DEVELOPING MARS-BASED CLINICAL SCENARIOS FOR AN EARTH INDEPENDENT MEDICAL OPERATIONS (EIMO) – BASED DECISION SUPPORT SERVICE

- Prashant Parmar[1], Arian Anderson[2], Marina Parker[3]
- 1. University of Texas Medical Branch, 2. University of Colorado School of Medicine, 3. Analytical Mechanics Associates

Agenda

- **Objective**
- **Background**
- **Approach**
- **Output**
- **Challenges & Limitations**
- **Lessons Learned**

Background

- As crewed missions move beyond Low-Earth Orbit, pre-mission planning cannot fully buy down the medical risks of exploration-class missions.

- For Martian missions, an Earth-Independent Medical Operations-based Medical System (EIMO-MS) will need to be implemented.

MEDICAL RISK INCREASES WITH DISTANCE FROM EARTH

International Space Station → Gateway → Lunar Surface → Mars Transit

CURRENT STATE

- 180-day to 360-day mission duration
- Strong consumables resupply
- Real-time communications
- Regular sample returns to Earth
- Emergency evacuations possible
- Relatively large internal volume
- Limited onboard medical care (Earth-reliant)

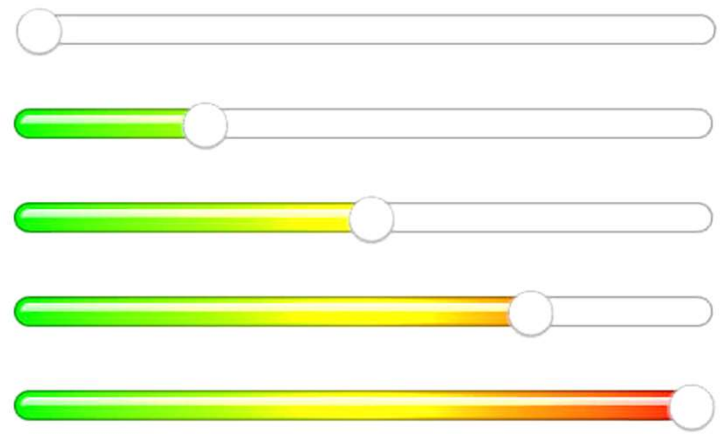
EXPLORATION CLASS MISSIONS

- 650-day to > 900-day mission duration
- No consumables resupply (pre-positioning possible)
- No real-time communications + blackouts
- No sample returns to Earth
- No evacuations possible
- (Likely) much smaller internal volume
- Expanded onboard medical care (crew/vehicle-reliant)

Background

- On-board care will increasingly become the responsibility of the astronauts for primary management.
- Terrestrial assets will continue to be paramount in pre-mission screening and planning, as well as health maintenance and prevention activities.
- New capabilities and procedures that enable progressively more robust and resilient systems and crews will reduce risk and increase probability of deep space exploration mission success.

A Progressive Approach



Credit – Marina Parker and EIMO Systems Engineering Team

Outcomes from various EIMO TIMs

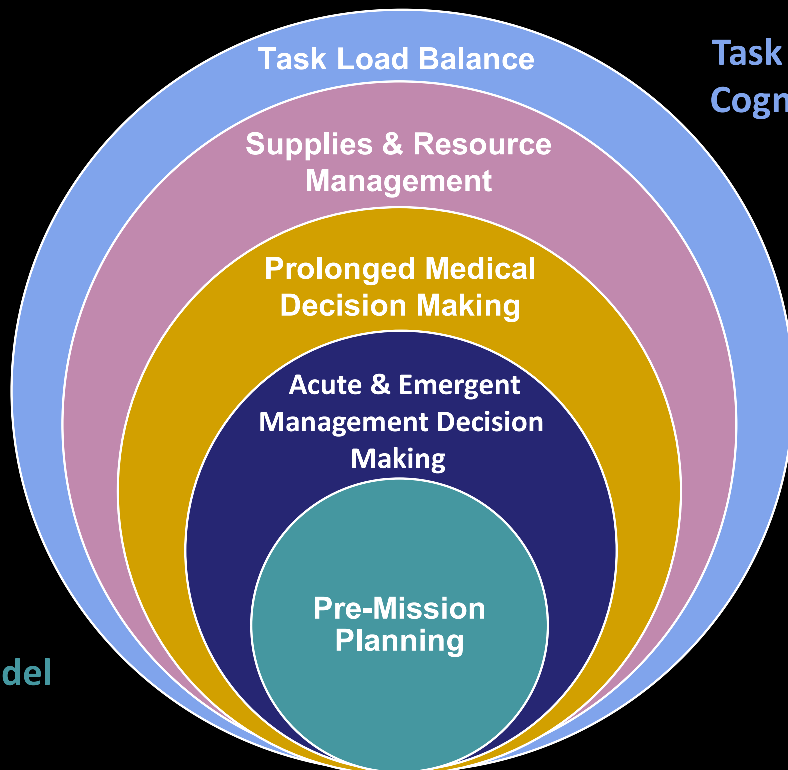
Task Switching
Cognitive Load

Limited Mass/Volume
∅ Re-supply

↑ On-Board KSAs*

Medical KSA* and/or augmentation tools

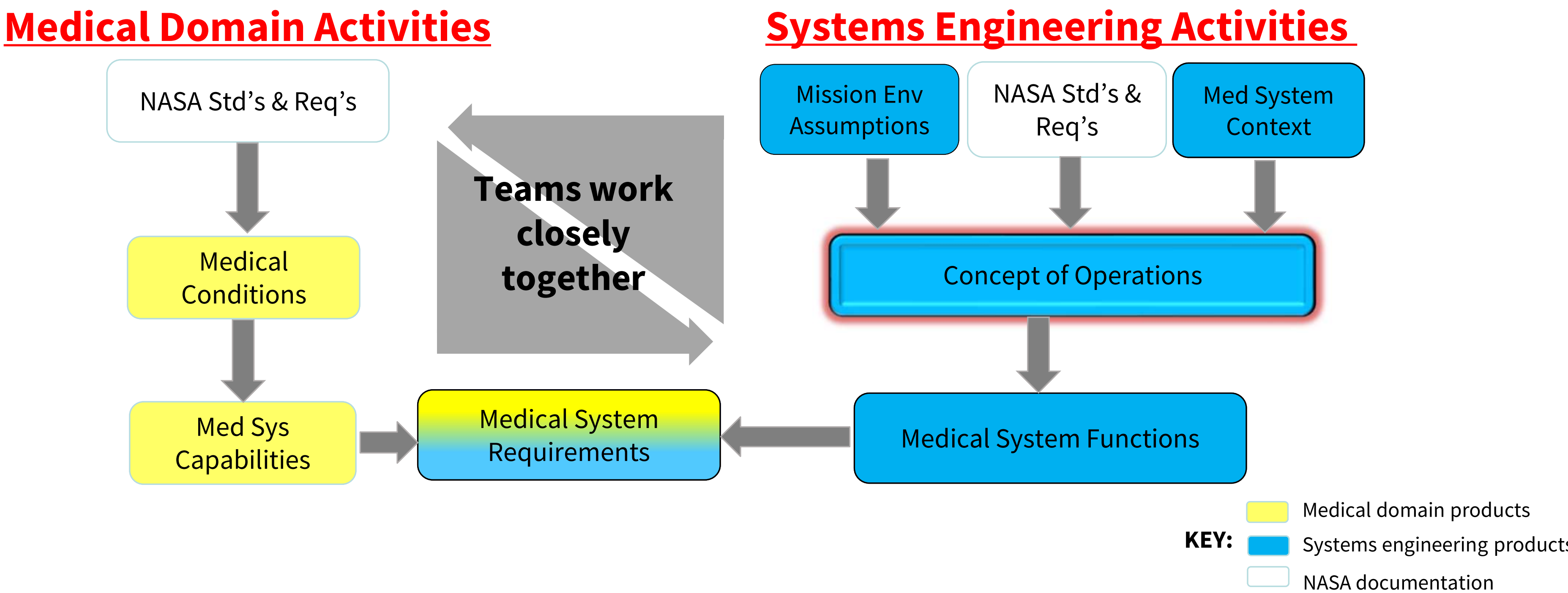
Medical Model



*KSA = Knowledge, Skills, and Abilities

Credit – Marina Parker and EIMO Systems Engineering Team

SIO SE Process: integrating clinical and systems engineering inputs to generate recommendations for medical system design



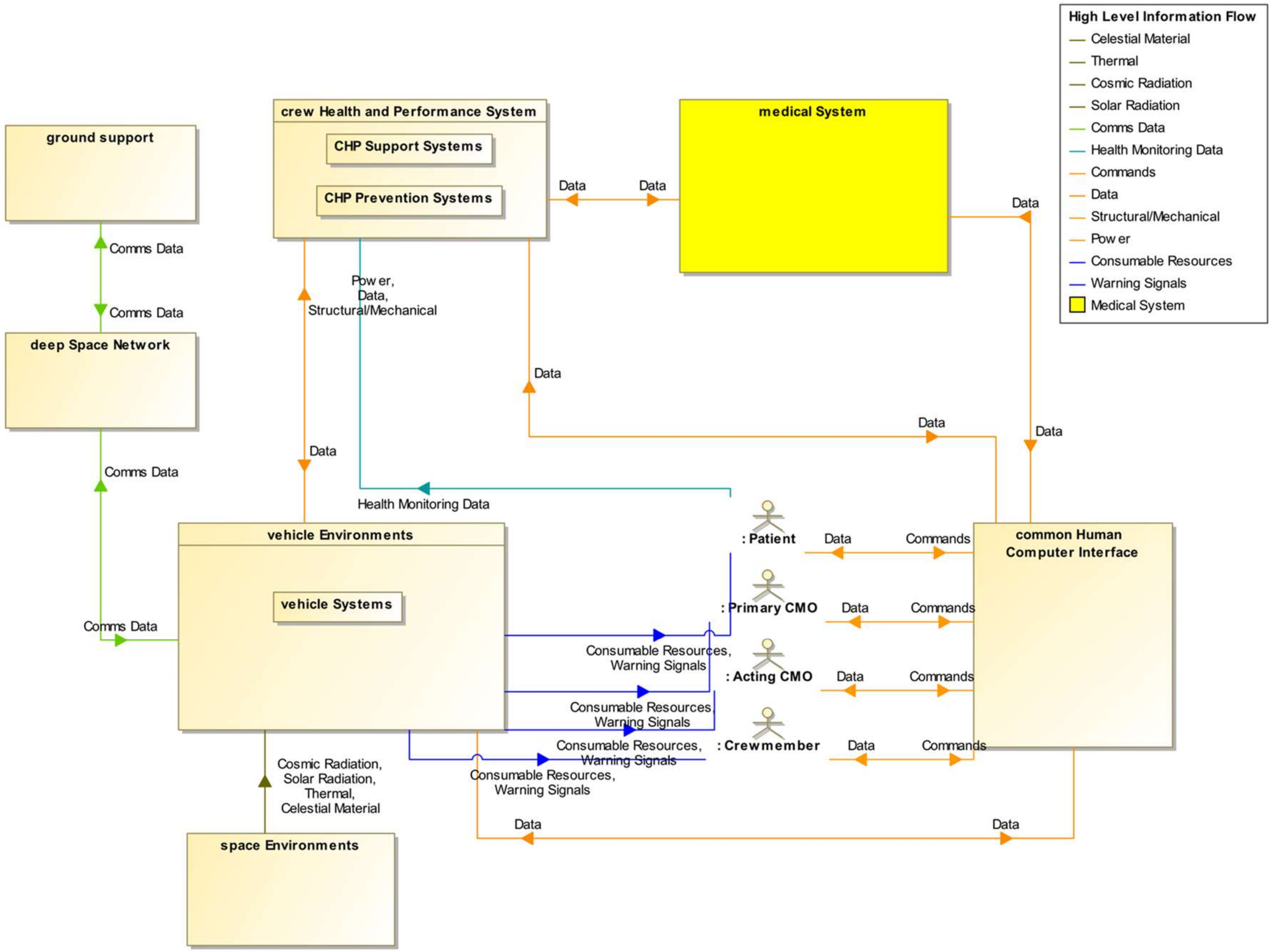
Credit – Marina Parker and EIMO Systems Engineering Team

Objective

- Development of a Concept of Operations document helps guide and anchor future development of a potential EIMO-MS
- A series of scenarios of escalating complexity were created with a combination of clinical and systems engineering expertise to help elucidate the needs and requirements of such an autonomous system
- These scenarios highlight the four critical domains of EIMO-MS:
  - Pre-mission Planning
  - Acute and Prolonged Medical Decision Making
  - Resource Management
  - Task Load Balance

Timeline and Crew Assumptions

- DRM: 30-sol surface Martian mission as described in HEOMD-415
- ~300 days in Deep Space Transport from Earth to Mars -> 10 sol Mars insertion -> 30 sol surface mission
- 4 astronauts total, two of which will transfer to the surface in the Mars Descent Vehicle with a Pressurized Rover
- All crew have basic Crew Medical Officer (CMO) training. One crewmember is trained to a physician level of competency (designated as a Primary Crew Medical Officer / PCMO)



High Level Information Flow
Celestial Material
Thermal
Cosmic Radiation
Solar Radiation
Comms Data
Health Monitoring Data
Commands
Data
Structural/Mechanical
Pow er
Consumable Resources
Warning Signals
Medical System
ground support
Comms Data
Comms Data
deep Space Network
Comms Data
Comms Data
crew Health and Performance System
CHP Support Systems
CHP Prevention Systems
medical System
Data
Data
Data
Pow er,
Data,
Structural/Mechanical
Data
Data
Data
Data
Health Monitoring Data
vehicle Environments
vehicle Systems
: Patient
: Primary CMO
: Acting CMO
: Crewmember
Data
Commands
Data
Commands
Data
Commands
Data
Commands
common Human
Computer Interface
Consumable Resources,
Warning Signals
Consumable Resources,
Warning Signals
Consumable Resources,
Warning Signals
Consumable Resources,
Warning Signals
Cosmic Radiation,
Solar Radiation,
Thermal,
Celestial Material
space Environments
Data
Data

Components of EIMO

Examples of components / resources of EIMO-MS

- **-Clinical Decision Support Service**
- **-Access to crew wearables**
- **-Access to crew Electronic Health Records (EHR)**
- **-Access to crew schedules**
- **-Real-time video monitoring and feedback**
- **-Access to medical resource list**
- **-Access to full ship equipment list**
- **-Virtual reality Just-in-time Training Modules**
- **-Augmented Reality for real-time procedural guidance**
- **-Consistent across all areas**

Key Medical System Function List in EIMO ConOps

Analyze imaging data.	Provide audio and video communication data transfer, as well as data transfer of laboratory data (including video) to Earth.	Provide treament capabilities	Utilize Probabilistic Risk Assessment (PRA) to recommend resource usage.
Analyze patient data	Provide crew guided procedures in support of earth independent medical operations.	Provide XR capabilities.	Provide a means to monitor the effect of deep-space missions on the efficacy of medical consumable resources.
Assist with storing medical information	Provide crew training on crew emergency medical evacuation independent of any Earth-based support.	Recommend diagnostic and treatment plans	Provide access to medical reference database.
Provide differential diagnosis	Automatically recognize crewmember level of proficiency to tailor level of support and provided information.	Recommend medications	Provide advanced learning techniques (identify, prevent, and treat health threats).
Communicate with Ground	Provide evidence-based medical data architecture for long-duration, exploration-class missions. Example, to provide a differential diagnosis.	Recommend treatment options	Provide prospective memory prompts
Diagnose medical conditions	Provide high resolution (spatial and spectral) images that are suitable for diagnostic purposes.	Provide medical imaging	Use AI-enabled DSS for medical decision support.
Evolve differential diagnosis as adaptations to input data occur.	Provide resources (e.g., hardware, software, technology) in support of crew emergency medical evacuation independent of any Earth-based support	Utilize Ground medical support to manage care.	Provide space-based data-driven knowledge, skills, and abilities (KSA) that can augment support for the earth independent medical operations mission.
Identify health concerns	Provide on demand medical training.	Utilize human-automation teaming	Provide the ability to generate resources in-mission.
Ingest data for likely-diagnosis recommendations and record keeping.	Provide pre-flight training for prevention, diagnosis, and treatment of accepted medical conditions	Manage Resources	
Integrate space-based medical system with vehicle/Habitat systems.	Provide procedures with and without pormpting	Utilize the inventory system	

Approach

- **Each scenario consists of:**
  - Context Section – objectives and applicable spaceflight environment
  - Highlighted Assumptions – any deviations from current standards
  - Clinical Narrative – relevant clinical decision pathways in a “story” structure
  - Systems engineering (SE) activity diagram – the SE “translation” which acts as the logistical core of each scenario and demonstrate how the MS will interact with crew, ground support, and other in-flight systems

Scenario List

- Scenario 01: Deconditioning, Landing Ops Planning, Scheduling
- Scenario 02: Barotrauma and Self-medical Management
- Scenario 03: Insomnia and Escalation of Medical Management
- Scenario 04: Musculoskeletal Injury and PCMO Incapacitation
- Scenario 05: Behavioral Health and Chronic Medical Care
- Scenario 06: Kidney Stone and Diagnostic Tools
- Scenario 07: Obstructed Kidney Stone and Advanced Procedures
- Scenario 08: Emergent Treatment and Prolonged Critical Care
- Scenario 09: Traumatic Injury and Medical Futility

Example – Scenario 8

Context:

- Pressurized rover emergent medical event – ground support not feasible.
- Electrocution injury leads to cardiac arrest and the MS and CHP Support Systems assist in the immediate evaluation and guidance on lifesaving treatment.
- MS acts as a multidisciplinary resuscitation team; assists crewmember responding to the situation with both logistics support and device/capability support for single person resuscitation
- MS also assists with logistics and coordination for post-resuscitative care between the patient, responding crewmember, PCMO, and Ground Support.
- Crew Member (CM) 2 is the PCMO

Example – Scenario 8

Narrative Highlights

- CM1 touches faulty wires protruding from a panel and collapses
- MS receives off-nominal vital data from CM1's wearables
- MS activates emergency response mode (begins recording large volumes of data, generating a report, rerouting system priorities, rerouting communication priorities, and pulls up an interface to assist CM2 based on their training level)
- MS guides PCMO through primary survey and generates an initial dataset (EKG, vital sign data) for CM2 to review on a display

Example – Scenario 8

Narrative Highlights (continued)

- CM2 starts Basic Life Support.
- After two rounds of manual CPR, patient transferred to a designated medical treatment area and automated CPR device with AED is placed on patient. Defibrillation is performed.
- Post-defibrillation, CM1 has Return of Spontaneous Circulation (ROSC). The MS detects this and pauses CPR.
- The MS assists in post-arrest care by suggesting an acute management plan including an IV pump managed by the MS along with medication suggestions.

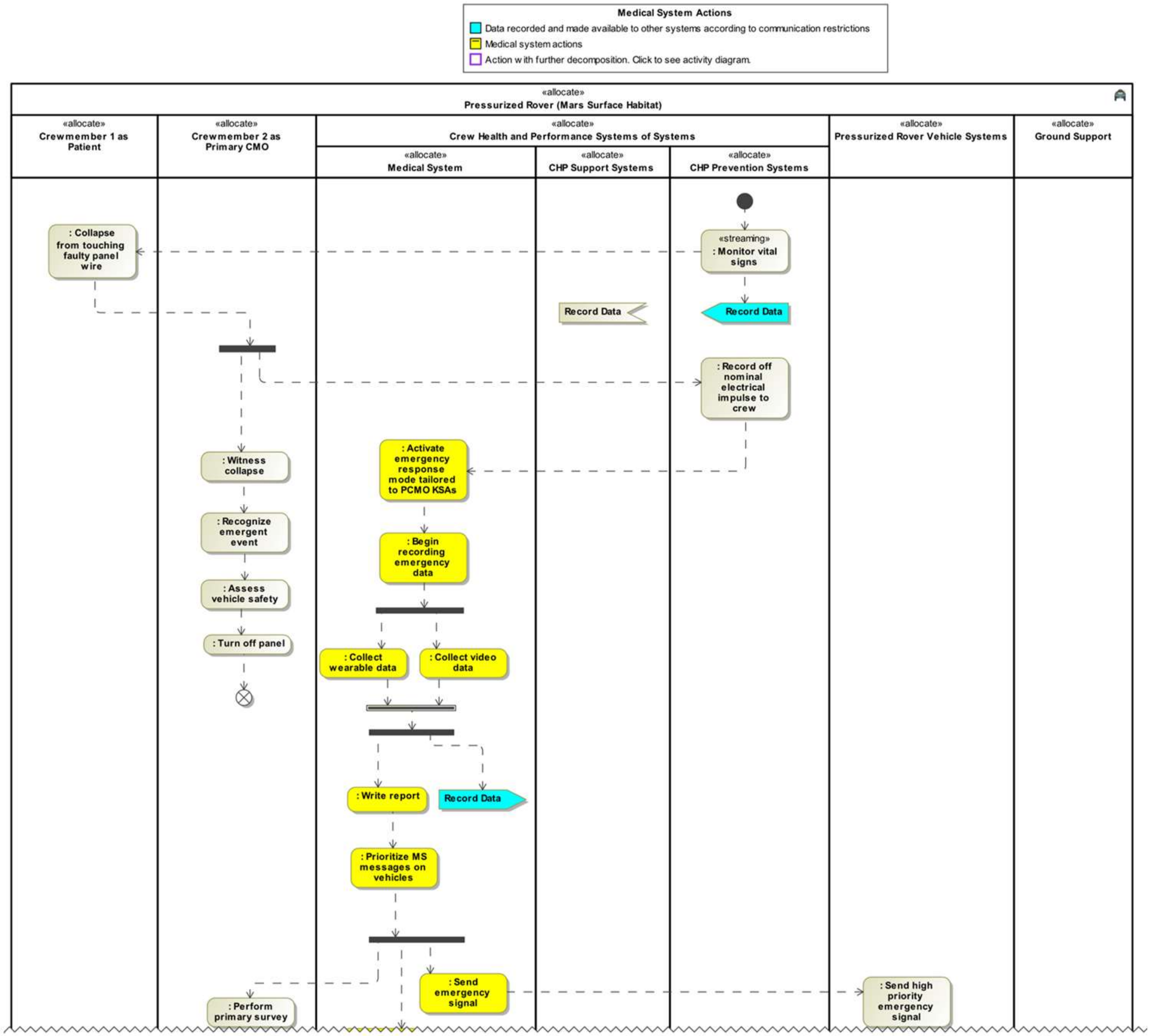
Example – Scenario 8

Narrative Highlights - conclusion

- MS assists the PCMO in generating and finalizing a synthesized medical report to ground support

- MS coordinates with ground support to adjust crew schedule to allow for the medical event and recovery

- Early termination of surface operations



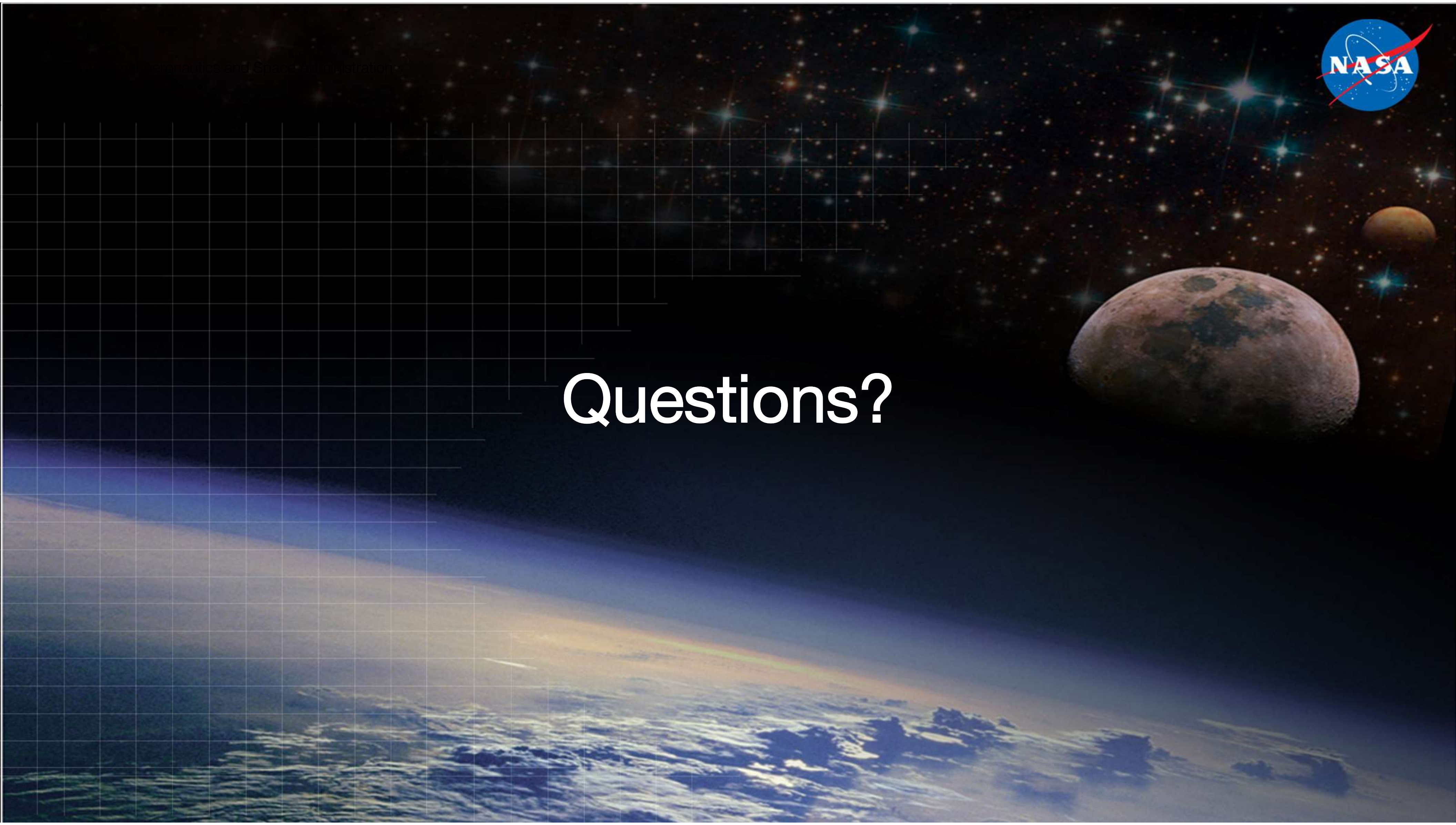
Partial activity diagram example

Challenges & Limitations

- All components of a future Mars mission have yet to be finalized, so all assumptions are subject to change
- Clinical narratives were crafted making assumptions about near-future technology and standards of care that could be subject to change
- The "translation" of a clinical narrative to an activity diagram was very resource-intensive and manpower-intensive and so streamlining the process would be ideal

Lessons Learned

- Close communication between the clinical and systems engineering teams was paramount to success
- While the ConOps itself is an evolving document during the creation process, as many anchor-points as possible should be agreed upon in advance
- Initial agreement of definitions is critical when multiple people are crafting the ConOps


National Aeronautics and Space Administration
Questions?

Additional Example – Scenario 7

Context:

This scenario is a continuation of a worsened state of symptoms and diagnoses that occurred in Scenario 6 and highlights how the MS, CHP Support Systems, and CHP Prevention Systems can assist with a revised diagnosis in a worsening medical scenario as well as provide surgical assistance with JITT, preparation, monitoring, resource management, and post-operative follow-up. The MS augments the PCMO's KSAs to support ultimate PCMO autonomy. This scenario also highlights the greatest number of individual EIMO capabilities.

Diagnosis is based on probabilistic analysis informed by the input data of symptoms, test results, traditional risk scores, and a predictive model of kidney stone formation. The MS, CHP Support Systems, and CHP Prevention Systems can assist in enhanced data collection, real-time ultrasound guidance, a preliminary interpretation of imaging, and assisting the PCMO in formulating a final imaging interpretation. While the MS, CHP Support Systems, and CHP Prevention Systems are not in Autonomy mode in this scenario, this also highlights that Ground Support may receive incomplete information due to communications issues, emphasizing the PCMO as the final decision maker.

This scenario assumes that the PCMO has the required KSAs to perform minimally invasive procedures and will have to perform the necessary procedure through reliance on JITT, the MS's integrated AI algorithms, and the MS's extended reality (XR) capabilities. In this scenario, the surgical procedure is performed with AI guidance, utilizing the expertise of the integrated AI system and the available resources on-board.

Post-operatively, the CHP Support Systems and CHP Prevention Systems then coordinate follow-up resource management including medication management and surgical site monitoring, and the MS coordinates schedule adjustments

Narrative Highlights

- CM1, diagnosed with a kidney stone, agrees to an enhanced monitoring protocol. Symptoms progress after one week with worsening vitals and worsening pain medication use
- MS recommends re-evaluation, and automatically generates an encounter report while the PCMO re-evaluates
- MS advises re-collection of tests and imaging including ultrasound. It compares this with references images of hydronephrosis from its database. It displays an updated probability model for stone passage and complications

Narrative Highlights (con't)

- MS performs a tradespace analysis and recommends placement of a percutaneous nephrostomy tube for the best outcome given location of the kidney stone and ground support agrees
- PCMO reviews the procedure through XR JITT
- PCMO performs the procedure with AR augmented assistance from the MS
- MS assists in recovery including schedule adjustment and postoperative medication management

- **Narrative Highlights (conclusion)**
  - After ~30 days, the patient has improved and an imaging reassessment demonstrates that the stone is amenable to non-invasive interventions
  - After successful intervention, the MS assists in scheduling and guiding drain removal