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

Calculate Outcome(s)

Check constraints

Determine “maximum” medical kit
Are Constraints Satisfied?

1. Add Resources Back?
   - Yes → Satisfied?
   - No → Identify least influential resource

2. Satisfied?
   - Yes → Check constraints
   - No → Remove one unit

3. Calculate Outcome(s)

4. STOP

- Yes → Add Resources Back?
- 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>
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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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</tbody>
</table>
CHI Distribution by Medical Kit

Medical Kit: Minimum, Optimum, Maximum

Crew Health Index (%) vs. Percent of Trials

0 10 20 30 40 50 60 70 80 90 100
Optimization Scenario 2

• Minimize resources subject to constraints on the outcome(s)
  • Define outcome requirements
    • Pr(evac) ≤ 10%
    • CHI ≥ 90%

• Identify the medical kit
Optimization Scenario 2

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

1. Run Simulation
   (~50 thousand trials)

2. Identify all combinations of medical conditions

3. Randomly select combinations of events to treat

4. Calculate mass, volume, etc.

5. Check constraints

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

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

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

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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>
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</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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