Optimizing Medical Kits for Space Flight

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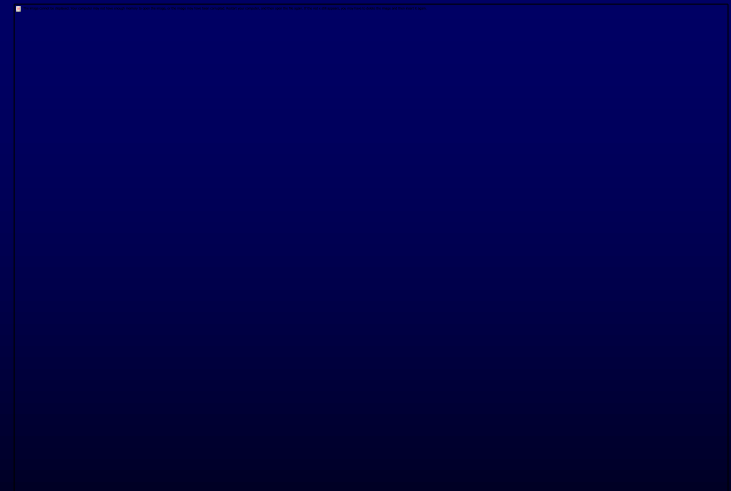
NASA, Johnson Space Center, Houston, TX

Winter Simulation Conference
Baltimore, MD 2010

Introduction

- Space is an inherently hostile environment

- Altered incidence, mitigation and recovery from adverse medical events

- Medical system
  - Physical limitations
  - Limited resupply

http://antwrp.gsfc.nasa.gov/apod/ap100522.html

Optimization Goal

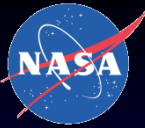- Optimize medical kit using IMM results
  - Specific mission profile

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

http://spaceflight.nasa.gov/gallery/images/shuttle/sts-133/html/sts133-s-002.html

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.
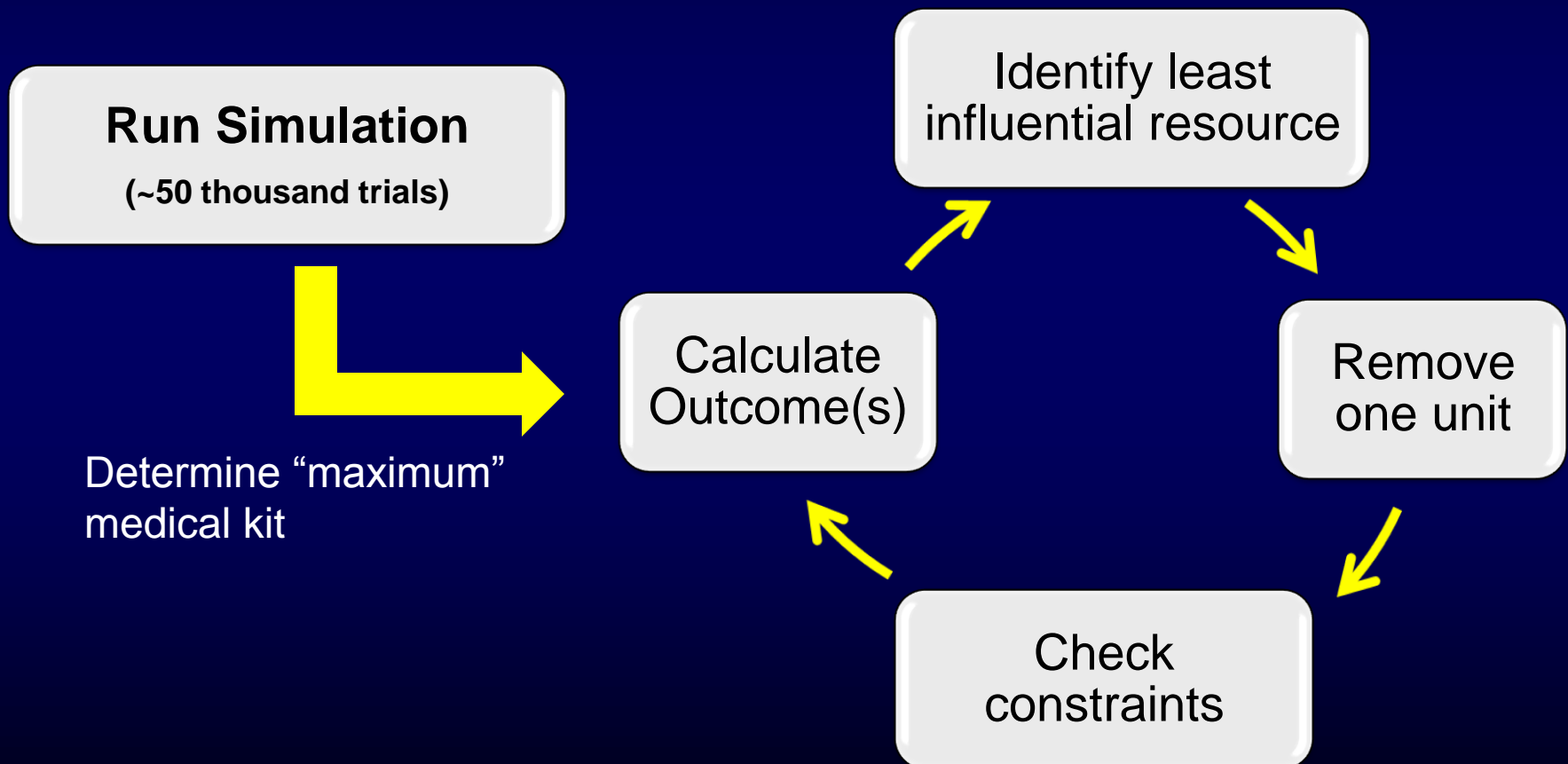
Consider Scenario 1

- Best outcome given resource constraints
  - Define resource requirements
    - Maximum mass
    - Maximum volume

  - Decide which outcome(s) are of interest
    - Maximize CHI
    - Minimize Pr(evacuation)

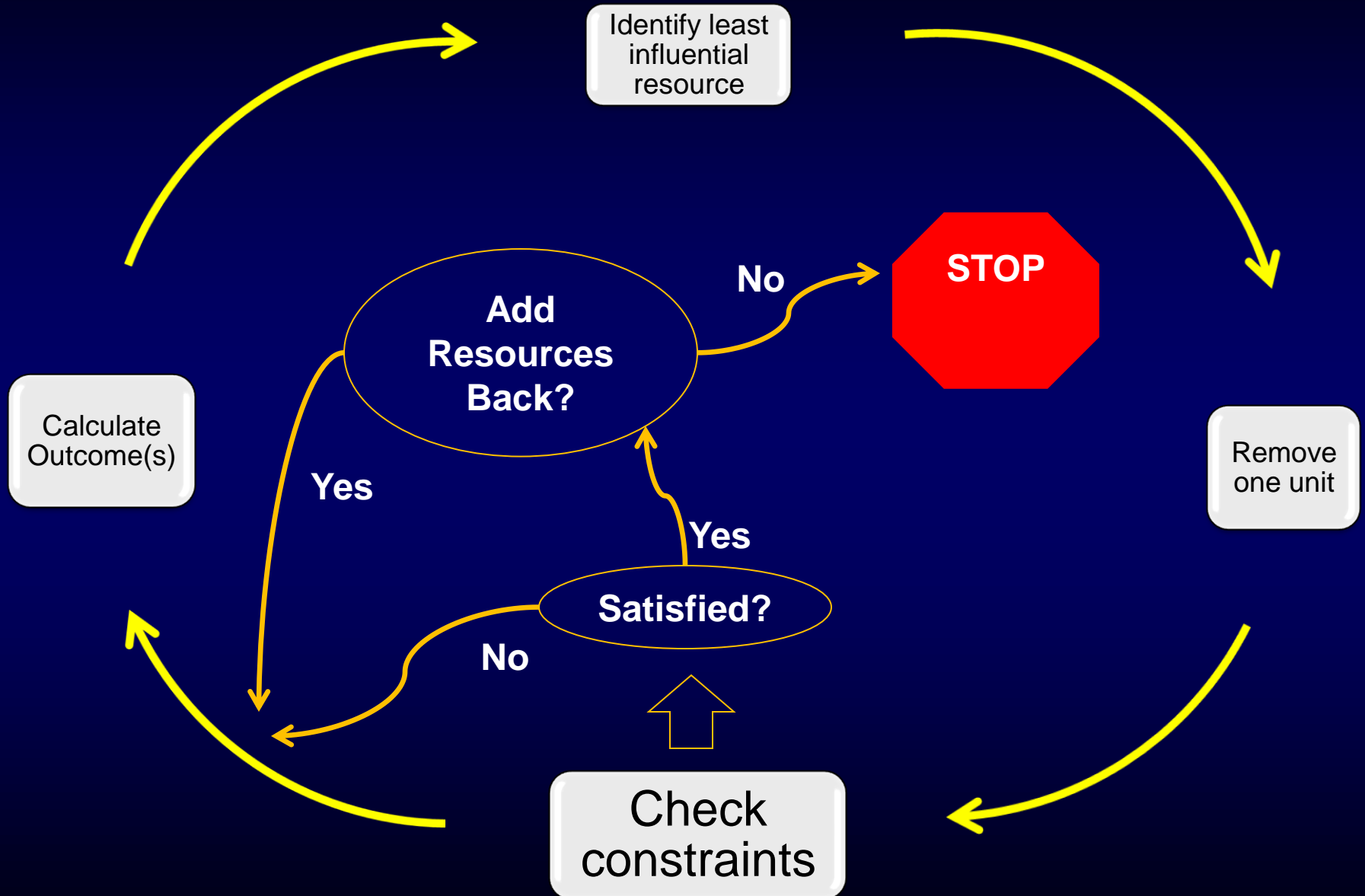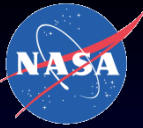 - Fill medical kit with the most efficient set of medical resources

Optimization Scenario 1

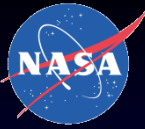- Maximize outcome(s) of interest subject to resource constraints

Run Simulation

(~50 thousand trials)

Determine "maximum" medical kit

Identify least influential resource

Remove one unit

Check constraints

Calculate Outcome(s)

Are Constraints Satisfied?

Identify least influential resource

Add Resources Back? → No → STOP

Yes

Calculate Outcome(s)

Satisfied? → Yes

No

Check constraints

Remove one unit
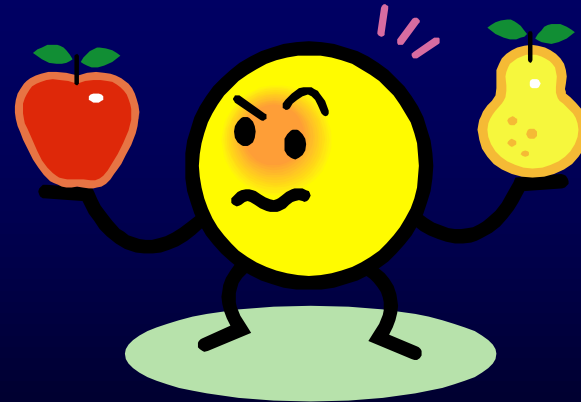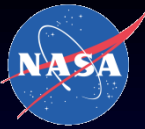
Additional Considerations

- 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)

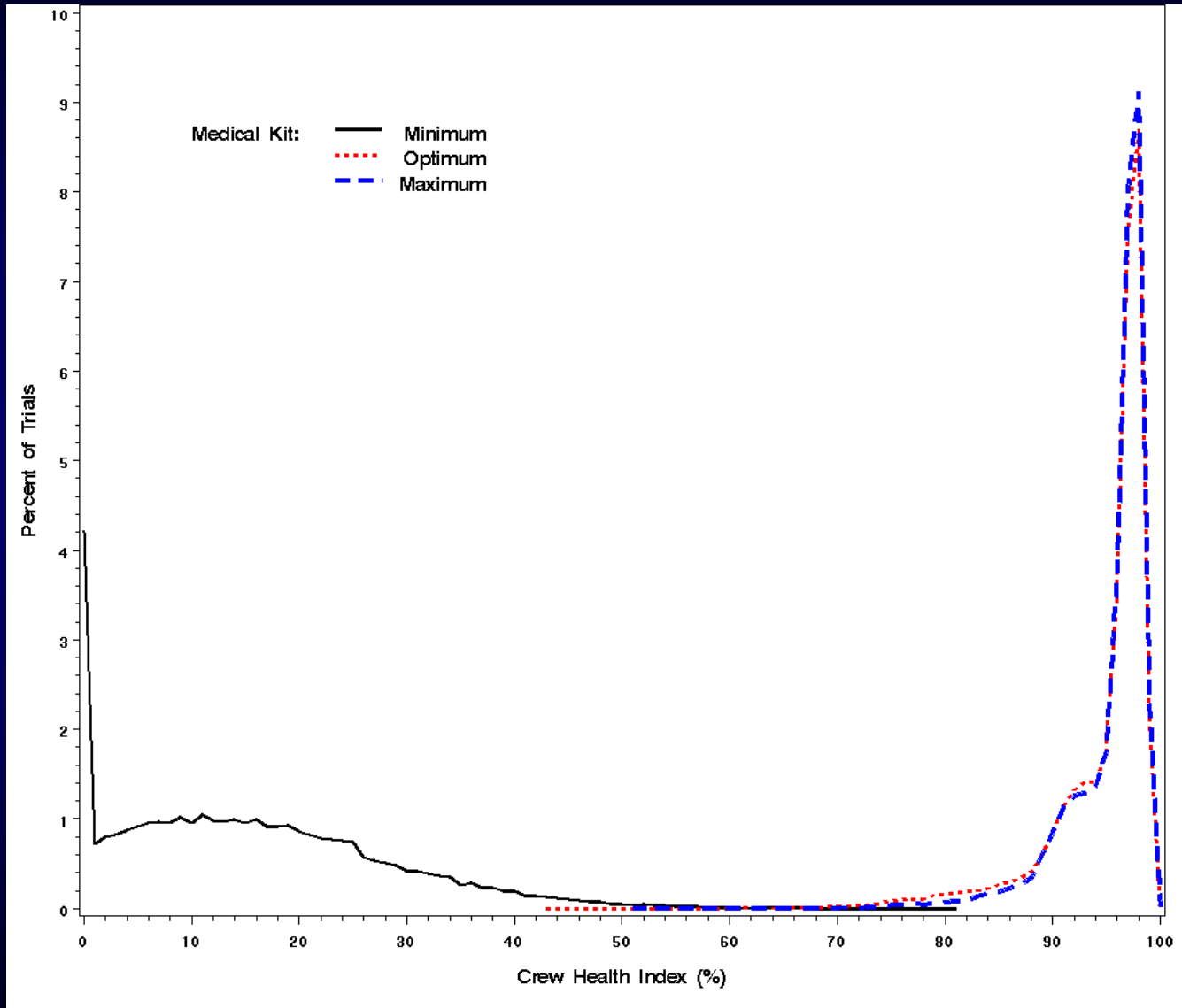- Resource constraints
  - 4.3 kg
  - 6421.7 cm3

http://www.nasa.gov/multimedia/imagegallery/iotd.html#

Results (24 days, 4 crew)

- ## Resource constraints
  - ### 4.3 kg
  - ### 6421.7 cm3

Parameter	Medical Kit		
	Minimum	Optimum	Maximum
Mass (kg)	0	3.42	67.3
Volume (cm3)	0	6421.7	191434
Mean CHI (SD)	15.2 (12.3)	94.3 (4.9)	94.9 (3.9)
Median CHI	13.5	96.3	96.4

CHI Distribution by Medical Kit

Optimization Scenario 2
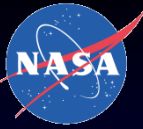
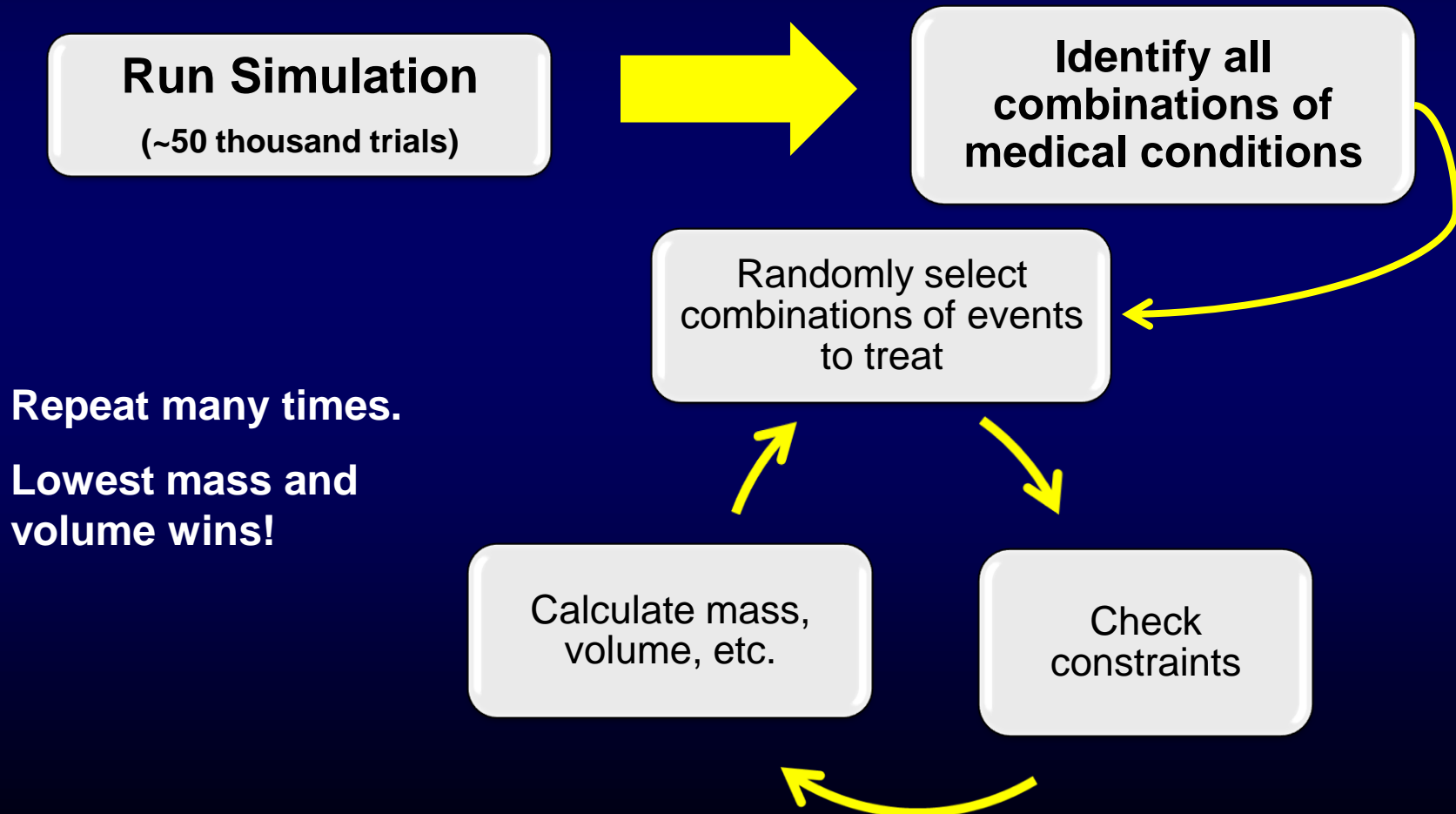- Minimize resources subject to constraints on the outcome(s)
  - Define outcome requirements
    - Pr(evac) ≤ 10%
    - CHI ≥ 90%

  - Identify the medical kit

Optimization Scenario 2

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

Run Simulation

(~50 thousand trials)

Identify all combinations of medical conditions

Randomly select combinations of events to treat

Repeat many times.

Lowest mass and volume wins!

Calculate mass, volume, etc.

Check constraints

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%

Parameter	Medical Kit		
	Minimum	Optimum	Maximum
Mass (kg)	0	38.66	81.86
Volume (cm3)	0	94,527.73	201,669.01
Mean CHI (SD)	78.27(8.52)	91.38 (3.74)	95.21 (2.35)
Evacuation Probability	16.01%	1.94%	0.37%

Additional Considerations

- Goal is to minimize resources

- Some conditions will not satisfy outcome constraints even if treated

- Resources are used to treat medical events
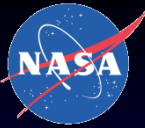 - Not primary prevention

Flexibility

- Resource inclusion and exclusion criteria
  - Flight surgeons

- Personal medical kits

- Customized metrics
  - Outcomes

Conclusions

- Trade-off
  - Occurrence
  - Impact

Acknowledgements

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