SENSITIVITY ANALYSIS OF THE INTEGRATED MEDICAL MODEL FOR ISS PROGRAMS

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• 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
• Best practices with computer modeling includes establishing the robustness of the model

• Robustness is the determination of how thoroughly the sensitivities of the model results to the variables and parameters of the model are known

• Infers an understanding of the sensitivity of the real-world system to potential changes in the variables and parameters of the system
  – Assuming the imitated system behaves like the real-world system

• Understanding the relative importance of variables and parameters, along with the relative ability to affect those variables and parameters, improves decision making
Sensitivity Analysis Methodology

• Saltelli: “Sensitivity Analysis is the study of how variation in the output of a model can be apportioned, qualitatively or quantitatively, to different sources of variation (input) and how the given model depends upon the information fed into it.”

• Partial Rank Correlation Coefficient (PRCC) Analysis
  – Provides the linear relationships between two variables (one input parameter and one output parameter) when all linear effects of other variables are removed after rank transformation
  – Rank Transformation: transforms non-linear monotonic relations to linear

• SRRC – Description goes here
  – Standardized regression-based coefficients measure the sensitivity of each input on each output, adjusted for all the other inputs
  – Rank Transformation: transforms non-linear monotonic relations to linear
• **KEEP IN MIND** the difference between an influential condition and a sensitive condition
  – Many conditions contribute substantially to the mean output of the model
    • Low sensitivity may indicate a “DC-signal effect” over the range of model application and parameter variance
    • Example: VIIP and EVAC
  – Parameter variance affecting model output (magnitude and variance) indicates a sensitive parameter
Using IMM for ISS missions

- IMM Provides probabilistic analysis of 100 medical condition occurrences and impact to mission outcomes
- Context: 32 person-missions representing ISS person-missions of NASA astronauts Expedition 14 and later; also used in RWS validation
- Output:
  - Total Medical Events
  - Crew Health Index (crew available time – time lost due to medical events)
  - Evacuation
  - Loss of crew life

\[
CHI = \left(1 - \frac{QTL}{L}\right) \cdot 100\% 
\]
Total Medical Events

Sensitivity Estimates - Treated Timeline TME

Condition
- SLEEP DISORDER'
- EYE CHEMICAL BURN'
- URINARY RETENTION-SA'
- SKIN RASH'
- SKIN ABRASION'
- EYE IRRITATION/ABRASION'
- HEADACHE-LATE'
- 'DIARRHEA'
- BACK SPRAIN/STRAIN'
- BACKPAIN-SA'
- RESPIRATORY INFECTION'
- INSOMNIA-SA'
- HEADACHE-SA'
- NASAL CONGESTION-SA'
- SPACE MOTION SICKNESS...
- BAROTRAUMA/EAR SINUS...
- SHOULDER SPRAIN/STRAIN'
- CONSTIPATION-SA'
- DECOMPRESSION SICKNESS...
- HEADACHE-CO2 INDUCED'

Incidence Dist
- 'BETA'
- 'GAMMA'

PRCC
-0.6 -0.4 -0.2  0.0  0.2  0.4  0.6

SRRC
-0.6 -0.4 -0.2  0.0  0.2  0.4  0.6
Crew Health Index
Consideration of Evacuation

Sensitivity Estimates - Treated Timeline EVAC

Conditions:
- Nephrolithiasis
- Stroke/Cerebrovascular
- Hip/Proximal Femur Fracture
- Traumatic Hypovolemic
- Seizures
- Sepsis
- Dental Abscess
- Small Bowel Obstruction
- Atrial Fibrillation/Arrhythmia
- Angina/Myocardial Infarction
- Head Injury
- Retinal Detachment
- Wrist Fracture
- Smoke Inhalation
- Appendicitis
- Acute Compartment Syndrome
- Shoulder Dislocation
- VIIP-SA
- Acute Diverticulitis
- Chest Injury

Incidence Dist:
- Beta
- Fixed
- Gamma
- Lognormal
Loss of Crew Life

Sensitivity Estimates - Treated Timeline LOCL

Condition
- TRAUMATIC HYPOVOLEMIC...
  - 'SEPSIS'
  - CHEST INJURY
  - HEAD INJURY
- STROKE/CEREBROVASCUL...
- SUDDEN CARDIAC ARREST
- CARDIOGENIC SHOCK SECU...
  - 'APPENDICITIS'
- ABDOMINAL INJURY
- TOXIC EXPOSURE/AMMONIA...
- SMOKE INHALATION
- NEUROGENIC SHOCK
- MEDICATION OVERDOSE/A...
- ELBOW SPRAIN/STRAIN
  - 'DEPRESSION'
- SLEEP DISORDER
- HIP SPRAIN/STRAIN
- SMALL BOWEL OBSTRUCTION
  - HEADACHE-SA
  - SKIN ABRASION

Condition
- TRAUMATIC HYPOVOLEMIC...
  - 'SEPSIS'
  - CHEST INJURY
  - HEAD INJURY
- STROKE/CEREBROVASCUL...
- SUDDEN CARDIAC ARREST
- CARDIOGENIC SHOCK SECU...
  - 'APPENDICITIS'
- ABDOMINAL INJURY
- TOXIC EXPOSURE/AMMONIA...
- SMOKE INHALATION
- NEUROGENIC SHOCK
- MEDICATION OVERDOSE/A...
- ELBOW SPRAIN/STRAIN
  - 'DEPRESSION'
- SLEEP DISORDER
- HIP SPRAIN/STRAIN
- SMALL BOWEL OBSTRUCTION
  - SKIN ABRASION
  - HEADACHE-SA
Conclusions

• Successfully implemented a rigorous quantification of model sensitivity to parameter uncertainty
  – Differs from and augments influential conditions estimate currently used by IMM

• Many sensitive conditions in the CHI, EVAC, and LOCL cases do not appear in the sensitivity estimates of the total number of medical events
  – these conditions having a low incidence rate, so the effect on TME is minimal
  – have a large effect such as prolonged impairment, evacuation, or death
Thank you!

Questions?
Backup - Untreated Total Medical Events

Sensitivity Estimates - Untreated Timeline TME

Condition:
- SLEEP DISORDER
- SKIN RASH
- SKIN ABRASSION
- EYE IRRITATION/ABRASSION
- HEADACHE-LATE
- DIARRHEA
- RESPIRATORY INFECTION
- BACK SPRAIN/STRAIN
- BAROTRAUMA/EAR SINUS
- SHOULDER SPRAIN/STRAIN
- HEADACHE-CO2 INDUCED
- NASAL CONGESTION-SA
- BACKPAIN-SA
- INSOMNIA-SA
- HEADACHE-SA
- VIHIP-SA
- URINARY TRACT INFECTION
- SKIN INFECTION
- SPACE MOTION SICKNESS
- ELBOW SPRAIN/STRAIN

Incidence Dist:
- 'BETA'
- 'GAMMA'
Untreated Consideration of Evacuation

Sensitivity Estimates - Untreated Timeline EVAC

Condition
- EYE CHEMICAL BURN'
- SLEEP DISORDER'
- SKIN ABRASION'
- FINGER DISLOCATION'
- SKIN RASH'
- DENTAL-ABSCES.
- URINARY RETENTION-SA'
- DECOMPRESSION SICKNES.
- EYE IRRITATION/ABRASION'
- HEADACHE-LATE'
- SKIN LACERATION'
- ‘NEPHROLITHIASIS'
- WRIST FRACTURE'
- BURNS SECONDARY TO FL.
- BAROTRAUMA/EAR SINUS.
- RESPIRATORY INFECTION'
- ‘DIARRHEA'
- ‘SEPSIS'
- HEADACHE-C02 INDUCED'
- BACK SPRAIN/STRAIN'

Incidence Dist
- ‘BETA'
- ‘FIXED'
- ‘GAMMA'
- ‘LOGNORMAL'

PRCC
-0.6 -0.4 -0.2 0.0 0.2 0.4 0.6

SRRC
-0.6 -0.4 -0.2 0.0 0.2 0.4 0.6
Untreated Loss of Crew Life

Sensitivity Estimates - Untreated Timeline LOCL

Condition
- 'SEPSIS'
- SMOKE INHALATION'
- TRAUMATIC HYPOVOLEMIC
- 'APPENDICITIS'
- HEAD INJURY'
- 'ANAPHYLAXIS'
- CHEST INJURY'
- STROKE/CEREBROVASCUL.
- SUDDEN CARDIAC ARREST'
- ACUTE DIVERTICULITIS'
- CARDIOGENIC SHOCK SEC..
- ABDOMINAL INJURY'
- NEUROGENIC SHOCK'
- TOXIC EXPOSURE/AMMONI..
- SLEEP DISORDER'
- SMALL BOWEL OBSTRUCTI..
- EYE CHEMICAL BURN'
- ABDOMINAL WALL HERNIA'
- SKIN RASH'
- URINARY RETENTION-SA'

Incidence Dist
- 'BETA'
- 'FIXED'
- 'GAMMA'
- 'LOGNORMAL'

PRCC
SRCC