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Sandia National Laboratories

Initial holistic capability for assessing resilience in space infrastructure

Munaf S. Aamir

msaamir@sandia.gov

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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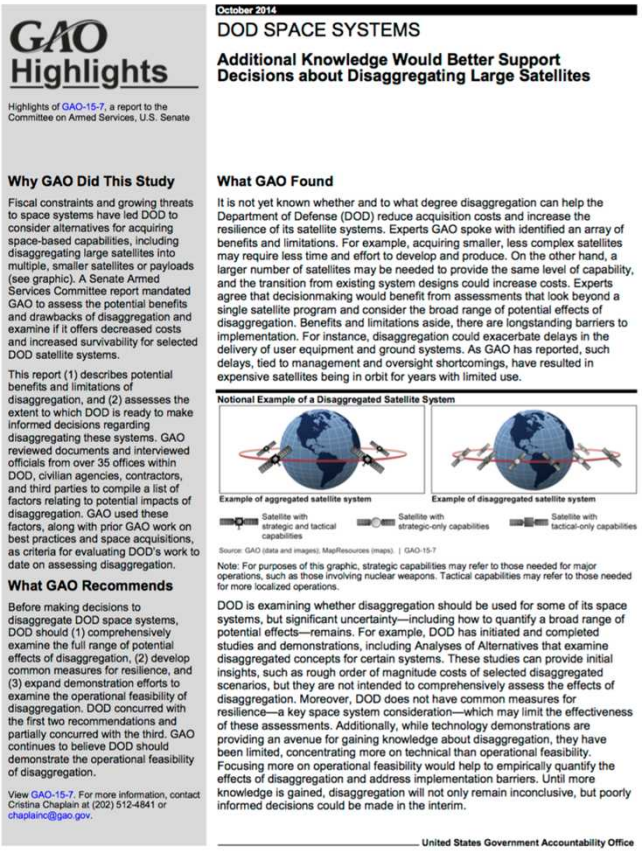
Introduction

- *PROBLEM:* U.S. space agencies "lack of common measures for key factors such as resilience" and agency leaders "agree the development of metrics to measure space system resilience is needed." (GAO 2014)
- Sandia is developing a scientifically-grounded resilience assessment methodology and is applying it to space-based missions.



GAO Highlights

Highlights of GAO-15-7, a report to the Committee on Armed Services, U.S. Senate

October 2014

DOD SPACE SYSTEMS

Additional Knowledge Would Better Support Decisions about Disaggregating Large Satellites

Why GAO Did This Study

Fiscal constraints and growing threats to space systems have led DOD to consider alternatives for acquiring space-based capabilities, including disaggregating large satellites into multiple, smaller satellites or payloads (see graphic). A Senate Armed Services Committee report mandated GAO to assess the potential benefits and drawbacks of disaggregation and examine if it offers decreased costs and increased survivability for selected DOD satellite systems.

This report (1) describes potential benefits and limitations of disaggregation, and (2) assesses the extent to which DOD is ready to make informed decisions regarding disaggregating these systems. GAO reviewed documents and interviewed officials from over 35 offices within DOD, civilian agencies, contractors, and third parties to compile a list of factors relating to potential impacts of disaggregation. GAO used these factors, along with prior GAO work on best practices and space acquisitions, as criteria for evaluating DOD's work to date on assessing disaggregation.

What GAO Recommends

Before making decisions to disaggregate DOD space systems, DOD should (1) comprehensively examine the full range of potential effects of disaggregation, (2) develop common measures for resilience, and (3) expand demonstration efforts to examine the operational feasibility of disaggregation. DOD concurred with the first two recommendations and partially concurred with the third. GAO continues to believe DOD should demonstrate the operational feasibility of disaggregation.

View GAO-15-7. For more information, contact Cristina Chaplain at (202) 512-4841 or chaplainc@gao.gov.

What GAO Found

It is not yet known whether and to what degree disaggregation can help the Department of Defense (DOD) reduce acquisition costs and increase the resilience of its satellite systems. Experts GAO spoke with identified an array of benefits and limitations. For example, acquiring smaller, less complex satellites may require less time and effort to develop and produce. On the other hand, a larger number of satellites may be needed to provide the same level of capability, and the transition from existing system designs could increase costs. Experts agree that decisionmaking would benefit from assessments that look beyond a single satellite program and consider the broad range of potential effects of disaggregation. Benefits and limitations aside, there are longstanding barriers to implementation. For instance, disaggregation could exacerbate delays in the delivery of user equipment and ground systems. As GAO has reported, such delays, tied to management and oversight shortcomings, have resulted in expensive satellites being in orbit for years with limited use.

Notional Example of a Disaggregated Satellite System

Example of aggregated satellite system

Example of disaggregated satellite system

Satellite with strategic and tactical capabilities

Satellite with strategic-only capabilities

Satellite with tactical-only capabilities

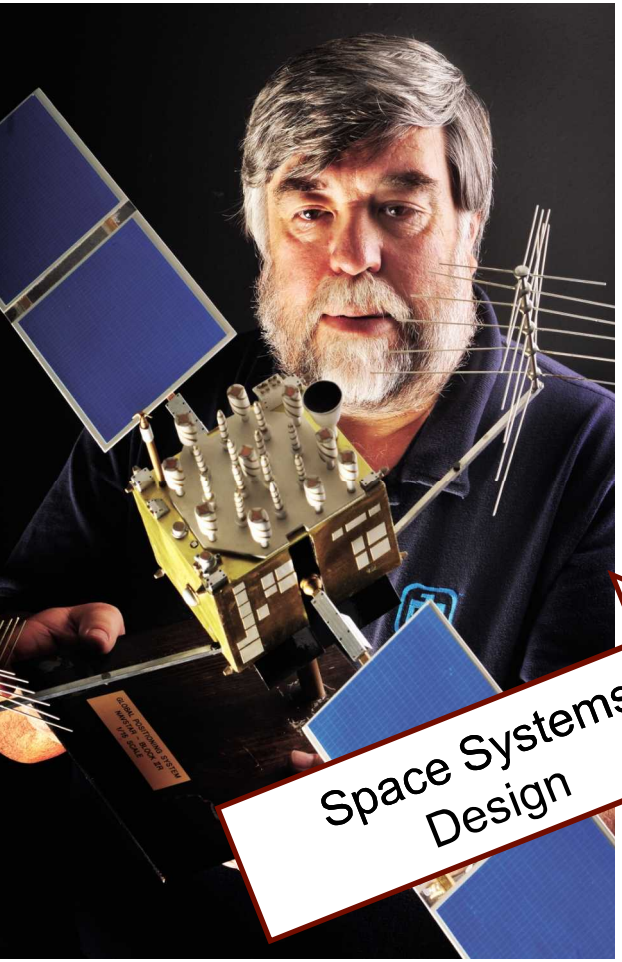
Source: GAO (data and images); MapResources (maps). | GAO-15-7

Note: For purposes of this graphic, strategic capabilities may refer to those needed for major operations, such as those involving nuclear weapons. Tactical capabilities may refer to those needed for more localized operations.

DOD is examining whether disaggregation should be used for some of its space systems, but significant uncertainty—including how to quantify a broad range of potential effects—remains. For example, DOD has initiated and completed studies and demonstrations, including Analyses of Alternatives that examine disaggregated concepts for certain systems. These studies can provide initial insights, such as rough order of magnitude costs of selected disaggregated scenarios, but they are not intended to comprehensively assess the effects of disaggregation. Moreover, DOD does not have common measures for resilience—a key space system consideration—which may limit the effectiveness of these assessments. Additionally, while technology demonstrations are providing an avenue for gaining knowledge about disaggregation, they have been limited, concentrating more on technical than operational feasibility. Focusing more on operational feasibility would help to empirically quantify the effects of disaggregation and address implementation barriers. Until more knowledge is gained, disaggregation will not only remain inconclusive, but poorly informed decisions could be made in the interim.

United States Government Accountability Office

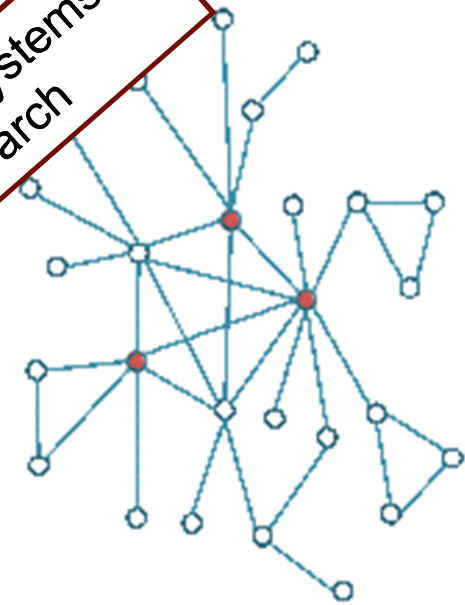
Sandia's has unique capabilities …



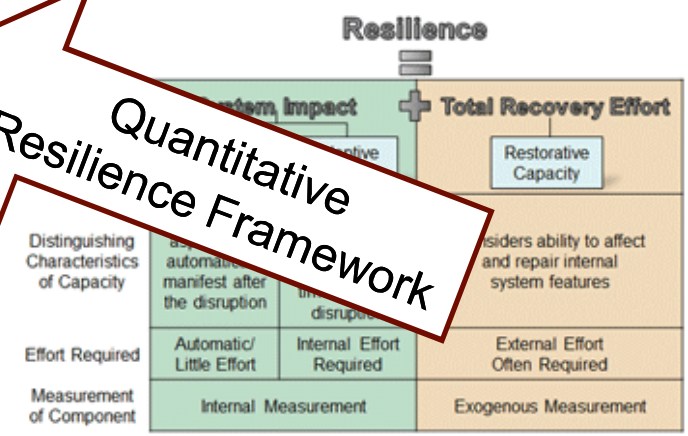
Space Systems Design

Quantitative Space Resilience Assessment Capability

Complex Systems Research



Quantitative Resilience Framework



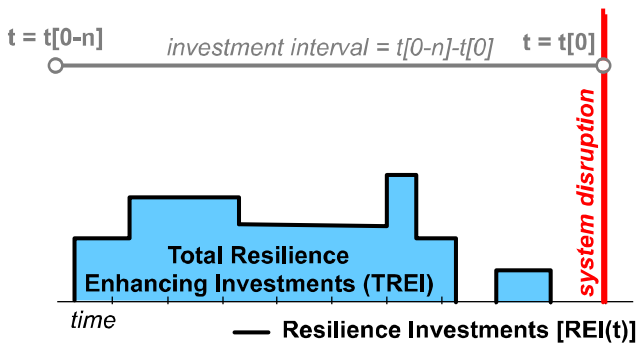
Sandia's Infrastructure Resilience Framework

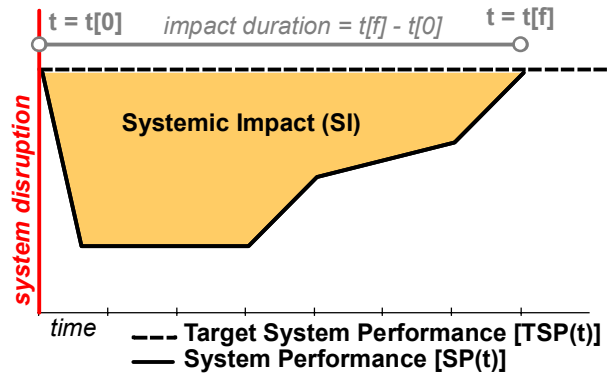
$$CRC = TREI + SI + TRE$$

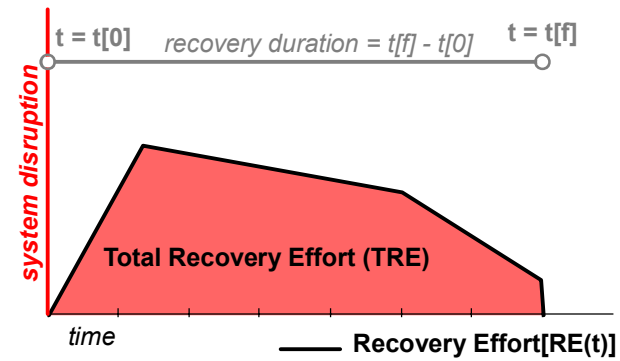
Total resilience enhancing investments is the cost of the investments prior to disruption expected to enhance resilience.

Systemic impact is the cost from the deviation of given target performance over time.

Total recovery effort is the cost of the effort used to recover performance over time.







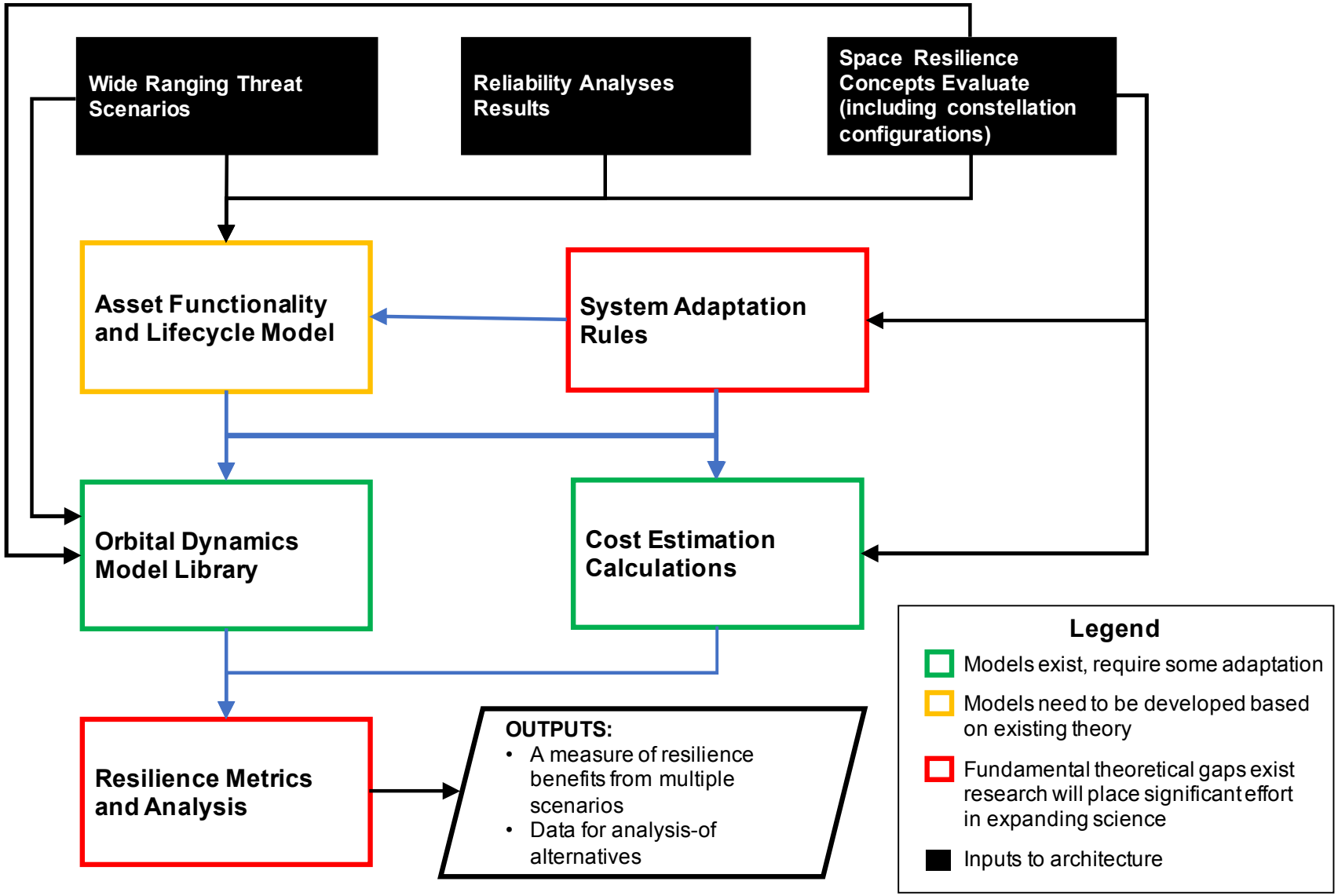
$$TREI = \int_{t_{0-n}}^{t_0} [REI(t)]\, dt$$

$$SI = \int_{t_0}^{t_f} [TSP(t) - SP(t, TREI)] dt$$

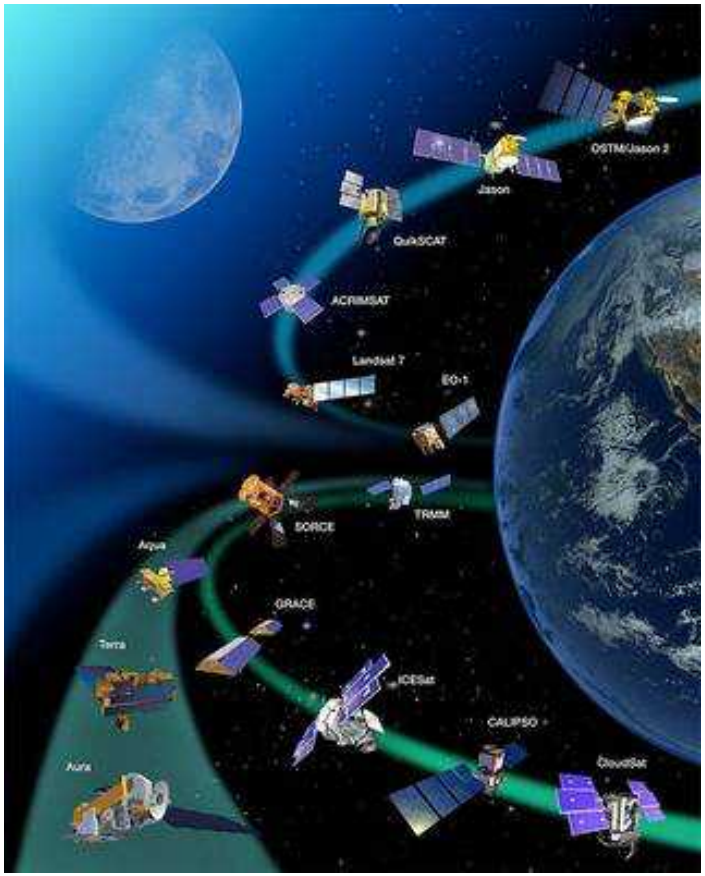
$$TRE = \int_{t_0}^{t_f} [RE(t, TREI)]\, dt$$

(modified from: Biringer, Vugrin, Warren 2013)

Space Resilience Conceptual Architecture



Example Performance Metrics



(NASA image)

The performance metrics depend on the system of interest (some illustrative examples):

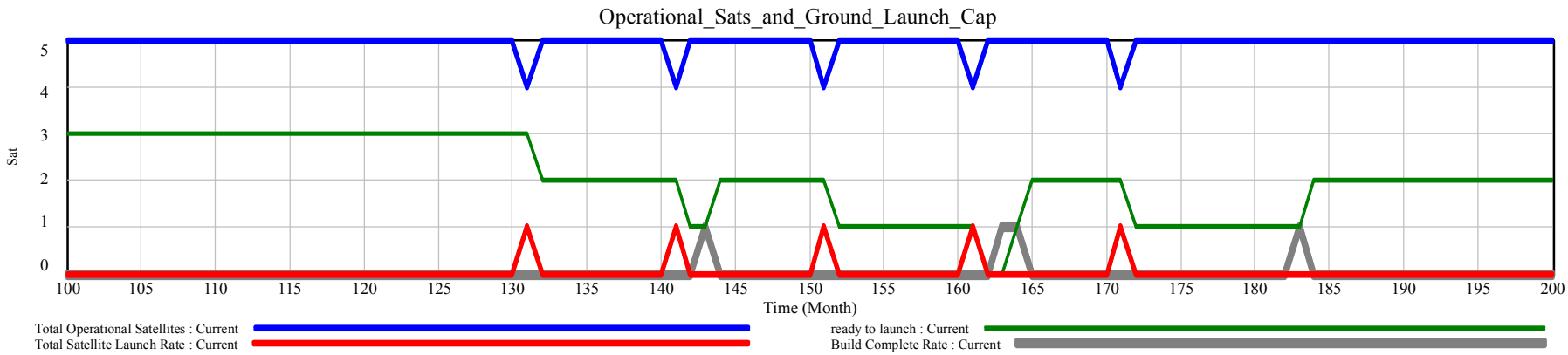
- **Sat TV / Radio:** coverage, latency
- **Sat Phone:** reception, latency
- **GPS:** Ability for ground to receive 3-4 signals
- **Weather/environmental:** mean observation time
- **Sat Internet:** reception, packets dropped

We will select a system of interest based on the availability of data on systems of interest.

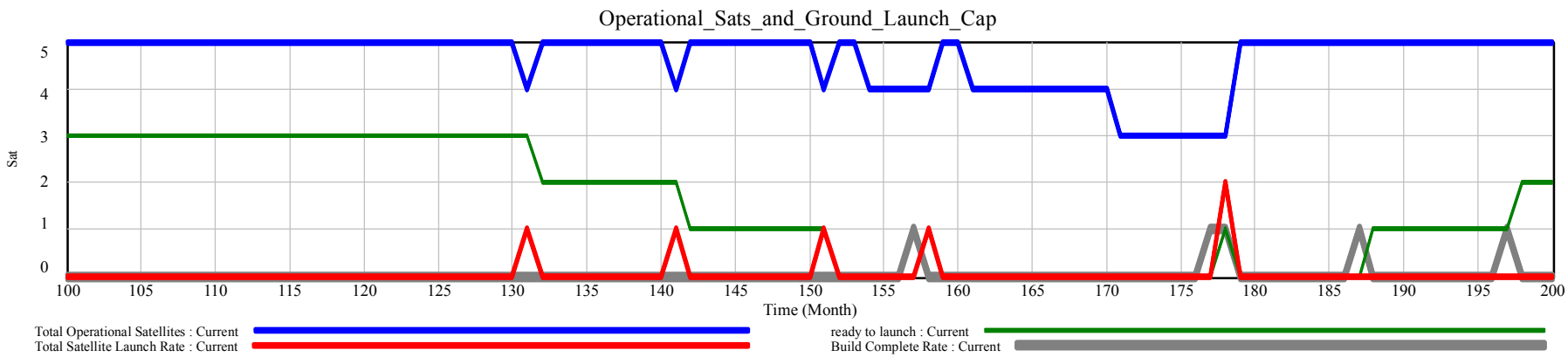
Initial Developments: Supply Chain Model

Asset supply chain model can represent high-level consequences of failures given key parameters and disruptions

BASELINE



DISRUPTED*



* Also assumes a longer build time

Research Directions and Conclusion

- Development of disruption scenarios using data
- Defining mission relevant resilience metrics
- Modelling functional components
- Characterizing adaptation

- Resilience of space systems is an area needing further research
- Sandia is developing a resilience assessment methodology for space-based missions