System of Systems Operational Availability Modeling

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Overview

- Background and definition of System of Systems (SoS) Operational Availability (A_o)
- A_o calculations
  - System and SoS A_o calculation and interpretation challenges
  - Requires defined mission durations/operations
    - Fixed vs. variable mission durations
      - Variable mission durations arise from required operating hours to complete missions
- Example SoS A_o simulation results
  - A_o for individual systems as part of a SoS
  - Lower and higher reliability cases
  - Variable mission durations for fixed operating hours

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Background

- A_o is a Department of Defense (DoD) required Key Performance Parameter (KPP) for acquisition programs
  - Represents the operational capability being provided/purchased
- A_o can have different definitions and is evaluated for defined mission durations, utilizations, degraded states, and sustainment CONOPs
  - Makes assessments and comparisons difficult
  - Leads to misunderstandings and misinterpretations
- A_o for a SoS has additional complexities

A_o Definitions

- Well-understood, high-level A_o definition

$$A_o = \frac{Uptime}{Uptime + Downtime}$$

$$= \frac{Total\ Time - Downtime}{Total\ Time}$$

$$= \frac{Operating\ Time + Operable\ Time}{Operating\ Time + Operable\ Time + Downtime}$$

  - Operable time (or standby time) usually defined as part of A_o

- Common equation estimator of A_o

$$A_o = \frac{MTBF}{MTBF + MDT}$$

where MTBF is Mean Time Between Failures and MDT is Mean Downtime

  - Static, steady-state estimation of A_o
  - Can be misapplied
  - MTBF can be scaled by utilization for intermittent use systems
  - MDT has to be calculated for the specific mission duration

System A_o

- A_o is calculated, estimated, and modeled for
  - A specifically defined collection of ***hardware***
  - Performing specifically defined ***operations***
  - Over a specifically defined ***timeframe***
  - With specifically defined ***reliability*** and ***maintainability*** operational performance characteristics, and
  - Specifically defined ***sustainment*** assumptions
- Any reported A_o reflects and depends upon all the above assumptions
  - Changes to any one of these definitions changes A_o
- Comparison of A_o to requirements, other system A_os, or across tradeoffs requires "synching up" above definitions to make comparisons valid
- Definitions and assumptions must be addressed for each intended use of A_o models
  - Assessing current performance
  - Comparison to KPP requirements
  - Prediction of test results
  - Determining sparing strategies

System of Systems

- SoS definition
  - A SoS is comprised of a set of systems, each performing a defined task or mission, in which at least one system can be dependent on one or more other systems
    - SoS level performance is emerging and cannot be assessed by assessing individual system performances separately, except for the case where the systems operate (and are maintained) independently of each other
    - System dependencies can be of varying complexity
      - Required sequential or parallel system tasks
      - System functional redundancies
      - R of N systems operating
      - Combinations of these
- SoS becoming more common
  - More autonomous systems functioning with other systems
  - Increased network-centric functionality
  - Effectiveness and requirements established for increased system synergies accomplishing increasingly complex missions

SoS A_o

- System A_o concepts are relevant to SoS A_o, but SoS adds complexity
- SoS A_o
  - Defined as percentage of mission time the SoS is “up” (operating or operable), over a specified time interval involving defined dependent system operations
  - Dependency of systems implies that individual system(s) can be operable while another system is down
    - Produces increased A_o for individual systems within the SoS (not the same system A_o as the systems operating independently)
  - Functional interdependencies and complex interrelated sustainment operations must be accounted for in system and SoS downtimes
    - Adds additional complexity
  - Further complicated by intermittently used systems whose utilizations are considerably less than 100% over the mission duration
  - Requires more specification of the SoS systems, boundaries, and missions
- Simulation modeling is usually required to capture complex operating, operable, and downtime hours and to accurately roll up individual system availabilities to higher SoS levels

SoS A_o for Independent Systems in a SoS

- If all systems in the SoS are operated and maintained independently, the SoS A_o is equal to the product of the individual system A_os

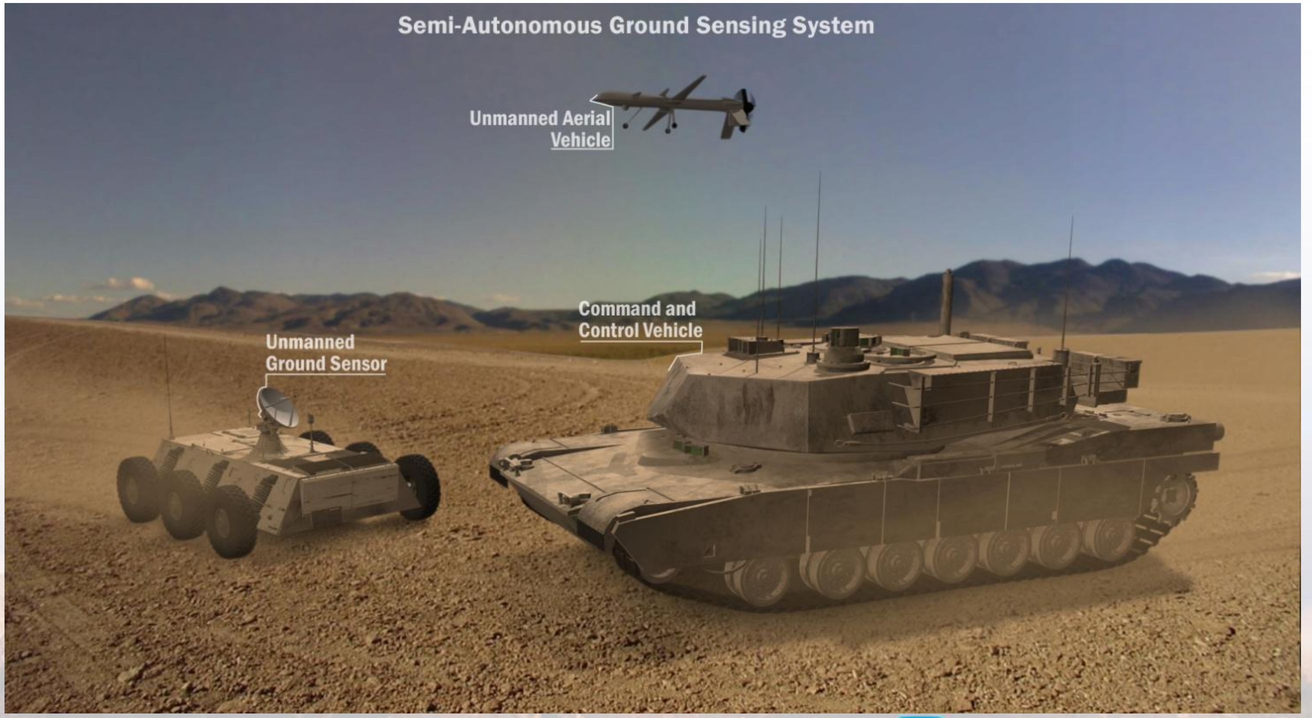
$$SoS\ A_o = \prod_{i=1}^{n} A_{o_i}$$

where A_{o_i} is the i^{th} independent system A_o

  - All systems are required for the mission
  - Means that failure of one system does not impact the status of the other system(s)
  - This SoS A_o represents the percent of mission time that all systems are available (operating or operable)
- Equation sometimes misunderstood as pertaining to all SoS A_o calculations, even with dependent systems

Example SoS

- Semi-Autonomous Ground Sensing System (SAGSS) is a notional SoS to perform an IED detection mission
- SAGSS is comprised of multiple systems executing a particular mission
- Systems within the SAGSS SoS
  - Unmanned Ground Sensor (UGS) System
  - Unmanned Aerial Vehicle (UAV)
  - Command & Control Vehicle (C2V)
  - Transport Vehicle (TV)



SAGSS Problem

- Need to understand SoS-level availability drivers
  - Support and sparing strategies/CONOPs
- Complex SoS
  - Once transported, UGS and UAV are required to operate concurrently to perform detection
    - If UAV fails during the mission, UGS becomes operable, and vice versa, but SAGSS SoS is in a failed state (down or inoperable)
  - TV only required for parts of the mission
  - C2V required during all required operational hours
  - Based on coverage rates, must perform a fixed number of hours of detection
    - Total mission duration is variable
    - Variable downtime is added to fixed operating time
- SoS A_o accounts for dependent system utilizations

SoS A_o Simulation

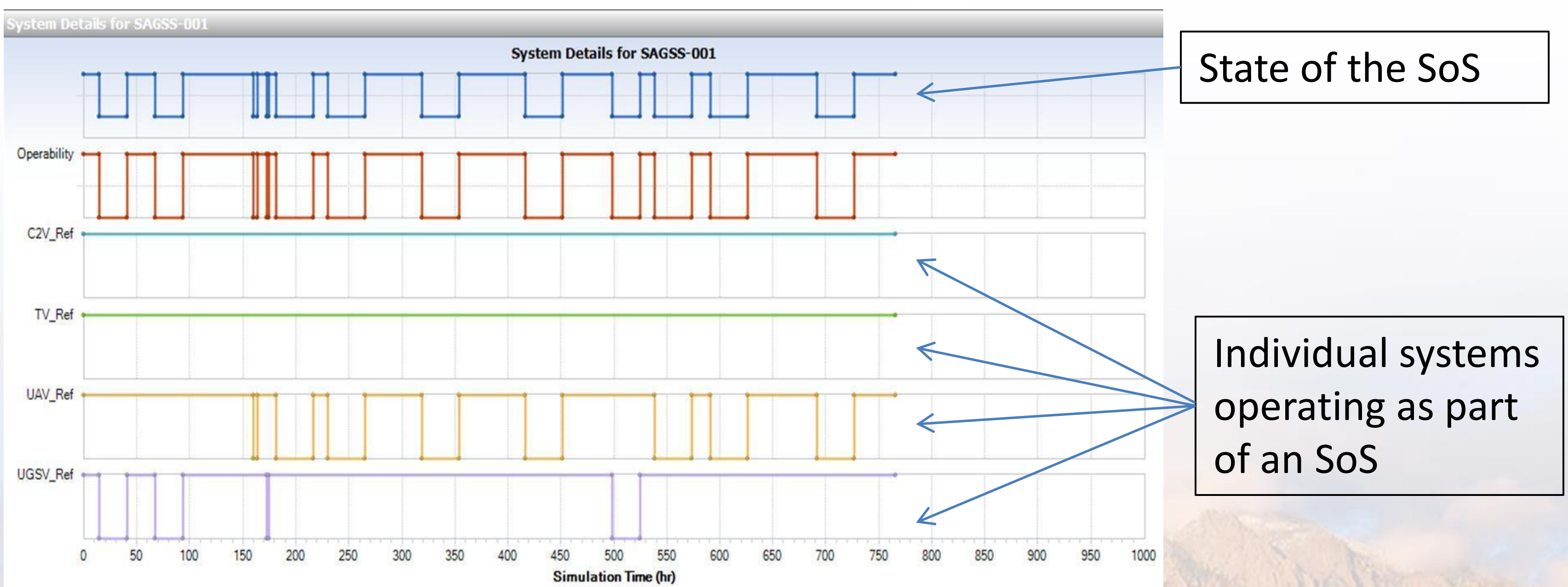
- SoS A_o for dependent systems and the individual system A_os within the SoS cannot usually be calculated without simulation
- Use Systems of Systems Analysis Toolset (SoSAT) to analyze SoS A_o
  - Stochastic simulation of system mission and sustainment operations
  - Variability in input parameters
  - Developed by Sandia for several Army programs
  - Developed specifically to address and scale to complex SoS problems
  - Can model thousands of systems, each represented by thousands of subsystems/components
  - Currently being applied for U.S. Army, Navy, Air Force, and Marines programs

SoS A_o Simulation Calculations

- Simulation keeps track of defined SoS uptime and downtime to calculate SoS A_o as

$$A_0 = \frac{Uptime}{Uptime + Downtime}$$

- Simulation allows for complex mission and system definitions and dependencies
- Single trial exhibit of SoS and system states (“up” or “down”) over a mission segment



Notional SAGSS SoS A_o Simulation Cases

- Individual system reliabilities will impact not only SoS A_o but also the individual system A_os within the SoS
- Impacts higher for lower reliability
  - Impacts of lower individual system reliability on SoS A_o and individual system A_os greater than for higher reliability
  - A_o asymptotes as reliability increases
- Notional SAGSS SoS example analyzed for
  - Lower reliability case
  - Higher reliability case

Summary of Notional SAGSS SoS A_o Results

Lower Reliability Case

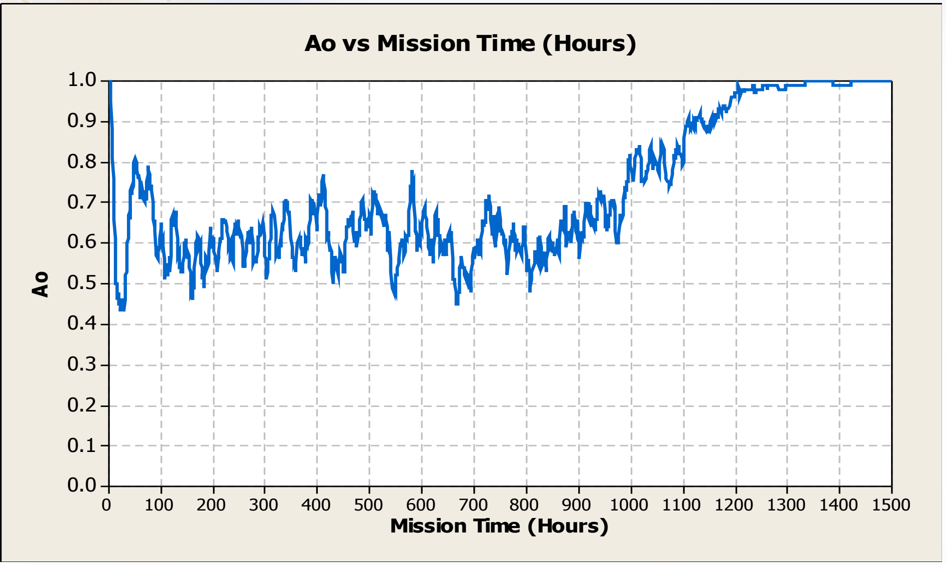
System	MTBF (Hours)	Average Number of Failures per Mission *	Mean Downtime per Failure (Hours)	Mean Downtime per Mission * (Hours)	Percent Total SAGSS Downtime	Average A_o
SAGSS SoS	**-**	**18.8**	**22.0**	**413.0**	**100%**	**0.618**
UAV	*50*	*10.3*	*28.0*	*287.6*	*69.6%*	*0.734*
UGSV	*100*	*4.7*	*25.5*	*120.6*	*29.2%*	*0.888*
C2V	*150*	*3.8*	*1.3*	*4.8*	*1.2%*	*0.995*
TV	*10,000*	*0.0*	*35.0 (none observed)*	*0.0*	*0.0%*	*1.000*

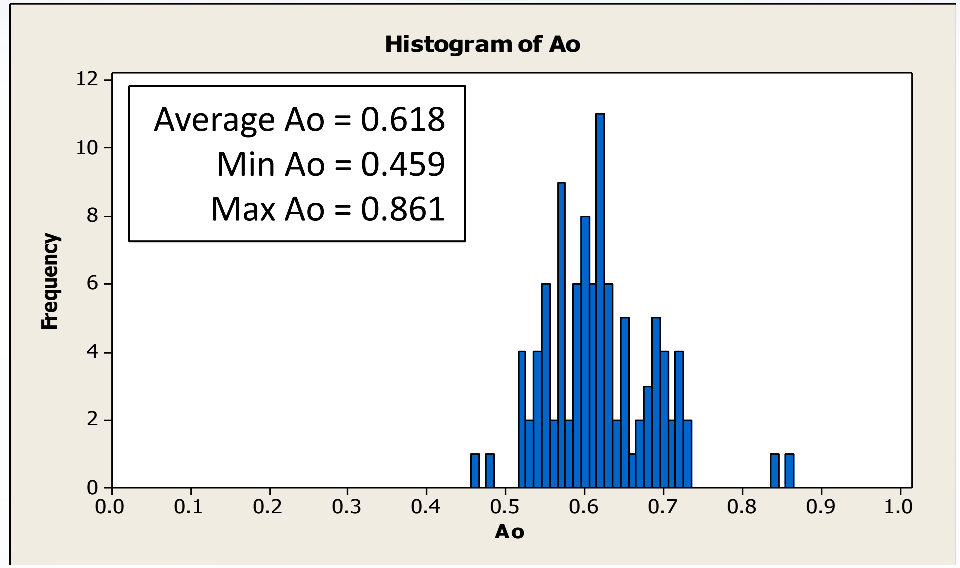
** Mission = Completed 500 hours of remote sensor time*

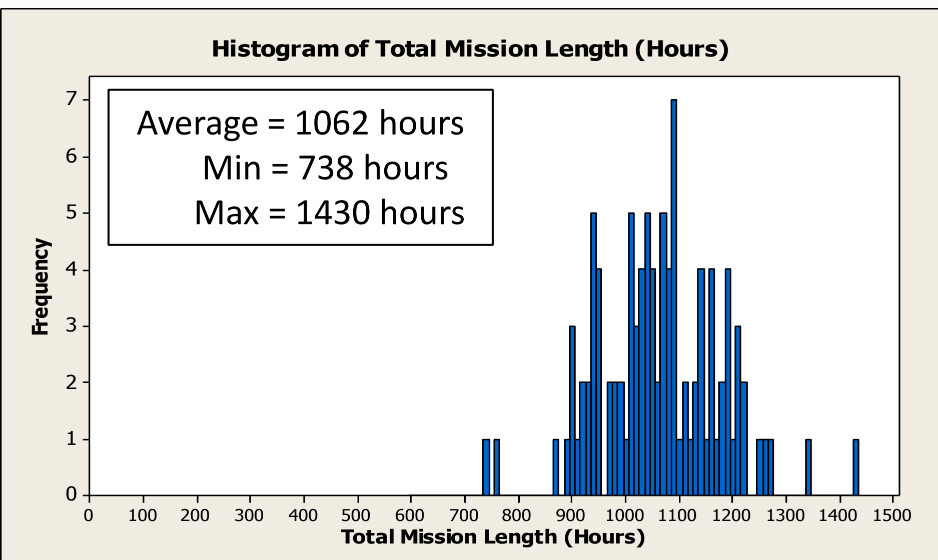
Low reliability of individual systems can have large impact at SoS level, but a low-reliability system will increase (inflate) the other individual system A_os as part of the SoS

Notional SAGSS A_o vs. Time, A_o Distribution, and Mission Length Distribution

Lower Reliability Case



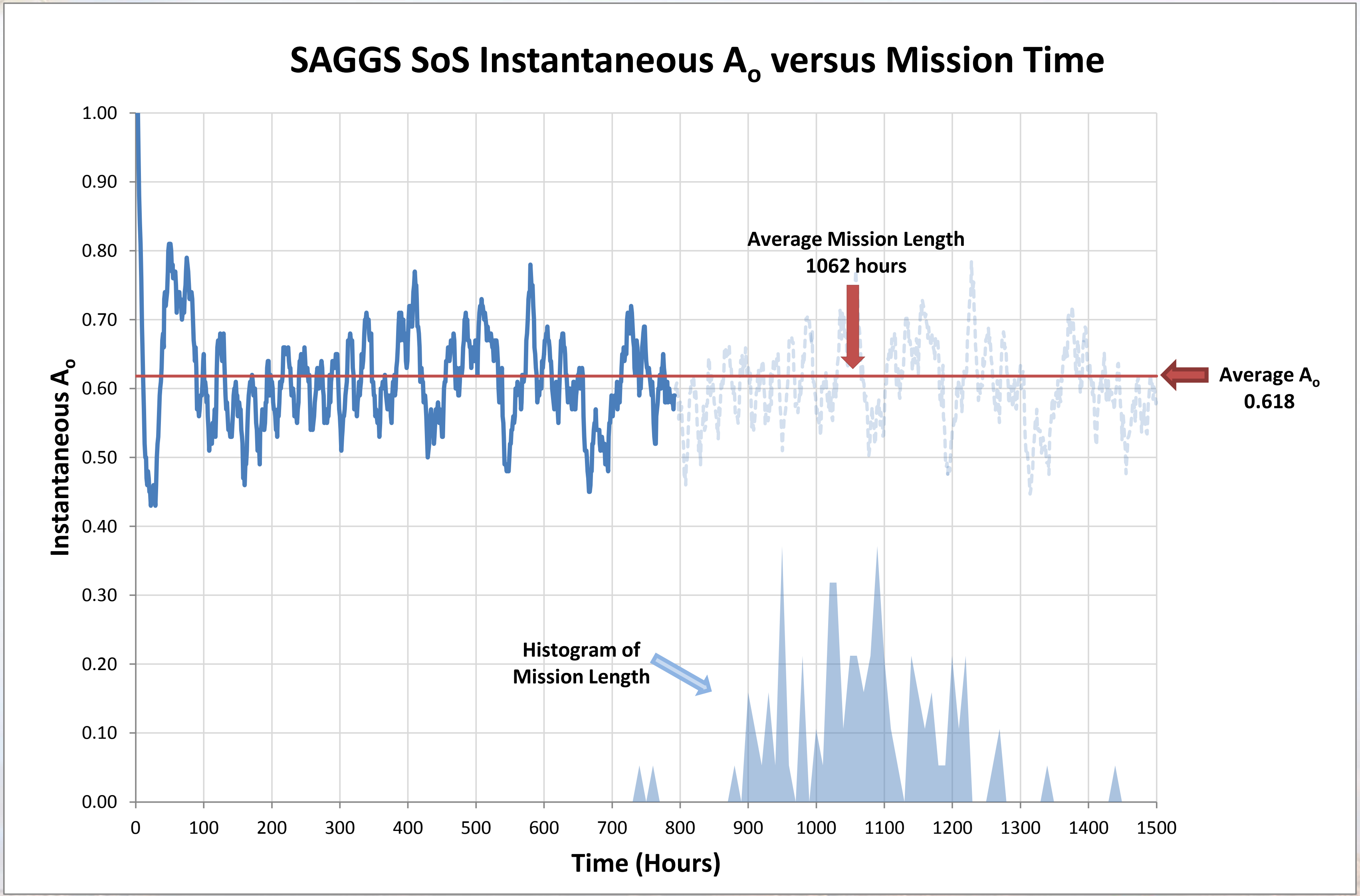




- For A_o vs. time, plot is average across simulation trials
  - All systems must be operating at end of mission
  - As mission time increases, number of trials decreases and A_o increases
- Considerable variability in A_o and mission length distributions

Notional SAGSS SoS A_o vs. Time with Mission Length Distribution

Lower Reliability Case



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Summary of Notional SAGSS SoS A_o Results

Higher Reliability Case

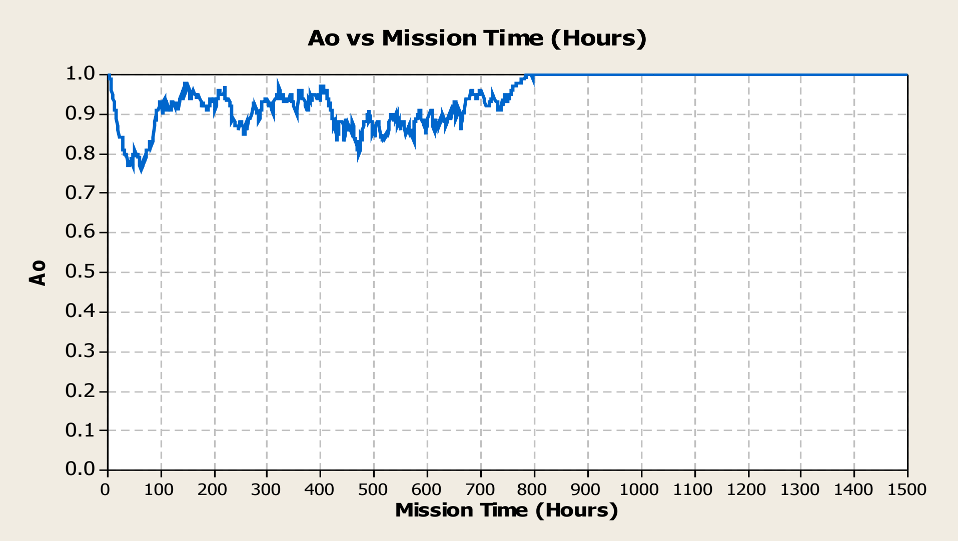
System	MTBF (Hours)	Average Number of Failures per Mission *	Mean Downtime per Failure (Hours)	Mean Downtime per Mission * (Hours)	Percent Total SAGSS Downtime	Average A_o
SAGSS SoS	**-**	**3.6**	**21.1**	**76.0**	**100%**	**0.898**
UAV	*300*	*1.5*	*26.3*	*39.5*	*51.9%*	*0.948*
UGS	*500*	*1.4*	*25.3*	*35.7*	*47.0%*	*0.952*
C2V	*800*	*0.7*	*1.3*	*0.9*	*1.1%*	*0.999*
CP	*10,000*	*0.0*	*35.0 (none observed)*	*0.0*	*0.0%*	*1.000*

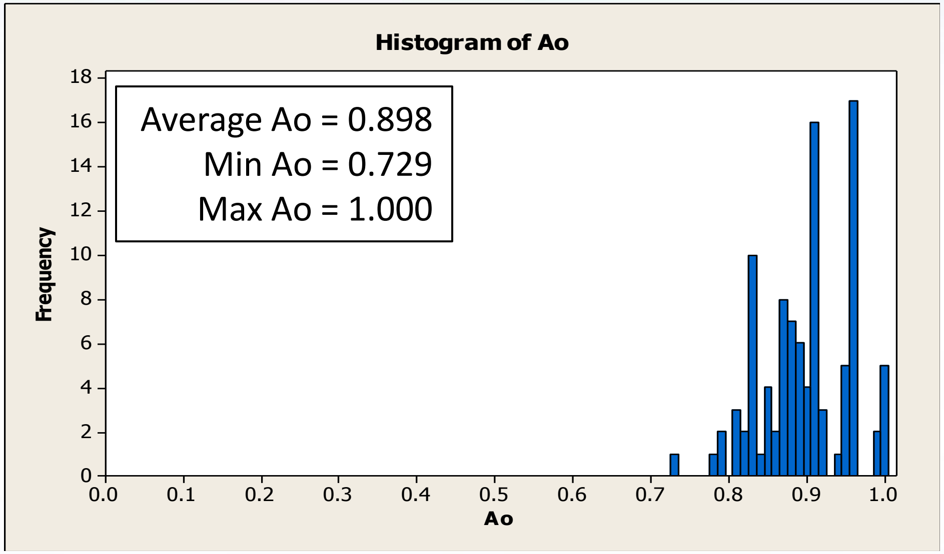
** Mission = Completed 500 hours of remote sensor time*

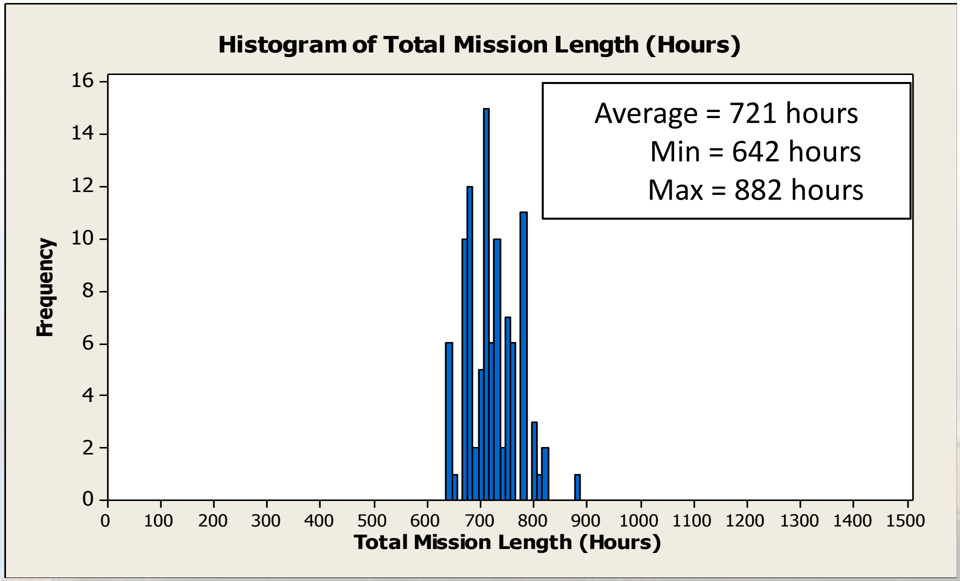
High reliability of individual systems have smaller impacts at SoS level, in comparison to lower reliability

Notional SAGSS A_o vs. Time, A_o Distribution, and Mission Length Distribution

Higher Reliability Case







- For A_o vs. time, plot is average across simulation trials
  - All systems must be operating at end of mission
  - As mission time increases, number of trials decreases and A_o increases
- Less variability in A_o and mission length distributions in comparison to lower reliability case

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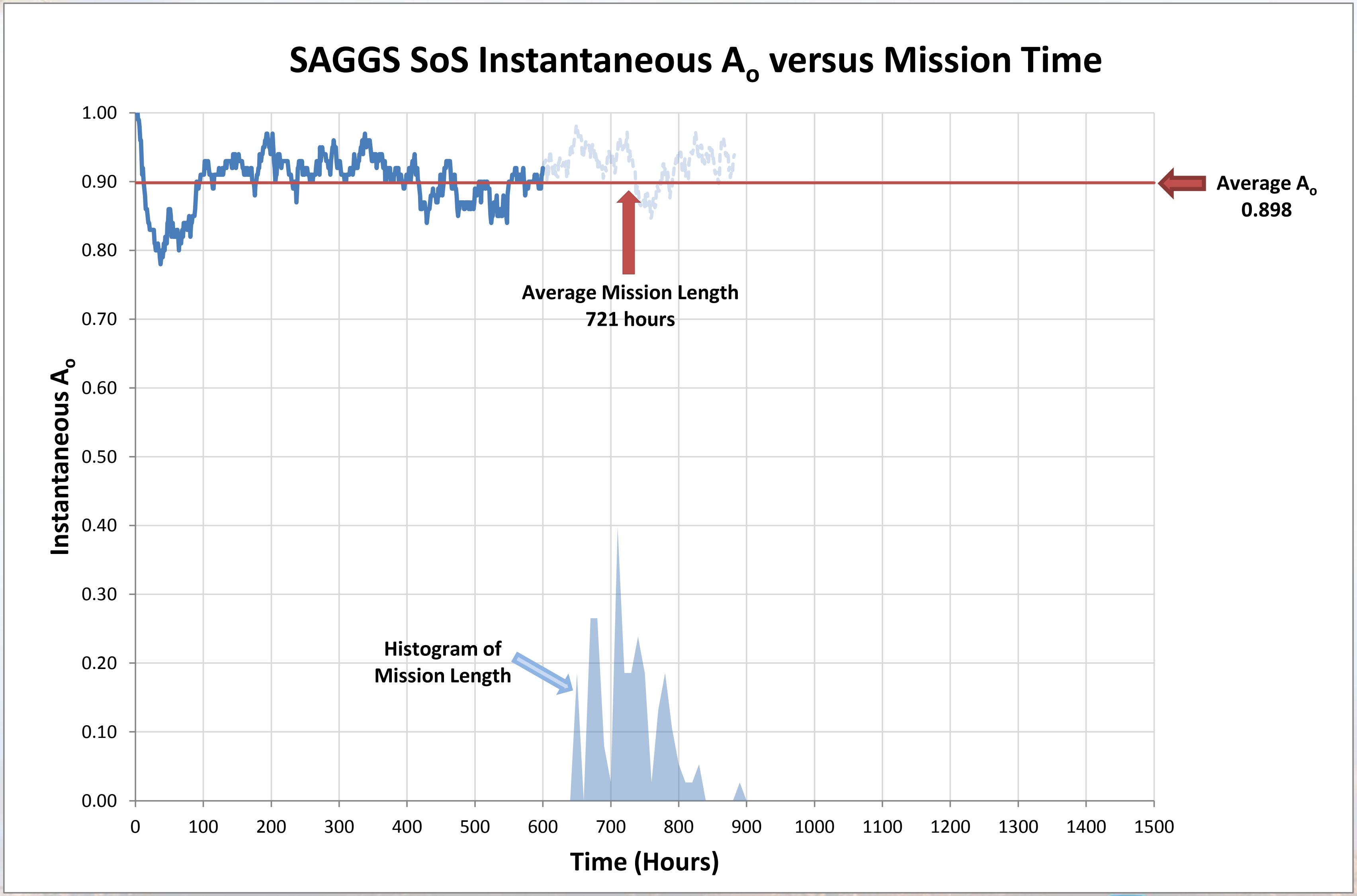
Notional SAGSS SoS A_o vs. Time with Mission Length Distribution

Higher Reliability Case



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Summary

- System A_o concepts are relevant to SoS A_o, but SoS adds complexity
  - Functional interdependencies and complex interrelated sustainment operations must be accounted for in system and SoS downtimes
  - Further complicated by intermittently used systems whose utilizations are considerably less than 100% over the mission duration
  - Requires specification of the SoS systems, boundaries, and missions
  - Dependencies of systems imply that individual system(s) can be operable while another system is down
    - Produces increased A_os for individual systems within the SoS (not the same system A_os as the systems operating independently)
- SoS functionality becoming more prevalent with robotic systems and networked operations
- For most SoS problems, simulation will need to be used to calculate SoS A_o
  - No equation estimators for SoS A_o