The Journey to Mars

- Exploration Mission – 1
- Launch Complex 39B, Kennedy Space Center (KSC)
  - Space Launch System (SLS)
  - Orion
  - Ground Systems Development & Operations (GSDO)
Ground System Development & Operations (GSDO)

- **Evolvable Launch Architecture**
  - Space Launch System (SLS)

- **Upgrades and modifications across KSC**
  - Launch Complex 39B
  - Mobile Launcher
  - Vehicle Assembly Building
  - Umbilicals

- **Critical Design Review – October 2015**
Launch Probability

- GSDO requires safe and reliable ground systems
- Launch Probability is a key Technical Performance Measure
  - Applicable to SLS, Orion, and GSDO
  - Seeking no less than 90% for each launch attempt
- GSDO Launch Probability Requirements
  - Inherent Launch Availability
    - 98% for each launch attempt
    - @ 24 hours
  - Operational Availability
    - 80% between launch attempts
    - @ 360 hours or 14 days
Reliability, Maintainability, Availability (RMA)

- RMA team analyzes the integrity of hardware chosen for GSDO ground systems
  - Failure and Repair Data
    - Historical data from previous programs
    - Manufacturer
    - Subject Matter Expertise
    - Ancillary Handbooks
- RMA analysis verifies GSDO requirements
- Integral part of the design review process
- Critical reliability analysts interface directly with design and operations engineers
GSDO RMA Allocations

◆ Allocation is an iterative process

◆ Allocation Issues:
  ▪ Change in the number of subsystems under analysis
  ▪ Increase in the number of components per subsystem
  ▪ Original allocations derived from preliminary designs
    ▪ Eighteen subsystems were not meeting requirements

◆ Literature suggests reallocation
  ▪ Models that include both reliability and maintainability parameters absent from the literature
  ▪ Maintainability allocation methods not applicable to GSDO
Methodology

Software

- PTC Windchill Quality Solutions
- Reliability Prediction and Reliability Block Diagrams (RBD) modules
- Assumes exponential distribution for failure and repair rates
- MIL-HDBK-217F Parts Count Calculation Model
- Monte-Carlo Simulations at 1,000,000 iterations
Methodology

◆ Reliability
  ▪ The probability that a system (or component) will fail at or after a predetermined time \( t \)
  ▪ Failures rate sources
    ▪ Manufacturer
    ▪ Historical Data
    ▪ Ancillary handbooks – Non-electronic Parts Reliability Database (NPRD) 2016, Electronic Parts Reliability Database (EPRD) 2014
  ▪ Mean Time Between Failures (MTBF)
    \[
    R(t) = e^{-\lambda t}, \text{ where } \lambda = \frac{1}{MTBF}, \ t = 24 \text{ hours}
    \]
    ▪ \( \lambda \) is the subsystem or component failure rate
**Methodology**

**Maintainability**

- The ability of a subsystem to be restored or repaired to an operational state within a given time period
- Values are estimated using subject matter experts (i.e., operations engineers)
- Mean Time to Repair (MTTR)
  - Corrective Maintenance

\[ M(t) = 1 - e^{-\mu t} \]
\[ \mu = \frac{1}{MTTR} \]
\[ \mu \text{ is the constant repair rate} \]
\[ MTTR_{SS} = \frac{\sum (\lambda_i \cdot MTTR_i)}{\sum \lambda_i} \]
Availability

- Function of reliability and maintainability
- The probability that a repairable subsystem will operate satisfactorily at a given point in time during the period of analysis
- Point Availability analysis
  - Excludes logistic and administrative delays

\[ A(t) = \frac{\mu}{\lambda+\mu} + \frac{\lambda}{\lambda+\mu} e^{-(\lambda+\mu)t} \]
◆ Reallocations were based on changes to the launch architecture
◆ Initial Allocations did not reflect current designs
◆ Verify analysis is correct for current designs
Recommendations

Consider reallocation for:

- Any increase in the number of components without a change in the design strategy (e.g., added redundancy, quality of hardware)
- Subsystems that contain a mix of upgraded and legacy components with historically high failure rates and considered single points of failure
- Significant changes to the launch architecture
GSDO is creating a robust ground systems architecture

GSDO requirements incorporate safety and reliability for successful launch activities

RMA Analysts interface directly with and provide recommendations to design teams to ensure verification of requirements

- Continuously perform RMA analyses through subsystem verification and validation
Reallocations - Reliability

- $R(t) = e^{-\lambda t}$
- $\lambda = \frac{1}{MTBF}$
- $t = 24$ hours
- $R_{GSDO} = \prod_{i=1}^{n} R_i(t) = R_1 * R_2 * \cdots R_n$
- Reliability is a lower-bound measure
- Cause for reallocation
  - Change in the launch architecture
    - Number of subsystems & components
Reallocations - Maintainability

- $M(t) = 1 - e^{-\mu t}$
- $\mu = \frac{1}{MTTR}$
- $t = 24$ hours
- $MTTR_{GSDO} = \frac{\Sigma(\lambda_{SS} \times MTTR_{SS})}{\Sigma \lambda_{SS}}$
- Maintainability is an upper-bound measure
- Cause for reallocation
  - Adjustment factor not applicable for all subsystems
Reallocations - Availability

\[ A(t) = \frac{\mu}{\lambda + \mu} + \frac{\lambda}{\lambda + \mu} e^{-\left(\lambda + \mu\right)t} \]

\[ \lambda = \frac{1}{MTBF} \]

\[ \mu = \frac{1}{MTTR} \]

\[ t = 24 \text{ hours} \]

 Availability is a lower-bound measure

 Increase in Availability Estimates
  - Reallocations of reliability and maintainability
  - Change in the number of subsystems under analysis