Satisfied?

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

Add Resources Back?
- Yes
- No
  - STOP
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>
</tr>
<tr>
<td>Median CHI</td>
<td>13.5</td>
<td>96.3</td>
<td>96.4</td>
</tr>
</tbody>
</table>
CHI Distribution by Medical Kit
Optimization Scenario 2

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

• Identify the medical kit
Optimization Scenario 2

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

- Randomly select combinations of events to treat
- Identify all combinations of medical conditions
- Calculate mass, volume, etc.
- Check constraints

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(Evacuation) < 2%

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

- Evacuation constraints
  - 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 (cm³)</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>
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<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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