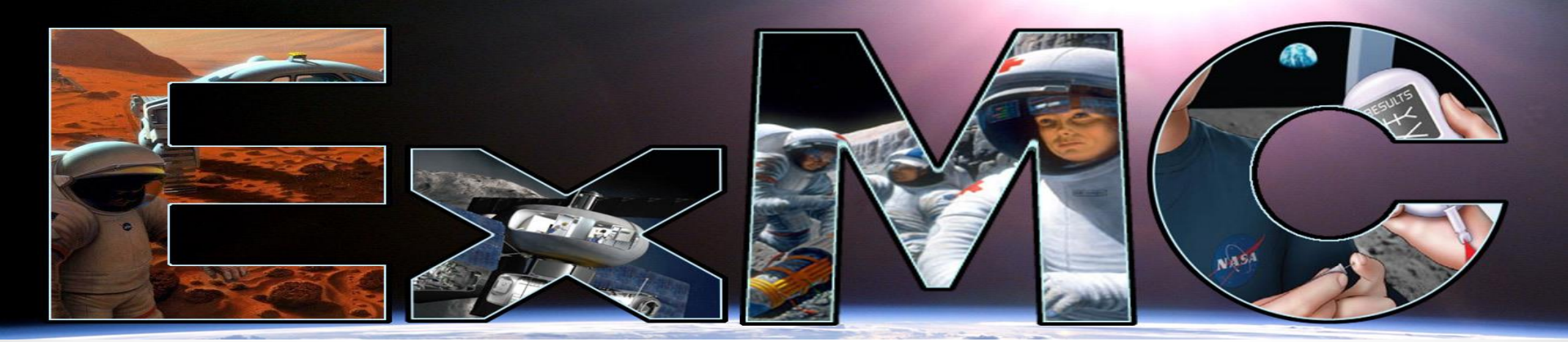


Exploration Medical Data Architecture

Big Data Big Think Forum
April 6, 2016

Erik Antonsen MD, PhD, FAAEM
Element Scientist

Sandeep Shetye
Chief Data Architect

Exploration Medical Capabilities – Data is a Challenge

- ISS and exploration: Different Medicine requires different capabilities
- What can we learn from ISS?
- A vehicle and a ground challenge
- Risk Modeling – what are we worried about?
- Needs Analysis – what do we think we need?
- Data Architecture – Medicine as a system

HUMAN EXPLORATION

NASA's Path to Mars

EARTH RELIANT

MISSION: 6 TO 12 MONTHS
RETURN TO EARTH: HOURS

Mastering fundamentals aboard the International Space Station

U.S. companies provide access to low-Earth orbit

PROVING GROUND

MISSION: 1 TO 12 MONTHS
RETURN TO EARTH: DAYS

Expanding capabilities by visiting an asteroid redirected to a lunar distant retrograde orbit

The next step: traveling beyond low-Earth orbit with the Space Launch System rocket and Orion spacecraft

MARS READY

MISSION: 2 TO 3 YEARS
RETURN TO EARTH: MONTHS

Developing planetary independence by exploring Mars, its moons and other deep space destinations

www.nasa.gov

Motivation

Medical Risk: Given that medical conditions will occur during human spaceflight missions, there is a possibility of adverse health outcomes & decrements in performance during these missions and for long term health

The medical system supports healthy crew to enable completion of mission objectives. We are concerned with health and prevention, not just catastrophic events.

To minimize mission medical risk through medical system design and integration into the overall mission and vehicle design.

4

Mission Constraints

Exploration missions are different:

- Harsher environmental constraints
- Shrinking resources (mass, volume, power, etc.)

- **No evacuation option**
- **Limited if any resupply**
- **Delayed or absent communications**

Exploration may require “Stay and Fight” Medicine, not “Retreat” Medicine.

- The only resource growing is data handling capability (Moore’s Law)

5

Medical and Research Data Processing

- Biomedical Data Reduction and Analysis
  - Around 100 pages pdf
  - Preparation is pre-mission through 45-60 days post flight

- Mission Associated Summary of Health
  - Detailed Medical Report
  - 500 page pdf
  - Takes a team 6 months to create

Some version of both of these processes will need to be incorporated and **automated** in exploration missions.

Challenges

- No single medical database stores all information that is complete
- Leveraging extensive quantity of medical research being published on an ongoing basis
- Integrating new data sources into existing medical systems
- Existing industry systems have limitations
    - Limited utilization and scope
    - Design for specific purpose and difficult to personalize
- Access to knowledge base and other medical data
- Machines can assist but can’t replace humans

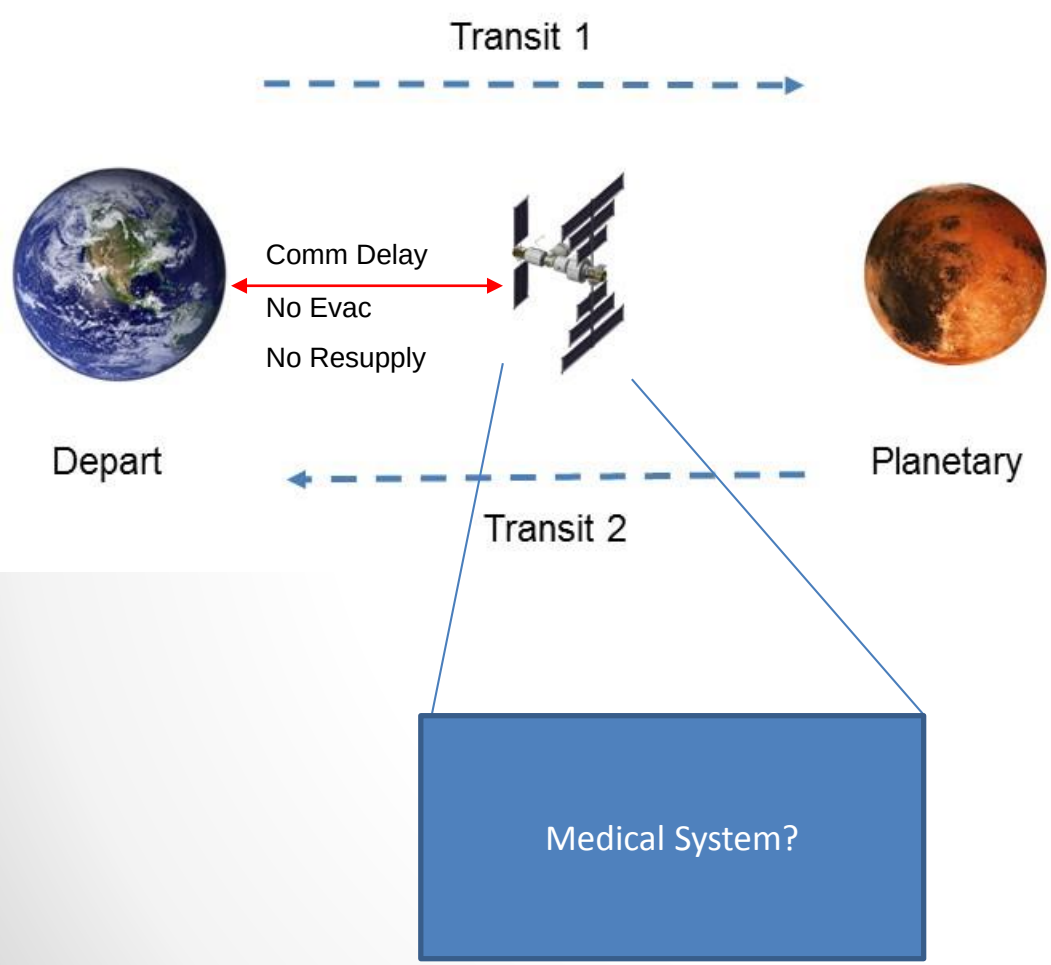
7

How do we get there?

- Risk Mitigation Strategy
  - Planning
    - Concept of Operations Development (Ops Risk Reduction)
  - Characterization of Risk
    - Models and Metrics – Integrated Medical Model (IMM), MONSTR prototype
    - Active Data Gathering – Medical Consumables Tracker (MCT), biosensors, Flexible Ultrasound
  - Active Risk Reduction
    - Medical Data Handling – Exploration Medical System Demonstrator (EMSD), Medical Data Architecture
    - Technology Development – Oxygen Concentrator Module, Medical Suction, IVGen…
    - Training
    - Medical Decision Support
    - Integration of Medical with Vehicle Designers and ECLSS SMTs

Medical System Development

The Goal



Provide the crew with the best chance to accomplish mission and get home healthy

Medical Operations

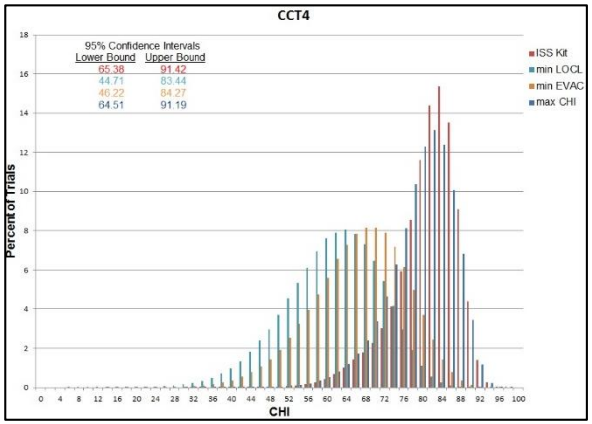
- Nominal Operations
- Contingency Operations
  - Routine
  - Urgent
  - Emergent

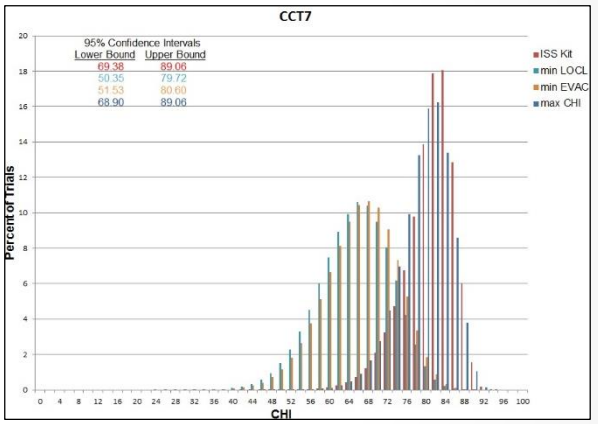
Risk Characterization

- Identify the medical conditions that are likely to occur.
- Identify how likely and how often they might occur.
- Identify what resources are desired to address them.

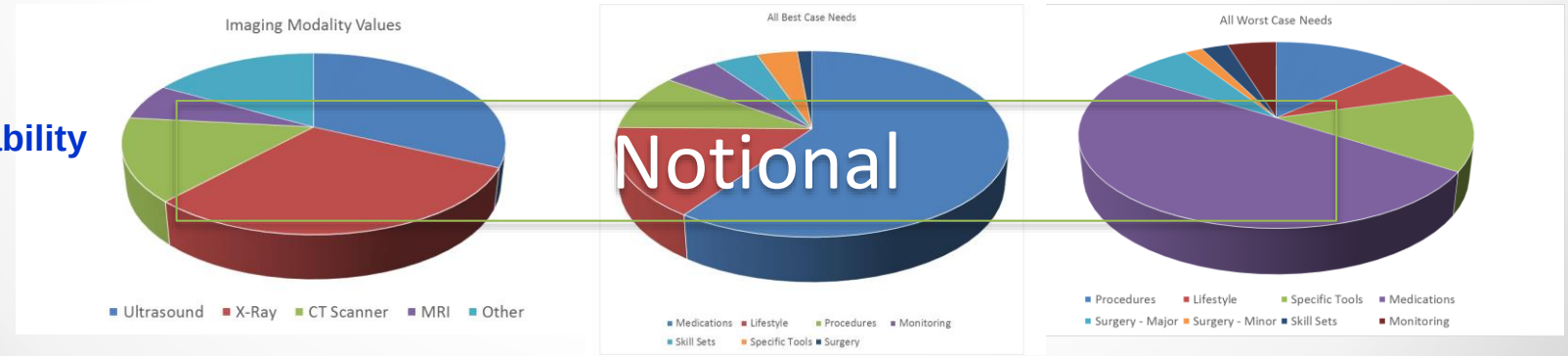
Medical Optimization Network for Space Telemedicine Resources (MONSTR)

Event Probability (IMM)





Medical Capability (MONSTR)



Notional

Draft Data Only

The IMM Medical Conditions

SKIN
- Burns secondary to Fire
- Skin Abrasion
- Skin Laceration

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

EARS, NOSE, THROAT
- Barotrauma (sinus block)
- Nasal Congestion (SA)
- Nosebleed (SA)
- 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 (SA)
- Abdominal Injury
- Acute Cholecystitis
- Acute Diverticulitis
- Acute Pancreatitis
- Appendicitis
- Diarrhea
- Gastroenteritis
- Hemorrhoids
- Indigestion
- Small Bowel Obstruction

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

NEUROLOGIC
- Space Motion Sickness (SA)
- Head Injury
- Seizures
- Headache
- Stroke
- Paresthesia
- Headache (SA)
- Neurogenic Shock
- VIIP (SA)

MUSKULOSKELETAL
- Back Pain (SA)
- Abdominal Wall Hernia
- Acute Arthritis
- Back Injury
- Ankle Sprain/Strain
- Elbow Dislocation
- Elbow Sprain/Strain
- Finger Dislocation
- Fingernail Delamination (EVA)
- Hip Sprain/Strain
- Hip/Proximal Femur Fracture
- Knee Sprain/Strain
- Lower Extremity Stress fracture
- Lumbar Spine Fracture
- Shoulder Dislocation
- Shoulder Sprain/Strain
- Acute Compartment Syndrome
- Neck Injury
- Wrist Sprain/Strain
- Wrist Fracture

PSYCHIATRIC
- Insomnia (Space Adaptation)
- Late Insomnia
- Anxiety
- Behavioral Emergency
- Depression

GENITOURINARY
- Abnormal Uterine Bleeding
- Acute Prostatitis
- Nephrolithiasis
- Urinary Incontinence (SA)
- Urinary Retention (SA)
- Vaginal Yeast Infection

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

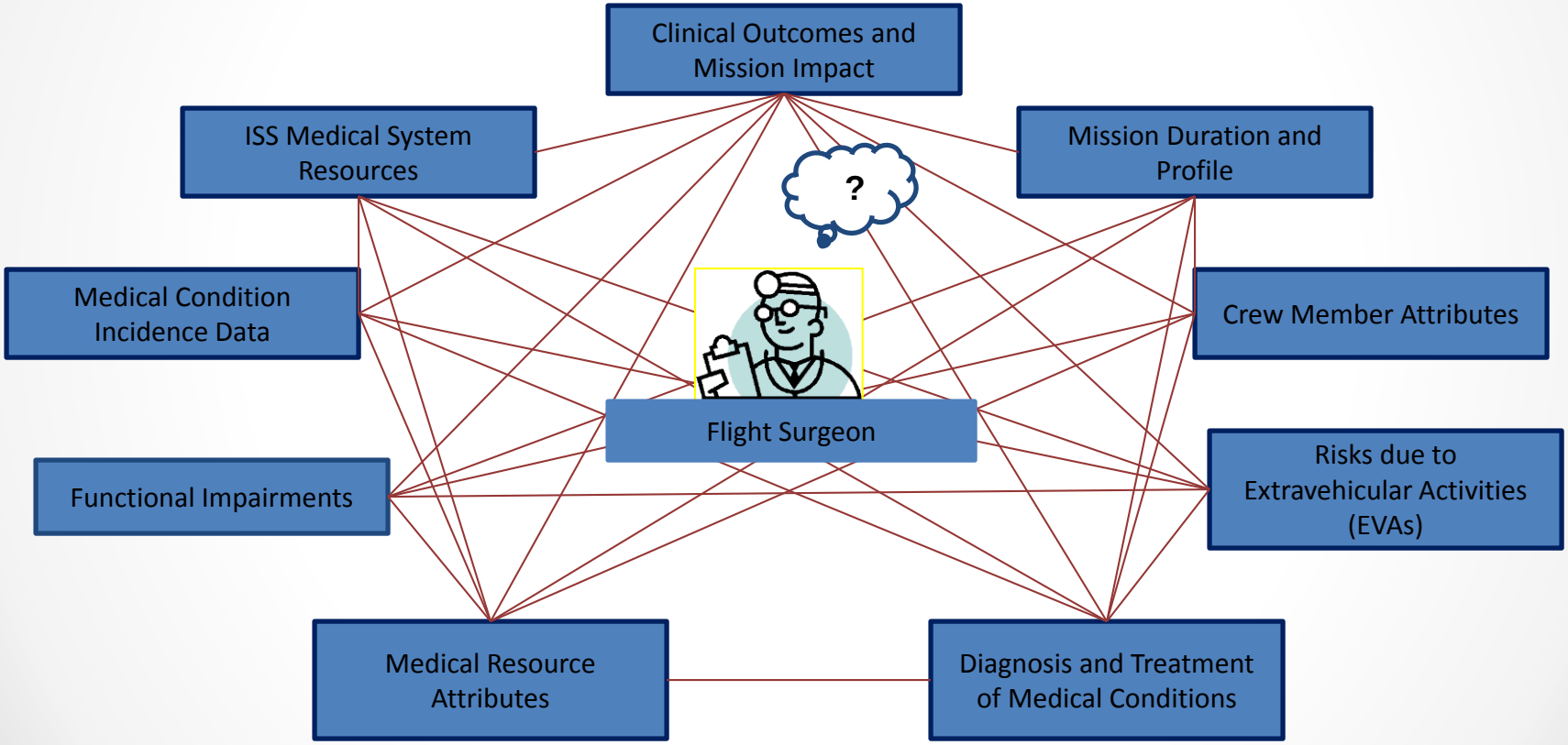
IMMUNE
- Allergic Reaction
- Anaphylaxis
- Skin Rash
- Medication Reaction

ENVIRONMENT
- Acute Radiation Syndrome
- Altitude Sickness
- Decompression Sickness (EVA)
- Headache (CO_2)

47 have occurred in spaceflight

Without IMM

What is the likelihood of a medical evacuation?	What is the risk of Loss of Crew Life due to illness on ISS?	What medical devices should we have on ISS?	What should be in the Exploration Medical Kit?



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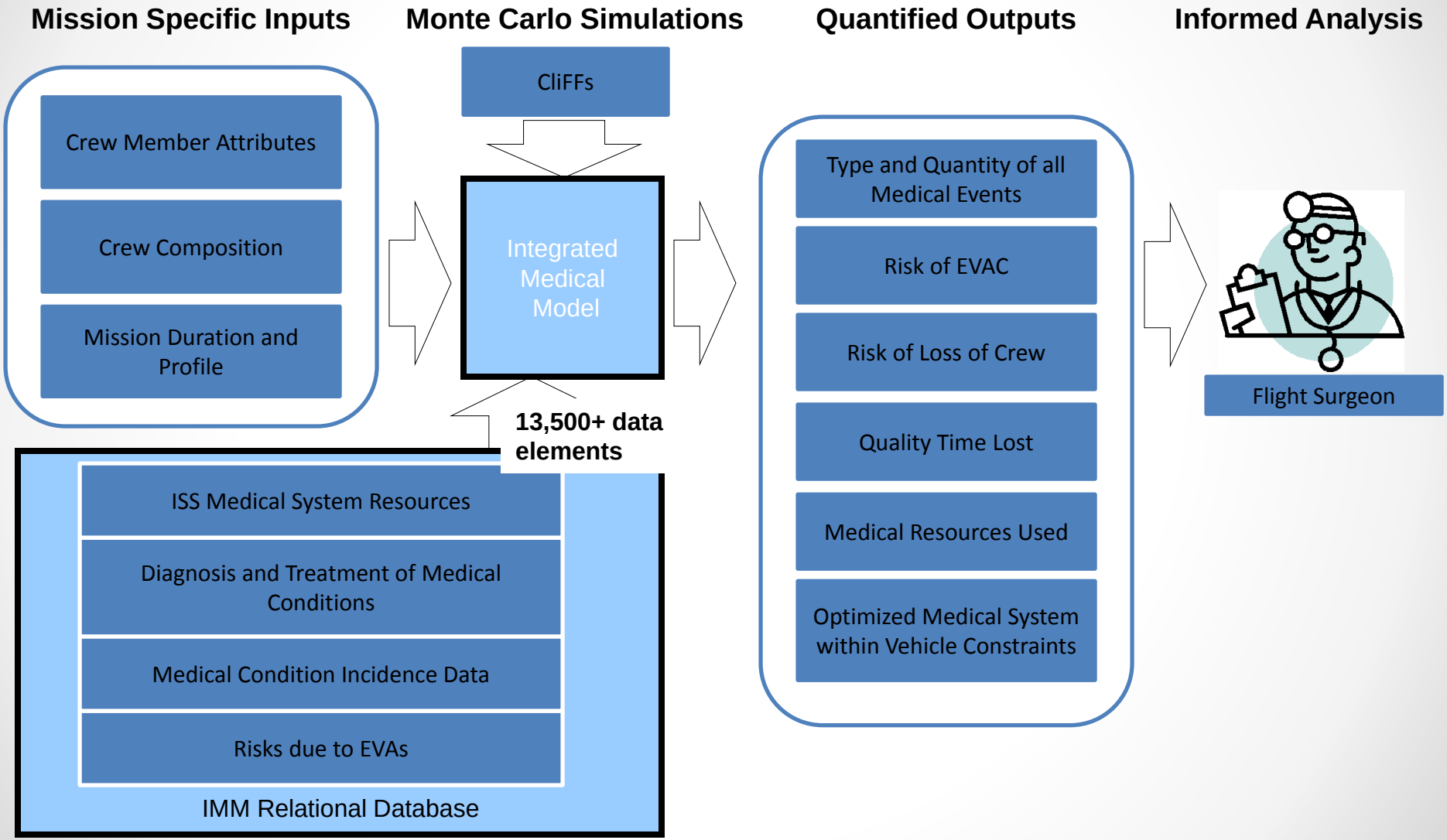
Provides a tool to help informed decision making



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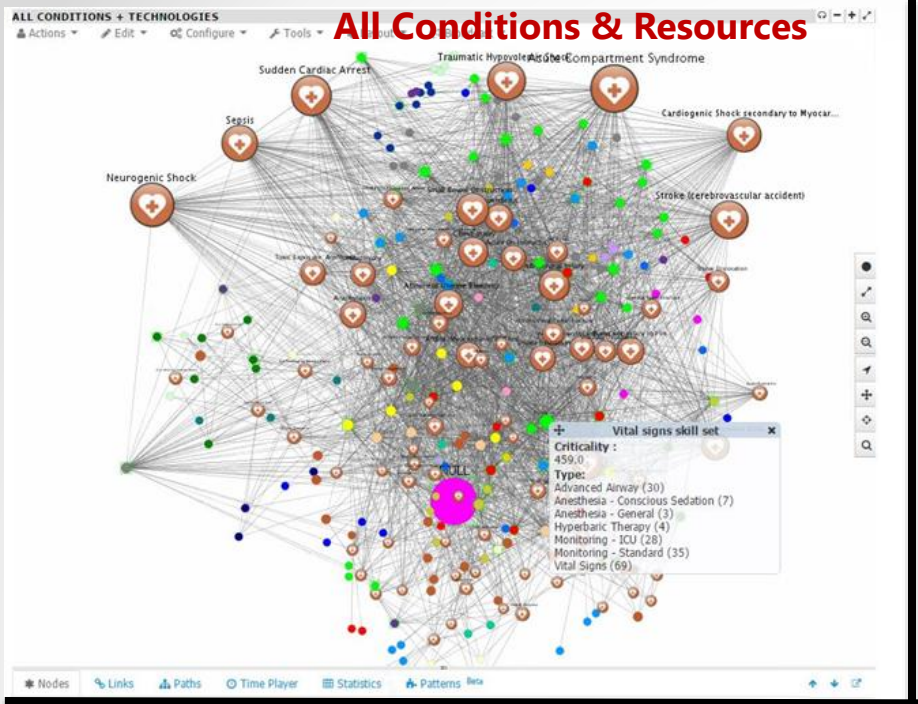
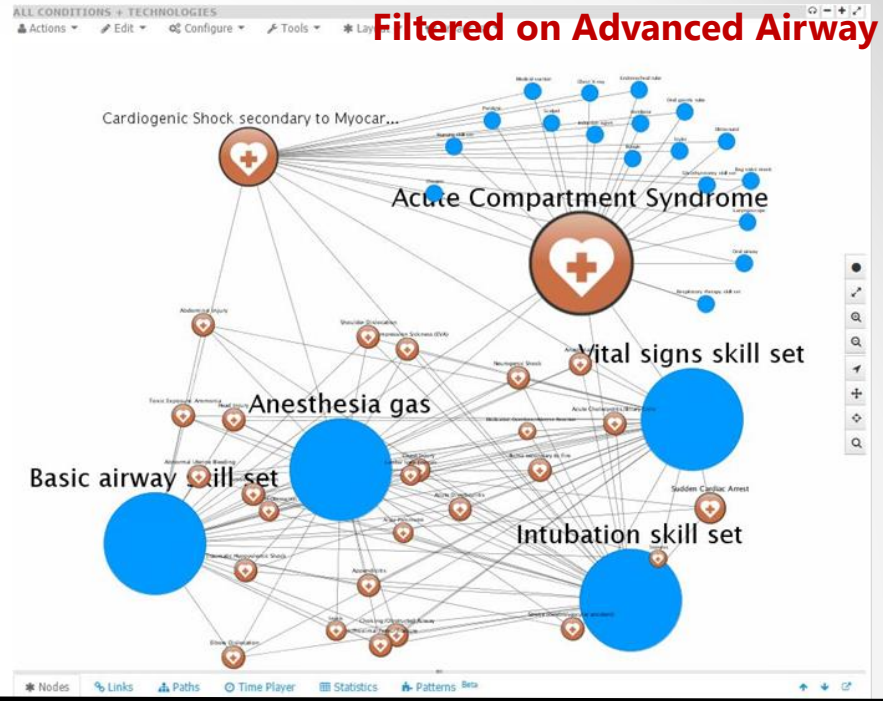
MONSTR

- MONSTR provides a way of quantifying a ‘Needs Analysis’
- Uses the same 100 conditions as IMM
- Identifies resources ‘desired’ for diagnosis and treatment (In an ideal world)
- Ranks those resources on:
  - Medical criticality and generalizability to multiple conditions
  - Incorporates Probability of Occurrence
  - Provides a ‘value’ estimate to help prioritize research investments

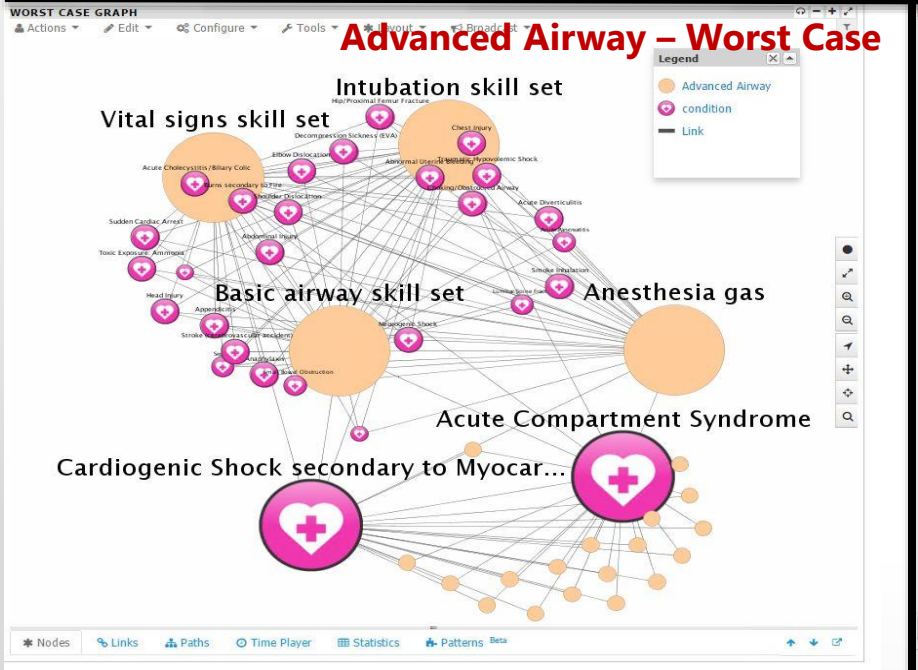
All Conditions & Resources



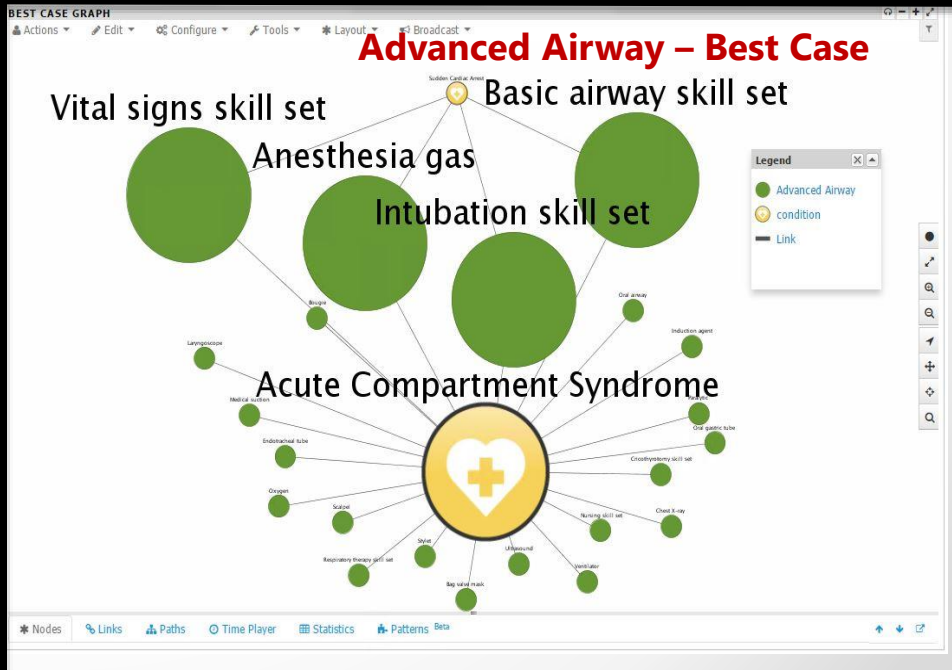
Filtered on Advanced Airway



Advanced Airway – Worst Case



Advanced Airway – Best Case



What's Next?

- Once you've characterized the medical risk and assessed what you need to address it, what is next?

Put those needs together in a system designed to maximize good outcomes and minimize medical errors.

MEDICAL DATA ARCHITECTURE

Active Risk Reduction

- A comprehensive medical system to support the crew in Exploration Missions targeting autonomy.

- In order to do this, ExMC will need integration with vehicle systems – single point solutions are not desirable for Exploration Missions.

- *Medical System*
  - *Provide for centralized medical care*
  - *Enhance available knowledge base*
  - *Provide for electronic training needs*
  - *Monitor supplies for crew*
  - *Monitor crew as needed*
  - *Streamline communication with ground flight surgeons*
  - *Decrease likelihood of medical errors*

Medical System Integrates with other needs

- Behavioral Health and Performance
  - Dashboard program
  - Actiwatch
  - Technology for monitoring and intervention needs to communicate with this system
- Human Health and Countermeasures
  - Exercise countermeasures and monitoring
  - Laboratory and analysis capability
  - These tools provide early warning for medical issues and crossover for rehabilitation needs
- Space Human Factors and Habitability
  - Training methods and procedures
  - Crew interface for the medical system
  - Medical Hab design
- Space Radiation
  - Radiation monitoring
  - Long-Term Health Effects
- Other Vehicle Systems
  - Environmental sensors (CO_2 levels, cabin temperature, etc.)
  - Vital signs monitoring via use of vehicle cameras
  - Medical system integrated with vehicle data, hardware and information systems

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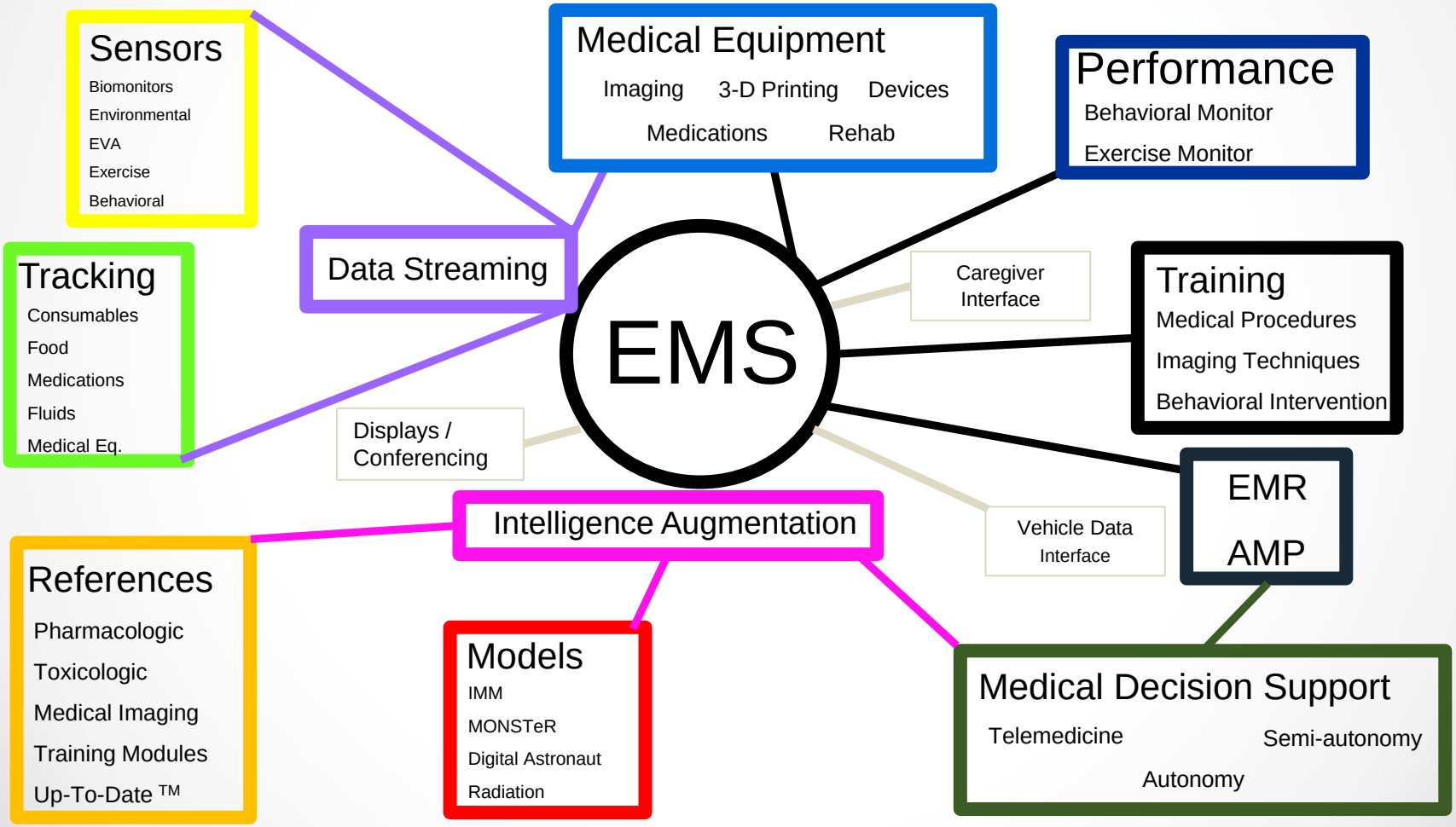
Medical System Capture Diagram



Data Architecture and Medical Data Analytics

- Data Architecture
  - Capture and collect from disparate data sources
  - Transform and integrate all data
  - Provide uniform access to data
  - Build analytics datamarts

- Analytics of patient health data
  - Monitor data
  - Process data and infer adverse health events
  - Aid crew medical officer in a broad range of diagnostic tasks
  - Enhance crew safety

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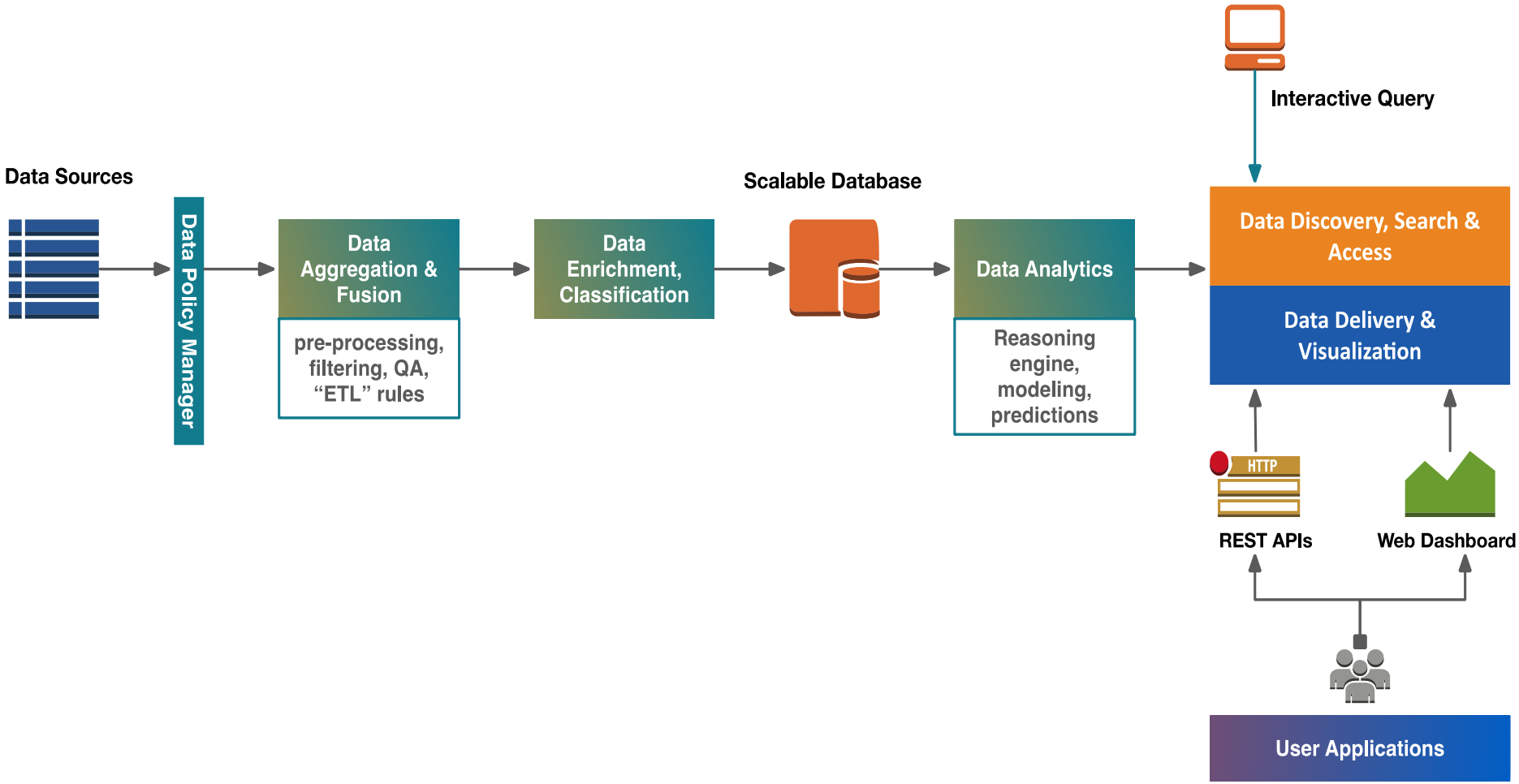
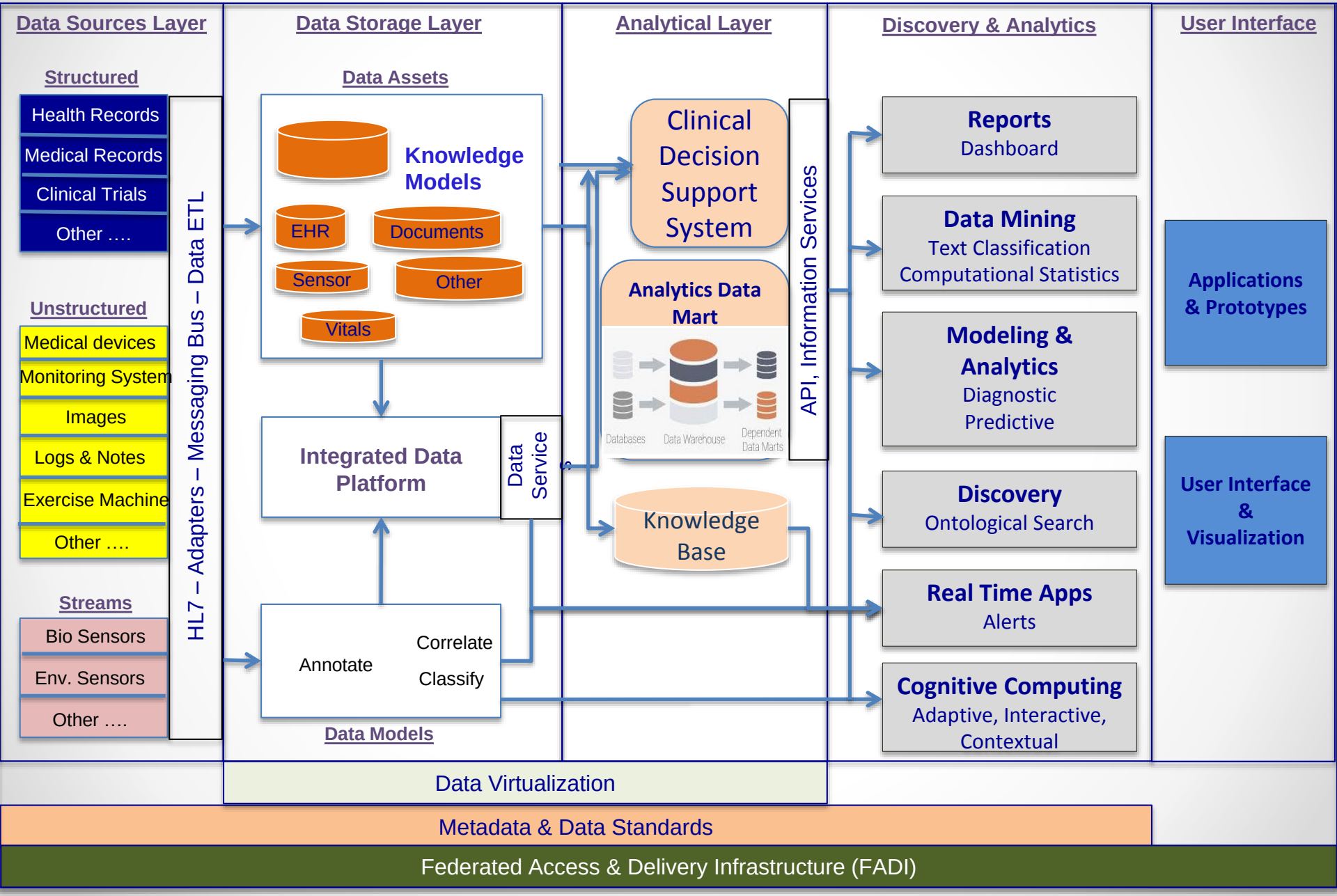
Data Transformation Model



ExMC Data Architecture



Medical Decision Support System (MDSS)

A knowledge system designed to use patient medical data and medical knowledge to generate case-specific assessment and recommendations to help medical staff make medical decisions

Collaborative effort with Canadian Space Agency

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Hybrid Approach for Implementation

- Knowledge based
  - Use of knowledge bases
  - Inference engine
  - Decisions based on rules
- Non-knowledge based
  - Machine learning
  - Neural Networks (ANN/CNN) and algorithms
  - Derive knowledge from patient data
  - Learn from decision trees

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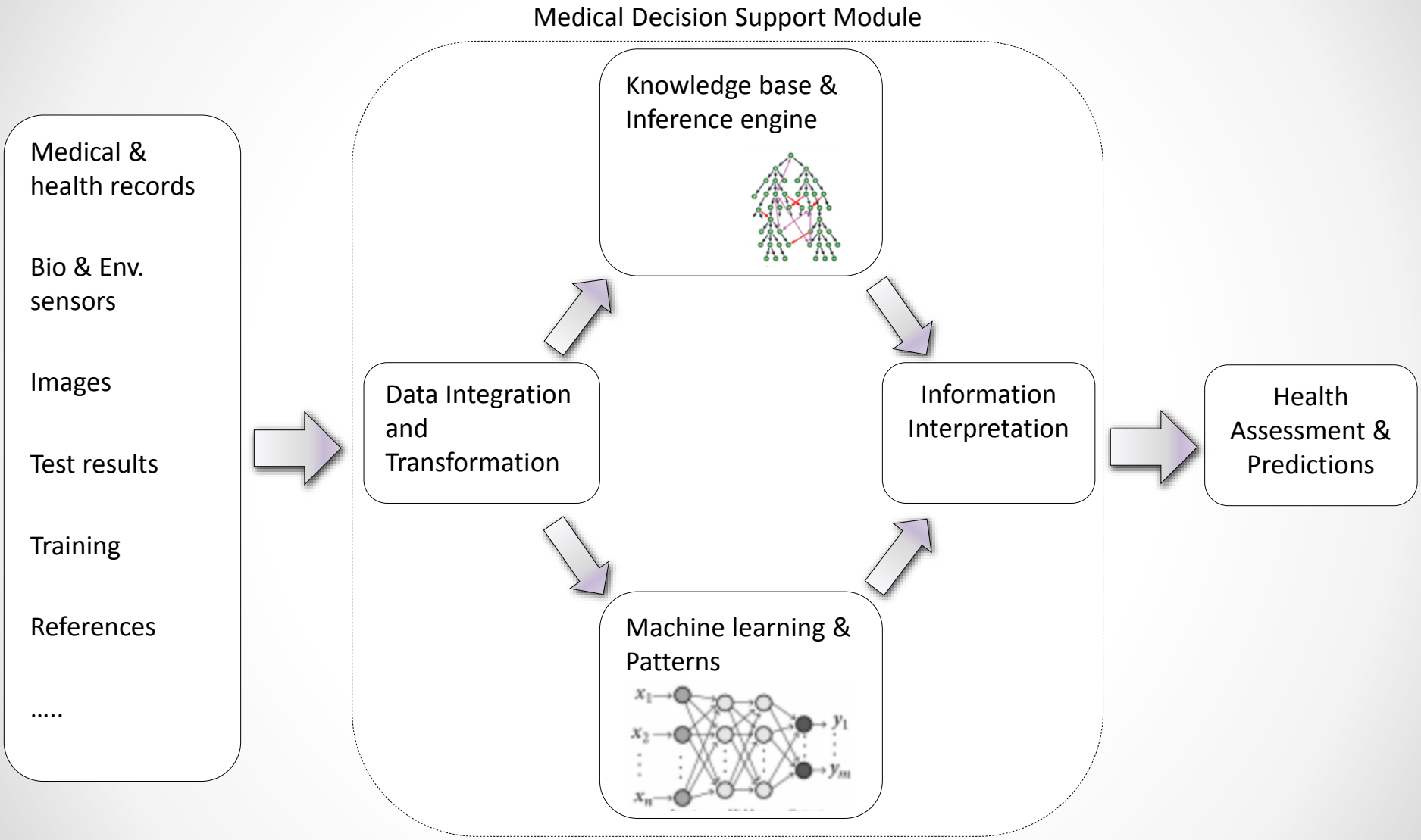
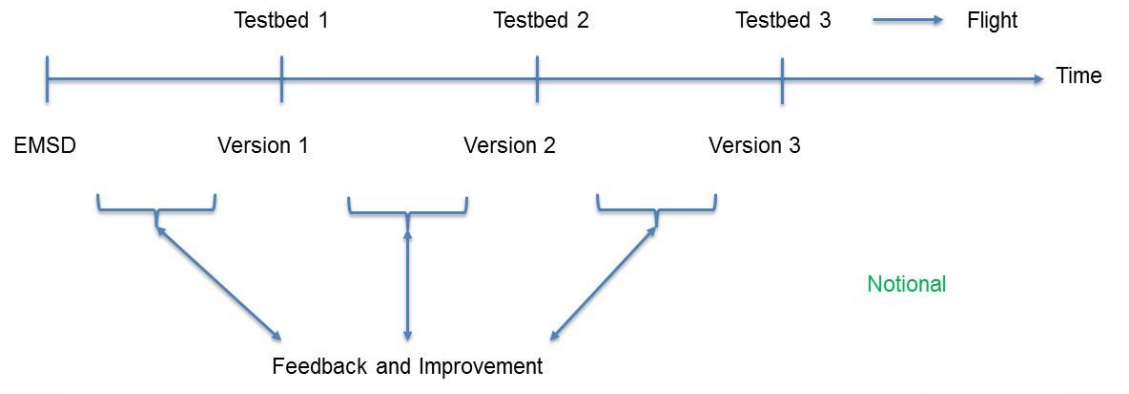
Medical Decision Support Module



Medical System Development

- Initial Focus is on Use Cases defined with the Clinical Team
- Later development is driven by the Concept of Operations
- An early testbed with a subset of systems is created from use cases
- An incremental and iterative testing pathway is created to build up the system



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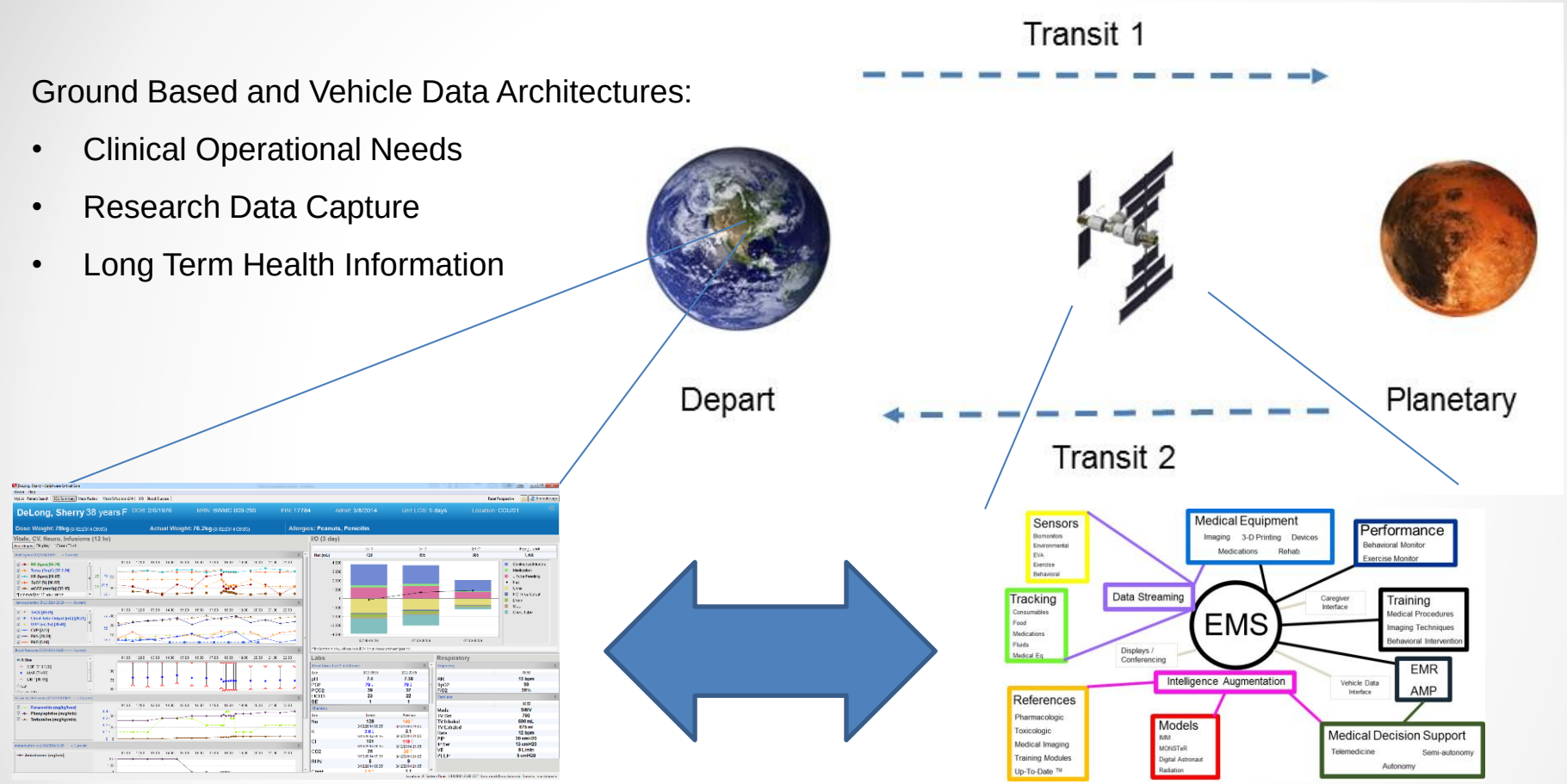
Medical Data Architecture

Ground Based and Vehicle Data Architectures:

- Clinical Operational Needs
- Research Data Capture
- Long Term Health Information



- Flight Surgeon/BME
- External Consults

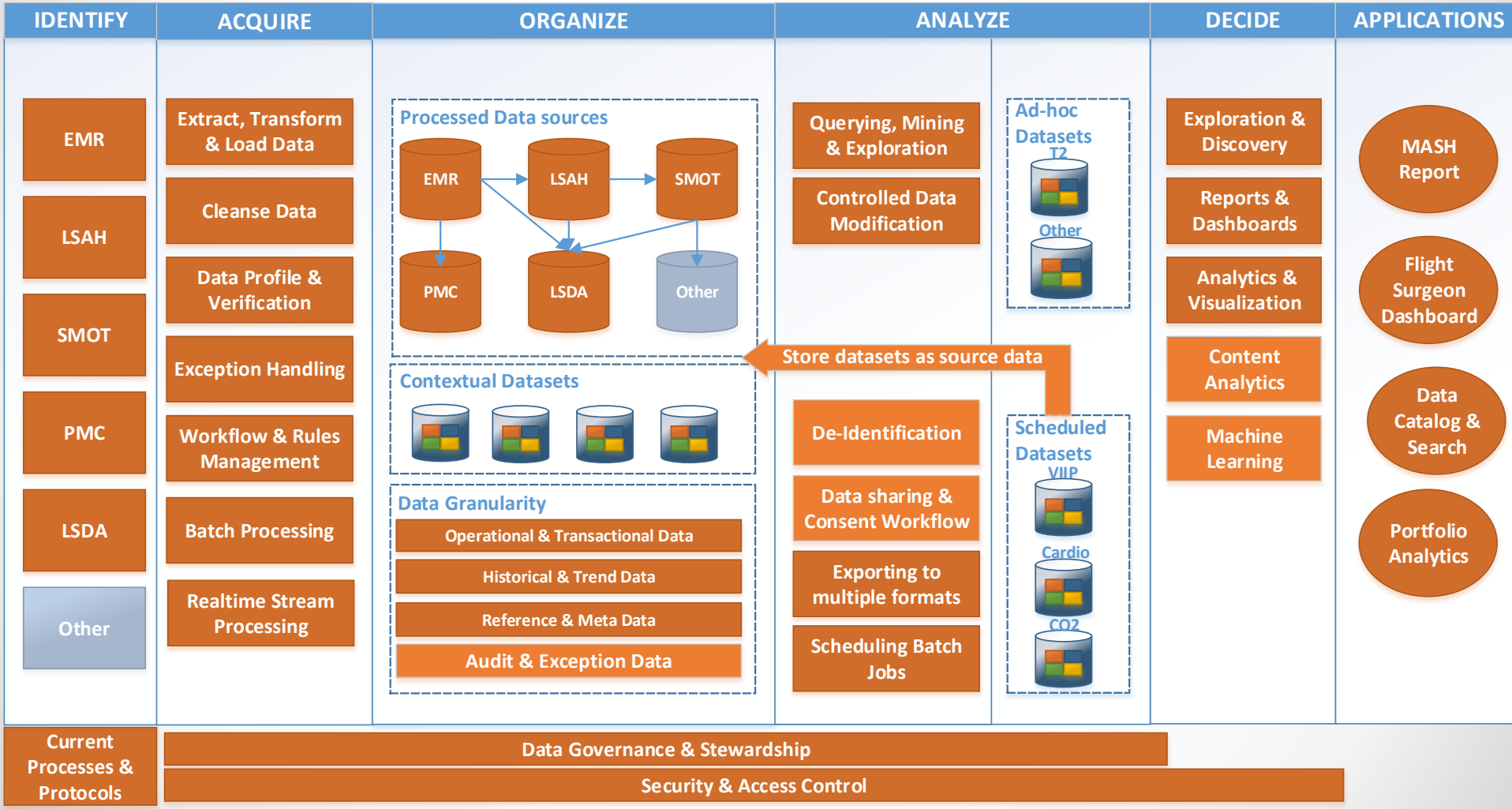
Mirrored Delayed Data Presentation for situational awareness/support

Vehicle Exploration Medical System

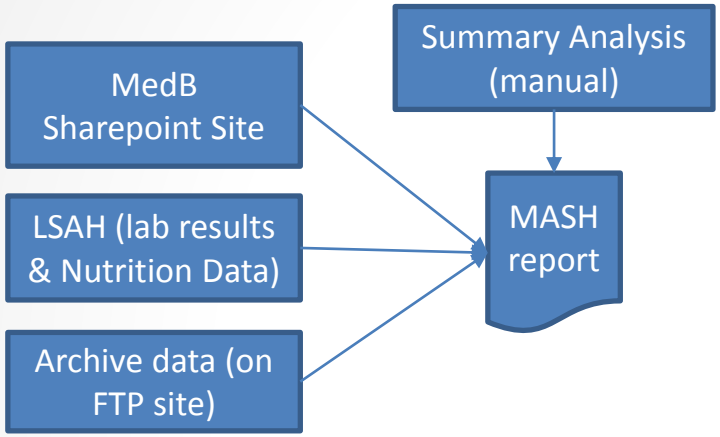
- Crew Medical Officer
- Crew Medical Support

Real-Time Data Processing for Crew

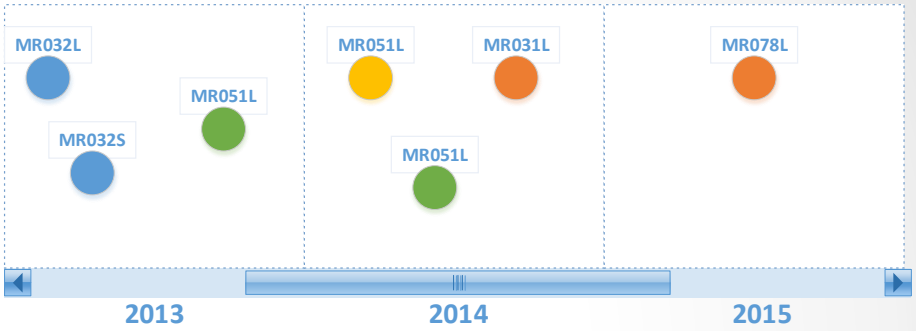
Ground-based Data Architecture



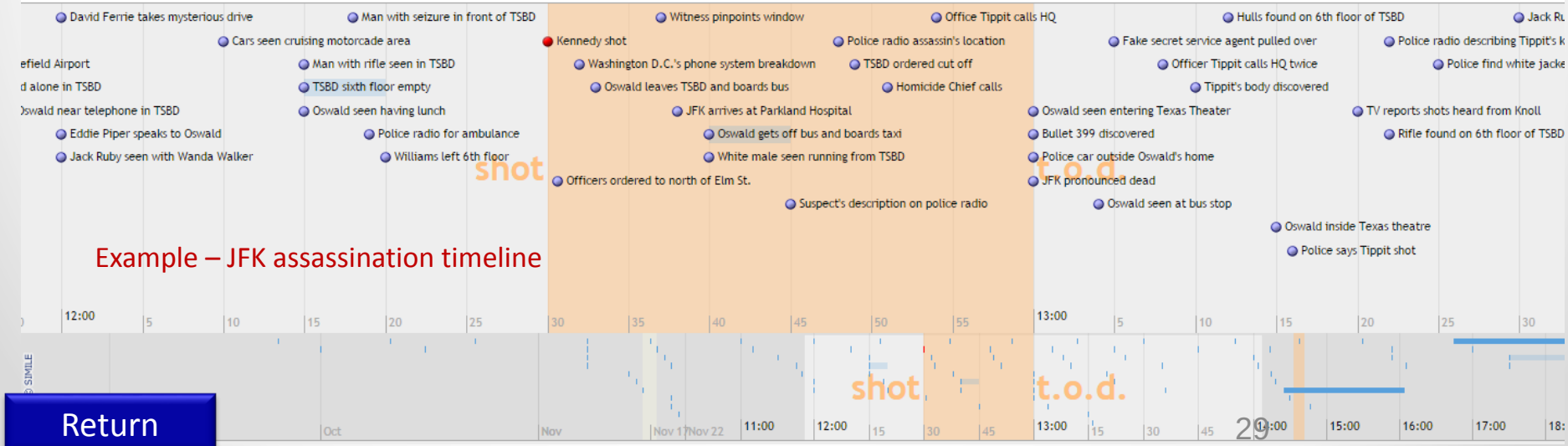
Sample Visualizations



MedB test timeline by Crew Member



Colors represent the type of test – Immunology, Env. Monitoring, EVA, Bone & Calcium Physiology



Return

Summary

- The ExMC research plan builds on what is known about medicine and physiology in spaceflight to
  - Characterize the likely medical risks
  - Identify medical needs to address those risks
  - Map out a medical system to optimize crew response to those risks
    - Medical Data Architecture
    - Medical Decision Support to Crews
    - Interface with Ground Data Architecture for clinical and research needs
  - Engage in a testing pathway to validate and improve that system

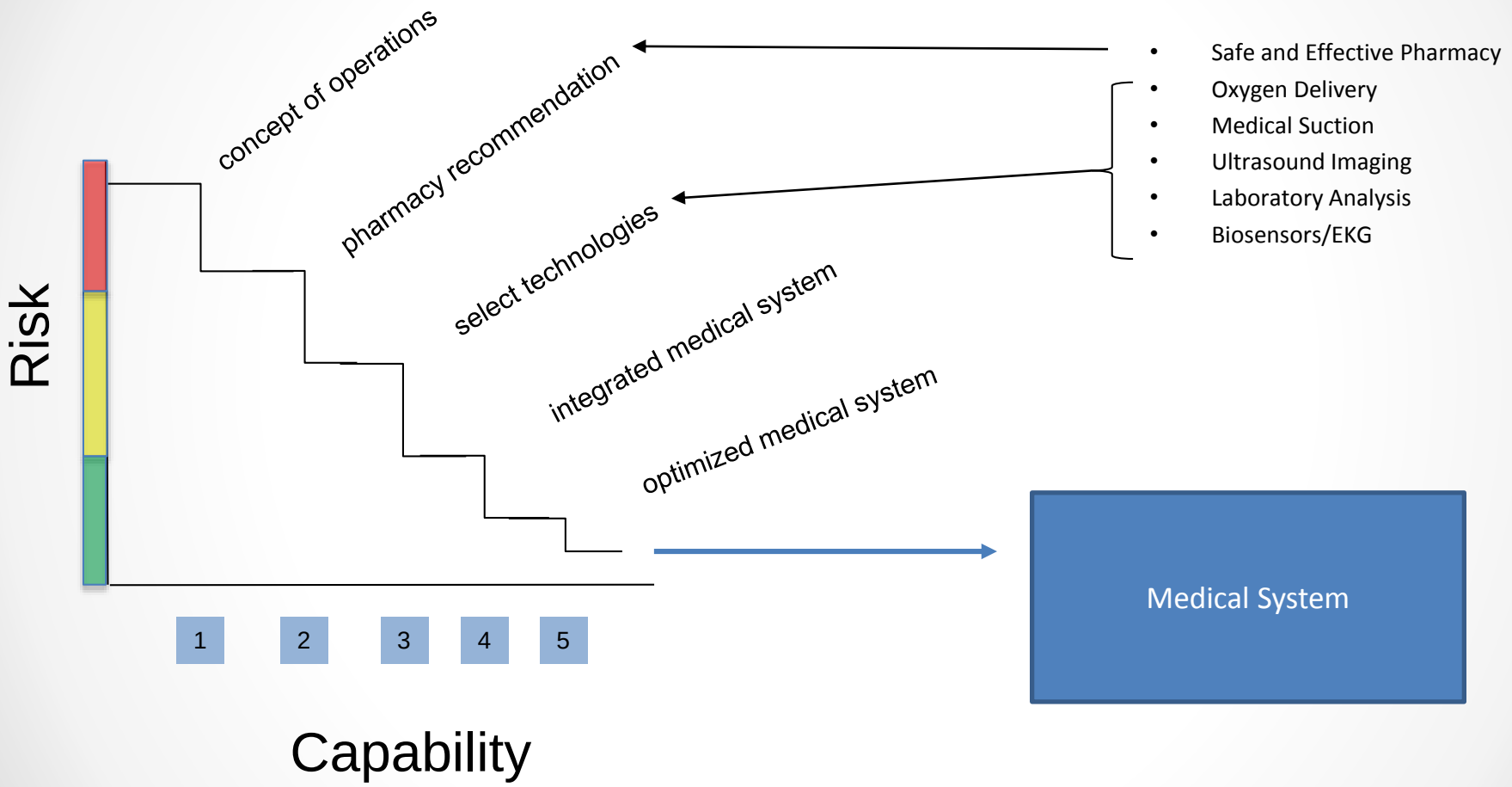
- This necessitates integration with vehicle design concepts early in the design cycle

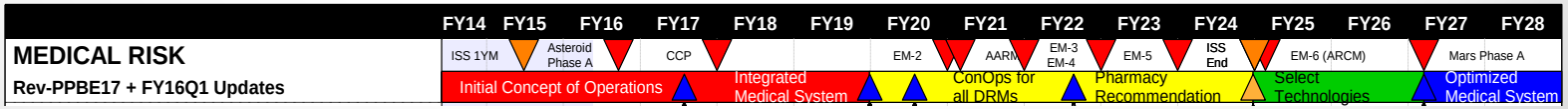
- It's all about the DATA and knowledge gleaned from data that enable good decisions

- Data Architecture and Data Management approaches are keys to Mission Success

BACKUP SLIDES

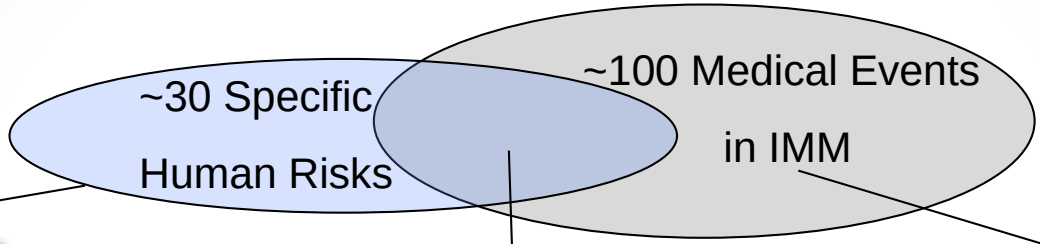
System Approach Reduces Medical Risk





Spaceflight Medical Events Risk

Top 100 In Mission Medical Events and 30 Specific Human Risks



- Aerobic Capacity
- Dynamic Loads (overlap)
- Electric Shock
- HSDI
- Immune (some overlap)
- Micro (some overlap)
- Muscle
- Nutrition/Food
- Neuro-vestibular
- Long Term Osteoporosis
- Medication Storage
- Orthostatic Intolerance
- Radiation (long term)
- Sunlight Exposure
- Team Cooperation

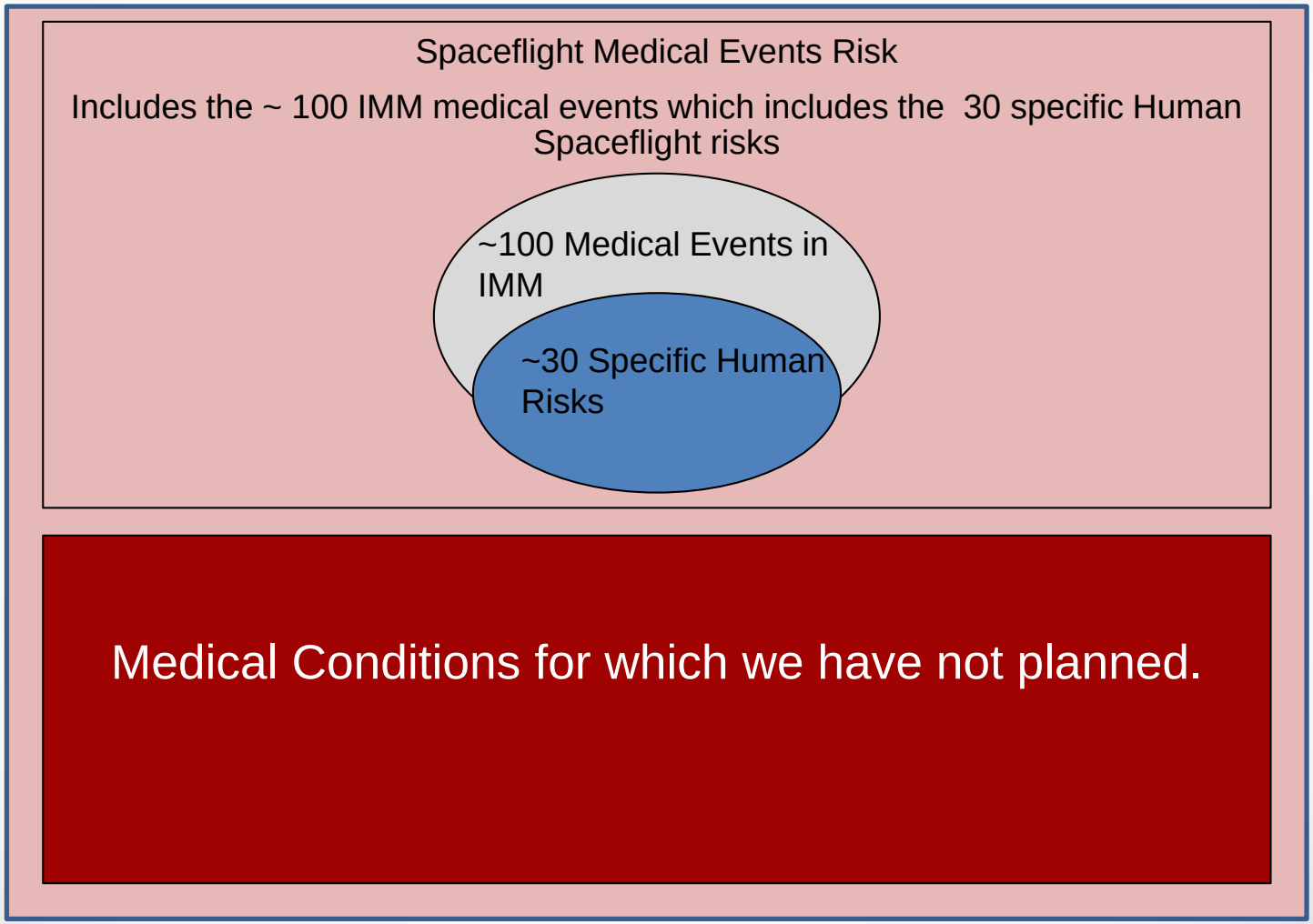
- Acute Radiation
- Altitude Sickness
- Cardio
  - Angina/ Myocardial Infarction
  - Atrial Fibrillation/ Flutter
  - Stroke
  - Sudden Cardiac Arrest
- Back Pain
- Behavioral/Depression
- Bone Fracture
- Carbon Dioxide (headache)
- Celestial Dust Exposure
- Decompression Sickness
- EVA Injuries
- Hearing Loss
- Renal Stones
- Sleep
- Specific Toxic Exposure
- Urinary Retention
- VIIP

- Abdominal Injury
- Abdominal Wall Hernia
- Abnormal Uterine Bleeding
- Appendicitis
- Acute Diverticulitis
- Anaphylaxis
- Eye Abrasions
- Dental
- Diverticulitis
- Gall Bladder
- Hernia
- Indigestion
- Med Overdose/Reaction
- Pancreatitis
- Sepsis
- ……
- …..

Spaceflight Medical Events Risk

This risk will integrate the likelihood and consequence of all human spaceflight risks for each DRM

Medical Risk

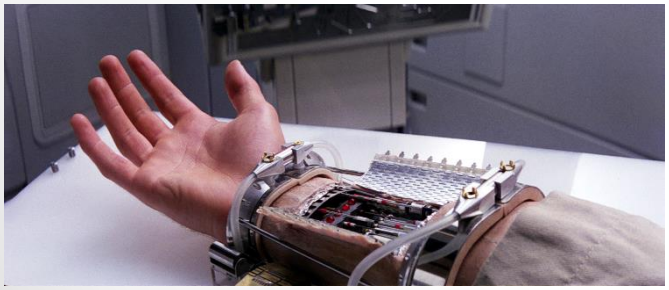


Risk Characterization

But what if it happens?

- Secondary Prevention
- Diagnosis
- Treatment
- Chronic Management
- Rehabilitation

Medical Capability



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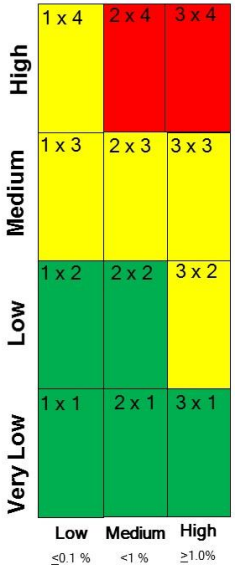

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For known risks:

How do we decrease this?

Keep it from happening?

- Selection
- Screening
- Primary Prevention
- Vehicle Design Standards
- Mission Architecture

Challenges

- Networked Complexity
- Communication
  - Centers
  - Elements
  - Outside HRP – SD, EA, HSRB, OCHMO and many others
- Increment and Iterate
  - Modified agile system development approach needed
  - Flexibility in approach
- Optimization pathway
  - The solution today is likely not the solution in 10 years
  - Flexibility in architecture
  - Standards definition and upgrades

How are resources ranked?

- Summed across all conditions

$$M_C = (1)\sum_{i=1}^{100} CR1_i + (2)\sum_{j=1}^{100} CR2_j + (3)\sum_{k=1}^{100} CR3_k$$

$$WM_C = (1)\sum_{i=1}^{100} (CR1_i)(p_i) + (2)\sum_{j=1}^{100} (CR2_j)(p_j) + (3)\sum_{k=1}^{100} (CR3_k)(p_k)$$

Mc = Aggregate Criticality Score

WMc = Weighted Aggregate Criticality Score

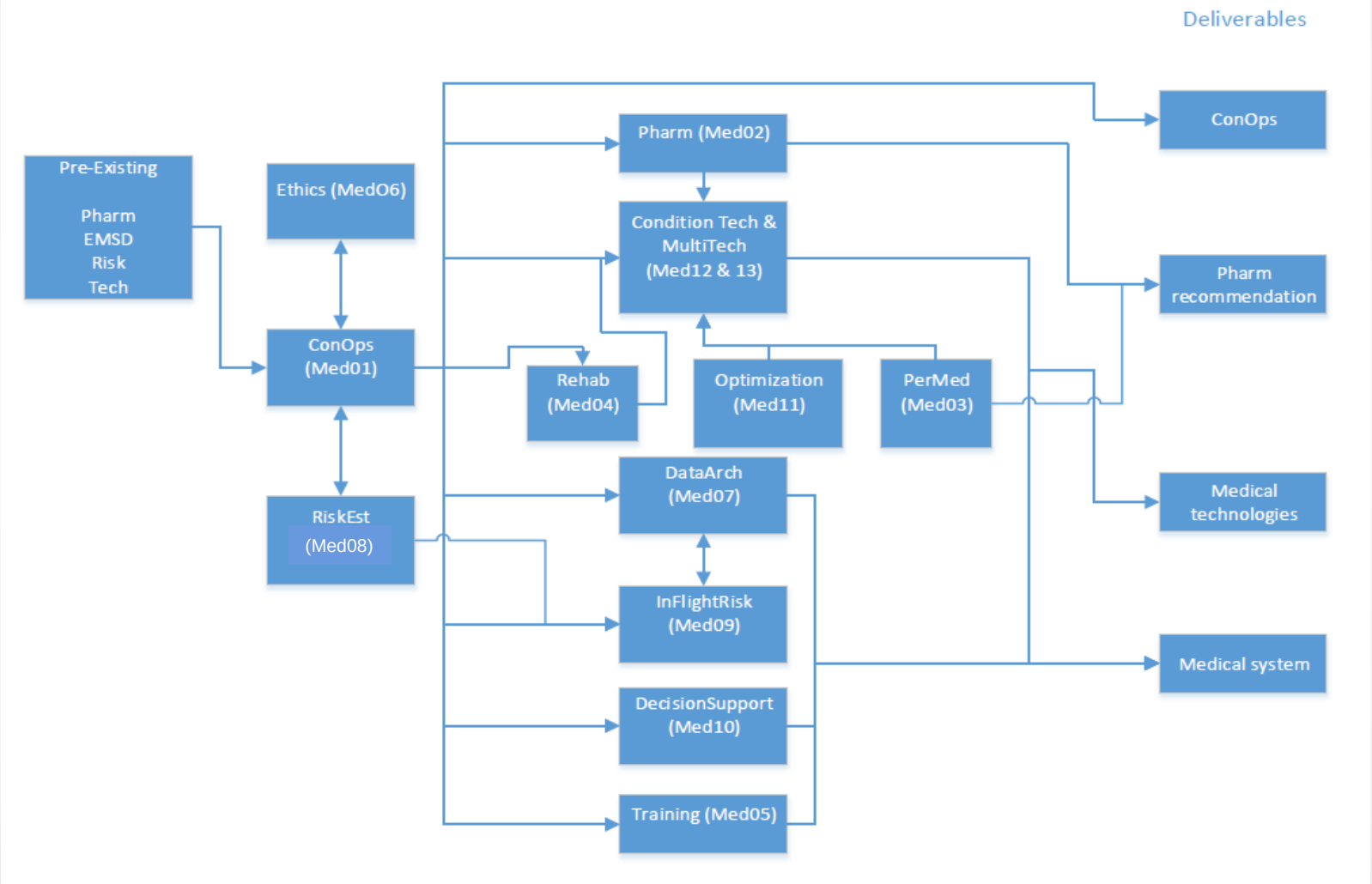
CR1 = Resource Criticality Score of 1

CR2 = Resource Criticality Score of 2

CR3 = Resource Criticality Score of 3

P = Probability of Occurrence

Gap Conceptual Flow



The Concept of Operations Drives System Design

Notional

Medical Risk

New Gaps

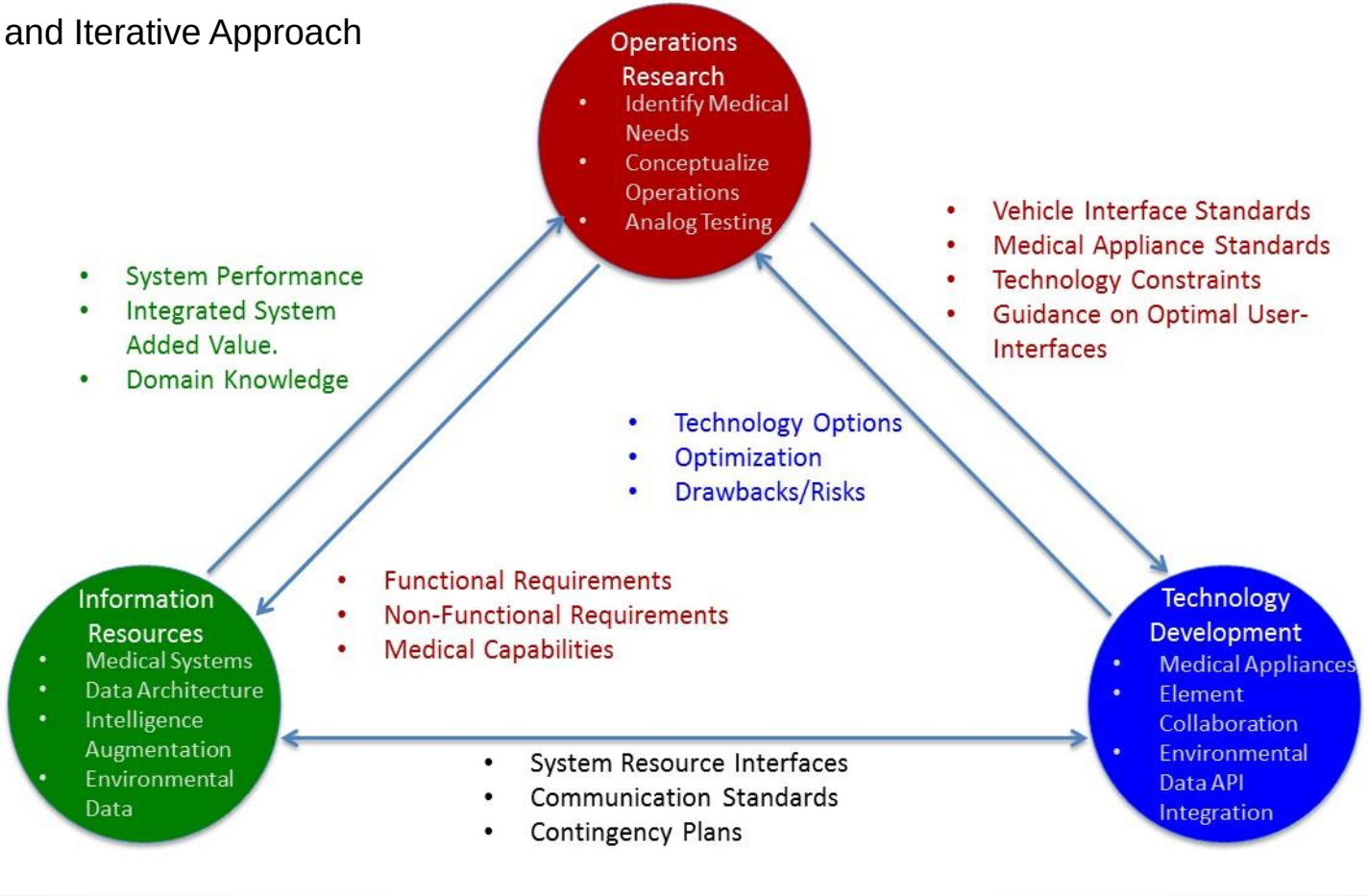
Med01	We do not have a concept of operations for medical care during exploration missions.
Med02	We do not have the capability to provide a safe and effective pharmacy for exploration missions.
Med03	We do not know how we are going to apply personalized medicine to reduce health risk for a selected crew.
Med04	We do not have a defined rehabilitation capability for injured or de-conditioned crew members during exploration missions.
Med05	We do not know how to train crew for medical decision making or to perform diagnostic and therapeutic medical procedures to enable extended mission or autonomous operations.
Med06	We do not know how to define medical planning or operational needs for ethical issues that may arise during exploration missions.
Med07	We do not have the capability to comprehensively process medically-relevant information to support medical operations during exploration missions.
Med08	We do not have quantified knowledge bases and modeling to estimate medical risk incurred on exploration missions.
Med09	We do not have the capability to predict estimated medical risk posture during exploration missions based on current crew health and resources.
Med10	We do not have the capability to provide computed medical decision support during exploration missions.
Med11	We do not have the capability to minimize medical system resource utilization during exploration missions.
Med12	We do not have the capability to mitigate select medical conditions
Med13	We do not have the capability to implement medical resources that enhance operational innovation for medical needs

How to decompose the work

Incremental and Iterative Approach

Pedigree:

DoDAF



Relationships between research divisions in the Exploration Medical Capability Element.

Background

- Exploration Medicine is unique:
  - **NO regular resupply of materials**
  - **NO real-time communications**
  - NO potential for **evacuation** if serious medical concerns arise.

- Medical care includes:
  - Screening
  - Prevention
  - Diagnostic capability
  - Treatment capability
  - Follow up care and Rehabilitation
  - Prognosis

- Characterize the likely medical risks
- Identify medical needs to address those risks
- Create a medical system to optimize crew response to those risks
- Engage in a testing pathway to validate and improve that system
- Work with vehicle engineers and flight surgeons to ensure useful implementation of that system

Exploration may require “Stay and Fight” Medicine, not “Retreat” Medicine.

ExMC Responsibilities

Risk Title: Risk of Adverse Health Outcomes & Decrements in Performance due to Inflight Medical Conditions

Description: Given that medical conditions will occur during human spaceflight missions, there is a possibility of adverse health outcomes and decrements in performance during these missions and for long term health.

Other ExMC Risks:

1. Risk of bone fracture due to spaceflight induced changes in bone.
2. Risk of ineffective or toxic medications due to long term storage.
3. Risk of renal stone formation.