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**

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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

Incidence Rate	⇨	Time to occurrence	⇨	Best Case or Worst Case?	⇨	Treated or Untreated?	⇨	FI, duration, EVAC, LOCL

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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

Crew	Condition	Start Time	Worst case	Treated	CP1 FI (%)	CP1 DUR	CP2 FI (%)	CP2 DUR	CP3 FI (%)	CP3 DUR	EVAC	LOCL
B	Sepsis	1267										
C	Sepsis	4012										

| Incidence Rate | ⇨ | Time to occurrence | ⇨ | Best Case or Worst Case? | ⇨ | Treated or Untreated? | ⇨ | FI, duration, EVAC, LOCL |

Best Case or Worst Case?

- Worst case probability upper bound and lower bound defined in iMED

- $P_{worst\ case}$ drawn from uniform distribution

- Example: Sepsis

$$WC_{upper\ bound} = 0.38,\ WC_{lower\ bound} = 0.38 \longrightarrow P_{worst\ case} = 0.38$$

Crew	Condition	Start Time	Worst Case	Treated	CP1 FI (%)	CP1 DUR	CP2 FI (%)	CP2 DUR	CP3 FI (%)	CP3 DUR	EVAC	LOCL
B	Sepsis	1267	0									
C	Sepsis	4012	1									

| Incidence Rate | ⇨ | Time to occurrence | ⇨ | Best Case or Worst Case? | ⇨ | Treated or Untreated? | ⇨ | FI, duration, EVAC, LOCL |

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

Crew	Condition	Start Time	Worst Case	Treated	CP1 FI (%)	CP1 DUR	CP2 FI (%)	CP2 DUR	CP3 FI (%)	CP3 DUR	EVAC	LOCL
B	Sepsis	1267	0	1								
C	Sepsis	4012	1	1								

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:

Sepsis Outcomes	Clinical Phase 1		Clinical Phase 2		Clinical Phase 3		
	FI	Duration	FI	Duration	FI	EVAC	LOCL
Treated, Best case	100	1	2-36	24-168	0	0	0
Treated, Worst case	100	1-2	16-58	48-72	0-58	100	29-70
Untreated, Best case			16-58	48-72	16-58	100	0-100
Untreated, Worst case			38-75	48-72	38-75	100	100

Crew	Condition	Start Time	Worst Case	Treated	CP1 FI (%)	CP1 DUR	CP2 FI (%)	CP2 DUR	CP3 FI (%)	CP3 DUR	EVAC	LOCL
B	Sepsis	1267	0	1	100	1	12	97	0	3010	0	0
C	Sepsis	4012	1	1	100	1.4	28	64	100	305.6	1	0

Incidence Rate ⇨ **Time to occurrence** ⇨ **Best Case or Worst Case?** ⇨ **Treated or Untreated?** ⇨ **FI, duration, EVAC, LOCL**

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

$$1 - \frac{\sum QTL}{L * n} = CHI$$

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
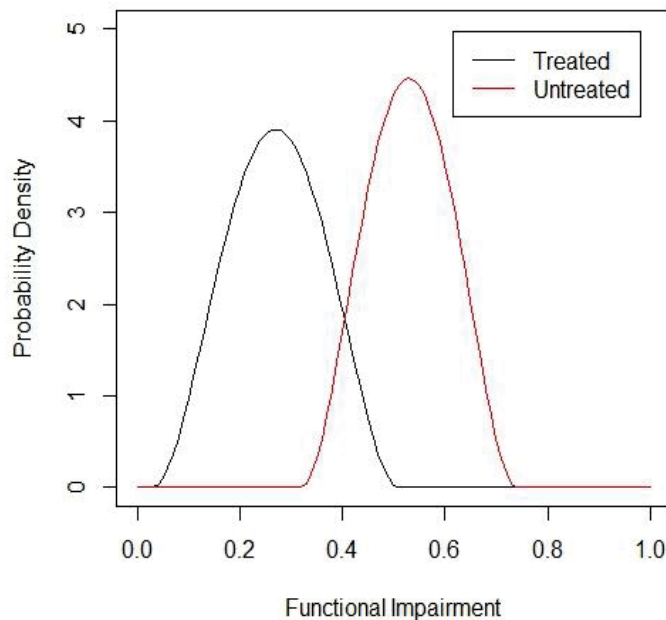
IMM v4.0:

- Introduce continuum between distributions defined for treated and untreated scenarios

- New distributions defined by proportion of resources available
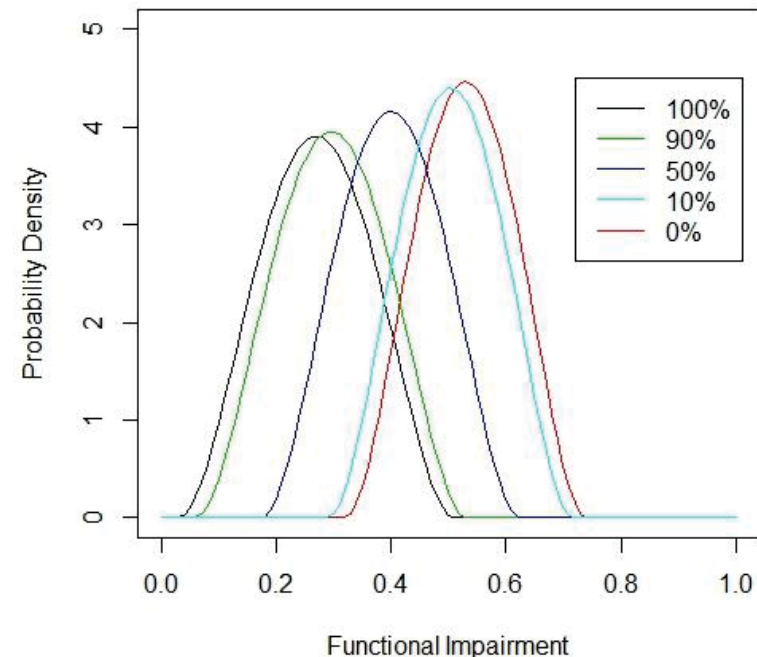
Alternative Treatment

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
- ■ v4.T
- ■ v4.TPT
- ■ v4.0

v3 – IMM version 3.0
v4.T – IMM with timeline only
v4.TPT – IMM with timeline and partial treatment
v.4.0 – IMM version 4.0 (timeline + partial treatment + alternative treatment)
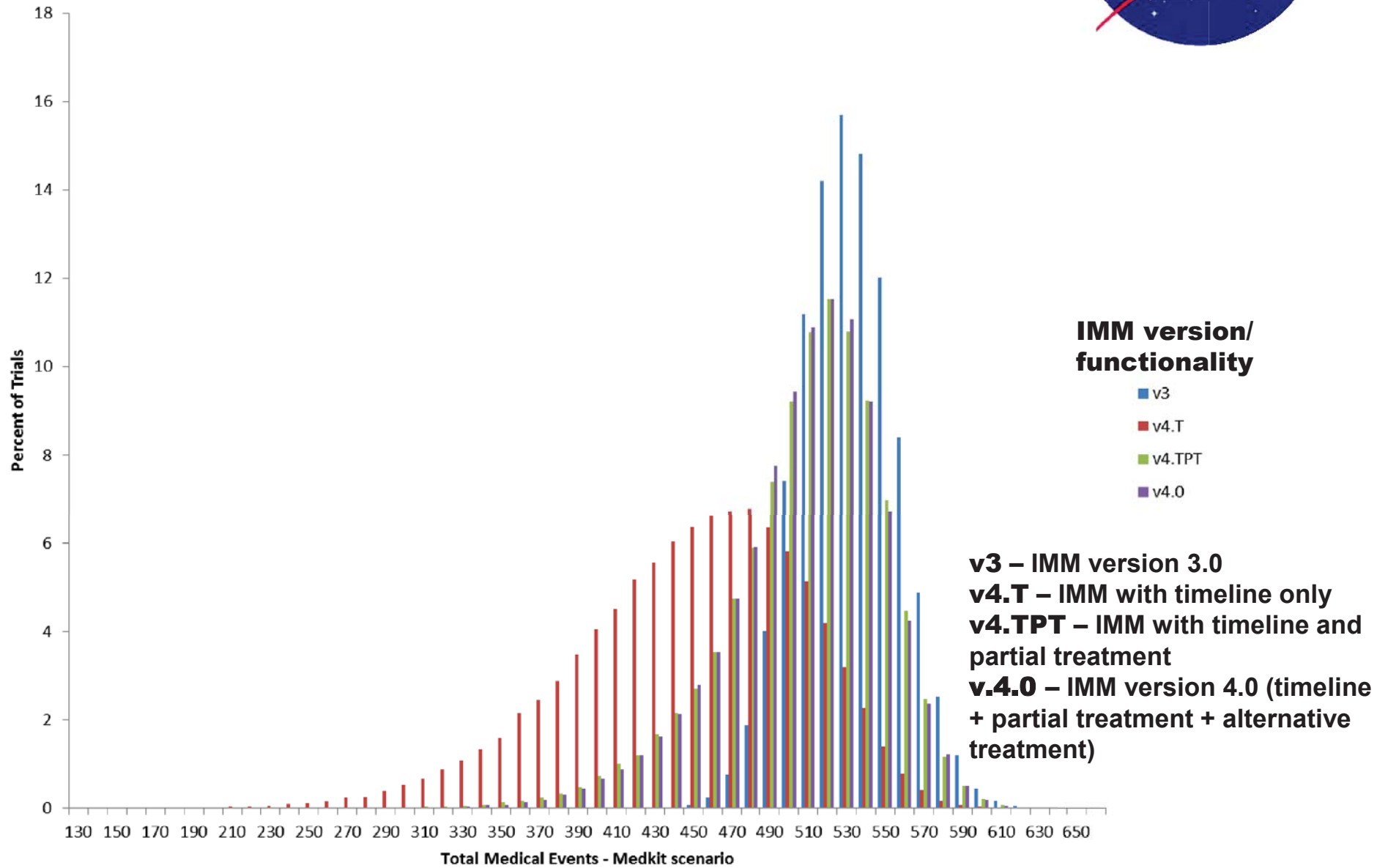
Mars (6 crew, 2.5 years)
Crew Health Index
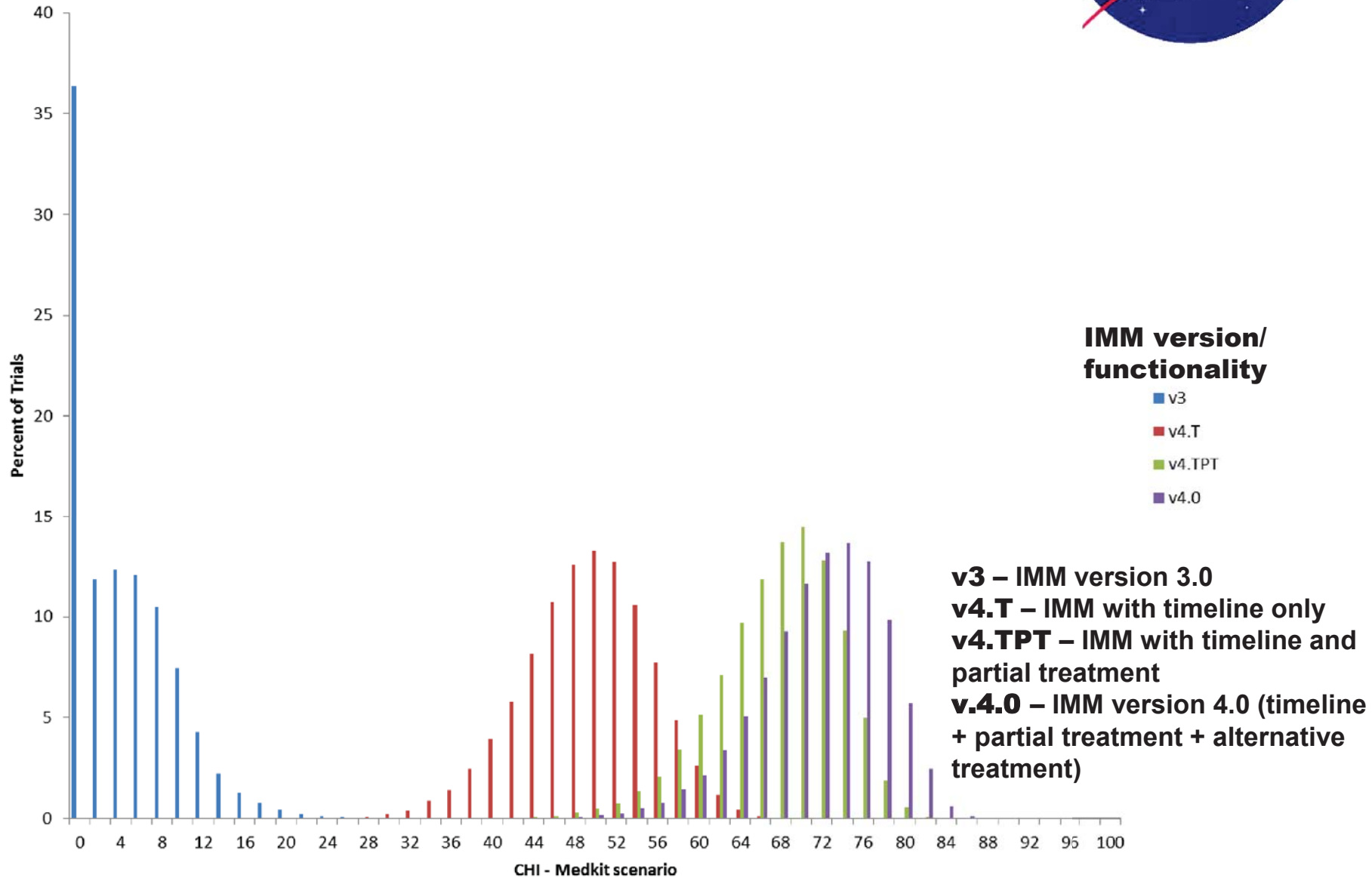
Mars (6 crew, 2.5 years)
Evacuations

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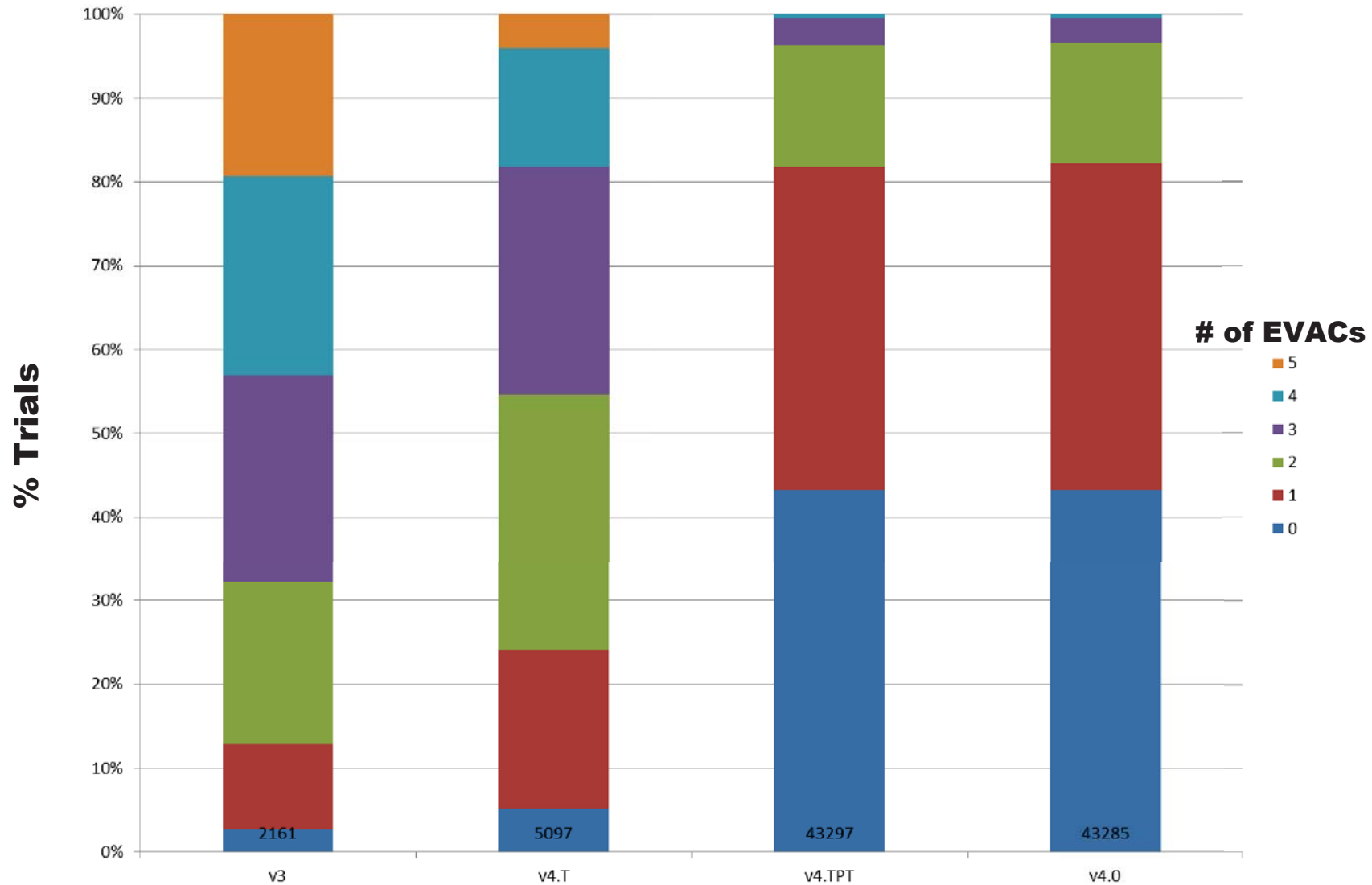
Mars (6 crew, 2.5 years)
Loss of Crew Life

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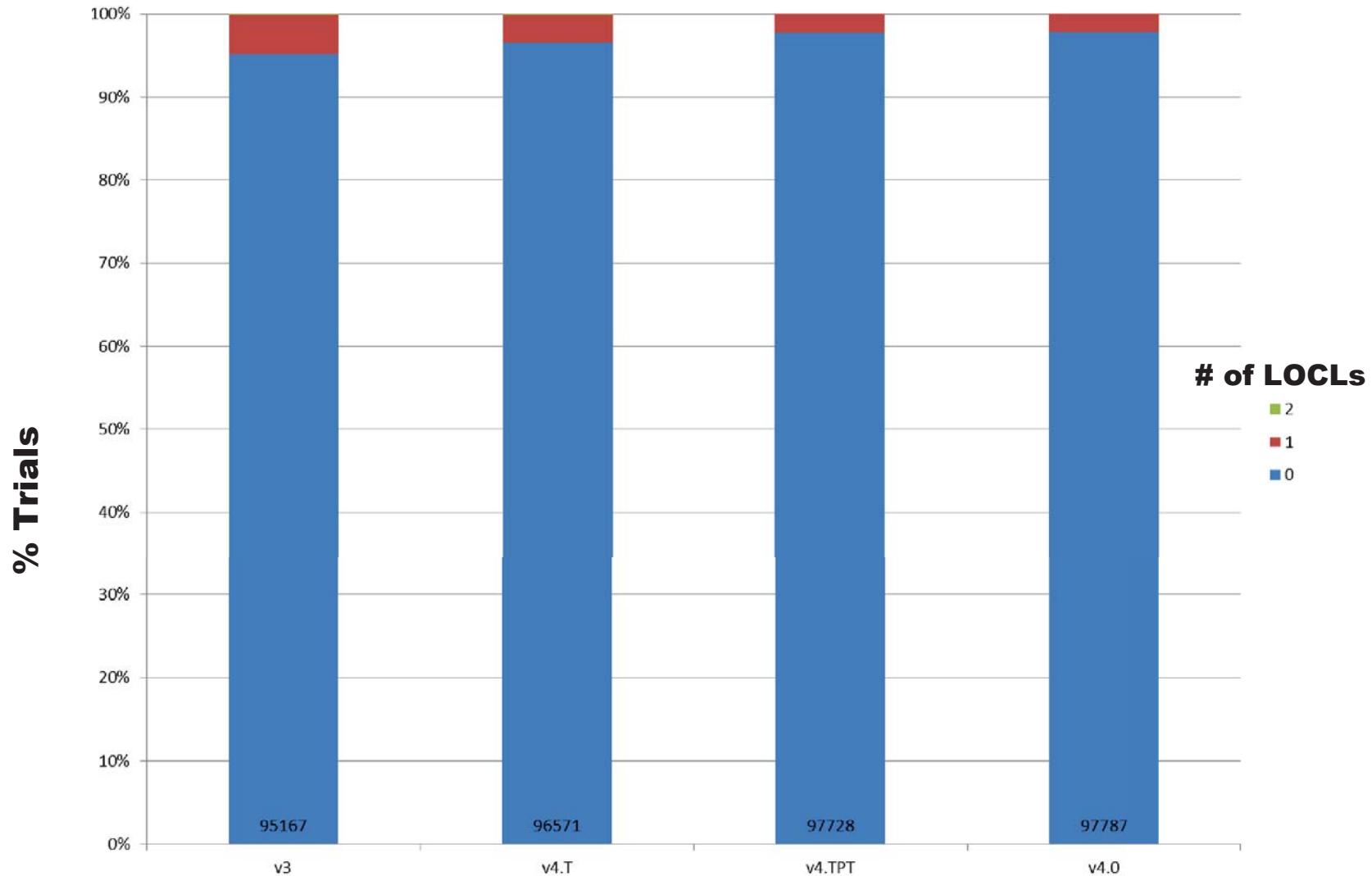
ISS (6 crew, 6 months)
Total Medical Events
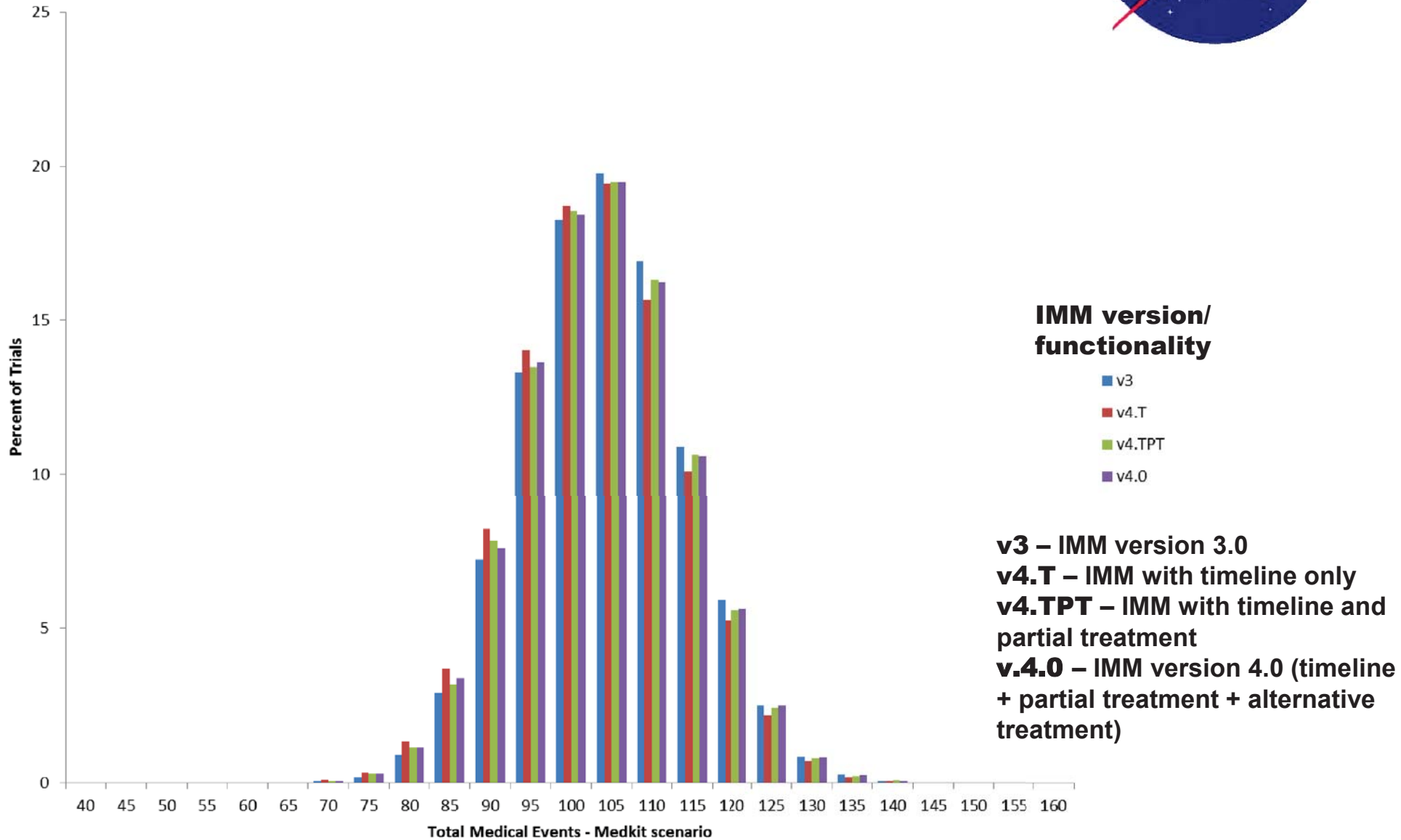
ISS (6 crew, 6 months)
Crew Health Index

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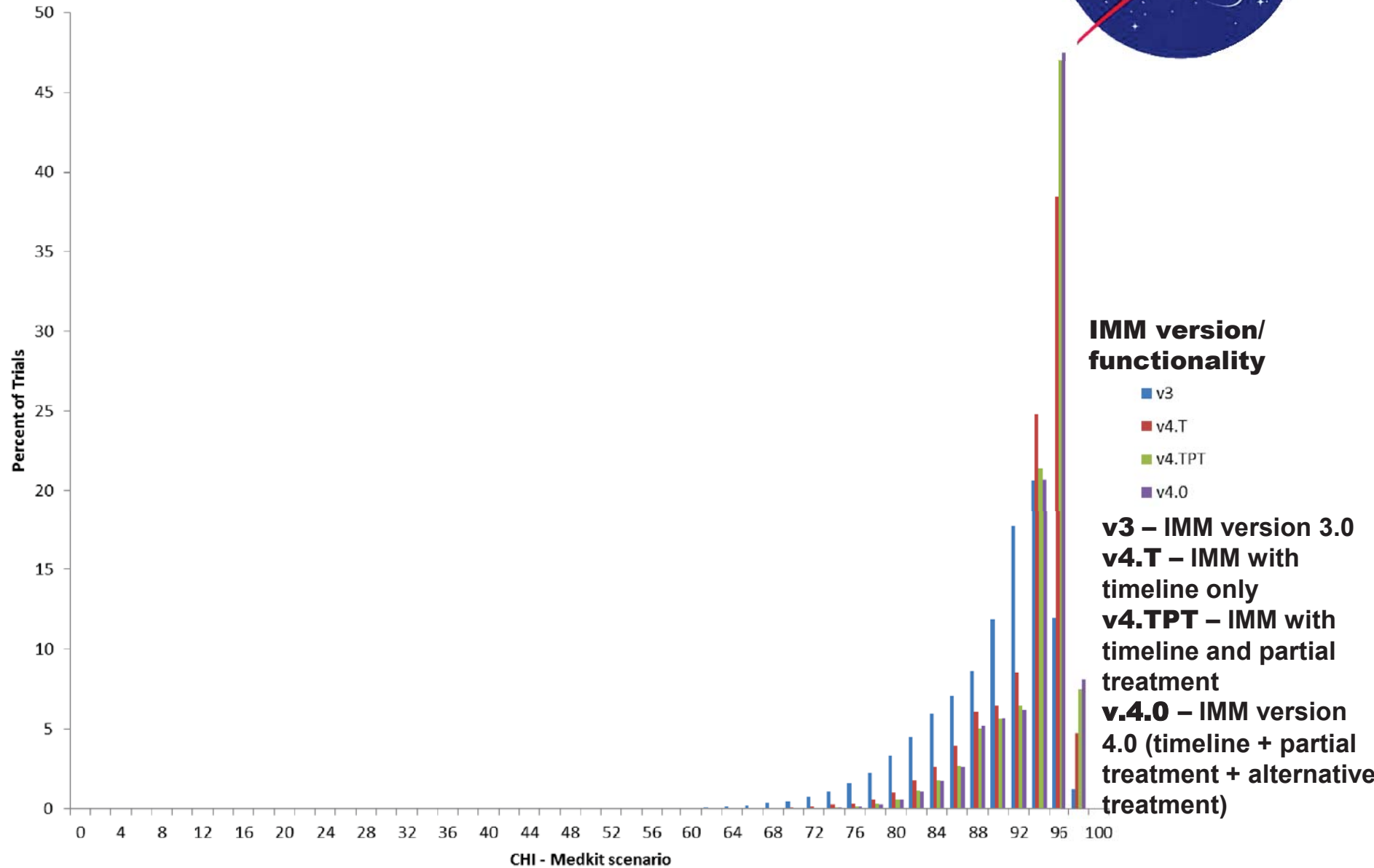
ISS (6 crew, 6 months)
Evacuations

National Aeronautics and Space Administration
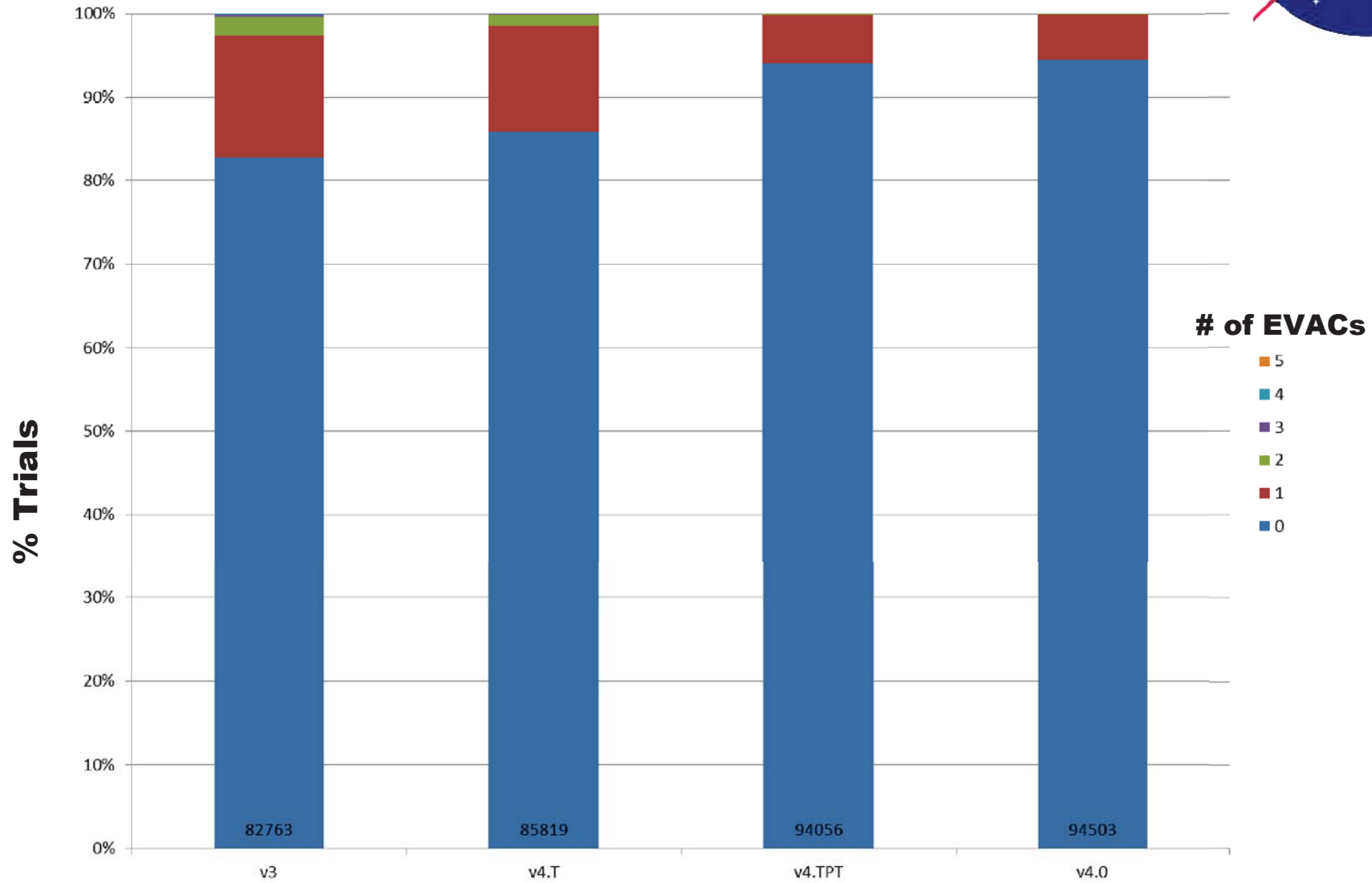
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Loss of Crew Life

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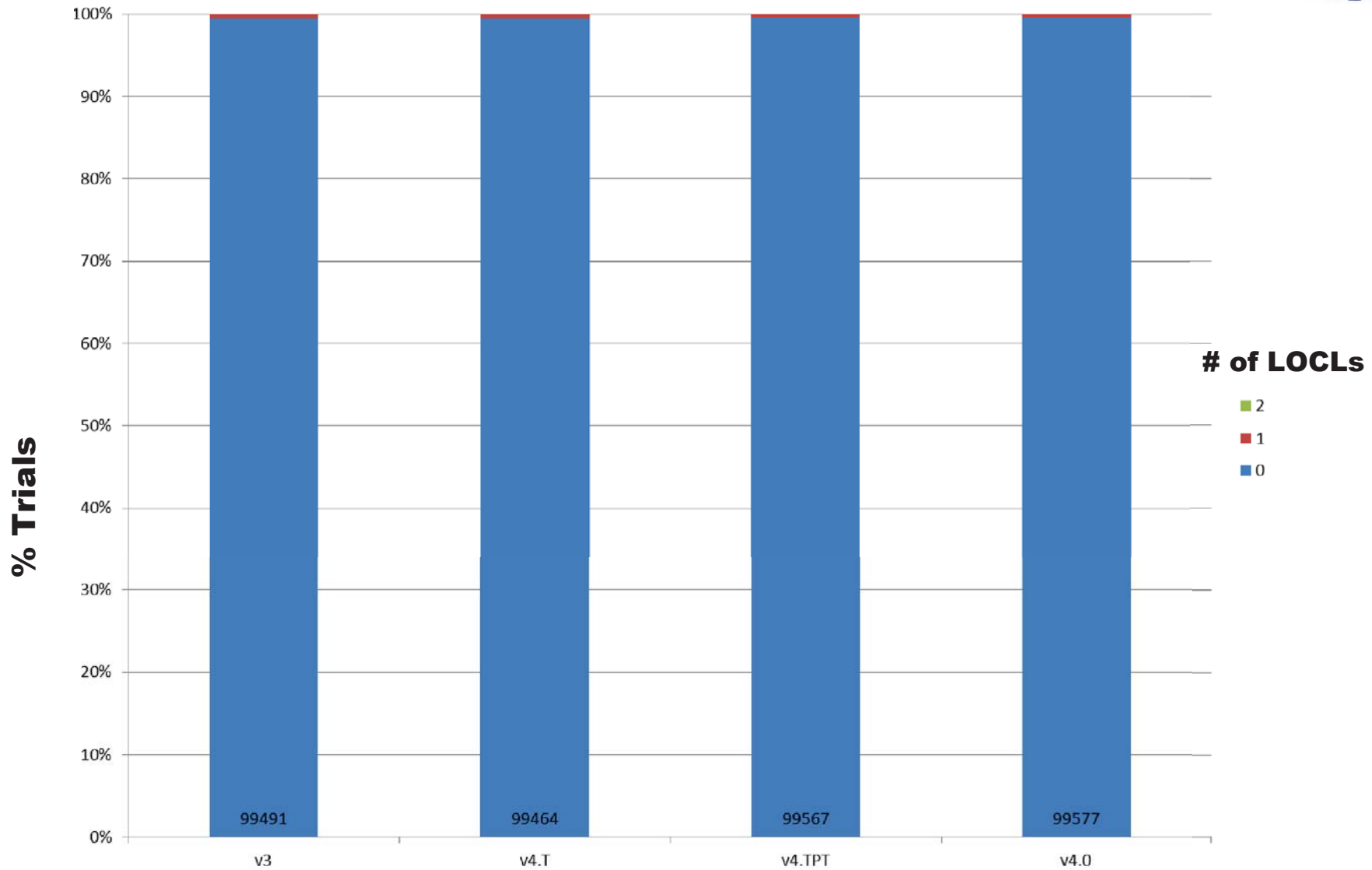
Conclusions

- **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?