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<https://escholarship.org/uc/item/30c414w4>

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Publication Date

2009-09-15

Supplemental Material

<https://escholarship.org/uc/item/30c414w4#supplemental>

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Tobler's walking model using Optimal Path as Line or Pathdistance in ArcGIS

Original URL: <https://mapaspects.org/node/3744/>

This content also appears in this open-access UC Berkeley course
<https://bcourses.berkeley.edu/courses/1289761/pages/in-class-exercise-11-dot-2-cost-distance>

Many cartographic distance calculations are performed in coordinate systems where space is divided into equal-sized units. In practice, however, people often conceive of distances in terms of time or effort. In mountainous settings the isotropic assumptions of metric map-distance calculations are particularly misleading because altitude gained and lost, and other obstacles such as cliff faces, are typically not factored into the travel estimate. Cost-distance functions are a means of representing such distances in terms of units of time or caloric effort.

In this exercise we will use an algorithm, one based primarily on slope from a topographic surface, to derive both an optimal route across that surface (Optimal or Least-cost Path) as well as an estimated time to cross that surface. Please see the [Path distance explanation](#) from ESRI as well as the [manual on Path-distance](#) for more specifics on the feature we'll be using.

The ESRI Pathdistance function calculates movement with an 8 directional (Queen's move) algorithm and has the ability to incorporate customized anisotropy. This is a relatively sophisticated cost function as compared with other GIS environments (see [J. Herzog's 2014 paper](#) comparing various platforms).

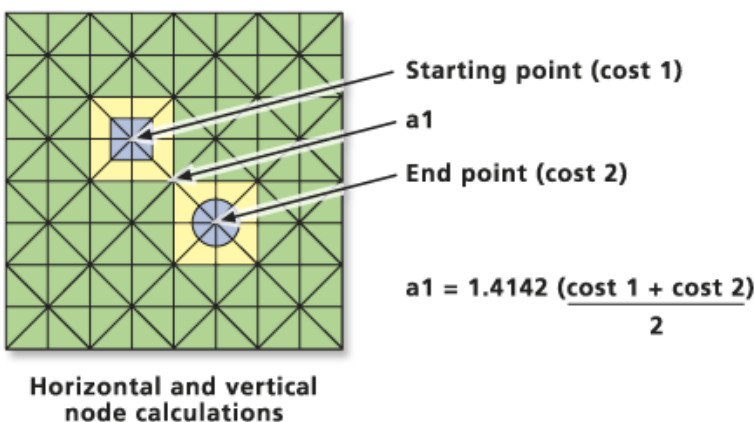


Figure 1. Explanation of Queen's move distance function from the ESRI documentation.

In this exercise we are performing a Path Distance calculation where the cost function is modified by supplying a [custom Vertical Factor Table](#) that is built from an empirically derived hiking function published by [Tobler, 1993](#). Tobler's function estimates time (hours) to cross a raster cell based on slope (rise/run) as calculated on a DEM.

I have converted data provided by Tobler into a structure that ArcGIS will accept as a [Vertical Factor Table](#) for the Path Distance function. In other words, ArcGIS makes these sorts of calculations easy by allowing you to enter customized factors to the cost function.

2023 Update: Support for a custom Vertical Factor Table has been broken in some versions of Arcmap and ArcGIS Pro. As of ArcGIS Pro 3.2 the PathDistance function is in the Distance Toolbox under Legacy. The current process is to create an Allocation and Backlink rasters using a Vertical Factor Table as described, and then calculate Optimal Path by Cell using those rasters as inputs. The Euclidean and PathDistance tools are now found under Toolbox > Spatial Analyst Tools > Distance > Legacy >

Implementation

Practice data

1. Demonstration shapefiles for the study area in Peru can be found in [Chivay shapefiles.zip](#).
https://escholarship.org/content/qt30c414w4/supp/Chivay_shapefiles.zip
Download and unzip these into your work folder.
2. The ESRI GRID raster srtm30_utm and srtm30_hs (hillshade) can be found in [DEM.zip](#).
<https://escholarship.org/content/qt30c414w4/supp/DEM.zip>
Unzip this folder into your project folder as well.

Software

This was developed using ESRI Vertical Factor tables therefore you must be running ArcGIS. Ensure you are licensed for the Spatial Analyst extension

In ArcGIS Pro: Project menu > Licensing...

If Spatial Analyst is not checked click "Configure your licensing options" button to enable.

PART A. ISOTROPIC TIME ESTIMATE

Distance and time estimates based on 4 km/hr speed on an isotropic surface

For teaching purposes I recommend having the class begin by generating a cost distance on an ISOTROPIC surface first and generate isochrones, perhaps at 15 minute intervals, on this isotropic surface. The isotropic and anisotropic results can then be compared.

The legacy tool in Pro is

Toolbox > Spatial Analyst Tools > Distance > Legacy > Euclidean Distance

Load the shapefiles **Sites.shp** and **Source.shp** into a new project. *Note that these are coordinate system UTM 18 South in Peru and a new project will assume the coordinate system of whatever data is loaded first.*

Input Feature: Source.shp

Output cell size: 30

2. Create raster showing isotropic distance in minutes

The output is a raster showing the metric distance from the site.

Let's assume for the purposes of this example that hiking speed is 4 km/hr regardless of the terrain, which works out to 1000m each 15 min.

- To transform the Euclidean Distance raster output into units of time (minutes) we can perform a Spatial Analyst menu > Raster Calculator expression using this information:
 $15 \text{ min} / 1000 \text{ meters} = 1 \text{ min} / 66.66 \text{ meters}$

To construct that equation in Raster Calculator to get the raster to display in units of minutes we would divide the distance raster by 66.66. Built up the equation like so:

[Raster name] / 66.66

3. Convert to isochrones

- Create contours using the output raster with
Spatial Analyst toolbar > Surface Analysis > Contour...
- Then use the good Calculation raster as your input surface, choose 30 as your interval and use the defaults for the rest.

The land is very steep in this area, especially in the cliff bands near the obsidian source. There must be a better way to estimate travel times!

PART B. ANISOTROPIC TIME ESTIMATE USING PATH DISTANCE or DISTANCE ACCUMULATION

An algorithm is needed to convert from Slope to Time.

In ArcGIS the PathDistance or Distance Accumulation (in new versions of Pro) functions can be used to conduct anisotropic distance calculations if we supply the function with a custom Vertical Factor Table with the degree slope in Column 1 and the appropriate vertical factor in Column 2. The vertical factor acts as a multiplier, and multiplying by a

Vertical Factor of 1 has no effect. The vertical factor table we will use was generated in Excel and it reflects Tobler's Hiking Function by using the reciprocal of Tobler's function. This function was used in Excel:

TIME (HOURS) TO CROSS 1 METER

or the reciprocal of

$$\text{Meters per Hour} = 0.000166666 * (\text{EXP}(3.5 * (\text{ABS}(\text{TAN}(\text{RADIANS}(\text{slope_deg})) + 0.05))))$$

Thus for 0 deg slope which Tobler's function computes to 5.037km/hr, the result should be $1/5037.8 = 0.000198541$

You can download the file that we will use for these values here.

<https://escholarship.org/content/qt30c414w4/supp/ToblerAway.txt>

The reverse is used for travel in the opposite direction, towards the source.

<https://escholarship.org/content/qt30c414w4/supp/ToblerTowards.txt>

An abbreviated version of this [ToblerAway](#) file looks like this

<u>Slope (deg)</u>	<u>Vertical Factor</u>
-90	-1
-80	-1
-70	2.099409721
-50	0.009064613
-30	0.001055449
-10	0.00025934
-5	0.000190035
-4	0.000178706
-3	0.000168077
-2	0.000175699
-1	0.000186775
0	0.000198541
5	0.000269672
10	0.000368021
30	0.001497754
50	0.012863298
70	2.979204206
80	-1
90	-1

Figure 2. Abbreviated version of the custom Vertical Factor table based on Tobler 1993

2. Pathdistance Calculation

Zoom your Data extent to 250,000 and pan the screen around until you can see both the Chivay Source point and the sites in the Study Area. If you are working on a laptop you may need to use a smaller scale like 1:300,000.

Go to ArcToolbox > Spatial Analyst Tools > Distance > Legacy > Path Distance...

Update: in newer versions of Pro one can use the Distance Accumulation function also found under the Distance Toolbo

- Input: ChivaySource
- Output: <default>
- Input cost:<blank>
- Input surface: *srtm30_utm* (our 30m DEM)
- Output Backlink raster: *backlink1*

- Open the "Vertical factor parameters" field
- Input Vertical Raster: *srtm30_utm*
- Vertical Factor: Table (scroll down to bottom of menu list)
- Use the ToblerAway.txt file saved to your hard drive.

If the job runs a long time and the output raster is huge you may contain the processing extent by clicking the Environments... tab > Extent: "Same as Display"

Multiply this anisotropic result by 60 because it's in **hours**.

Spatial Analyst Tools > Map Algebra > Raster Calculator...

PathDist1_shp * 60

Now generate 30 min contours on this layer as you did earlier

Turn off all layers except "srtm30_utm", the isotropic (Euclidean) contours and the anisotropic 30 min contours. Note the differences in the two cost surfaces (best to symbolize using different colors)

Info tool one can point-sample distances along the way against the isotropic and anisotropic surfaces, and subtracting one raster from another in Raster Calculator can be interesting.

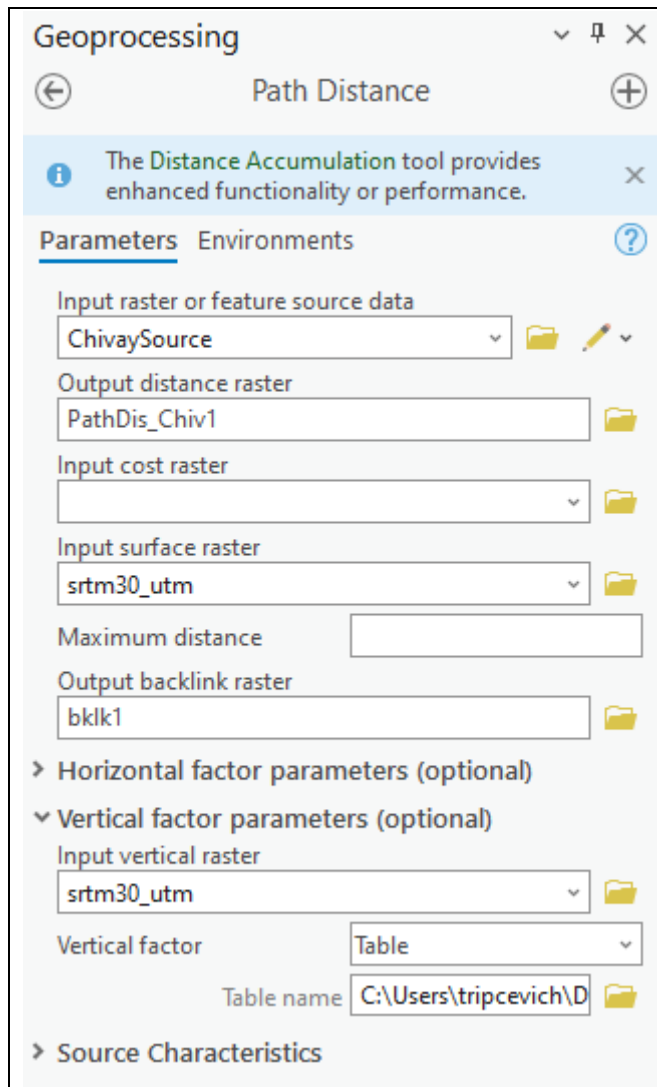


Figure 3. Legacy PathDistance function

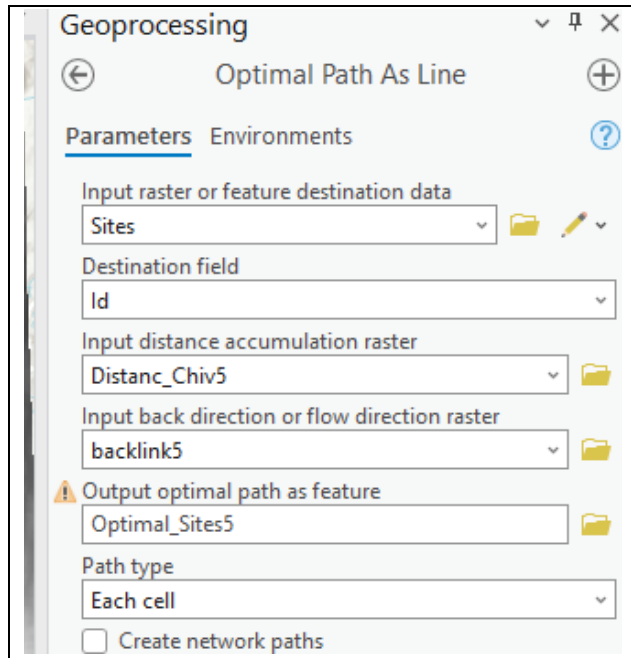


Figure 4. Optimal Path as Line from ArcGIS Pro

PART C. GENERATING LEAST-COST PATHS BETWEEN SITES

The Backlink grid generated as part of the PathDistance or Distance Allocation function will now be used to calculate least-cost paths between the source and sites in the region.

Use the legacy tool Cost Path as Polyline or, in newer versions of Pro the Optimal Path as Line tool.

- Use the Backlink grid generated earlier.
- Destinations: Sites.shp
- Input Cost Distance Raster: anisotropic_hours (use the hours not the minutes one)
- Input Cost Backlink Raster: aniso_bklk

Carefully examine the output to ensure the anisotropic analysis worked properly. Do the paths appear to avoid steep climbs and descents? Are gentle downslopes the fastest travel routes? Often paths avoid steep hills and choose to follow valleys, as you might do if you were planning to walk that distance.

If you conduct this analysis in a landscape you're familiar with do you think that the travel distance calculations are accurate?

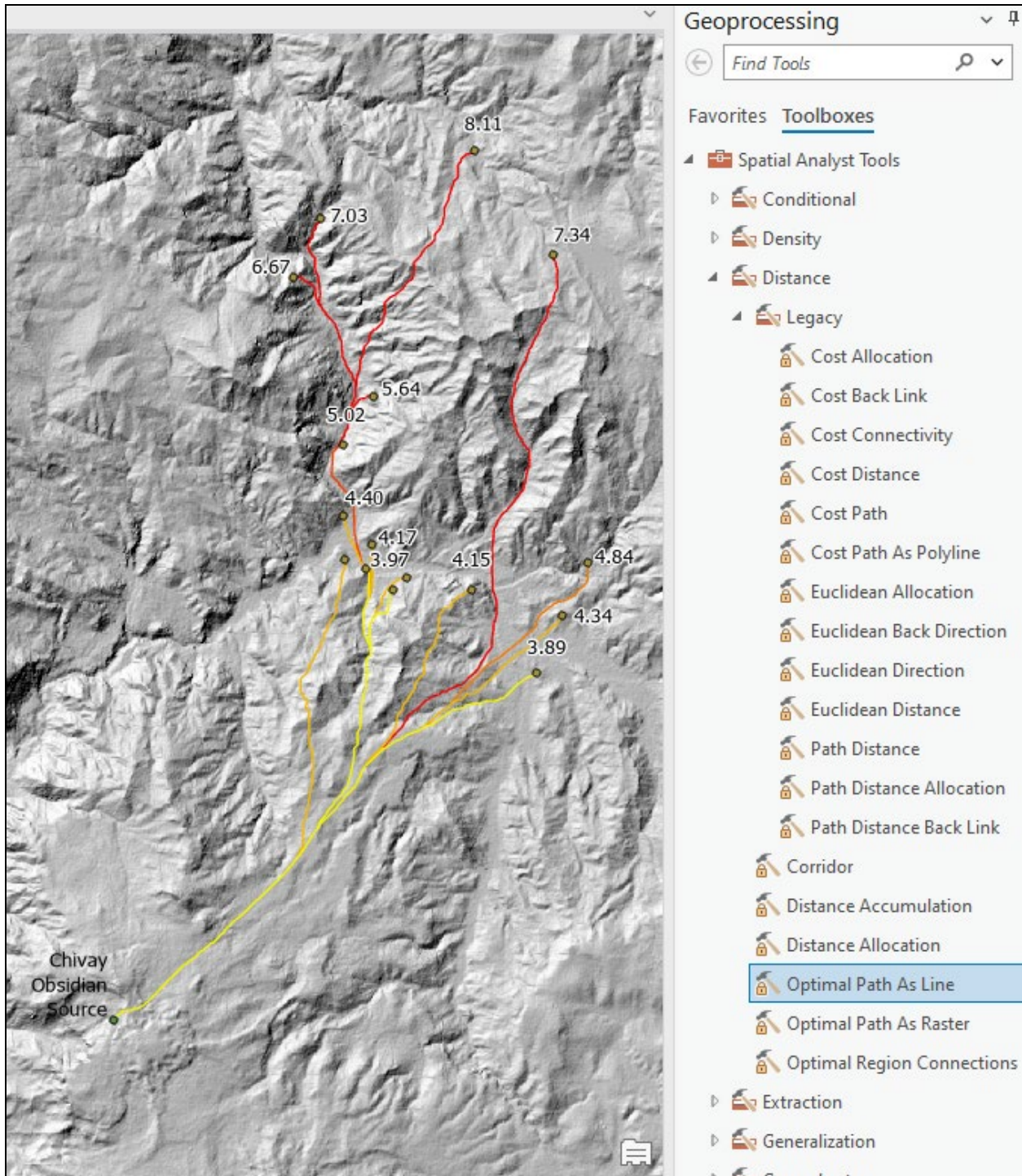


Figure 5. Geoprocessing Toolbox and output from Optimal Paths as Line at sites near the Chivay Obsidian Source