



ExMC Systems Engineering Status

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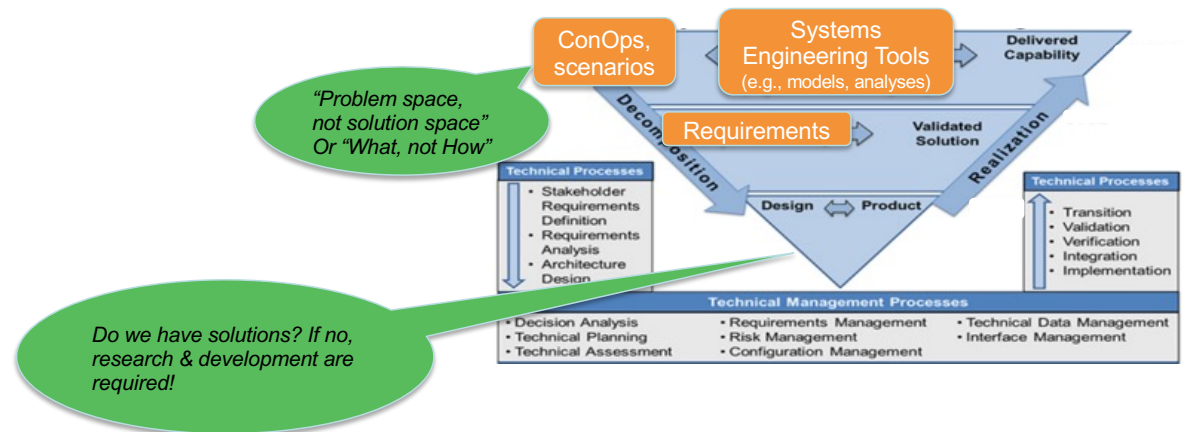
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2023 NASA Human Research Program Investigators' Workshop

13 February 2024

Expanding the Boundaries of Space Medicine and Technology

- Long-Duration Lunar Orbit and Lunar Surface (LDLOLS) Medical System Foundation 2.0
- Earth Independent Medical Operations (EIMO)
- 2023 Artemis Crew Health and Performance (CHP) System Model
- NASA ExMC Website
- Model-Based Systems Engineering Accomplishments



Challenges of Exploration

- Approximately 1000 days with little or no resupply
- Resource constraints (e.g., mass, volume, power, data)
- No evacuation capability
- Communications delays and disruptions
- Isolation, radiation exposure
- Skills erosion over time
- Increased crew autonomy – ready access to comprehensive data to support decision making
- Unknown effects on crew health and performance

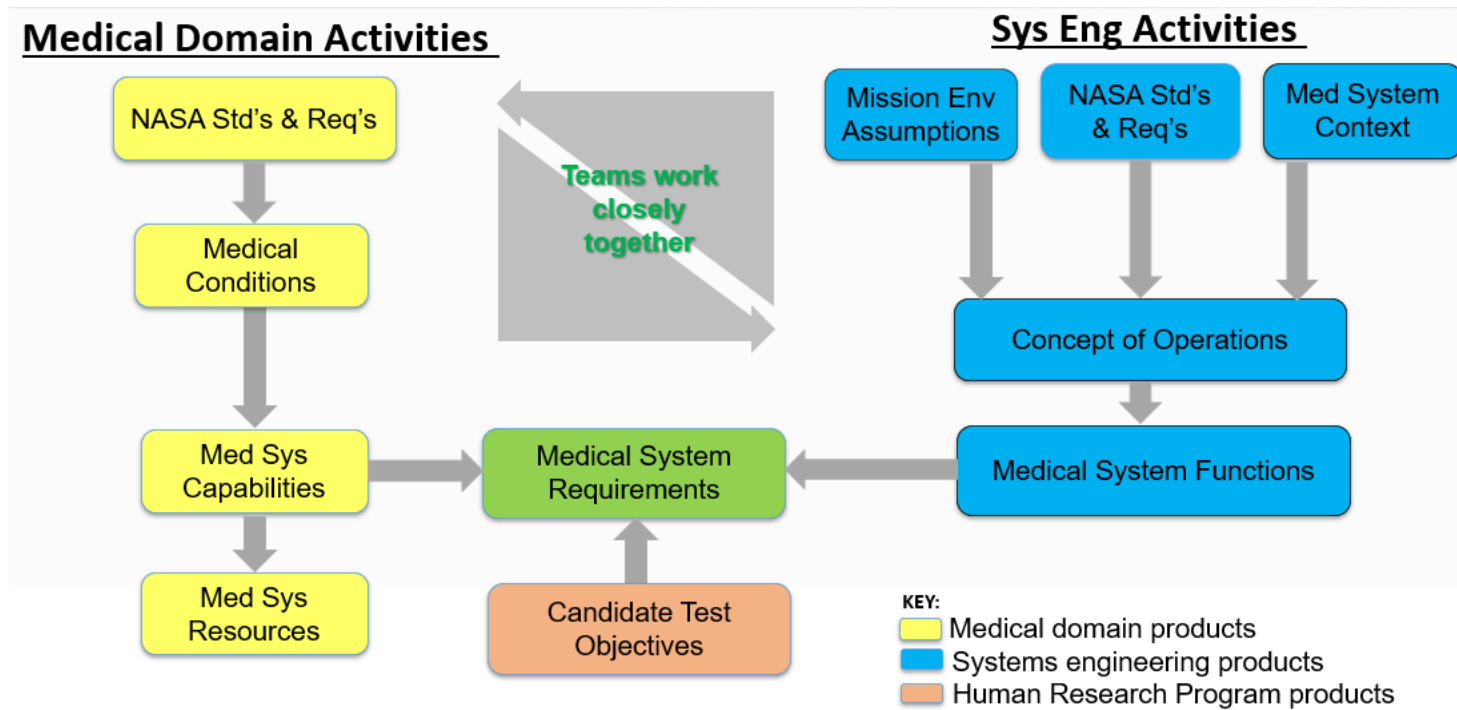
The Human Research Program (HRP) Exploration Medical Capability Element (ExMC) uses a Systems Engineering (SE) approach to understand the needs and challenges of exploration medical and CHP systems.



<https://io.jsc.nasa.gov/photos/10272/hires/S96-01091.jpg/>

- **MBSE is the formalized application of modeling to support system requirements, design, analysis, verification and validation, beginning in the conceptual design phase and continuing throughout development and later life cycle phases.**
- **Benefits:**
 - Consistency
 - Configuration management
 - Communication of requirements and their relationships
 - Reviews
- **Model: Simplified version of a concept, phenomenon, relationship, structure or system**
 - Facilitate understanding
 - Aid in decision making – examine ‘what if’ scenarios
 - ExMC models typically consist of a ConOps, requirements and other model elements
- **MBSE Related Tools**
 - MagicDraw
 - Cameo Collaborator: Publish MagicDraw model in web view format
 - JIRA
 - Cradle
 - Microsoft Teams

- A process of integrating clinical and systems engineering inputs to generate recommendations for medical system design



LDLOLS Medical System Foundation 2.0*

- Updates to align with NASA Spaceflight Human-System Standards
 - NASA-STD-3001, Volume 1, Rev B and Volume 2, Rev C
- Approved by ExMC Control Board in 2023



Long-Duration Lunar Orbit and Lunar Surface Medical System Foundation

Version: 2.0.1

A Medical System Foundation is a system model that contains both Systems Engineering products and Clinical Data. It is meant to serve as a starting point for NASA programs that are developing mission- and vehicle- specific medical systems. New users of this web report are recommended to reference the accompanying context, process and history document while viewing the report: [Medical System Foundation for Level of Care IV Long-Duration Lunar Orbit and Lunar Surface: Context, Process, and Project History](#).

The Medical System is a subsystem of the Crew Health and Performance (CHP) system; it interfaces with the other CHP subsystems and vehicle systems external to the CHP system. The Medical System Foundation model captures systems engineering and clinical content and the relationships that exist between and among them. The model includes a Concept of Operations (ConOps), a list of functions traceable to the ConOps content, requirements derived from the functions, a set of medical conditions that could occur in-flight, medical capabilities, and example resources that could be used to diagnose or treat these conditions.

Information about the Medical System Foundation

- Navigation Support
- Model Stakeholders and Architecture
- Contact Information and Model Version
- Context, Process, and Project History
- How to use this tool with IMPACT
- Glossary and Acronyms
- Applicable Documents
- Reference Documents

System Inputs

The guiding inputs of the Medical System Foundation Model include NASA standards, program-specific requirements related to medical care, and assumptions regarding mission operating environments and interfaces between the Medical System and other systems.

- NASA Standards and Related Requirements
- Mission Environment Assumptions
- Medical System Context



Landing Page

(Scrolling down)

Concept of Operations and Functional Decomposition

The Medical System Foundation systems engineering content consists of a Concept of Operations (ConOps) and System functions.

The ConOps includes stakeholder needs, system goals, mission constraints, operating environments, and representative scenarios that highlight potential needs the system must fulfill.

System functions and subfunctions are derived from the ConOps via a functional decomposition process. These functions served as an input to the requirements development process.



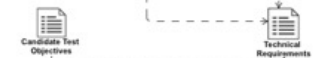
Clinical Content

The Medical System Foundation clinical content includes medical conditions and the derived clinical capabilities and associated resources needed to diagnose and treat those medical conditions. The clinical capabilities served as an input to the technical requirements derivation process. These contents as well as the traceable relationships between them live in this section.



Technical Requirements

The Medical System requirements represent the functional and non-functional System needs and are driven by the content documented in the ConOps (e.g., scenarios and functions), clinical capabilities, NASA standards and historical documents, and parent system requirements. Interface requirements were also developed, which represent medical needs that are allocated to other systems based on the proposed system architecture. The Medical System functional, non-functional, and interface requirements are defined within NASA as Level 4 and have traces to their Level 2 and 3 parent requirements, NASA Standards and historical documents, and the clinical capabilities.



[About this model](#)

*NASA internal access, by request

EIMO Concept of Operations (ConOps)

Content

- ▼ Purpose and Scope
 - Purpose
 - Scope
 - Design Reference Mission Summary
 - Terminology
 - Applicable documents table
 - Reference Documents
- ▼ System Description and Assumptions
 - Stakeholders
 - Stakeholder Need
 - Goals
 - Objectives
 - Assumptions
 - System Description and Context
 - Environments
- > Scenarios
- > Appendices

Baseline Draft

Version information

Version information



Earth-Independent Medical Operations

Version: 0.0.1

Model History
Server Version: Commit #528
Modified: Nov-17, 2023, 1:51:08 PM

Purpose and Scope

Purpose

There is a need for a significant exploration medical operations paradigm shift from previous spaceflight missions, including Space Transportation System (STS), International Space Station (ISS), and Lunar Orbit missions, that is primarily driven by the hazard of distance from Earth. These increasingly complex exploration missions will be resource constrained (e.g., mass, power, volume, data), significant real-time communication challenges, and no resupply or evacuation capabilities. To evolve into an autonomous medical approach, a multi-faceted strategy is needed to optimize all aspects of human health and performance in space. Collectively, this paradigm shift to Earth-Independent Medical Operations (EIMO), i.e., the gradual transition of medical care and decision making from terrestrial to space-based assets, enabling astronaut health and performance and reducing overall mission risk. The above mentioned EIMO-related constraints require medical system development to be tight with mission, vehicle, suit design, and data architecture to provide a sufficient medical infrastructure and enable mission success.

An EIMO Medical System (MS) of systems is envisioned for EIMO, whereby inputs are obtained from numerous sources. Such data sources include reference databank time monitoring via wearable sensors, point-of-care diagnostics, and environmental controls, and the system will include advanced training tools to enable increased autonomous medical care to aid a crew medical officer in the event of an emergent medical situation when ground support is either unavailable or the time delay is available support is inapt.

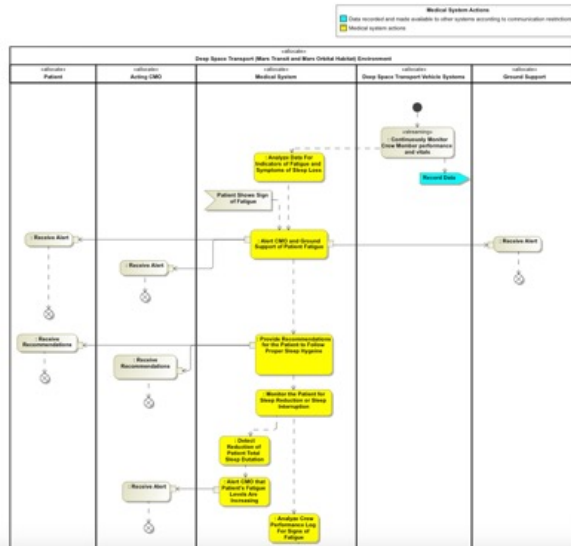
Marina Parker will present:

'EIMO Concept of Operations,' Today at 3:15pm CT

ConOps:

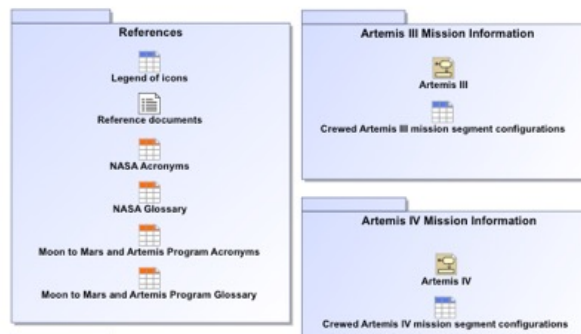
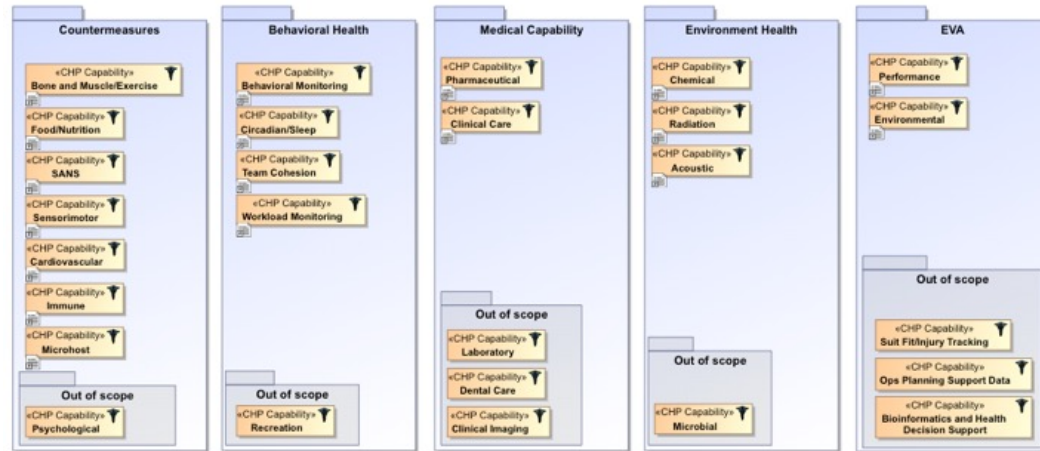
- Joint development effort between the ExMC Systems Engineering & ExMC Clinical Science Teams.
- Comprised of the needs, goals, and objectives; supported by nine medical scenarios in an MBSE model.

Activity Diagram for Scenario 03. Sleep disturbance



- A **system model** built with the desktop tool MagicDraw
- Seeks to help visualize and analyze the CHP capabilities of an Artemis mission
- Focused on Artemis III and Artemis IV missions
- Used existing Program requirements from Exploration Systems Development Mission Directorate (ESDMD)

CHP System Dashboard



2023 Artemis CHP System Model

Version: 0.1.0

Model History =

Server Version: Commit #378

Modified: Sep 28, 2023, 6:14:13 PM

More to come at 11:30am CT, immediately following this presentation!

ExMC Products

The ExMC element promotes human health and performance in space by advancing medical systems design and risk-informed decision-making for exploration beyond low-Earth orbit.



Short-Duration Lunar Orbit

Learn more about the Short-Duration Lunar Orbit Medical System Model.

[Read More](#) 



Long-Duration Lunar Orbit and Lunar Surface

Learn more about the Long-Duration Lunar Orbit and Lunar Surface Model.

[Read More](#) 

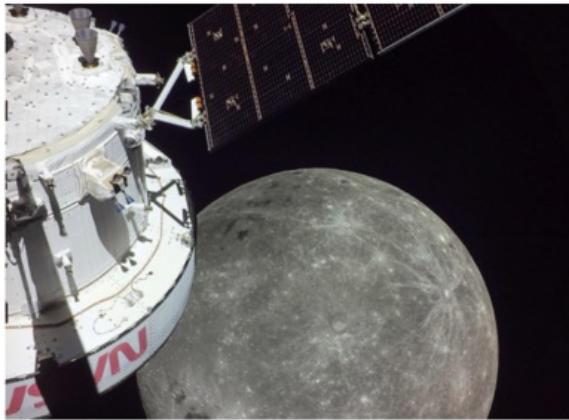


Clinical Decision Support

Learn more about the Clinical Decision Support project.

[Read More](#) 

Introduction to the Short-Duration Lunar Orbit (SDLO) Medical System Model



Credit: NASA

What is the purpose of the SDLO model?

ExMC's SDLO model represents a medical system foundation that provides a set of information for a Gateway-like mission of 42 days or less. It consists of a Concept of Operations (ConOps), an Accepted Medical Condition List (AMCL), and a SDLO medical system model which includes medical requirements. We call it a "foundation" because it is intended to be a starting point for missions with similar profiles. We expect someone will be able to take this foundation and tailor it for their own use by customizing the ConOps, changing some of the AMCL, or modifying other functional requirements to suit a particular mission profile.

How do I view the SDLO model?

To access the SDLO model, click on the link below. Some content (such as tables) may take a few seconds to load because of the amount of information being displayed.

[Medical System Foundation for Level of Care IV: Short-Duration Lunar Orbit](#)

<https://www.nasa.gov/hrp/exmc/short-duration-lunar-orbit-model/>



SDLO Model Landing Page

The screenshot shows the 'Medical System Foundation for Level of Care IV: Short-Duration Lunar Orbit' landing page. It features a 'Content Diagram' at the top, a 'Medical System Foundation' title, and several informational sections:

- About this HTML Report:** Explains that the report contains visualizations and links for a Level of Care IV mission, generated from a Systems Engineering modeling tool.
- About this Diagram:** Provides instructions on how to use the report, including a link to a 'Guide for Using HTML Report'.
- Each gray box shows one of the Habitat systems and its constituent parts (groupings of functionalities and capabilities). The Medical System is dark gray and the focus of the current model. It includes the full content. The light gray boxes indicate systems that interface with the Medical System. Click the System Content icon to see the Medical System content for each of the systems.**

The main diagram is a hierarchical tree structure of systems:

- Habitat System** (Dark Gray)
 - Medical System (Dark Gray)
 - Medical System Content
 - Clinical Care
 - Imaging
 - Laboratory Management
 - Pharmacy Management
 - Environmental Monitoring System (Light Gray)
 - Environmental Monitoring System Content
 - Acoustic Environment Monitoring
 - Internal Atmosphere Monitoring
 - Micro-g/Acceleration Environment Monitoring
 - Microbial Environment Monitoring
 - Radiation Environment Monitoring
 - Toxicological Environment Monitoring
 - Wellness System (Light Gray)
 - Wellness System Content
 - Behavioral Health Management
 - Nutrition Management
 - Physiological Health Management
 - Sleep Management
 - Task Performance Support System (Light Gray)
 - Task Performance Support System Content
 - Crew Interfaces
 - Task Management
 - Training
 - Maintenance System (Light Gray)
 - Maintenance System Content
 - Waste Management (Light Gray)
 - Waste Management System Requirements with Relationships
 - Crew & Tracking (Light Gray)
 - Crew & Tracking
 - Power (Light Gray)
 - Power
 - Propulsion (Light Gray)
 - Propulsion
 - EV (Light Gray)
 - EV
 - ECLSS (Light Gray)
 - ECLSS
 - Structures (Light Gray)
 - Structures Requirements with Relationships
- Crew Health and Performance System** (Light Gray)
 - Data System (Light Gray)
 - Data System Content
 - Advanced Analytics
 - Data Source Interfaces
 - Data Storage
 - Data User Interfaces
 - Descriptive Analytics
 - Testbed & Research System (Light Gray)
 - Testbed & Research System Content
 - Research
 - Testbed
 - Extravehicular Activity Support System (Light Gray)
 - Extravehicular Activity Support System Content
 - EVK Crew Health Support
 - EVK Performance Support

Additional features include a 'Legend' at the bottom right, 'Glossary' and 'Acronyms' sections, and a 'Disclaimers' icon at the bottom left.



Introduction to the Long-Duration Lunar Orbit and Lunar Surface (LDLOLS) Model



Credit: U.S. Human Space Flight Plans Committee

What is the purpose of the LDLOLS model?

ExMC's LDLOLS model represents a medical system foundation that provides a set of information for a Gateway-like mission of 9 months (6 months in Lunar Orbit, 3 months on the Lunar Surface). It includes of a Concept of Operations (ConOps), an Accepted Medical Condition List (AMCL), and a system model which includes medical requirements. The model is labeled as a "foundation" because it is intended to be a starting point for missions with similar profiles. We expect someone will be able to take this foundation and tailor it for their own use by customizing the ConOps, changing some of the AMCL, or modifying other technical requirements to suit a particular mission profile.

How do I view the LDLOLS model?

To access the LDLOLS model, click on the link below. Some content (such as tables) may take a few seconds to load because of the amount of information being displayed.

[Medical System Foundation for Level of Care IV: Long-Duration Lunar Orbit and Lunar Surface](#)

LDLOLS Model Landing Page

Diagram Specification Appears in

Content Diagram Medical System

Medical System Foundation for Level of Care IV: Long-Duration Lunar Orbit and Lunar Surface

Version 1.0.11

A Medical System Foundation is a system model that contains both Systems Engineering products and Clinical Data. It is meant to serve as a starting point for NASA programs that are developing mission- and vehicle-specific medical systems. New users of this web report are recommended to reference the accompanying context, process and history document while viewing the report: [Medical System Foundation for Level of Care IV: Long-Duration Lunar Orbit and Lunar Surface, Context, Process, and Project History](#).

The Medical System is a subsystem of the Crew Health and Performance (CHP) system. It interfaces with the other CHP subsystems and vehicle systems external to the CHP system. The Medical System Foundation model captures systems engineering and clinical content and the relationships that exist between and among them. The model includes a Concept of Operations (ConOps), a list of functions traceable to the ConOps content, requirements derived from the functions, a set of medical conditions that could occur in-flight, medical capabilities, and example resources that could be used to diagnose or treat these conditions.

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- Reference Documents

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- NASA Standards and Related Requirements
- Mission Environment Assumptions
- Medical System Context

Concept of Operations and Functional Decomposition

The Medical System Foundation systems engineering content consists of a Concept of Operations (ConOps) and System functions.

The ConOps includes stakeholder needs, system

[ExMC Home](#) [About ExMC](#) [Products](#) [Meet the Team](#)



Introduction to the Clinical Decision Support (CDS) Concept of Operations (ConOps) and Candidate Requirements



Credit: NASA

What are the CDS ConOps and Candidate Requirements?

ExMC's Clinical Decision Support (CDS) Concept of Operations (ConOps) and Candidate Requirements is a set of information for a deep-space exploration mission where astronauts may have to provide Earth-independent medical care to a crewmember. CDS is a software tool that acts as an assistant to diagnose, treat, and prevent medical conditions. A spaceflight CDS system must provide real-time, on-board support to enable increased crew independence for managing anticipated and unanticipated medical conditions. In addition, a CDS system will increase Earth-independence by increasing the crew's ability to appropriately respond to medical events. The intent of the ConOps and candidate requirements are to provide a starting point for missions with similar constraints that may be customized to suit a particular mission needing a CDS system.

How do I view the CDS ConOps and Candidate Requirements?

To access the CDS model, click on the link below. Some content (such as tables) may take a few seconds to load because of the amount of information being displayed.

[Exploration Medical Capability Clinical Decision Support](#)



CDS Model Landing Page

Diagram
Specification
Appears in

[Content Diagram Home](#)

Exploration Medical Capability Clinical Decision Support Model

CDSS Paradigm
 Unlike ISS operations in LEO, future journeys traveling deeper into space will require an increased reliance on the ability to conduct Earth-independent Medical Operations (EMO). Depending on the orbital positions of Earth and Mars when the crew reach Mars, one-way communication delays can be more than 20 minutes^[1]. These communication delays will require the crew to detect, diagnose, and treat time-critical medical issues autonomously. Autonomous operation is defined here as performing self-directed clinical tasks without real-time Mission Control Center (MCC) support. In an emergency medical situation (acute and life-threatening), the crew will need to react swiftly, using locally available information. Preventative and routine health care may be a hybrid system with autonomous data collection and in-vehicle decision support to assist workflow or more critically during periodic lack of communication from planetary alignment, solar wind, or equipment failure. Medical inventory will also need to be used strategically in the absence of resupply missions or early return to Earth.

A physician astronaut could be included as a crewmember on a deep space mission, but even two or three physicians would not have the breadth of expertise necessary for addressing the full range of potential health-related issues on a multi-year mission. Moreover, if pre-flight crew training is viewed as a fixed resource, additional medical training before a mission means less training time devoted to other critical domains, such as extravehicular activity, spacecraft systems maintenance, or scientific research. Furthermore, there will likely be situations in flight where the CMO is the patient and requires care from clinically novice crew members. A possible solution lies in developing assistive technology and tools to increase the crew's medical Scope of Practice (medical procedures, processes and actions that an exploration crew can perform).

[1] Institute of Medicine (US) Committee on Creating a Vision for Space Medicine During Travel Beyond Earth Orbit. Safe Passage: Astronaut Care for Exploration Missions. Ball JR, Evans CH Jr, editors. Washington (DC): National Academies Press (US); 2001. PMID: 25057582

Model Directory

Concept of Operations (ConOps)

ConOps Home

➔

Requirements

CDS Requirements Overview

Acronyms

ConOps Acronyms

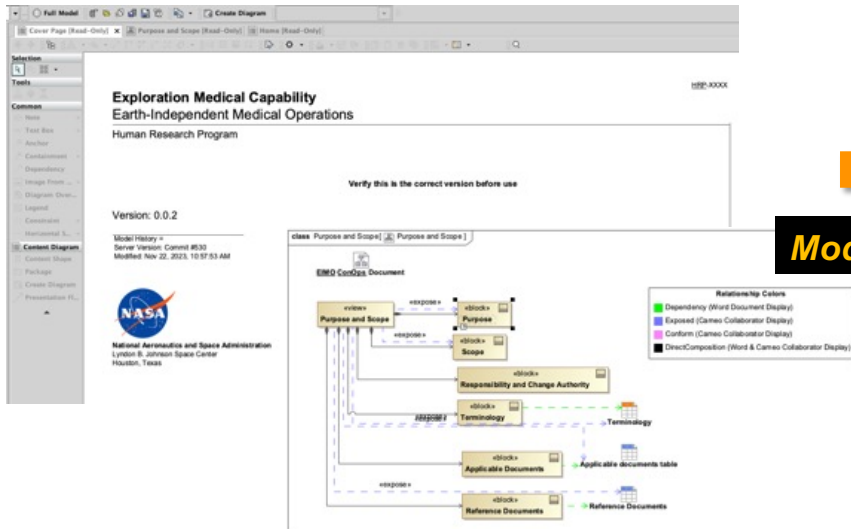
About this Model

About this Model

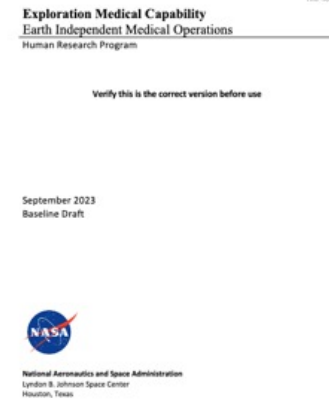
Contact
 ✉ EXMC-CL-SE-MRSP-1.lead@nasa.gov
 Version: 2.0.4

Model History #
 Server Version: Commit #304
 Modified: Nov 20, 2023, 8:20:49 AM

- Document generation method adapted from NASA MBSE Community of Practice tools.
- Communication with groups in ESDMD using ExMC system models
 - Shared Crew Health and Performance (CHP) system concepts with Moon to Mars and Gateway
 - Participated in the digital architecture workshop
 - Exchanged modeling practices
- New models available on the ExMC public website:
 - LDLOLS Medical System Foundation
 - CDS ConOps and Candidate Requirements



Model to Document



1.0 PURPOSE AND SCOPE

1.1 Purpose

There is a need for a significant exploration medical operations paradigm shift from previous spaceflight missions, including Space Transportation System (STS), International Space Station (ISS), and Lunar Orbit missions, that is primarily driven by the hazard of distance from Earth. These increasingly complex exploration missions will be limited by resource constraints (e.g., mass, power, volume, data), significant real-time communication challenges, and no resupply or evacuation capabilities. To evolve into a more autonomous medical approach, a multi-faceted strategy is needed to optimize all aspects of human health and performance in space.

Collectively, this paradigm shift is referred to as Earth-Independent Medical Operations (EMO), i.e., the gradual transition of medical care and decision making from terrestrial to space-based assets, enabling support of astronaut health and performance and reducing overall mission risk. The above mentioned EMO-related constraints require medical system development to be tightly integrated with mission, vehicle, suit design, and data architecture to provide a sufficient medical infrastructure and enable mission success.

An EMO Medical System (MS) of systems is envisioned for EMO, whereby inputs are obtained from numerous sources. Such data sources include reference databases, real-time monitoring via wearable sensors, point-of-care diagnostics, and environmental controls, and the system will include advanced training tools to enable increasingly autonomous medical care to aid a crew medical officer in the event of an emergent medical situation when ground support is either unavailable or the time delay is such that any available support is inapt.

This concept of operations (ConOps) provides a vision of medical care needs that can be used to guide the development of a MS for EMO. This EMO MS (also referred to as MS) will serve as the precursor to the system that is implemented in future exploration missions to Mars. This ConOps provides an overview of the stakeholder needs, system goals, and system objectives of an EMO MS while providing examples of the types of activities for which the system will be used during missions. The activities described in this concept of operations were carefully selected to represent a broad spectrum of medical conditions, to include conditions that are categorized as low-likelihood/low-consequence (LL/LC), low-likelihood/high-consequence (LL/H), and high-likelihood/low-consequence (HL/LC), effectively demonstrating a full curve of possibilities. In addition, this ConOps serves to inform the subsequent systems engineering process for developing technical requirements, system architectures, interfaces, and verification and validation approaches for the EMO MS. Where applicable, task-based human error analysis (TBEA) and Human in the Loop (HITL) may be informed by this ConOps to support systems and operations design.

1.2 Scope

This model-based report describes the ConOps for an MS, highlighting the five main components of EMO identified by stakeholders for which there is currently no NASA program-level ConOps. These components are Pre-mission Planning, Acute and Emergent Management Decision Making, Prolonged Medical Management Decision Making, Supplies and Resource Management, and Task Load Management. Exploration Systems Development Mission Directorate (ESDMD) Human Exploration and Operations Mission Directorate (HEOMD)-415 Version 1 and HEOMD Strategic Campaign Operations Plan for Exploration were used as the

- **Updated to the LDLOLS Medical System Foundation based on NASA-STD-3001 (Volume 1, Rev. B and Volume 2, Rev. C)**
- **Two new initiatives:**
 - Developed the EIMO ConOps
 - Originated the 2023 Artemis CHP System model
- **New content added to the ExMC public-facing website**
 - LDLOLS Medical System Foundation
 - Clinical Decision Support Concept of Operations and Candidate Requirements
- **ExMC SE continues to evolve the use of MBSE software tools**
 - Publishing documents from a MagicDraw model

<https://www.nasa.gov/hrp/exmc/products>

ExMC Systems Engineering Team:

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- Andrea Legreid
- John Odina
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- Marina Parker
- Tatyana Rakalina
- Alex Salimian
- Bill Toscano
- Sean Winther