Integration of MBSE Tools with Geospatial Visualization & Analysis Tools

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INNOSLATE®
THE MBSE SOLUTION

SPEC INNOVATIONS

Overview

- SPEC Innovations & Innoslate
- NASA's Break the Ice Challenge
- Digital Thread Using Innoslate
- Integration Between MBSE & Geospatial Tools
- Conclusions

SPEC Innovations & Innoslate

- Developed MBSE tool, Innoslate
  - Supports Systems Engineering Lifecycle
  - Based on Lifecycle Modeling Language (LML)
- Continuously Advancing Innoslate's Systems Engineering Capabilities
  - Sopatra
  - Github Integration
  - Ansys STK Integration
- In 2021, we became interested in using NASA's Break the Ice Challenge to demonstrate Innoslate's Digital Thread

NASA's Break the Ice Challenge (Phase 1)

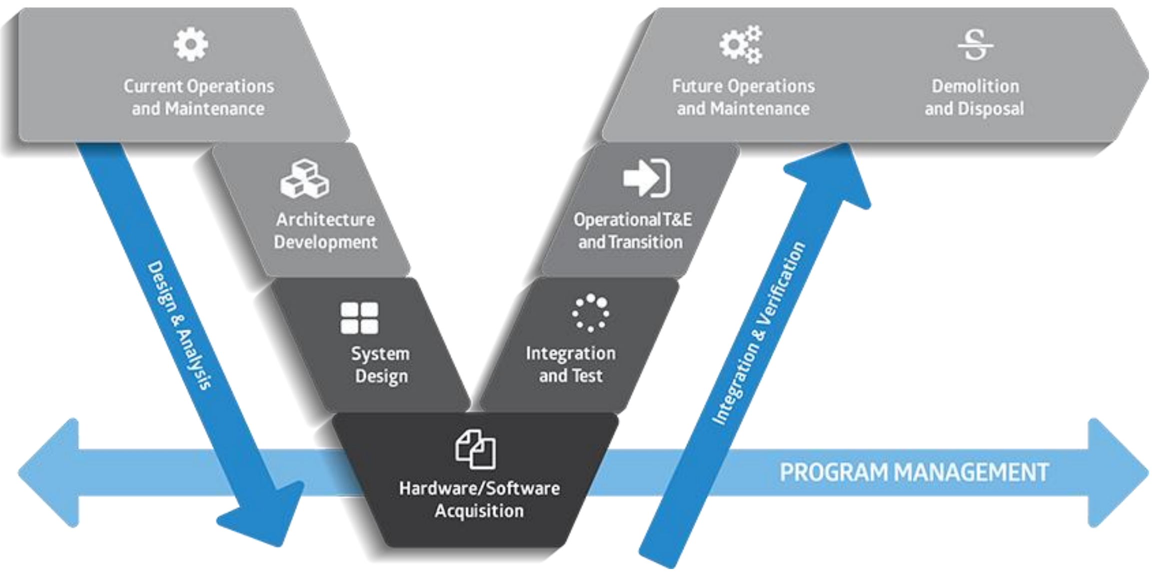
- NASA hosted a competition to seek solution architectures that address:
  - Excavating lunar regolith
  - Maximizing water delivered
  - Minimizing mass of equipment
  - Minimizing power consumption
- Goal:
  - Extract 10,000 kg of water from regolith in 365 Earth days

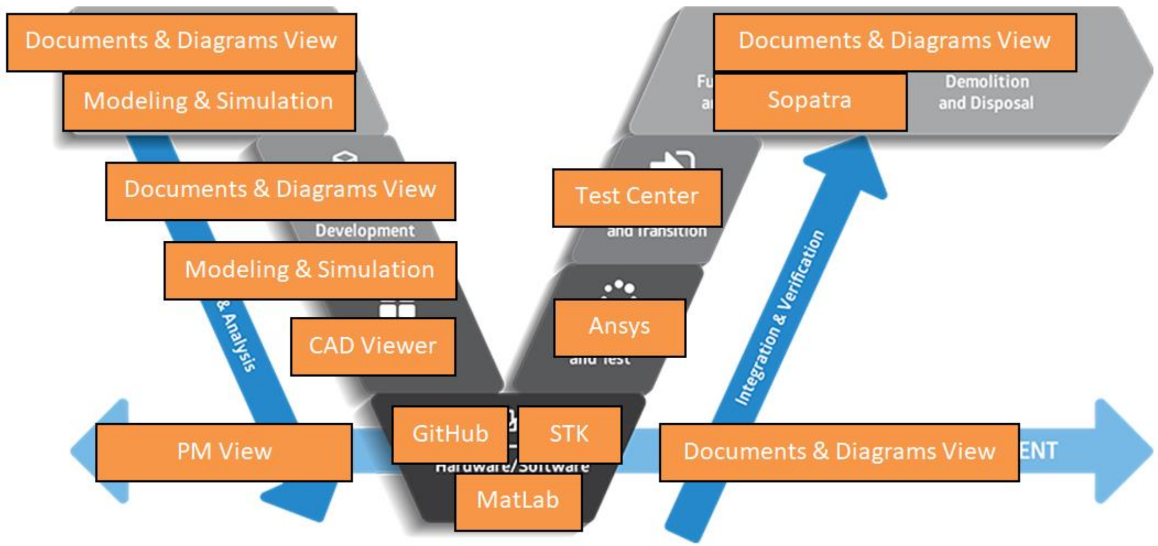
SPECTER Lunar Rover

- *"Space Prospect Exploration Convoy Transporting & Evaluating Regolith (S.P.E.C.T.E.R)"*
- System boundary scope constrained to a lunar rover system
- Produced a lunar rover prototype system using end-to-end systems engineering digital thread

Digital Thread Using Innoslate

- Systems Engineering Vee Model used to create digital thread for lunar rover prototype within Innoslate



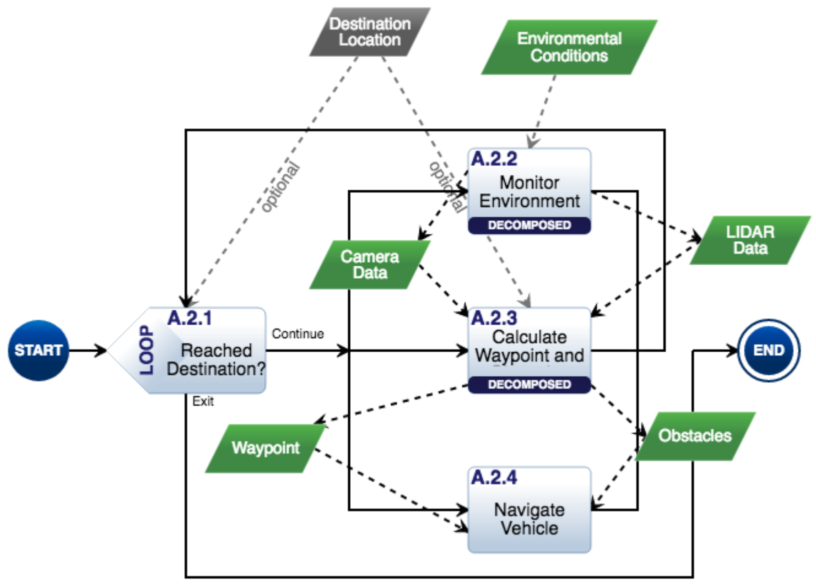


Integration Opportunity

- Desire to use high fidelity geospatial model to represent lunar rover system
- Previously established partnership with Ansys & Systems Toolkit (STK) in Summer 2020
  - Access to STK Pro enterprise licenses & support
- Innoslate & STK integration prototype developed as part of other efforts
  - Integration-capable components were brought together
    - Innoslate Action Diagram
    - STK Connect Module
    - Java Web Application (Custom-built)

Innoslate Action Diagram

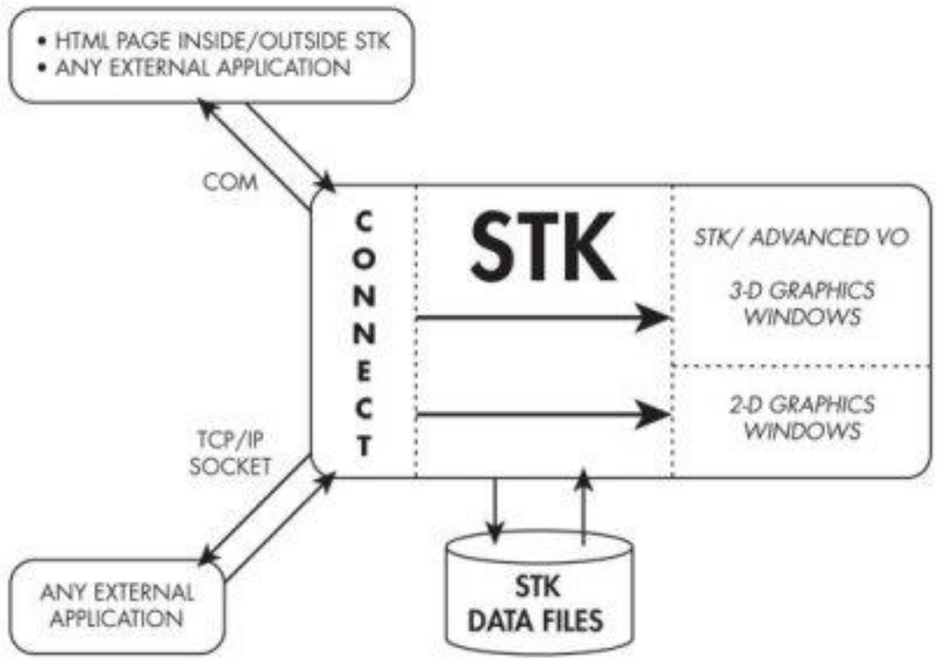
- Allows for an easy-to-understand display of functional flow or set of activities
  - Entities
    - Actions, I/Os, Resources
  - Diagram constructs
    - Decomposition, serial/parallel actions, flow constructs, etc.
  - Simulations
    - Discrete Event
    - Monte Carlo
  - Extensions
    - Javascript APIs
      - REST APIs enabled



Sample Innoslate Action Diagram

STK Connect Module

- Establish connection with STK enterprise application and work in a client-side environment
    - Independent of programming language; uses own syntax
- Has a documented library of commands
    - Allows for limited control of STK externally
    - Send & receive data in the form of text/string messages



STK Help "Getting Started with Connect" Diagram

Java Web Application (Custom)

- *"Build & Send, Parse & Return"*
- Functions as a local server (e.g. "localhost:8888")
- Holds custom Java code and uses a RESTful API to receive GET and send POST requests
  - Uses StkCon.java files (acquired from STK installation) to enable STK connection and communication
  - Helper methods are used to build and parse STK Connect commands and outputs into useful information

Mission Requirements

Excavate icy regolith at Excavation Site

Extract water from icy regolith using the NASA Water Extraction Plant

Deliver water to Delivery Site

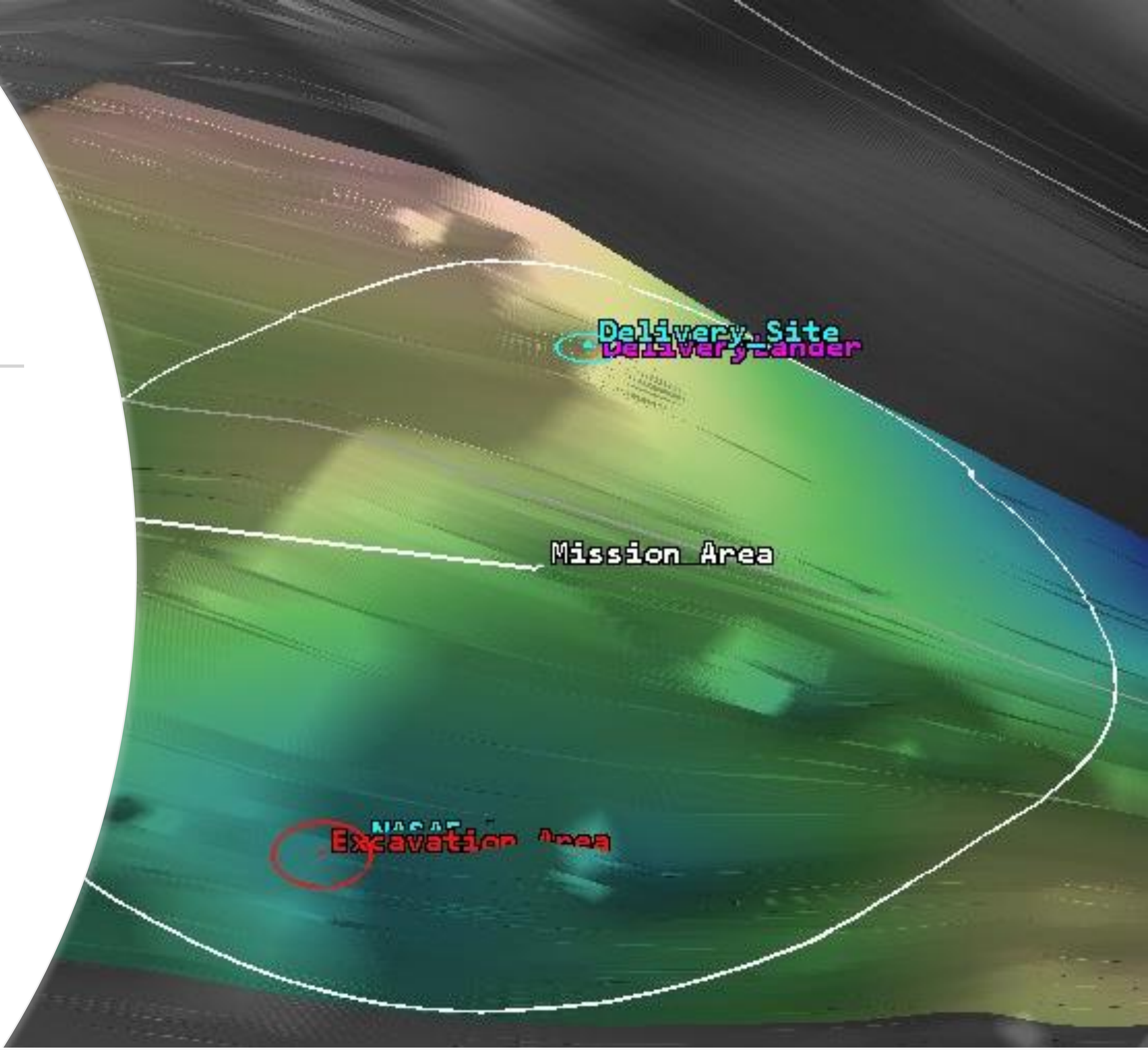
Additional performance parameters & environmental constraints provided by NASA

Integration Between MBSE & Geospatial Tools

- Alternative Rover System Scenarios
  - One Rover System
- Rover Route Analysis
  - Ansys/AGI's Systems Tool Kit (STK) used to model rover's travel route and calculate time to reach the mission's goal of collecting 10,000 kg of water
  - Fidelity increased by adding elevation, obstacles and cratered regions
  - Innoslate Action diagram created to execute rover's functionality: **Excavate** regolith, **Transport** regolith to Water Plant, and **Deliver** extracted water

STK Model

- Built to represent mission environment
- Object representation in STK:
  - The Moon = Central Body
  - Site locations = Lat./ Long. Coordinates
  - Rover = Ground Vehicle
  - Communication w/ Earth = Satellites
- Fidelity of STK model increased by adding lunar terrain elevation, obstacles and cratered regions



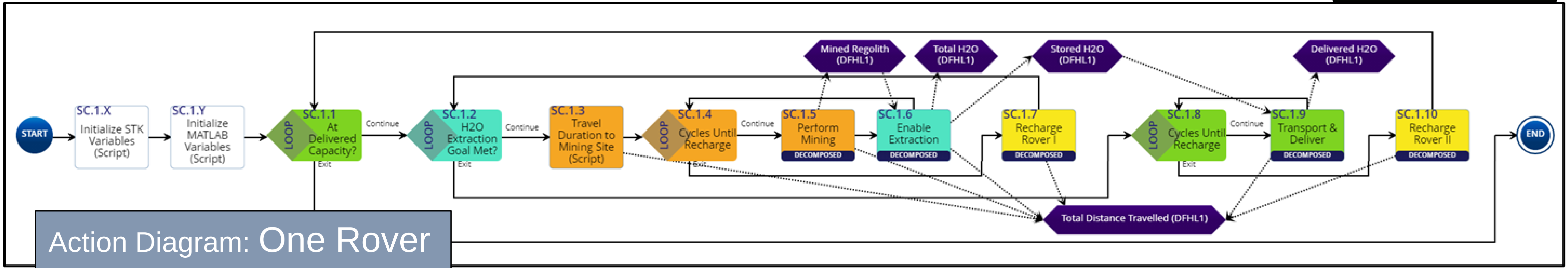
Rover Route Analysis Assumptions

- Same route between sites
- Rover moving at constant speed 0.3 m/s
- Rover excavation rate of 100 kg of regolith per hour
- Rover carrying capacity of 100 kg
- Rover can complete 10 excavation cycles before recharging battery
- One full charge is 4 hours
- Unloading regolith requires 15 minutes, and loading water requires 1 hour
- No degradation or failures

Integration Between MBSE & Geospatial Tools

- Innoslate – STK Co-Simulation
  - Action diagram simulates the mission scenario with STK
  - Represents one rover excavating regolith, transporting regolith to Water Extraction Plant, and delivering water for storage
  - Runs until 10,000 kg of water is collected or the rover reaches 365 Earth days on the Moon

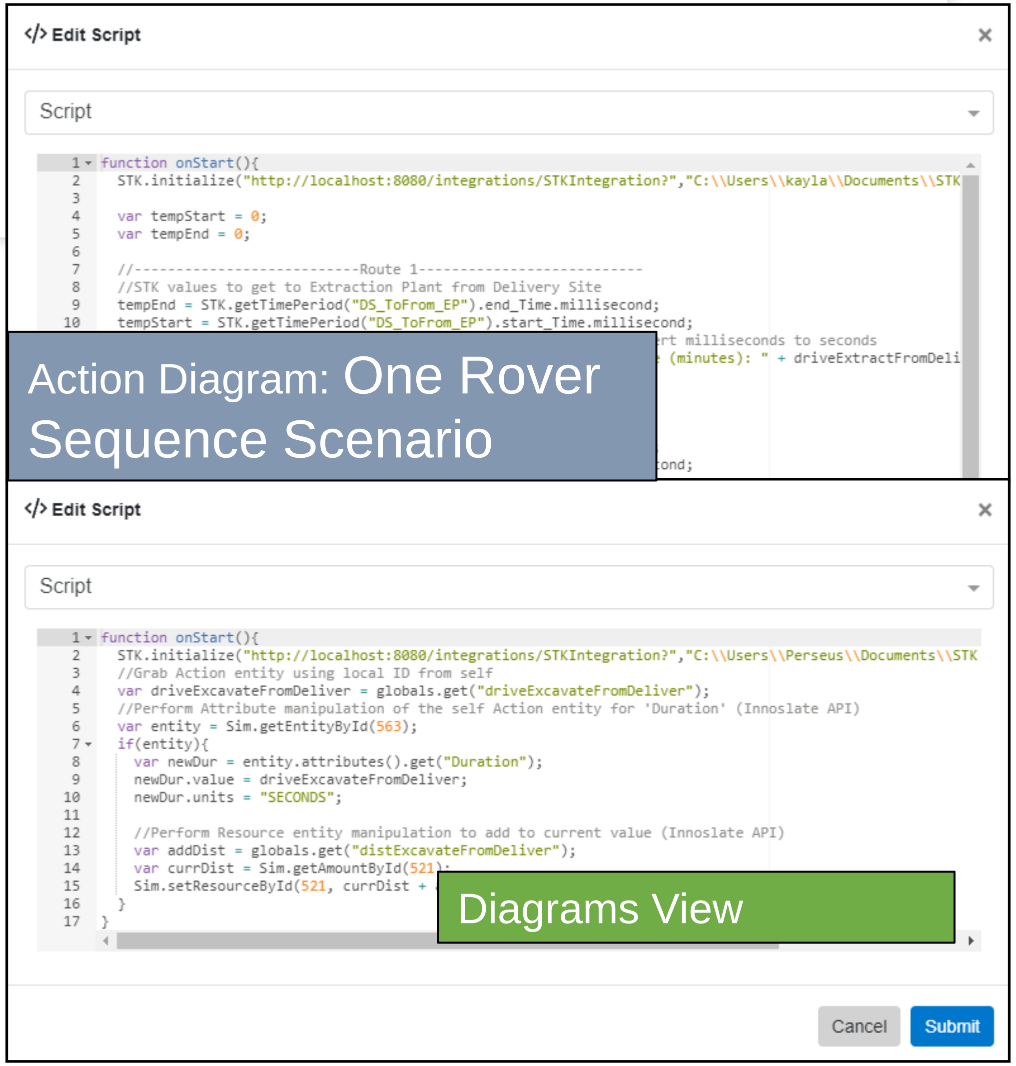
Diagrams View



Action Diagram: One Rover Sequence Scenario

STK – Innoslate Co-Simulation

- Scripts added to Action entities to communicate with STK model:
    - Initialize STK
    - Create global variables for time to traverse values acquired in STK
    - Calculate duration components (start & end times) and velocity vector components
    - Use duration components to calculate travel times between lunar sites
    - Aggregate values in Resource entities



Rover Route Analysis Verification

- Route distance results verified using a co-simulation with MATLAB
  - Velocity vectors in the X, Y, and Z planes were retrieved from STK through Innoslate
  - Function script written in MATLAB to calculate the magnitude of the lunar rover velocity

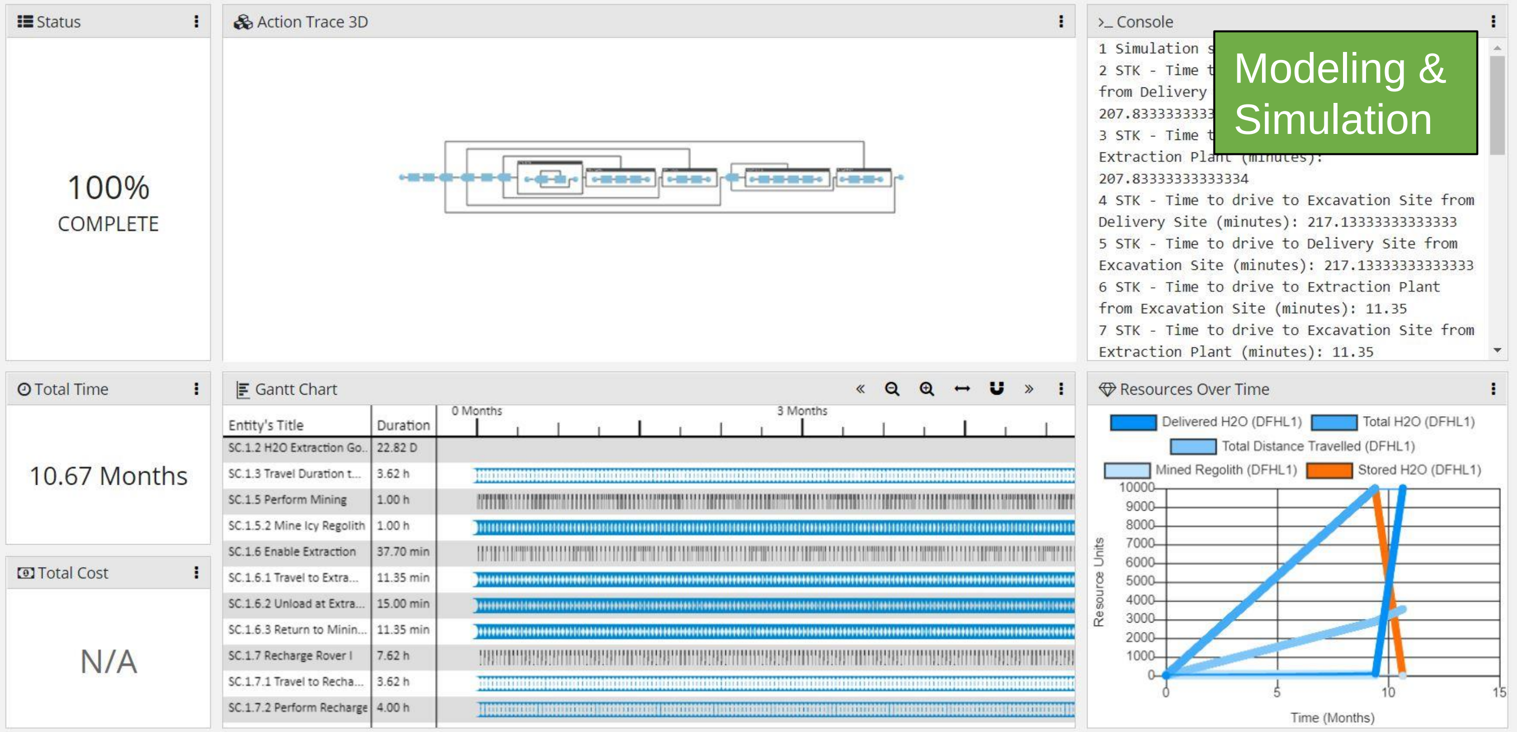
main.m | calcMagnitude.m

```
function [magnitude]=calcMagnitude(x,y,z)
% calculates magnitude of 3-dimensional vector
%   inputs will be retrieved from Innoslate but originating from STK
magnitude=sqrt(x^2+y^2+z^2);
end
```

Same route distance results calculated in Innoslate-MATLAB co-simulation

Integration Between MBSE & Geospatial Tools

- Scripts in Action entities used to co-simulate STK in Innoslate
- Calculated a duration of 10.67 months to collect 10,000 kg of water
- Calculated total distance of 3,500 km the rover will travel during the mission
- Majority of mission dedicated to excavation and extraction processes



Action Diagram: One Rover Sequence Scenario

Systems Engineering Implications & Findings

- System Reliability
  - 3,500 km is a gargantuan distance
    - In comparison, NASA's Opportunity has traveled 45 km in its lifecycle
- System Alternatives
  - Should tasks be divided among specialized rovers?
- System Bottlenecks
  - Hypothetical NASA extraction plant is a bottleneck to rover mining processes

Need for MBSE & Geospatial Tool Integration

- Scenarios often have geospatial constraints that MBSE tools do not take into account easily
- MBSE can benefit from recognizing and using the physical constraints of:
  - Orbital mechanics
  - Flight dynamics
  - Etc.

Benefits of MBSE & Geospatial Tool Integration

- Integrations provide better ways to represent the functional and physical models of the system
  - Closing gap between systems engineering & design engineering
- Ever closer to the "Digital Twin"
  - Care and consideration needed to determine how far integrations need to go
- Issues can highlighted early on in SE process

Thank You!

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