TRAVERSE PLANNING USING ELEVATION MODELS DERIVED FROM LROC NAC IMAGES. E. J. Speyerer[1], S. J. Lawrence[1], J. D. Stopar[1], and M. S. Robinson[1], [1]School of Earth and Space Exploration, Arizona State University, Tempe, AZ (espeyerer@ser.asu.edu).

Introduction: Recent lunar missions provide the planetary scientist community with vast amounts of new data enabling important insights into the geology of the Moon. In order to fully leverage these remotely sensed data products, future landers, rovers, and/or human explorers must collect precise ground-truth measurements. To facilitate the planning of these future surface missions, the Narrow Angle Camera (NAC) on the Lunar Reconnaissance Orbiter (LRO) has collected 0.5 m scale images of key exploration sites [1-6]. Analyses of the images reveal potential landing areas, sampling locations, and meter scale hazards. Using digital elevation models (DEMs) derived from NAC stereo observations [7] and datasets from other LRO instruments and recent missions, we have developed a tool to plan least energy traverse paths for future surface operations.

Traverse Planning Algorithm: To locate potential traverse options, a graph data structure is created to cover the entire exploration site (**Fig. 1**). The graph is made up of a grid of evenly spaced nodes that are typically several meters to 10s of meters apart. Each of the nodes is connected to up to eight neighboring nodes and each connection, or edge, is assigned a value that corresponds to the amount of energy required to traverse from the current node to the corresponding neighboring node.

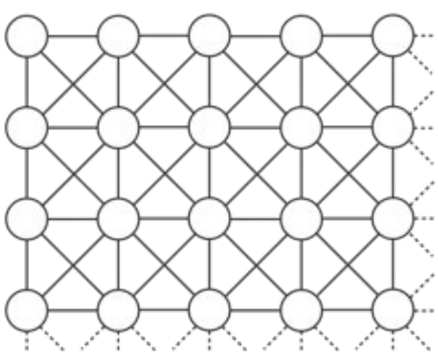

Figure 1. Example of the graph data structure

Dijkstra's graph search algorithm [8] is used to locate the least energy traverse from an initial node such as a landing site to all other nodes in the region of interest. An example of the algorithm is shown in **Fig. 2**. In this example, the starting point is the blue node in the upper left hand corner. In the initial state, the starting node has a value of 0 assigned to it while the remaining nodes have a weight of ∞ and are marked as unvisited. From the starting node, the energy required to traverse to the neighboring unvisited nodes is calculated and the values are applied to the corresponding nodes (UL → LL = 0 + 4 = 4; UL → UC = 0 + 10 = 10; UC → LC = 0 + 8 = 8). The initial node is then marked as visited and the process is repeated at the unvisited node with the lowest value, which in this case is the lower left node with a value of 4. From there, the energy required to traverse to the neighboring unvisited nodes is calculated (LL → LC = 4 + 2 = 6). Since this new value (6) is less than its previous assigned value (8), the node's value is replaced with the lower value. The lower left node is then marked as visited and the process repeats until the all the nodes in the graph are visited. Once completed the least energy path from the initial node to any other node in the graph is known.

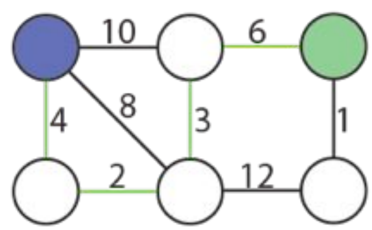

Fig. 2. Example of Dijkstra's algorithm with the green lines denoting the least energy path from the upper left to upper right node.

To calculate the least energy traverse for a given exploration site, the weights for each connection are dependent on an array of variables derived from the NAC DEM of the site, the model rover, and other data sources. For many of the key exploration sites, 0.5 m stereo observations were acquired with the NAC during the nominal LRO mission. From these stereo image sets, DEMs are generated with a typical ground sampling distance of 2 m. From the DEM, slope and corresponding aspect maps are derived. Based on the change in elevation, a weight is applied to each connection in the graph. This calculated weight is dependent on the orientation and direction of the slope. For example, a rover would require more energy to traverse up a slope than down the same slope. Likewise, a rover of a predefined design may be limited to a range of slopes (both down-track and cross-track) it can handle. If such a slope is identified, a weight of ∞ is applied to the corresponding connection.

Additional weights are applied to each connection based on the rover capabilities and the estimated surface properties of the site. For example, a large, heavy rover would require more energy to traverse the same distance than a smaller, more agile rover. However, a larger rover might handle rougher terrain better, giving it the advantage for a particular exploration site.

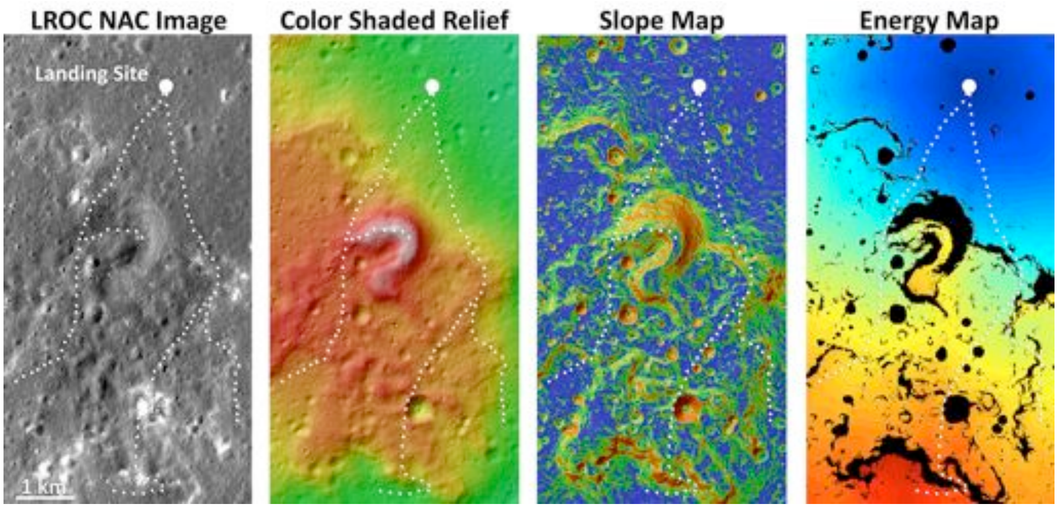

Fig. 3. Several potential low energy rover traverses in the Marius Hills region plotted on a NAC image (M111965782L/R) and corresponding shaded relief, slope, and energy map derived from a NAC DEM.

Traverse Maps: Maps derived from this algorithm show the energy required to traverse from the initial node to all the other nodes in the network (**Fig. 3**; far right). These maps also identify areas that are not accessible to the model rover given a predefined set of constraints such as the maximum traversable slope (black regions in the energy map). When using Dijkstra's graph search algorithm, the lowest cost path to travel to each node in the network is also stored. By selecting any traversable point on the map, the lowest cost path from the initial node is identified (**Fig. 3**; white dotted lines denote potential traverses to four potential measurement sites).

By studying NAC images and datasets acquired by other instruments on LRO and other recent missions, key sampling targets can be identified. Using our proposed framework, a traverse plan from a safe landing site to an array of key science and engineering targets can be produced.

Tool for Future Exploration: A traverse planning tool such as the one employed here is key for any future lunar mission planning activities. These maps identify least energy traverse paths, as well as delimit traversable and inaccessible areas around each exploration site. We also use this tool to identify the required capabilities and operational characteristics (rolling resistance, turning capability, max slope, etc.) a future prospecting rover would need in order to reach key targets of scientific interest at a specific site (**Fig. 4**). Future model development will focus on including other datasets and cost parameters such as boulder populations derived from Diviner measurements and LOLA-derived surface roughness to the weighting scheme. In addition, we will explore developing a framework to enable time dependent weighting such as the influence of solar illumination and surface temperatures.

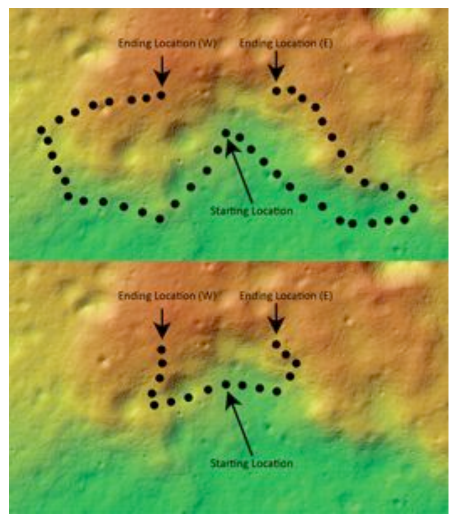

Fig. 4. (Top) Two least energy traverses in the Marius Hills region generated with a model rover that can traverse slopes up to 10° [W → 2.9 km; E → 3.0 km]. (Bottom) Two least energy traverses generated with a model rover that can traverse slopes up to 15° [W →1.0 km; E → 0.9 km].

References: [1] Robinson M. S. et al. (2010) *Space Sci. Rev.*, 150, 1-4, 81-124. [2] Gruener J. E. et al. (2009) *AGU Fall Meeting*, Abstract # U31A-0010. [3] Gruener J. E. and Joosten B. K. (2009*), LPI Contributions*, 1483, 50–51. [4] Jolliff B. L. et al. (2010) *LPS XLI,* Abstract #2412. [5] Lawrence S. J. et al. (2010) *LPI Contributions*, 1595, p. 35. [6] Lucey P. G. et al. (2009) *LPI Contributions*, 1483, pp. 73–74. [7] Burns et al. (2012) Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XXXIX-B4, 483-488. [8] Dijkstra (1959) Numerische Mathematik, 1, 269-271.