Validation of the NASA Integrated Medical Model: A Space Flight Medical Risk Prediction Tool

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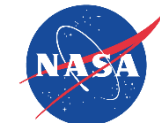
[1]NASA - Glenn Research Center

[2]KBRwyle

[3]MEI Technologies

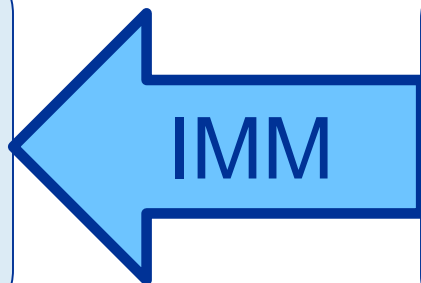[4]University of Texas Medical Branch

[5]NASA – Johnson Space Center

Quantifying Spaceflight Medical Risk

Human Spaceflight Involves Both Engineering and Medical/Health Risks

Mission and Vehicle Engineering and Design

Spaceflight Medical Community

Balance Medical and Vehicle Resource Limitations with Quantitative Medical Risk Information
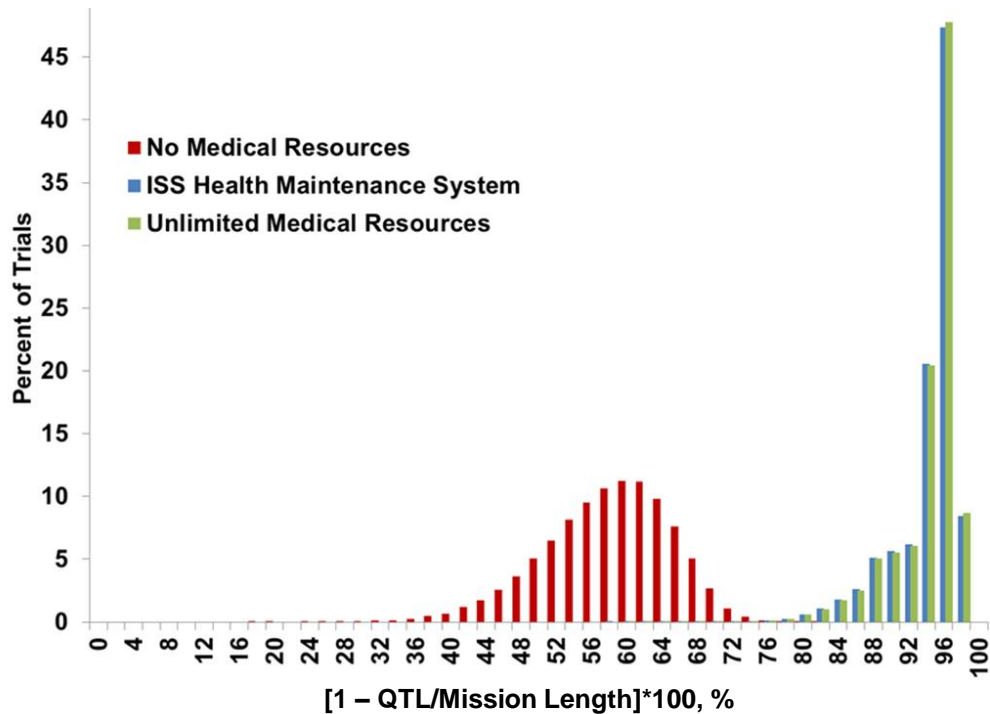
IMM

Quantitative Tools to Assess Medical Risk and Optimize Mission Medical Resources
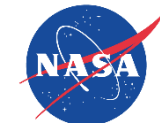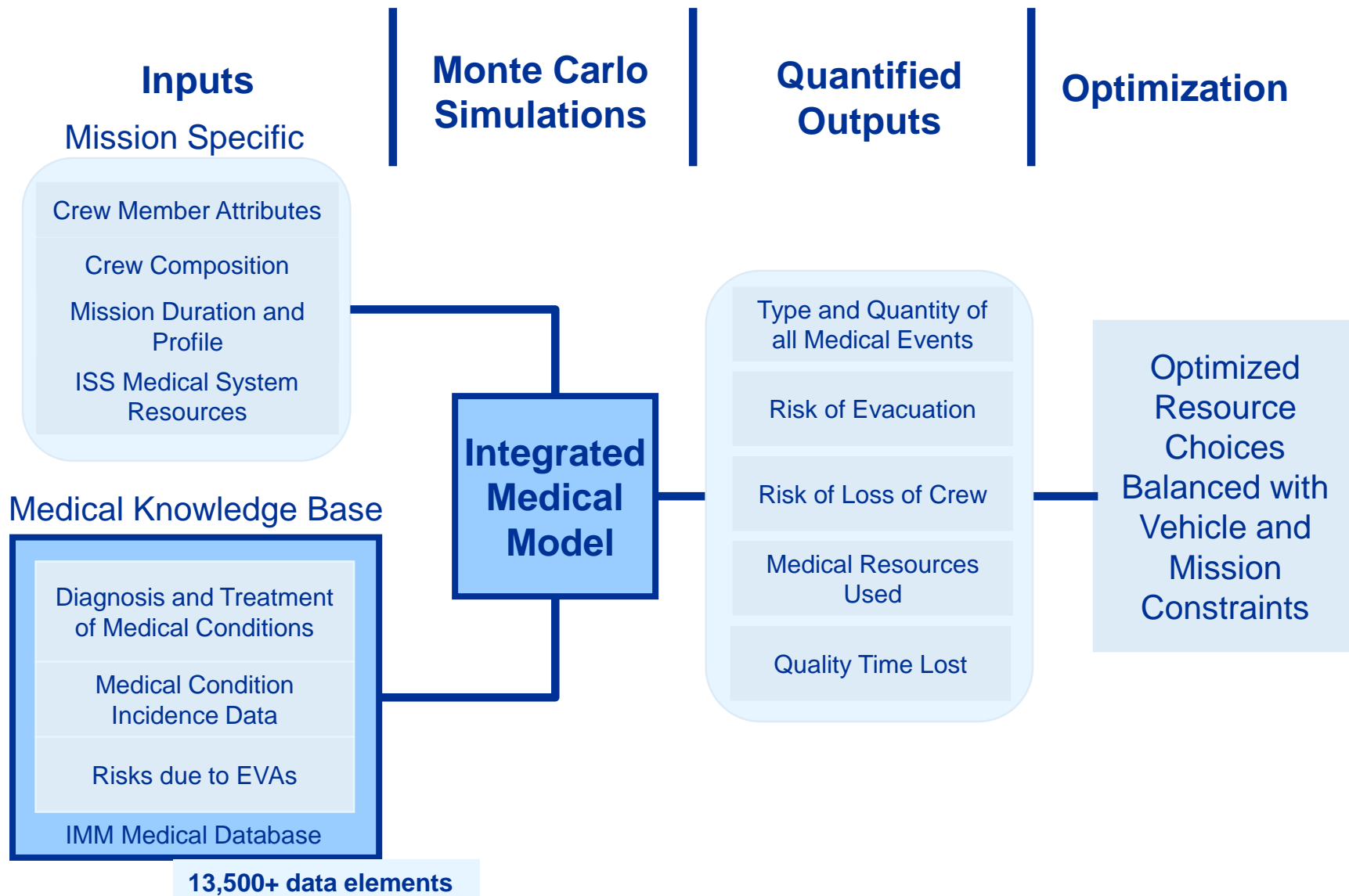
Integrated Medical Model : IMM

Stochastic simulation model that predicts in-flight medical events, the resources required to treat, and approximate impacts to the spaceflight mission.

- **No Medical Resources**
- **ISS Health Maintenance System**
- **Unlimited Medical Resources**

Percent of Trials

[1 – QTL/Mission Length]*100, %

- Mission medical risk
- Medical resource trade studies

IMM Workflow

| Inputs | Monte Carlo Simulations | Quantified Outputs | Optimization |

Mission Specific

Crew Member Attributes

Crew Composition

Mission Duration and Profile

ISS Medical System Resources

Integrated Medical Model

Type and Quantity of all Medical Events

Risk of Evacuation

Risk of Loss of Crew

Medical Resources Used

Quality Time Lost

Optimized Resource Choices Balanced with Vehicle and Mission Constraints

Medical Knowledge Base

Diagnosis and Treatment of Medical Conditions

Medical Condition Incidence Data

Risks due to EVAs

IMM Medical Database

13,500+ data elements
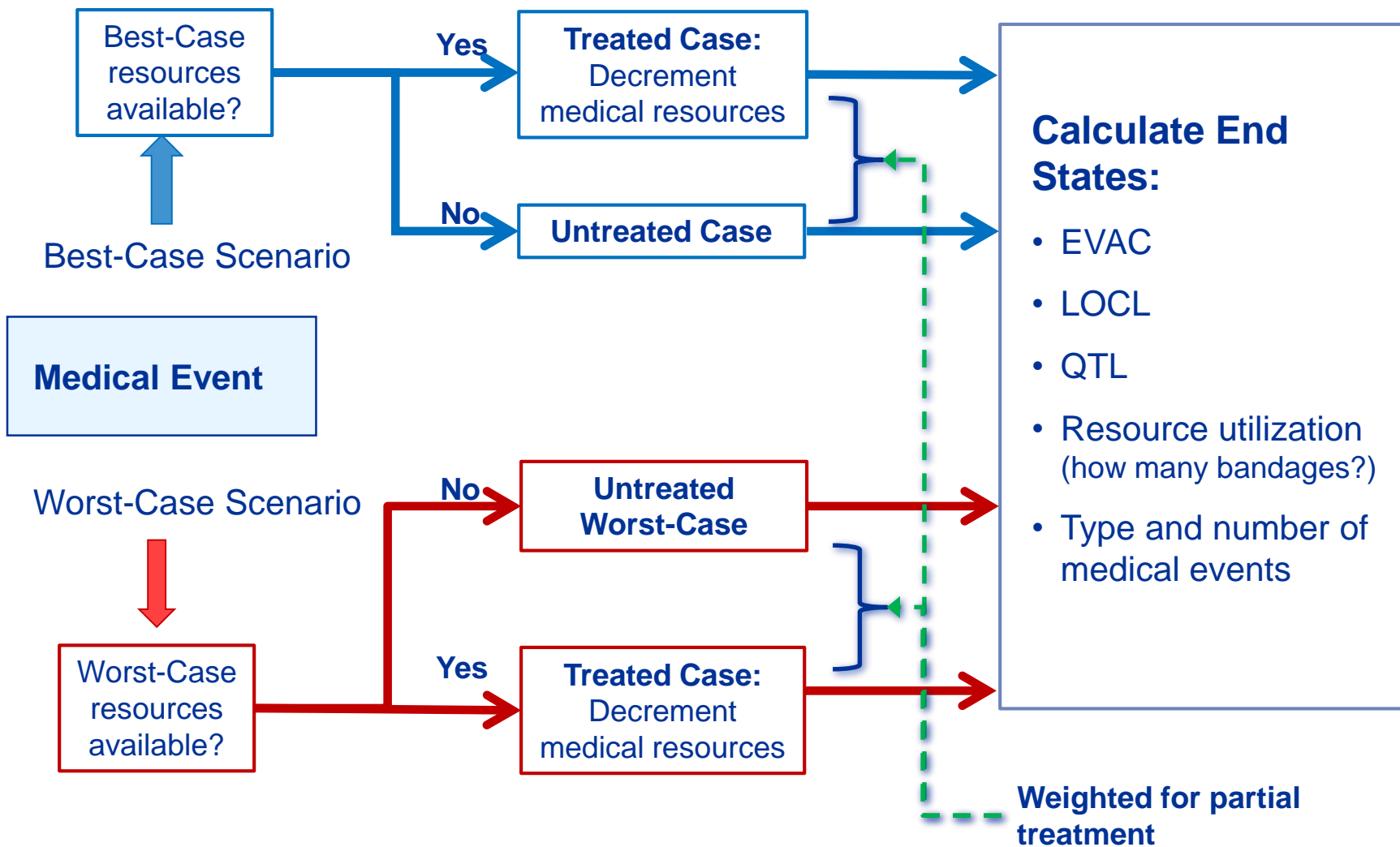
IMM Methodology

The IMM Medical Conditions

SKIN

Burns secondary to Fire
Skin Abrasion
Skin Laceration

EYES

Acute Angle-Closure Glaucoma
Eye Corneal Ulcer
Eye Infection
Retinal Detachment
Eye Abrasion
Eye Chemical Burn
Eye Penetration

EARS, NOSE, THROAT

Barotrauma (Ear/Sinus Block)
Nasal Congestion (SA)
Nose Bleed (space adaptation)
Acute Sinusitis
Hearing Loss
Otitis Externa
Otitis Media
Pharyngitis

DENTAL

Abscess
Caries
Exposed Pulp
Tooth Loss
Crown Loss
Filling Loss

CARDIOVASCULAR

Angina/Myocardial Infarction
Atrial Fibrillation / Atrial Flutter
Cardiogenic Shock secondary to Myocardial Infarction
Hypertension
Sudden Cardiac Arrest
Traumatic Hypovolemic Shock

GASTROINTESTINAL

Constipation (space adaptation)
Abdominal Injury
Acute Cholecystitis/Biliary Colic Acute Diverticulitis
Acute Pancreatitis
Appendicitis
Diarrhea
Gastroenteritis
Hemorrhoids
Indigestion
Small Bowel Obstruction

LUNG

Choking/Obstructed Airway
Respiratory Infection
Toxic Exposure: Ammonia
Smoke Inhalation
Chest Injury

IMMUNE

Allergic Reaction (mild to moderate)
Anaphylaxis
Skin Rash
Medication Overdose/Adverse Reaction

NEUROLOGIC

Space Motion Sickness (Space Adaptation)
Head Injury
Seizures
Headache (Late)
Stroke (cerebrovascular accident)
Paresthesia Secondary to Extravehicular Activity
Headache (Space Adaptation) Neurogenic Shock
VIIP (Space Adaptation)

MUSKULOSKELETAL

Back Pain (Space Adaptation)
Abdominal Wall Hernia
Acute Arthritis
Back Sprain/Strain
Ankle Sprain/Strain
Elbow Dislocation
Elbow Sprain/Strain
Finger Dislocation
Fingernail Delamination Secondary to Extravehicular Activity
Hip Sprain/Strain
Hip/Proximal Femur Fracture
Knee Sprain/Strain
Lower Extremity (LE) Stress fracture
Lumbar Spine Fracture
Shoulder Dislocation
Shoulder Sprain/Strain
Acute Compartment Syndrome
Neck Sprain/Strain
Wrist Sprain/Strain
Wrist Fracture

PSYCHIATRIC

Insomnia (Space Adaptation)
Sleep Disorder
Anxiety
Behavioral Emergency
Depression

GENITOURINARY

Abnormal Uterine Bleeding
Acute Prostatitis
Nephrolithiasis
Urinary Incontinence (space adaptation)
Urinary Retention (space adaptation)
Vaginal Yeast Infection

INFECTION

Herpes Zoster Reactivation (shingles)
Influenza
Mouth Ulcer
Sepsis
Skin Infection
Urinary Tract Infection

ENVIRONMENT

Acute Radiation Syndrome
Altitude Sickness
Decompression Sickness Secondary to Extravehicular Activity
Headache (CO_2)
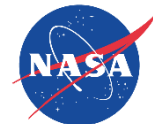
Spaceflight Medical Knowledge Database: iMED*

- Categorize astronaut symptomatology into conditions, flight medicine concerns, and resources

- Lifetime Surveillance of Astronaut Health (LSAH)
  - ISS Expeditions 1 thru 13 (2006)[*,**]
  - STS-01 thru STS-114 (2005)
  - Apollo, Skylab, Mir (U.S. crew only)

- Analog & terrestrial data
  - Bayesian and Independent models analyses

- Flight surgeon Delphi study
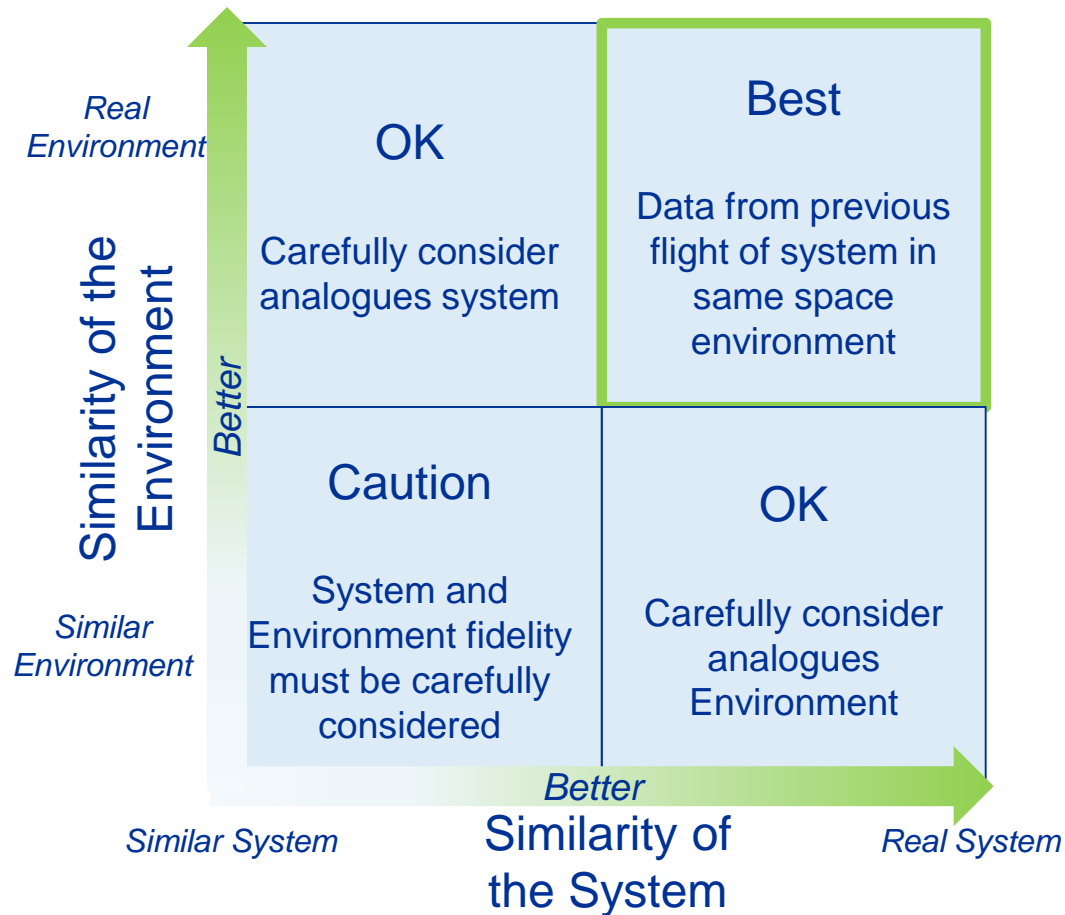 - *Russian medical data not used*

Have Occurred Inflight (47)

Are Possible (53)
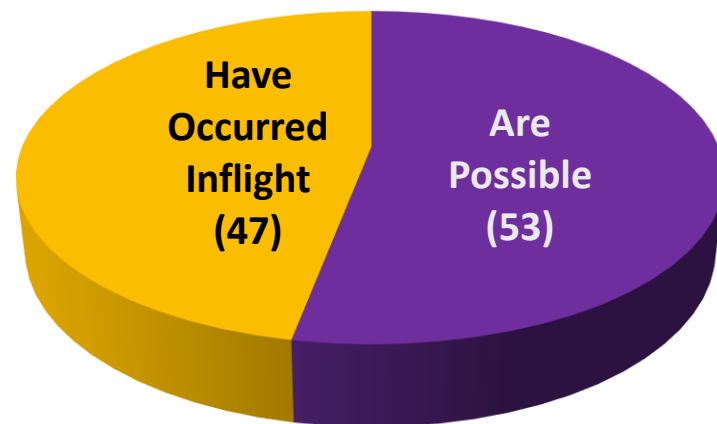
 * Integrated Medical Database, iMED
** More current data used for Spaceflight Associated Neuro-ocular Syndrome, SANS

Validation

Compare IMM predictions to relevant referent :
Real spaceflight observed medical events during real missions

What Data is Used for Comparison?

- Real World System (RWS): 31 ISS and 21 STS missions not previously incorporated into the primary IMM data repository

STS 115 through STS 135 and STS 107

ISS Expedition (Exp) 14 through 39/40 and ISS Exp 9

Image Credits: NASA

IMM Simulations of the RWS Missions

Equivalent simulations performed for each RWS mission profile using IMM v 4.0

- Length of mission

- Mission schedule (EVA)

- Crew complement (sex, limited medical history)

- ISS simulation assumed resupply of medical supplies

- 100 Medical condition set
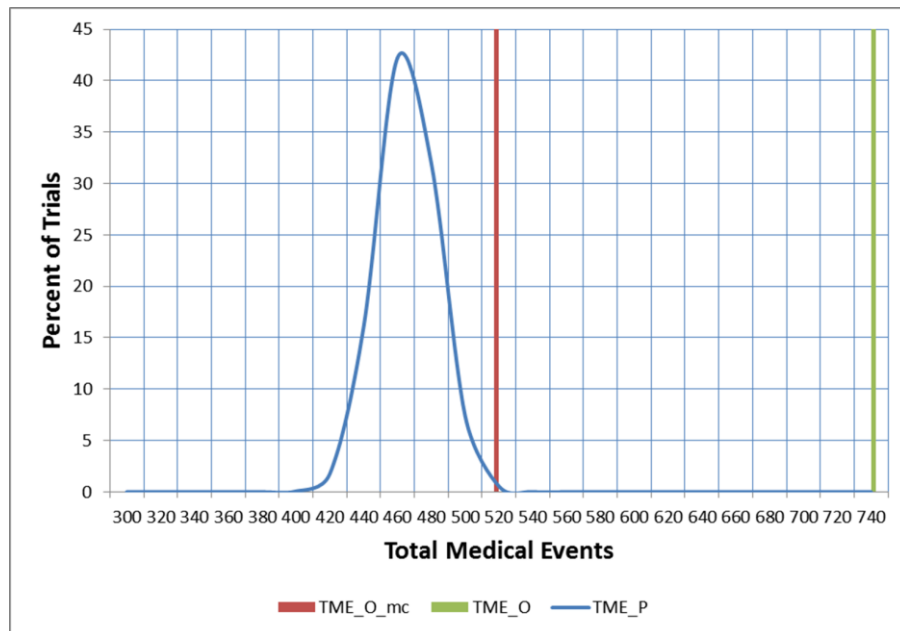
Observed and Predicted Outcomes

- Total medical events (TME)

- Medical consumable utilization

- Loss of crew life (LOCL) and
  potential need for evacuation (EVAC)*

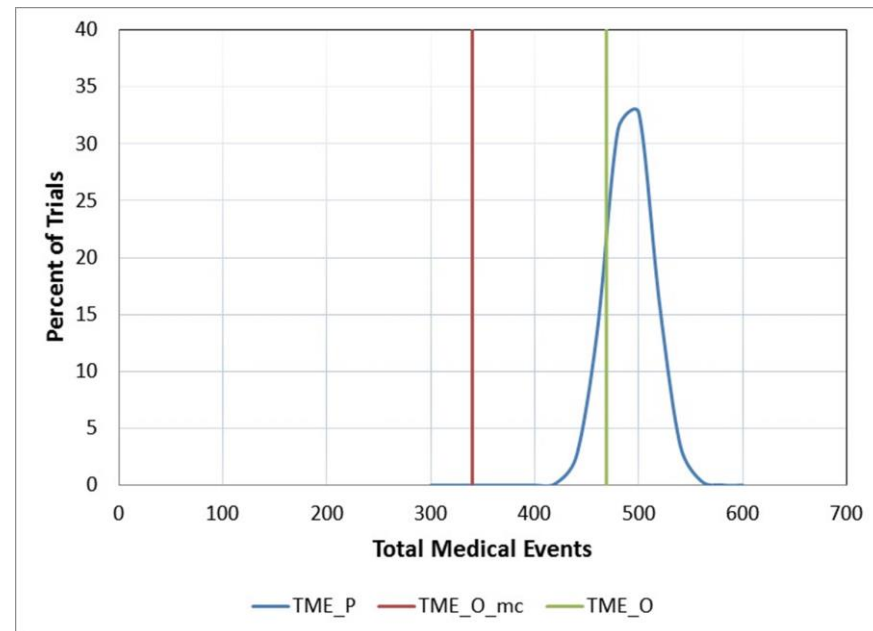* RWS had zero LOCL and EVAC events
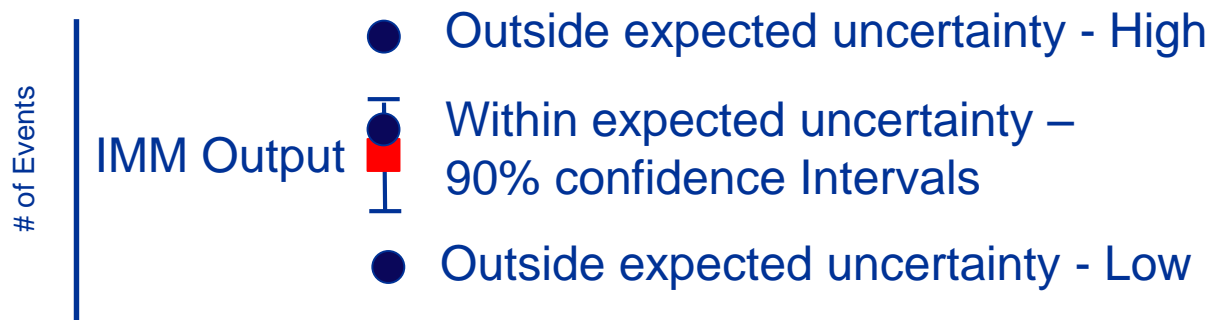
(Cumulative) Total Medical Events

STS

ISS

Predicted (P)
Observed (O)
Observed: IMM medical conditions list only (mc)

# Per Condition Comparison

# of Events

IMM Output ■

● Outside expected uncertainty - High

Within expected uncertainty –
90% confidence Intervals

● Outside expected uncertainty - Low

- 20% of the STS and 15% of the ISS medical events within expected uncertainty.

- 14% for STS and 24% for ISS medical events outside of the expected uncertainty.

- The remainder of the events had an indeterminate comparison.
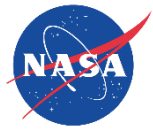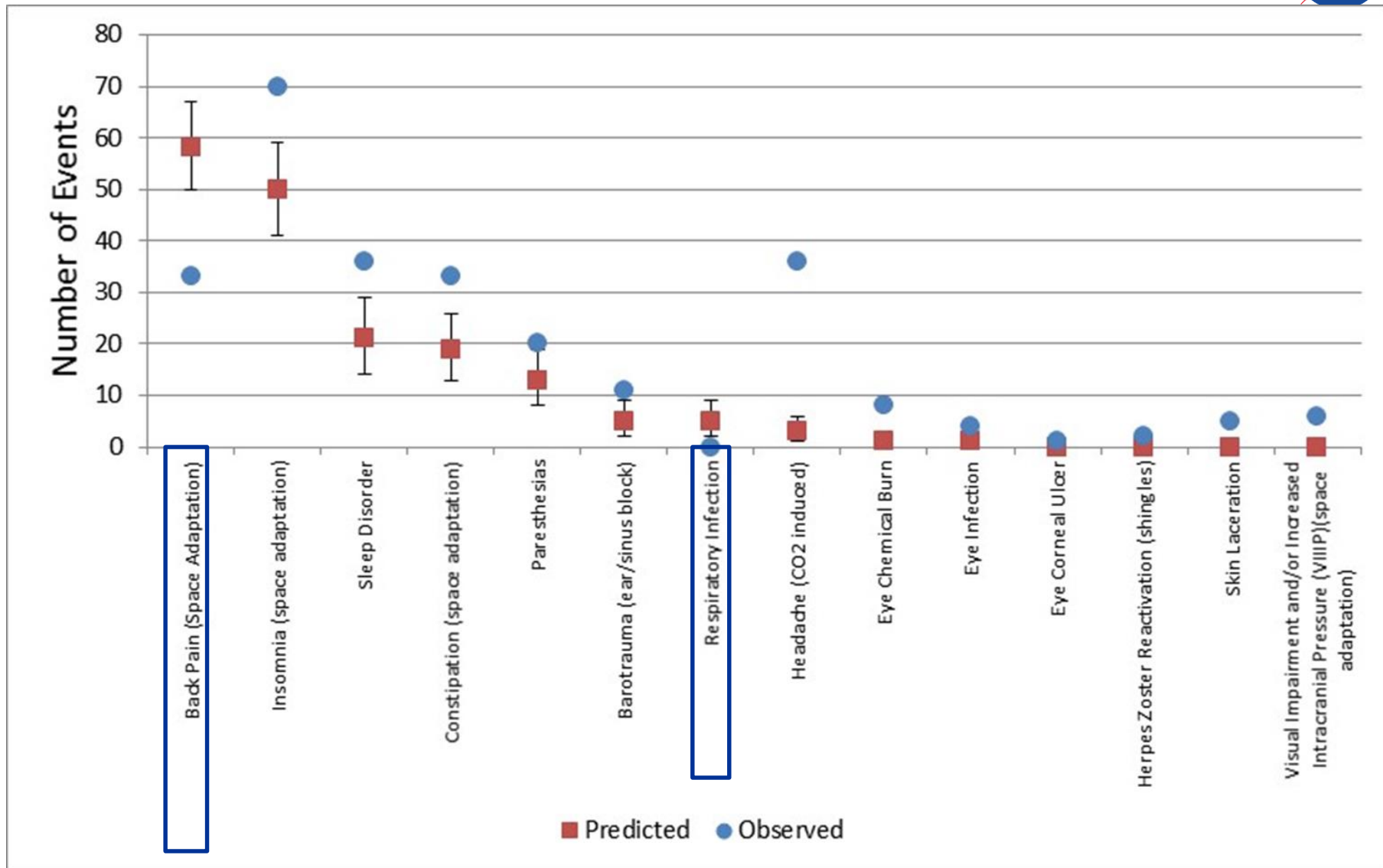
Out of Range ISS Conditions
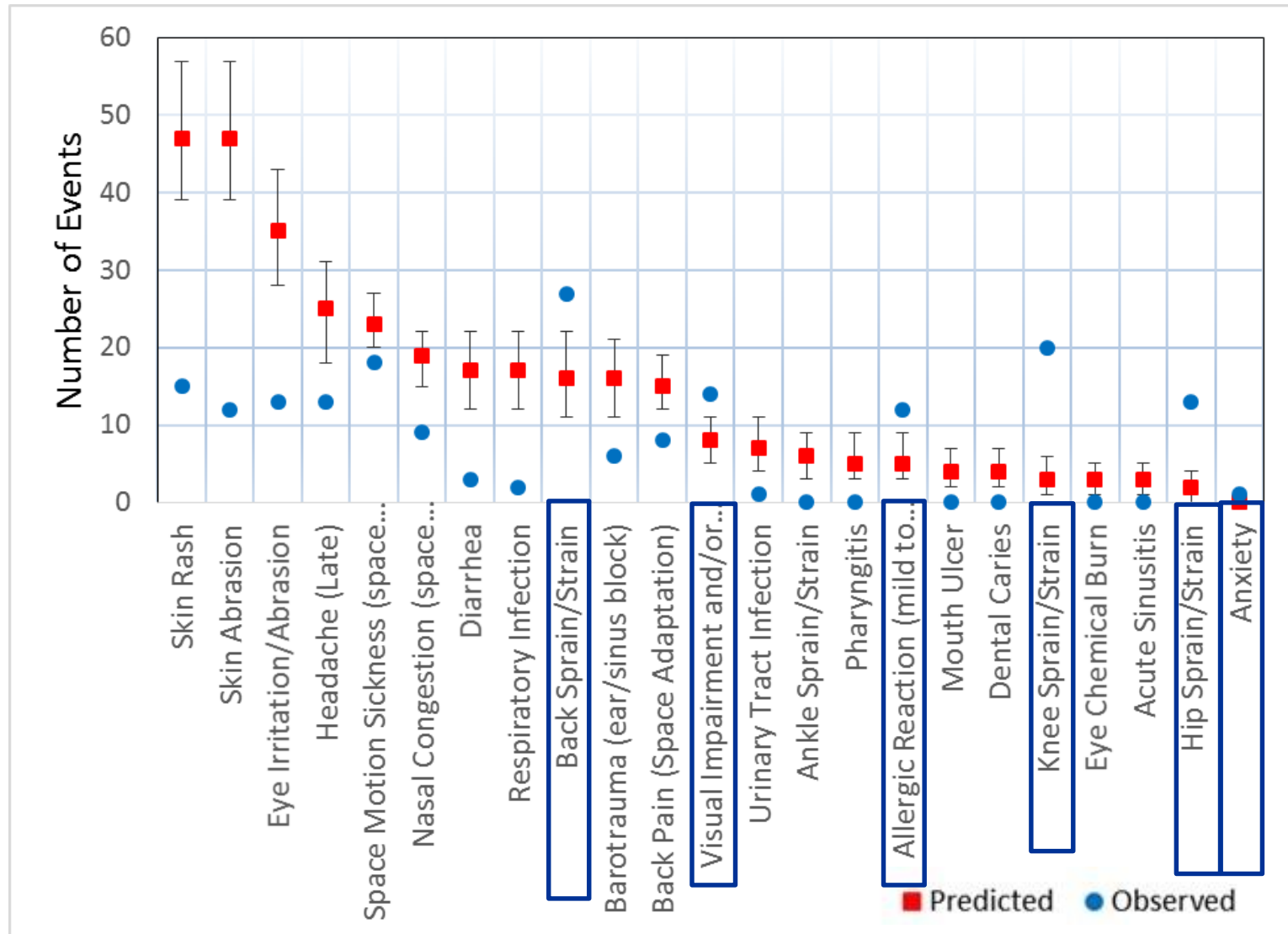
Over predicted the number of events for all but 6 conditions.

Out of Range STS Conditions

Under predicted the number of events for all but two conditions.

Medical Consumables

Medical Resource Category	STS			ISS		
	Observed	Predicted	Match	Observed	Predicted	Match
Antacids	10	13	Fair	10	12	Excellent
Antibiotics	7	8	Excellent	7	3	Fair
Antidiarrheals	11	7	Fair	11	8	Fair
Antiemetics	3	1	Excellent	3	6	Fair
Antifungals	9	10	Excellent	9	9	Excellent
Antihistamines	4	3	Excellent	4	4	Excellent
Antivirals	13	12	Excellent	13	14	Excellent
Decongestants	6	5	Excellent	6	7	Excellent
Hypnotics	2	2	Excellent	2	2	Excellent
Laxatives	12	11	Excellent	12	10	Excellent
Non-opioid Analgesics	1	4	Fair	1	1	Excellent
Ophthalmic Lubricants	8	9	Excellent	8	5	Fair
Opioid Analgesics	14	14	Excellent	14	11	Fair
Steroids	5	6	Excellent	5	13	Poor

Positive correlation between the IMM predictions with the observed RWS
STS: Kendall Tau-b = 0.76 and ISS: Kendall Tau-b = 0.57

LOCL and EVAC Comparison

STS	Predicted Number	90% Confidence Interval
EVAC RWS = 0	0	0, 1
LOCL RWS = 0	0	0, 0

ISS	Predicted Number	90% Confidence Interval
EVAC RWS = 0	0	0, 1
LOCL RWS = 0	0	0, 0

- Predicted counts are estimated using the median of the simulated distribution.

- A confidence limit of (0, 0) indicates that more than 95% of the generated LOCL counts was 0 as these confidence limits are estimated by the 5th and 95th percentiles of the simulation distribution.
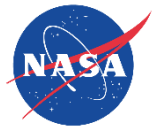
Potential Implications on Decision Making

- Variation exists in IMM predictive power for STS and ISS missions

- Decision should account for information limits
  - Longer mission profile - IMM tends to over predict incidences
  - Shorter mission profiles - IMM tends to under predict incidence.

- Difference in predictions
  - Different ISS and STS reporting conditions.
  - Combining all "mission type" data
  - Constant occurrence rate or fixed proportion.

Future Work (Some Already Done!)

- Incorporation RWS data into the iMED
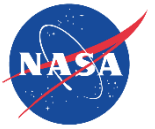
- Review of Treatment Pathway Data

Acknowledgments

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- Kelly Gilkey

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- Marlei Walton

Questions?