Mass and Volume Optimization of Space Flight Medical Kits

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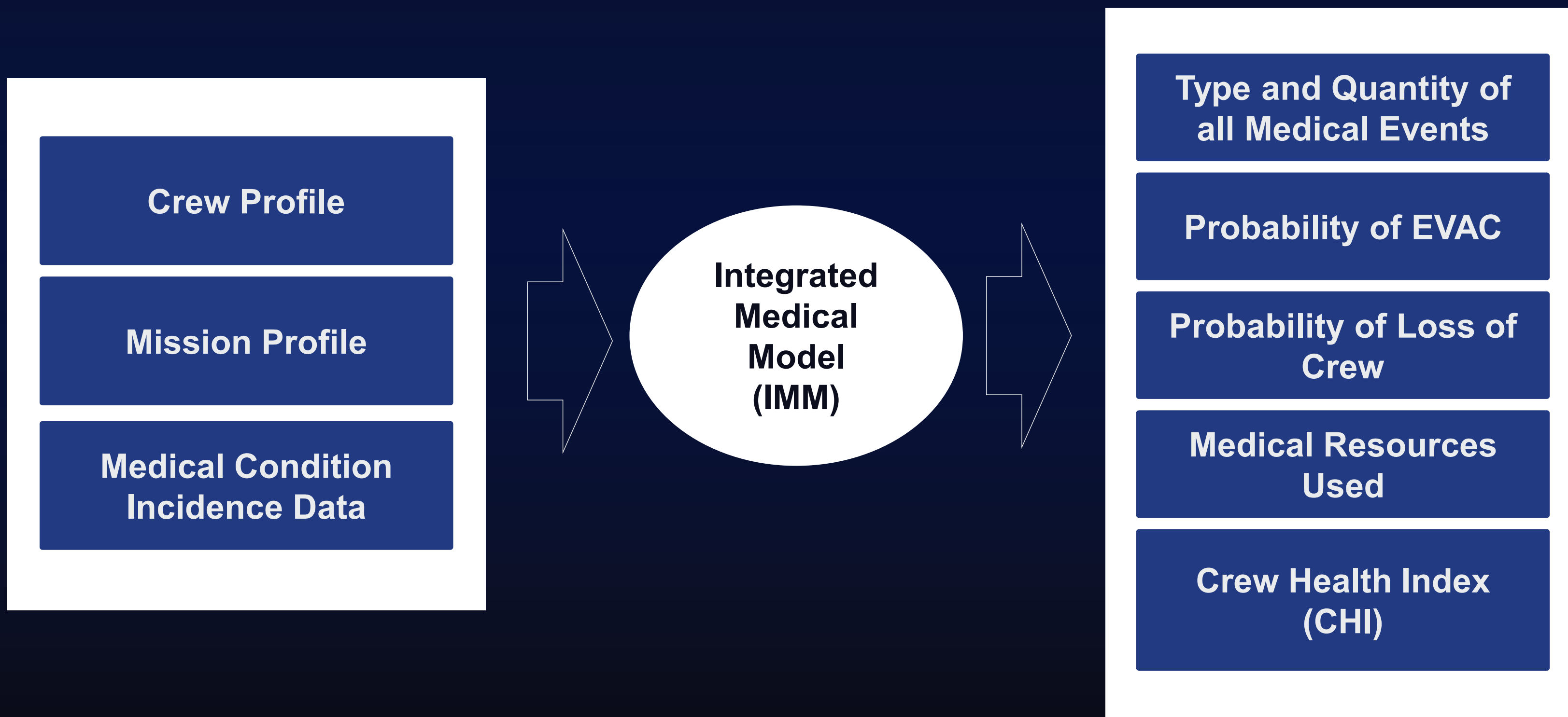
Outline

- Introduction & Background
  - Integrated Medical Model (IMM)
  - Optimization problem definition
- Approach
  - Knapsack problem
  - Dynamic programming
- Results
- Conclusion

What is "IMM"?

- Software-based decision support tool
- Uses Monte Carlo simulation to forecast medical outcomes for a mission and crew



Defining the Problem

Optimize the allocation of medical resources for a given mass, volume, and/or level of acceptable risk.

Which resources to include in medical kit / medical system such that…

crew health is maximized while meeting some mass and/or volume constraint?

or

we minimize mass and/or volume while meeting some acceptable level of risk?

Defining the Problem

Let T be a set of n medical treatments $\langle t_1, t_2, t_3, \ldots, t_{n-1} t_n \rangle$

Treatment t_i has mass m_i, volume v_i, and some benefit b_i

Objective: Maximize crew health while meeting some mass constraint M and/or volume constraint V

What is the subset $K \subseteq \langle t_1, t_2, t_3, \ldots, t_{n-1} t_n \rangle$ such that we:

Maximize $\sum_{i \in K} b_i$

Subject to $\sum_{i \in K} v_i \leq V$ and $\sum_{i \in K} m_i \leq M$

Defining the Problem

Let T be a set of n medical treatments $\langle t_1, t_2, t_3, \dots, t_{n-1} t_n \rangle$

Treatment t_i has mass m_i, volume v_i, and some benefit b_i

Objective: Minimize mass and volume subject to some acceptable level of risk R. Let B be the required total benefit of the kit to achieve R.

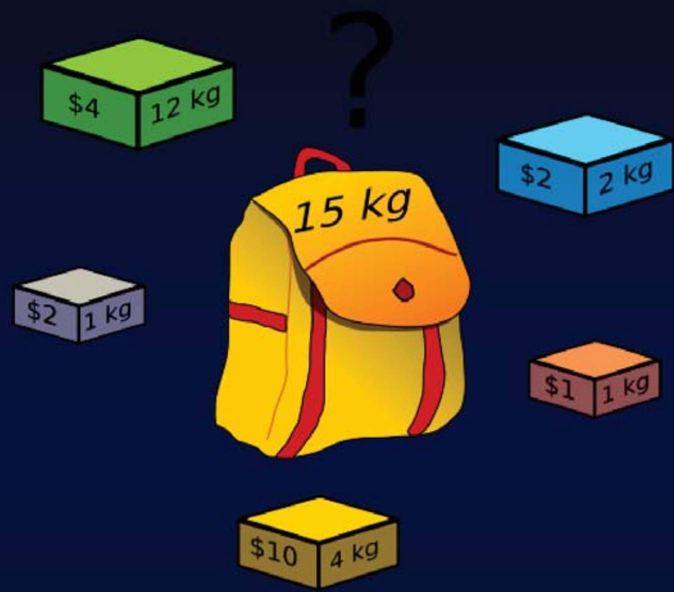
What is the subset $\mathrm{K} \subseteq \langle t_1, t_2, t_3, \dots, t_{n-1} t_n \rangle$ such that we:

Minimize $\sum_{i \in K} v_i$ **and** $\sum_{i \in K} m_i$

Subject to $\sum_{i \in K} b_i \geq B$

Approach

Classic combinatorial optimization problem: Knapsack Problem



- **Brute force: 2^n run time**
- **Dynamic programming: $n \times M \times V$ run time**
  - **Problem has optimal substructure**
  - **Use recursive function to build solution from solutions to sub-problems**

Approach

- Use IMM outputs to:
  - Define T – our set of treatments
  - Assign benefit values b_i to elements of T

Approach

Let T $= \langle t_1, t_2, t_3, \ldots, t_{n-1} t_n \rangle$ be the minimum set of resources for some *k* IMM trials so that all medical events are fully treated within any single trial

Approach

Objective: Maximize crew health subject to mass and volume constraints.

- Assigning benefit value b_i for treatment t_i
  - Maximize crew health index (CHI)*
    - b_i is a function of the frequency t_i is used during mission and the impact to CHI if the medical conditions requiring t_i go untreated
  - Minimize probability of evacuation (pEVAC)
    - b_i is a function of the frequency that medical conditions requiring t_i result in an evacuation

*CHI is a function of quality time lost

Approach

Objective: Minimize kit mass and volume subject to a risk threshold.

Assigning benefit value b_i for treatment t_i

- **Maximize crew health index (CHI)**
  - **b_i is a function of the mean contribution t_i makes to CHI over k IMM simulations**

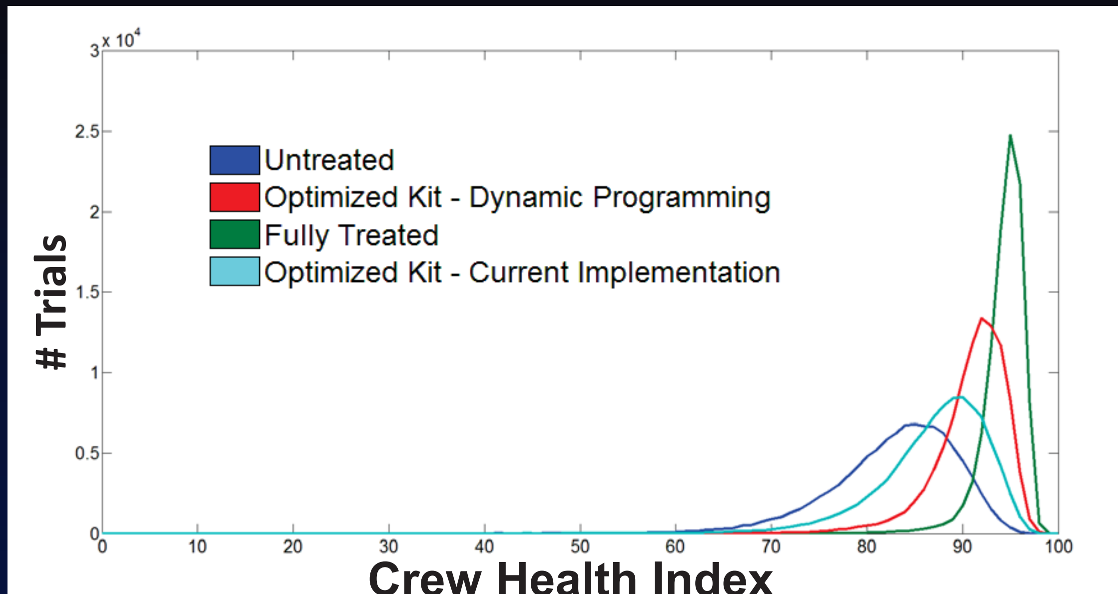
$$\sum_{i \in T} b_i = B_{tot}$$

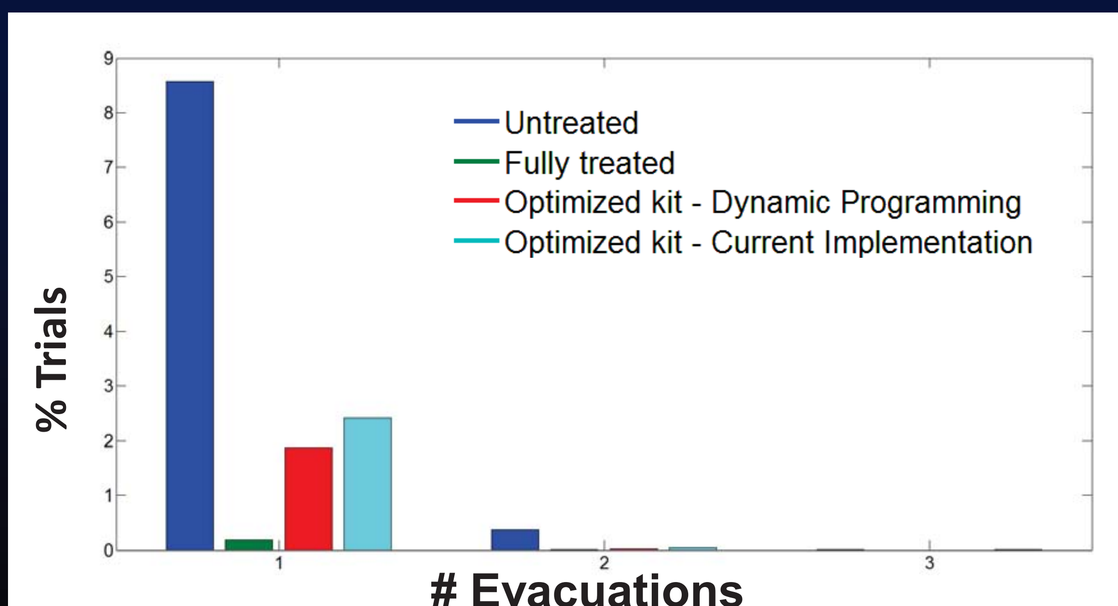
Find subset Q$\subseteq \langle t_1, t_2, t_3, \ldots, t_{n-1} t_n \rangle$ s.t. we:

Maximize $\sum_{i \in Q} v_i$ and $\sum_{i \in Q} m_i$ subject to $\sum_{i \in Q} b_i \leq B_{tot} - B$

Let K$= T \backslash Q$

Results – 4 crew, 14 day mission

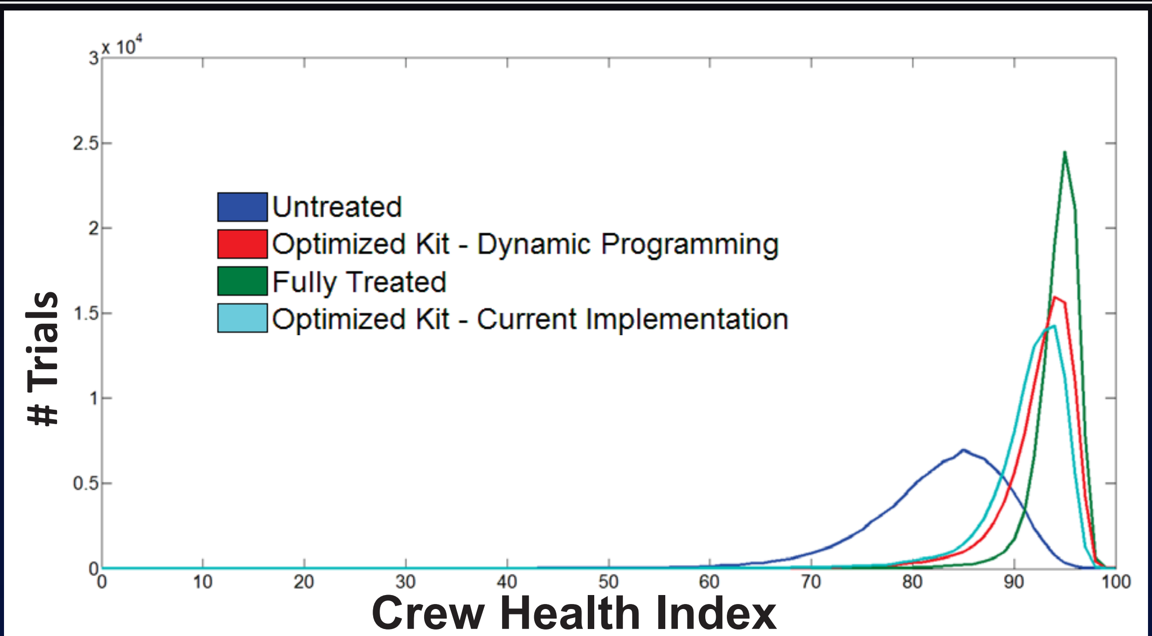


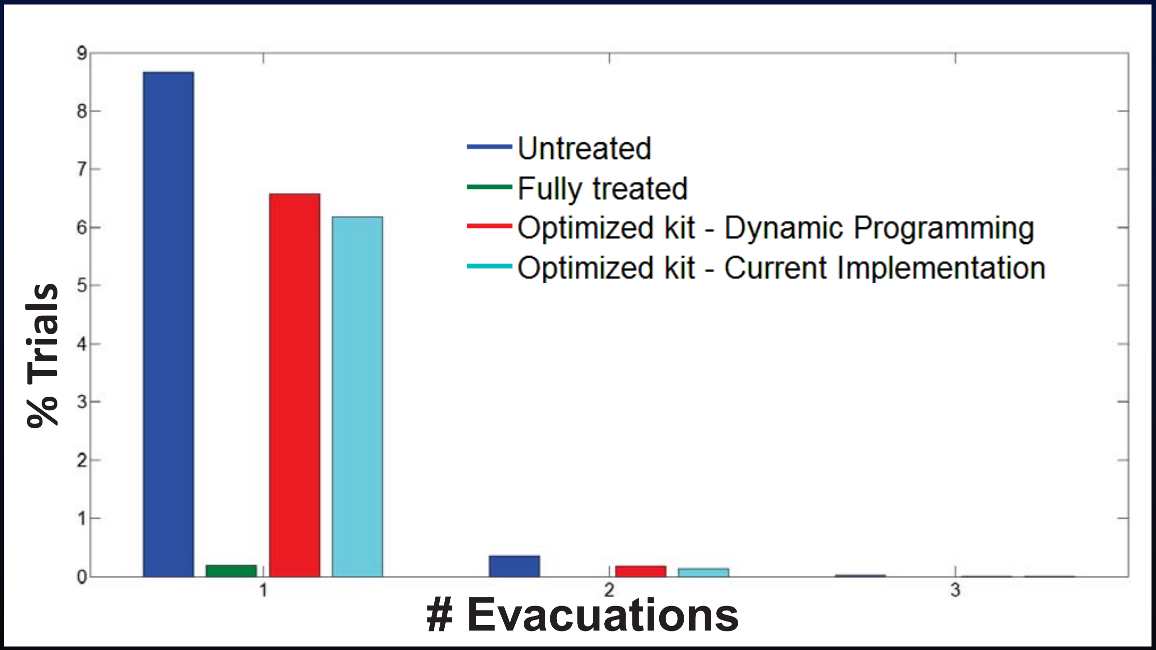


Optimization Priority:

Minimize pEVAC

Results – 4 crew, 14 day mission

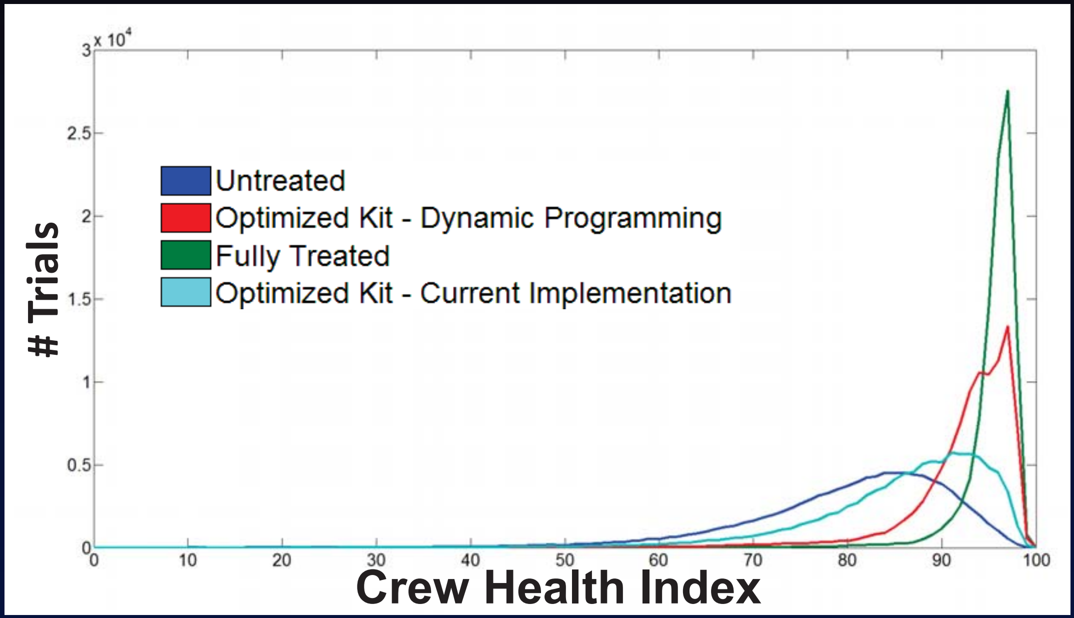


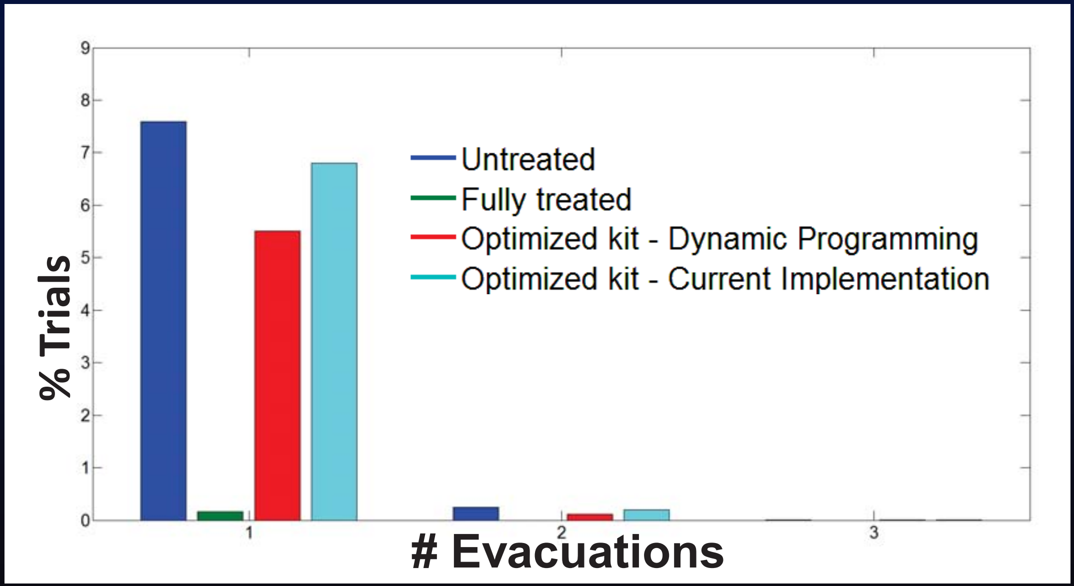


Optimization Priority:

Maximize CHI

Results – 2 crew, 24 day mission

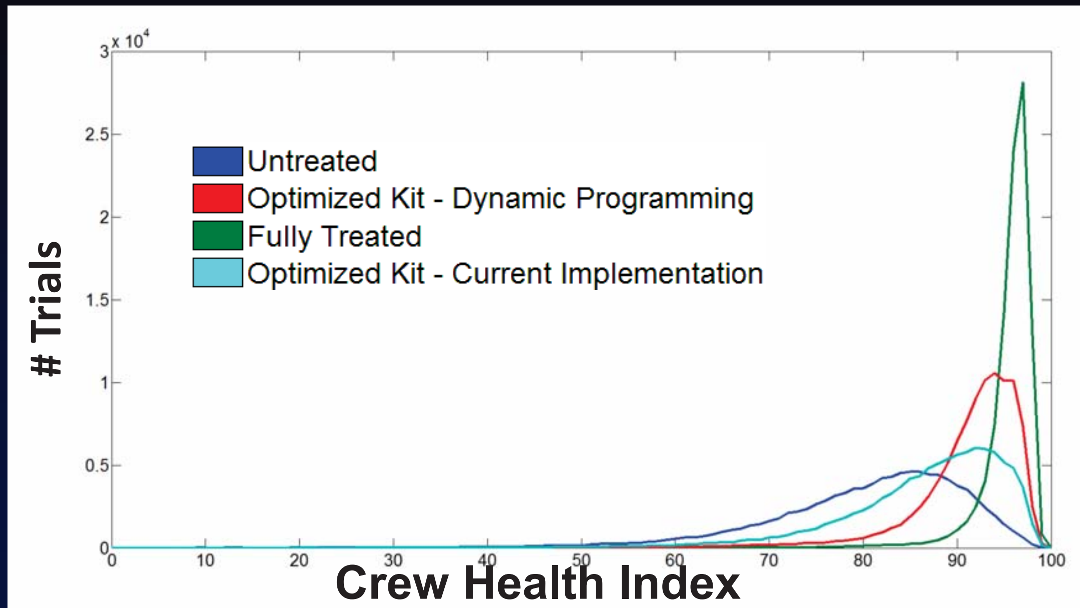


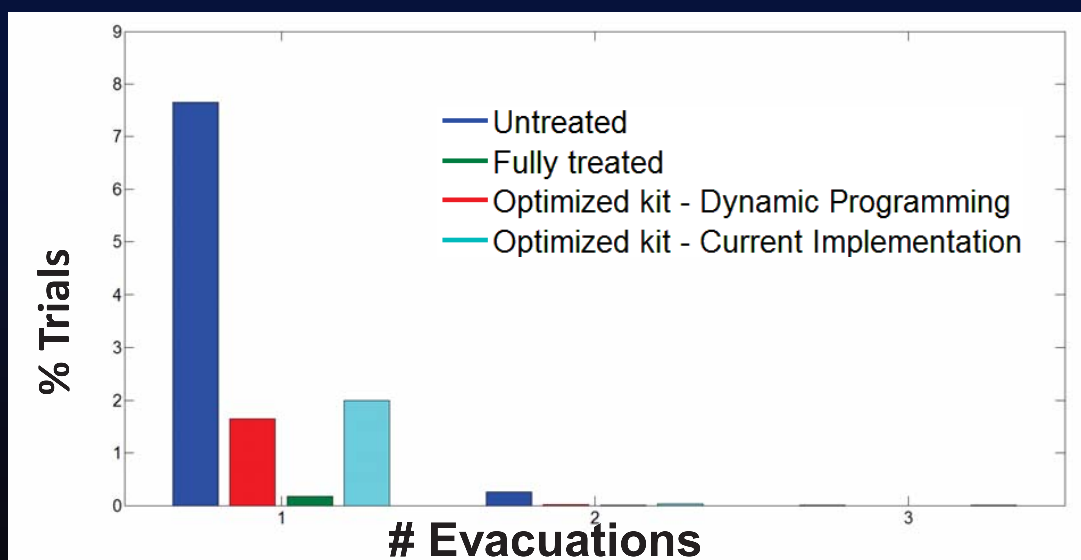


Optimization Priority:

Maximize CHI

Results – 2 crew, 24 day mission





Optimization Priority:

Minimize pEVAC

Conclusion

- Outcomes from mass/volume-constrained medical kits generated by the new approach more closely approach the best-case unlimited-resource scenario than previous implementations (Minard et al)
- Features of optimization algorithm include:
  - Group resources into 'treatments'
  - Ability to tailor resource benefit measures (b_i) according to optimization objectives and priorities
- Algorithm provides an efficient means to objectively allocate medical resources for spaceflight missions using the Integrated Medical Model

Minard CG, de Carvalho MF, Iyengar MS, "Optimizing medical resources for spaceflight using the Integrated Medical Model." Aviat Space Environ Med 2011 Sep;82(9):890-4.

Questions?

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