AN OPTIMIZATION APPROACH TO SUPPORT SCIENCE DECISION MAKING FOR LUNAR SURFACE EXPLORATION. Broddrick, J.T.[1], Achilles, C.E.[1], Banks, M.E.[1], Charney, D.W.[1], Denevi, B.W.[2], Edgar, L.A.[3], Ewing, R.C.[4], Feist, B.F.[1], Garry, W.B.[1], Huff, A.E.[5], Hurtado, J.M. (Jr.)[6], Lanza, N.L.[7], Miller, M.J.[1], Morse, Z.R.[1], Richardson, J.A.[1], Skinner, J.A., Jr.[3], Trainor, C.M.[1], Weitz, C.M.[8], Young, K.E.[1], [1]NASA (jared.t.broddrick@nasa.gov), [2]Johns Hopkins Applied Physics Lab, [3]USGS, [4]Texas A&M University, [5]Arizona State University, [6]The University of Texas at El Paso, [7]Los Alamos National Laboratory, [8]Planetary Science Institute

Introduction: Scientific exploration is one of the three pillars of NASA's Moon2Mars architecture [1], with crew surface extra vehicular activities (EVA) serving a critical enabling function. Development of surface EVA operational planning and execution, specifically integrating science and flight control teams (FCT), is currently being explored through analog scenarios. This integration, exercised, for example, through the Joint EVA and Human Surface Mobility Test Team (JETT) [2], allows for science input on EVA activities in near real-time through a Science Evaluation Room (SER), or Artemis science backroom, which integrates with the broader FCT through the Science Officer [3]. The SER works within the FCT to support dynamic EVA planning in response to changes in operational constraints as well as science opportunities and re-prioritization, increasing the mission science return and accelerating the accomplishment of the Moon2Mars science objectives.

The SER works within the FCT to provide recommendations to traverse execution in near real-time. One challenge is the requirement to deliver SER inputs to the FCT on operationally relevant timelines. Failure to do so may result in suboptimal execution of science exploration EVAs or even loss of key science objectives.

To close this gap, we present a network optimization tool to allow the SER to provide rapid input to the FCT in response to changes in operational constraints or science opportunities. Inputs are predicated on approved science objectives, and clear rationale must be provided to the FCT for any requested change. Accordingly, this tool incorporates the Science Traceability Matrix (STM), SER prioritization scheme, and station characterization and action planning with operational constraints such as duration, traverse speed, and distance to maximize science objectives based on SER priorities, consistent with FCT operational requirements.

Station Investigation Relevance and Priority (High, Medium, Low, Not addressed)					
Obj	Priority	P01	P02	P03	P04
A	High				
B	Medium				
C	Low				

Figure 1. Demonstrative STM used to define model parameters (action relevance and Station Priority) based on the JETT5 methodology for analog surface operations.

Method: As a proof of concept, we used an existing linear programing software package used to simulate optimal routes through cellular metabolism [4]. We built a Demonstrative Model with three STM objectives and four stations on a region of the Moon. The objectives were given an arbitrary prioritization and mapped to the stations through four possible crew actions. (Figs. 1 and 2). This station to STM mapping is consistent with the method used by the JETT5 Science Team to develop analog surface EVA science planning [5, 6].

We used a grid system with the landing site at the origin and the four stations placed across the positive x,y quadrant. Actions were assigned to each station and the accomplishment of those actions resulted in a numerical "reward" based on the ability of that action to achieve science objectives. The aggregate reward from each individual STM objective contributes to a global score (Science Yield), weighted by its priority.

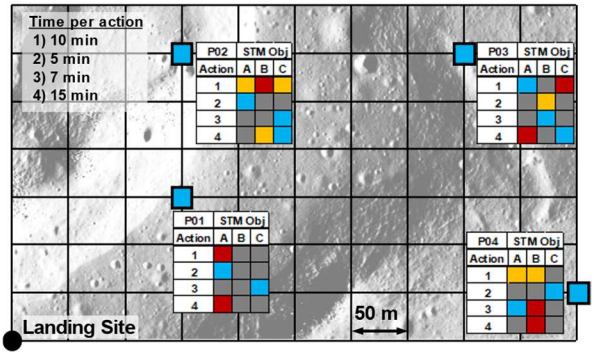

Figure 2. Demonstrative EVA station and action prioritization according to STM objective alignment, based on the JETT5 methodology. Blue boxes are stations. Color coding for action relevance is the same as in Figure 1.

Operational constraints included a requirement to start and end at the landing site, 5 minutes each for initial station characterization and "clean up," and variable total EVA time, traverse rate (fixed to 0.5 meters per second in our example), and time to perform each action (10, 5, 7, and 15 min for actions 1, 2, 3, and 4, respectively). Additional constraints and variables will be added in the future (e.g., sample mass, number of stations, traverse route constraints, illumination).

Optimization. We converted the connections (arcs) between these stations (nodes) into a mixed integer linear programming optimization problem (arcs = constraints, nodes = variables) with the objective to maximize Science Yield. For any action, the Science Yield is equal to the relevance of that action to an STM objective [3, 2, and 1 point(s) for High, Med., and Low relevance,

respectively], multiplied by the STM Objective Priority [3, 2, and 1 point(s) for High, Med., and Low priority, respectively]. This resulted in a model that computes the optimal station and action combination to maximize the Science Yield. These weightings can be adjusted by the SER as desired.

Results: We explored three test cases for the Demonstrative Model. First, we set the maximum EVA duration to 120 minutes and computed the optimal route (Fig. 3A). The model suggested performing Actions 1 and 2 at Station P01, followed by Actions 1 and 2 at Station P02, and finally Actions 1 and 3 at Station P04 before returning to the Landing Site. Second, we adjusted the STM Objective Priority order and computed the new optimal route (Fig. 3B). Under this situation, the model suggested performing all Actions at Station P02 followed by all Actions at Station P03.

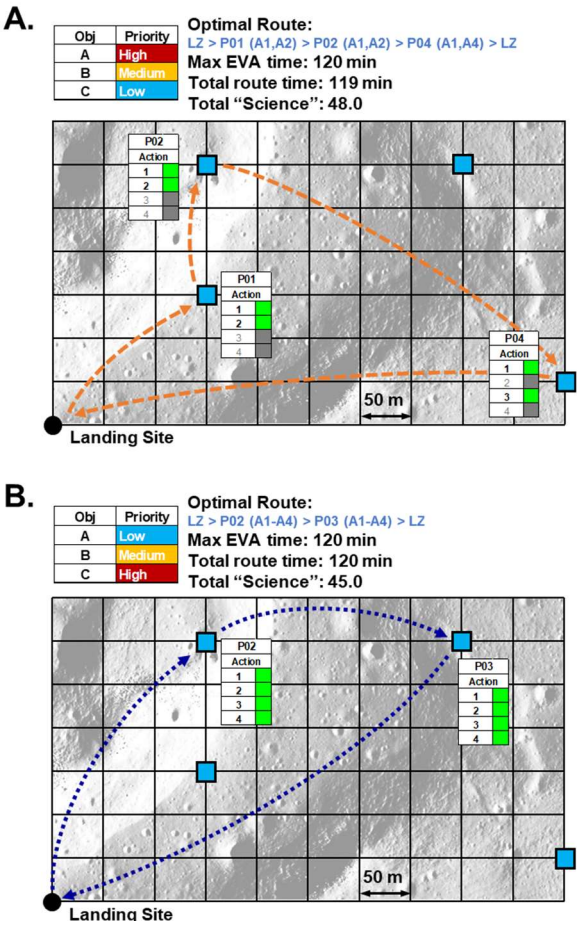

Figure 3. Demonstrative route and action planning based on STM priorities. (A) Computed optimal route for a 120 min. EVA with the indicated STM Objective Priorities. (B) Optimal route with changes to the STM Objective Priorities.

The previous test cases were relevant to SER planning activities. Next, we explored providing mid-EVA replanning input to the FCT.

Scenario: While executing the Route in Fig. 3A the crew finishes at Station P01 and FCT decides that the EVA needs to finish in 45 minutes back at the Landing Site. FCT asks SER to recommend changes to the plan to accommodate this operational change.

Using the model, and incorporating these new constraints (start at Station P01, max. time of 45 min), the model suggested performing Actions 2 and 4 at Station P03 (Fig. 4), requiring 41 minutes to complete and return to the Landing Site. Interestingly, Station 3 was not part of the original route. Using the model, we determined the EVA would need 66 minutes, instead of 45, in order for the original Station P04 to yield a larger Science Yield than Station P03. The parametrization and simulation was performed in less than a minute, demonstrating the operational relevance of the approach.

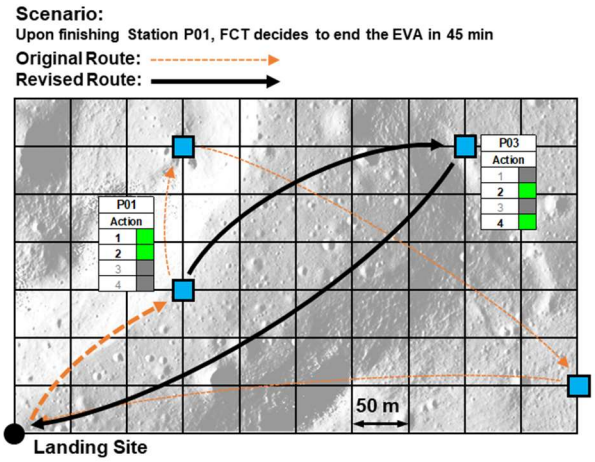

Figure 4. Dynamic replanning of EVA. The computed optimal route from Station P01 back to the Landing Site within 45 minutes, while maximizing Science Yield was determined to route through Station P03, in contrast to the original route.

Future Efforts: The results from the Demonstrative Model suggest this tool can accelerate SER decision making on operationally relevant timelines. Use in analog activities, such as JETT5 or follow-ons, which have over a dozen stations for a crew to explore and over a dozen actions per station, will provide needed validation of the utility of this tool for planning EVAs, replanning mid-EVA, or planning follow-on EVAs based on previous results. Further integration with FCT execution monitoring tools may provide additional efficiency gains, allowing rapid and iterative exploration of operational and science decision space by the FCT and SER.

References: [1] NASA (2023) Moon2Mars Strategy and Obj Dev. [2] Graff T.G., *et. al.*, (2023) 54th LPSC Abstract #1329. [3] Young K.E., *et. al.*, (2023) 54th LPSC Abstract #2460. [4] Ebrahim A., *et. al.*, (2013) *BMC Sys Bio*, *7*(1) 74. [5] Fagan A.L., *et. al.*, (2023) 54th LPSC Abstract #2046. [6] Achilles C.N., *et. al.*, (2024) 55th LPSC.