SYSTEMATIC TRAVERSE ENGINEERING WITH INTEGRATED ELLIPSES (STEWIE): SCIENCE BASED TRAVERSE PLANNING IN SUPPORT OF LUNAR SURFACE OPERATIONS. M. A. Hunter[1], H. C. Buban[1], L. A. Edgar[1], C. M. Fortezzo[1], T. M. Hare[1], A. E. Huff[2], and J. A. Skinner, Jr[1]., U.S. Geological Survey, Astrogeology Science Center, 2255 N. Gemini Dr., Flagstaff, AZ 86001 (mahunter@usgs.gov), [2]Arizona State University, School of Earth and Space Exploration, 781 Terrace Hall, Tempe, AZ, 85287.

Introduction: The accessible path of movement over any given terrain is limited by a combination of multiple factors, including rate of travel, timeframe, slope, hazards, visibility, and surface strength. Devising accurate traverse pathways for landscapes, especially those lacking transportation infrastructure, has motivated the development of predictive traverse concepts and computational toolsets. For example, digital terrain models (DTMs) and derivative surfaces are often used to perform least cost path analyses for traverses prior to visiting a particular site. However, operational constraints known prior to traverse are not always factored into routing computations and do not always adapt to unanticipated opportunities and obstacles during the mission. Lunar and martian rovers and traverse concepts build on these computational foundations to successfully automate terrain navigation and obstacle avoidance using (primarily) line of sight traverse applications [*e.g.,* 1-5] and predict how traverses could be completed using human or robot "field" scientists. Research into "over-the-horizon" (beyond line of sight) movement has expanded this work, though with a focus on syn-mission traversing to a single station [6]. Speyeyer *et al.* took an evolved approach to demonstrate these concepts for mission planning purposes, but again focused largely on "A-to-B" movement from a hypothesized landing site [7]. Despite concerted efforts to constrain traverses on worlds beyond Earth, most traverse planning tools do not yet sufficiently account for how human decisions drive real-time changes in least cost paths and traversable envelopes. Here, we summarize traverse concepts that are based on an envelope that is constantly shrinking across an extravehicular activity (EVA) due to time limitations, hazard-based traversability, and science prioritization.

Core Concepts: We name the science driven traverse planning concept that we are developing Systematic Traverse Engineering with Integrated Ellipses (STEWIE). The target application of this concept revolves around using geologic maps and high-resolution topographic data to define and update the operable space within mission limitations for a set of EVA science objectives. STEWIE initially defines the overall traversable area (*i.e.*, "ellipse") as a series of overlapping ellipses that become progressively smaller as EVA limitations increase. Likewise, pre-determined and prioritized science stations are liable to be *re*-prioritized across the extravehicular activity (EVA) timeline due to observations made at and between stations as well as shrinking consumables and remaining time. For example, Station #3 of a hypothetical traverse might be moved, re-prioritized, or scrapped entirely based on what was observed at Station #1 and how long science observations took at Station #2. As a result, the maximum spatial extent of exploration at any given point in the EVA depends on the remaining time and the priority ranking of stations. Eventually, the only possible route is a return to base camp.

STEWIE's constituent components are (1) a cost surface covering the entire potential area of operation, (2) a set of prioritized points (*i.e.,* science stations), and (3) beginning and end locations. Creating a cost surface is highly specific to the method of travel, such as walking or roving, and operational constraints, such as maximum slopes, line-of-sight restrictions, and local hazards. A cost surface is a synthesized raster dataset that weights and integrates several independent datasets of comparable spatial resolution, which most accurately depict the "cost" of traversing a single cell, normalized to consumable factor (*e.g.,* time, energy, oxygen). Inputs factors include slope, geologic composition, predicted slippage, viewshed, local roughness, hazards, and solar exposure. Because each of these factors require significant testing, refinement, and operational-specific parameters, there is no single algorithm that can be universally applicable to a body or mission. However, we intend to employ an iterative process of modeling these factors, testing them in the field, then gathering *in situ* feedback during surface operations to streamline adaptation of STEWIE in new areas of interest.

Proof of Concept: We used the ModelBuilder environment in Esri's ArcGIS to bring together its robust cost surface and network analysis geoprocessing tools to create a seamless STEWIE conceptual prototype. ModelBuilder's simple interface supports drag-and-drop geoprocessing with built-in validation and the ability to export to a Python script for further customization. The initial tool demonstrates how traverses between a starting point and multiple science stations can optimize observations while accounting for time/energy allocation and science priorities. The proof of concept for this prototype uses a slope map as the cost surface. This simplified approach allowed rapid testing and refinement of the logical execution of STEWIE without concern for adhering to real operational constraints. The STEWIE prototype has the following functionalities: Given a user defined maximum slope, the toolset creates a mask of the contiguously traversable area that contains the starting point and removes any objectives which are not within the masked area. Next, a least cost path analysis is performed for each objective to all others and merged, creating a network of all possible paths between points (**Figure 1A**). The network is then segmented by pixel boundaries and attributed with the inverse value of the slope (*i.e.*, higher slopes are more difficult to traverse so they need a lower 'speed'). This network and valid points are used as input for the Network Analyst geoprocessing tool to solve for the most efficient route as if it were a road system (**Figure 1B**).

Next Steps: The following functionalities are our next priorities for the STEWIE concept: (1) modelling rapid return-to-base routes to account for EVA malfunctions, (2) objectives that are dynamic based on syn-EVA science observations, (3) user-defined limitation parameters, and (4) real-time calculation and display of the total traversable ellipse. Eventually, we aim to advance this work through concept testing in the field (which will involve both rate and movement testing and comparison of STEWIE-predicted versus actual EVA for routes and traverse rates), software development to create an open-source standalone application, and optimized calculation of cost surfaces.

We envision future versions of STEWIE to significantly contribute to the following objectives and scenarios: (1) estimate traversable envelopes around a static base camp by analyzing best routes fo cardinal directions, (2) use geologic maps and slopes to help assess rates of movement across lunar terrain, (3) integrate GO-NO GO regions for EVA planning, (4) re-prioritizing, adding, and (or) removing science stations, and (5) including an immediate return to all time stamps.

References: [1] Helmich *et al.* (2007) *Aerospace Conference*. [2] Estlin *et al.* (2007) *Robotics and Automation*, [3] Heldmann *et al.* (2016), [4] Ono *et al.* (2015) *IEEE Aerospace Conference*, [5] Speyerer *et al.* (2013) *LPSC XLIV #1745*, [6] Rekleitis *et al.* (2009) *Experimental Robotics*, [7] Speyerer *et al.* (2016) *Icarus 273*, [8] Esri (2015) *Algorithms used by the ArcGIS Network Analyst Extension*.

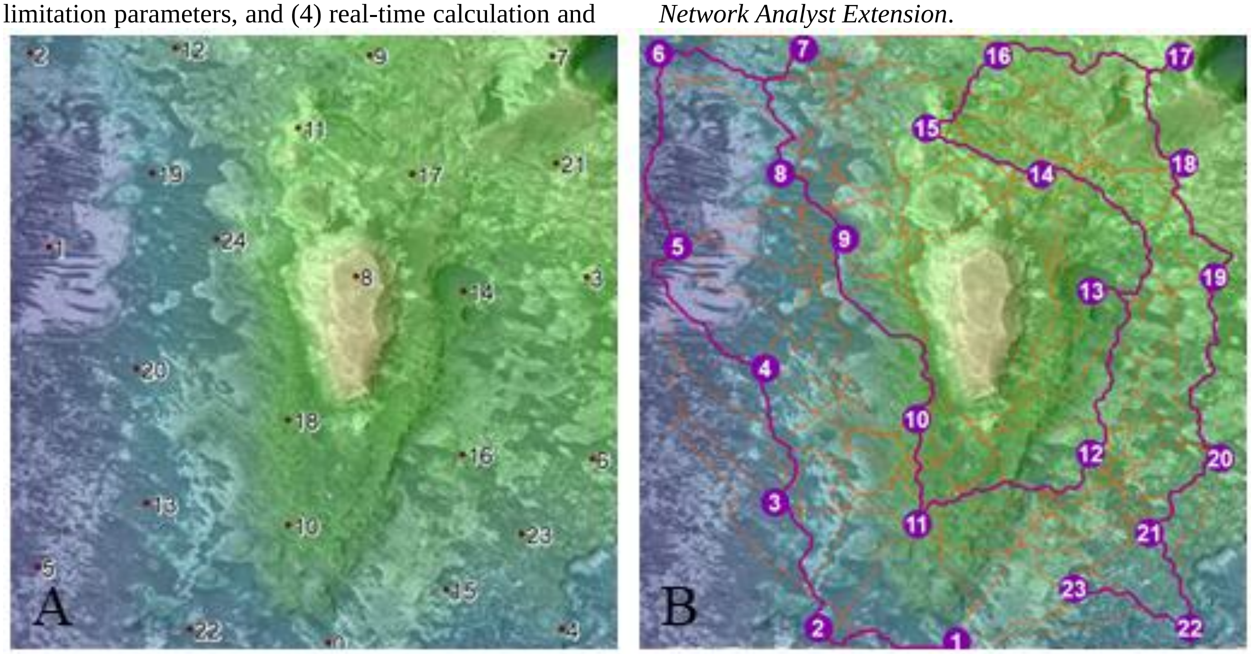

Figure 1. The constituent components of STEWIE concepts demonstrated on a HiRISE DEM in the Hadriacus Cavi region, Mars. Each panel is approximately 1 km across. Cool colors are low and warm colors are high. (**A**) Numbered stations overlain on the region of interest. Numbers are randomly ordered. Note the existence of location 8 on top of a 150 m tall mesa. (**B**) The network of least cost paths between all valid points (location 8 from A is removed due to slope inaccessibility), and network solution illustrating the most efficient route between all valid points.