National Park Service – Natural Resource Program Center

Inventory and Monitoring Program

Travel Time Cost Surface Model

Standard Operating Procedure

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Authors: Kirk Sherrill, Brent Frakes, Stephani Schupbach, and Peter Budde

Abstract: This document presents a travel time cost surface model (TTCSM) which calculates travel time from defined point and/or linear locations to other locations within a user defined area of interest (AOI). The TTCSM is designed to model travel time in national park units using readily available geospatial products such as road, trail, and stream networks, digital elevation models and land cover data to name a few. Output from the TTCSM are point to point specific travel time least cost paths (i.e. the modeled fastest path(s)) and raster maps in which each cell value is the modeled time required to reach the given cell from the specified starting point(s).

In order to derive accurate travel time estimates, the TTCSM is intended to be dynamic in nature with the ability to accommodate user (e.g., hiker / skier / ATVer / etc.), temporal (e. g. winter / summer data collection) and park specific needs. The essence of the TTCSM is deriving a meaningful travel cost surface. Travel cost is a function of the user defined and derived cost and speed surfaces. The cost surface defines the weight or impedance of traveling through a cell, while the speed surface defines the speed at which movement within the cell occurs. Speed is a function of the user defined average walking speed and slope, except on the road network where speed is equal to the defined road speed limit. Using the derived travel cost surface, travel time calculations are performed using either traditional cost distance or more robust path distance modeling methods.

The TTCSM is intended to be used as a tool to facilitate more efficient field data sampling design and planning. Currently, the TTCSM is packaged as a python script requiring only basic understanding of python programming, and a moderate level of proficiency in GIS.

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For questions and support please contact:
Kirk Sherrill, NRPC-NPS, at (970) 267-2166, kirk_sherrill@contractor.nps.gov
Brent Frakes, NRPC-NPS, at (970) 267-2156, brent_frakes@nps.gov

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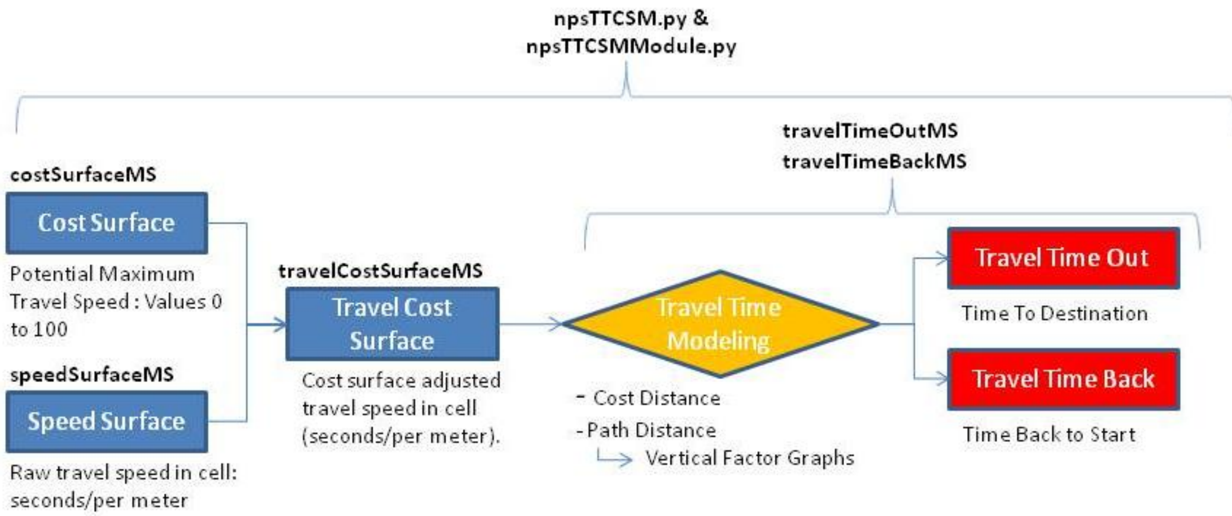
1. Introduction

The purpose of the Travel Time Cost Surface Model (**TTCSM**) is to use readily available, or easily obtainable, geospatial products in conjunction with cost distance modeling techniques in a geographic information system in order to model expected travel time from a desired location(s) to other location(s) within the defined area of interest. The TTCSM is intended to be used as a tool to help NPS staff be more efficient and effective at travel time planning efforts. An essential component of this model is the ability for the user to optimize the model in order to accurately represent their user specific needs and environments at a localized park unit scale. This document both discusses the conceptual logic of the TTCSM and also serves as a step-by-step user guide.

The TTCSM consists of five main functions: a Cost Surface (**CstSrf**), a Speed Surface (**SpdSrf**), a Travel Cost Surface (**TrCstSrf**), and Travel Time Out (**TTOut**) and Travel Time Back (**TTBack**) module. The TTCSM is pseudo linear in nature in that each function is one part of the whole model, where completion of a function is dependent upon the successful completion of the previous function within the TTCSM module script. A schematic of the model is given in Figure 1. The first function is the CstSrf model, which as the name suggests generates a CstSrf. The CstSrf defines the weight or impedance that is encountered when cross through the grid, and is defined by the input geospatial products and parameters that are tailored to meet the specific needs of the user. Next is the SpdSrf function which outputs a SpdSrf layer. The SpdSrf layer defines the velocity at which movement within a grid occurs. The TrCstSrf function outputs the TrCstSrf, which is derived by dividing the SpdSrf by the CstSrf. Finally, using the TrCstSrf, the TTOut and TTBack functions perform travel time modeling using either cost or path distance modeling methods.

Figure 1. Travel Time Cost Surface Model Schematic



The TTCSM can be used to derive one way or round trip travel times from the defined starting point(s). Standard model output includes a one-way distance travel time grid which has the travel time required to reach all other locations within the area of interest. Additionally, if specified, one way (travel out) or round trip (travel out and back) travel time least cost paths from the defined start and destination point(s) will be calculated.

The rest of this document will discuss the requirements needed to run the TTCSM, as well as provide a more thorough discussion of each of the aforementioned functions and introduced topics.

2. Cost Surface

Developing a representative CstSrf model is the first step in the TTCSM process. The CstSrf represents the amount of travel speed resistance or impedance which is encountered when crossing through a cell. The CstSrf model is a function of the variables used to define the user and park-specific travel costs when traveling through the landscape.

CstSrf generation is accomplished in an overlay manner, where all input layers are ranked in an order of overlay preference and subsequently stacked upon each other in the defined order. A key step in the TTCSM process is determining the data layers to use in CstSrf generation, assigning a Percent of Maximum Travel Speed (PMTS) for each layer, and determining the logic by which the layers will be overlaid. PMTS is defined as the percentage of maximum speed when compared to a travel time while walking on a smooth, cement path. PMTS is inversely related to travel time. As Table 1 shows, travel time increases exponentially as the relative PMTS approaches zero (Table 1).

Table 1. PMTS versus Travel Time

PMTS (% of maximum Speed)	Travel Time Units (e.g., Minutes)
100	1.0
95	1.1
90	1.1
85	1.2
80	1.3
75	1.3
70	1.4
65	1.5
60	1.7
55	1.8
50	2.0
45	2.2
40	2.5
35	2.9
30	3.3
25	4.0
20	5.0
15	6.7
10	10.0
5	20.0
0	Indefinite (Forever)

When traveling by foot, travel speed can be positively or negatively influenced by numerous factors. Possible CstSrf factors affecting the PMTS could include variables related to the presence or absence of trails and streams, terrain (slope, cliffs, etc.), land cover, soil types, and seasonality influenced travel factors (ex. snow versus mud season, etc.), to name a few. The number of relevant and important CstSrf factors to include in CstSrf generation is only limited by geospatial data availability and the desired level of complexity to incorporate in the travel time analysis. For each input variable travel cost factors are incorporated into the CstSrf model by assigning a PMTS value, where PMTS values range between 0 and 100.

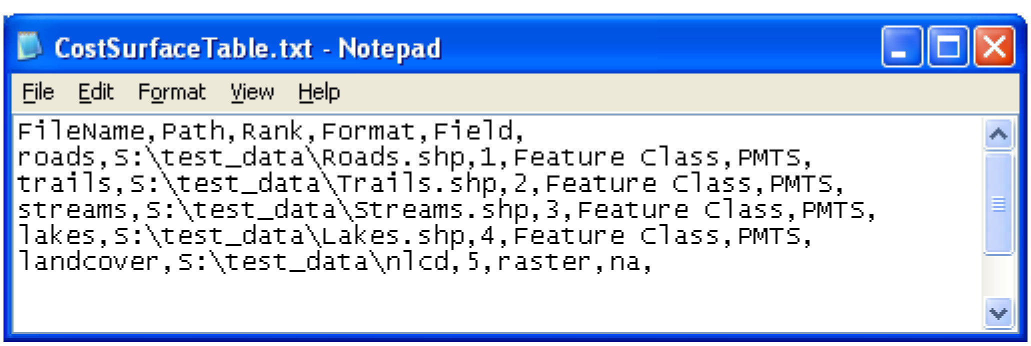
- A value of 0 represents an absolute barrier, indicating 0% movement relative to normal conditions.
- A value of 100 represents no impairment. Movement is 100% of what it would be without influence from a particular layer.
- A value of 50 is 50% as fast as it would be without the layer and takes twice as long to traverse.
- A value of 25 is 25% as fast as it would be without the layer and takes four times as long to traverse.

A CstSrf table is used to define the CstSrf factors, the PMTS that each factor will have, and the overlay logic that will be used to develop the CstSrf. This table should be in the format of a comma delimited text file where each row below the header line represents a CstSrf factor to be used in CstSrf generation. Data layers should be listed in the order that the layers are to be overlaid. Table 2 provides a description of the 5 fields that must be defined for each CstSrf factor, while an example CstSrf table is given in Figure 2.

Table 2. Cost Surface Table Description.

Header	Description
File Name	Generic Name of the CstSrf factor data layer.
Path	The absolute path to the CstSrf factor data layer.
Rank	The overlay ranking/order, a rank of 1 is the highest with order being sequential after this. A ranking of 1 represents the top most layer in the CstSrf while the lowest ranking represents the base (bottom) layer.
Format	The input layer format defined as either “Feature Class” or “Raster”.
Field	The field defining the PMTS. PMTS must be defined between 0 and 100.

Figure 2. Example CstSrf Impedance Table, “Standard” Scenario.




```
FileName,Path,Rank,Format,Field,
roads,S:\test_data\Roads.shp,1,Feature Class,PMTS,
trails,S:\test_data\Trails.shp,2,Feature Class,PMTS,
streams,S:\test_data\Streams.shp,3,Feature Class,PMTS,
lakes,S:\test_data\Lakes.shp,4,Feature Class,PMTS,
landcover,S:\test_data\nlcd,5,raster,na,
```

When using the TTCSM, likely the most difficult step in the work flow is determining which CstSrf factors to use and what PMTS values these factors should have. The key to successful CstSrf model development is (1) using your personal experience and knowledge of how each factor impacts travel; and/or (2) utilizing the cumulative knowledge and expert experience that is available from other staff members within your park. For example you could send out a questionnaire to park staff asking them to evaluate the impedance that is appropriate for the various land cover types.

2.1. Cost Surface Example

In this section a sample CstSrf model will be defined using what will be termed the “standard” TTCSM scenario. In the “standard” scenario the CstSrf is a function of five (5) CstSrf factors which are listed in decreasing overlay rank: roads, trails, streams, lakes, and land cover. Figure 2, is an example of a “standard” scenario CstSrf table. The methods outlined are quite general, and attempts should be made to gather as much information about each layer as possible. Knowing what cost values to assign to various layers is not an easy task. The following section provides examples that should not be considered as definitive cost values; ***your final CstSrf and the associated PMTS values should be carefully evaluated for each situation, tailored to your needs, and confirmed in the field.***

2.1.1. Streams

For streams, the Strahler (or Shreves) stream order provides a consistent and simple means of assigning travel cost (Table 3). In this case, order was calculated from the high resolution (1:24,000) National Hydrography Dataset (NHD 2006).

Table 3. Stream order and the corresponding PMTS.

Strahler Order	PMTS (% of normal)
1	70
2	60
3	50
4	30
5	20
6	10

2.1.2. Lakes

Unless boats or other watercraft are available to transport field crew across lakes, it is recommended to assign lakes as an absolute barrier to travel (i.e., 0).

2.1.3. Trails

In our example, trail condition was unknown, so we gave all trails a PMTS of 100. This value of 100 is based on the assumption that on-trail obstacles are absent. For this layer, the PMTS values may most accurately be defined by giving a questionnaire or through personal communication with park staff that have on the ground knowledge of trail conditions.

2.1.4. Landover

There are a number of potential land cover data sets that can be used, including the National Land Cover Dataset (NLCD 1992), GAP data (GAP 2006), or a local park vegetation map. In our example, we use the NLCD dataset. Table 4 shows the example costs for Rocky Mountain National Park.

The land cover data will need to be reclassified with an appropriate PMTS for each land cover class. Reclassification can be done using the reclassify tool in ArcGIS. If the user has a locally derived polygon land cover data set, it will need to be converted to a raster using a cell size equal to the DEM being used in the TTCSM. When using a polygon land cover dataset, it is important to understand how the water polygons overlap or do not overlap with the streams and lakes layer being using the analysis. In cases where the two do not overlap, water may be over represented.

Table 4. Example costs assigned to NCLD cover classes

NLCD Cover Class	PMTS (% of normal)
Open Water	0
Perennial Ice/Snow	15
Developed, Open Space	90
Developed, Low Intensity	90
Developed, Medium Intensity	90
Developed, High Intensity	95
Barren land	10
Deciduous Forest	70
Evergreen Forest	65
Mixed Forest	75

Dwarf/Scrub	75
Shrub/Scrub	75
Grassland/Herbaceous	80
Pasture/Hay	80
Cultivated Crops	80
Woody Wetlands	20
Emergent Herbaceous Wetlands	25

2.1.5. Roads

Roads travel speed is assumed to be a factor of the speed limit and/or road conditions, thus in most situation roads will be assigned a PMTS of 100. Road network travel speed (miles/hour) is defined by the "Velocity" field during SpdSrf generation.

3. Speed Surface

The SpdSrf module creates a grid which defines the travel speed, in seconds per meters, at which movement within a cell occurs. The SpdSrf is a function of three factors, road network speed, trail speed, and hillside slope speed. Trail speed and hillside slope speed are adjusted to reflect the user defined average walking speed on a flat smooth surface. After the three aforementioned speeds have been derived, the SpdSrf is generated in an overlay manner. The SpdSrf overlay order from the top layer to the base layer is 1) road network, 2) trail speed (i.e., trail network) and, 3) hillside slope.

3.1. Speed Calculation

Potential speed along a road is determined only by the speed limit with the assumption that the vehicle is powerful enough to maintain the speed for even the steepest hills. Road speed in miles/per hour is defined by the "Velocity" field in the road network layer. Trail and hillside slope speed are determined by slope (Degrees) (Theobald, 2010; Tobler 1993) where:

$$6 * EXP\left(-3.5 * ABS\left(TAN\left(\frac{Slope}{57.29578}\right) + 0.05\right)\right).$$

From this equation travel speed on a flat (slope equals zero) smooth surface is equal to 3.13 miles/hour. The TTCSM can be optimized to a more representative flat surface average travel speed using the "walkingSpeed" variable. The "walkingSpeed" variable in the master script defines the user specific average flat surface travel speed (in miles/hour). This average walking speed is independent of all other travel cost factors and is used to optimize the TTCSM to the appropriate walking speed per modeled scenario. Model default flat surface average travel speed is 3.13 miles per hour, this value should be changed as needed.

Where a trail exists, the slope is calculated to follow the contour of the trail, and speed calculation is performed using trail slope rather than the hillside slope. This is accomplished by calculating the slope along the trail and then subsequently overlaying the trail slope layer onto the hill side slope layer. Use of a modified trail slope layer can be justified because trails often follow a contour and are not as steep as the adjacent hillside.

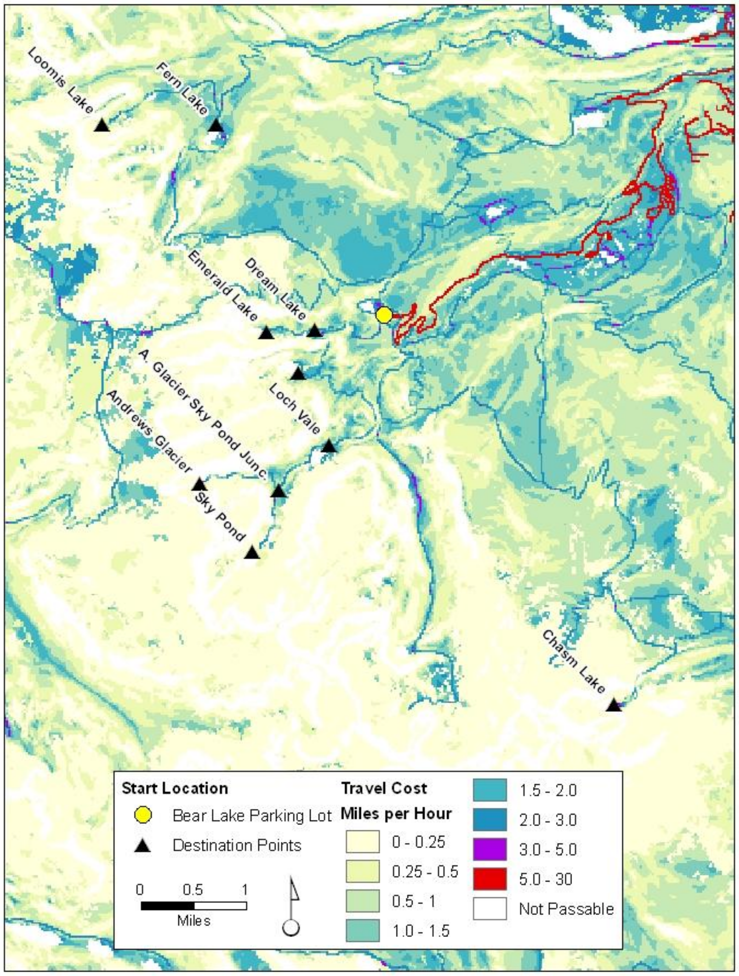
A maximum slope can be defined in order to specify a value above which a hillside is considered a cliff and is considered as an absolute barrier to travel. The model default is 40 degrees, although this may vary depending on land cover, hiking skills, gear, etc.

Slope directionality is not incorporated in the SpdSrf calculations, thus regardless of whether someone is traveling up or down a hill, travel speed will be slower than traveling along a flat path. In the TTCSM, the affect of slope directionality (with or against gravity) can be addressed using path distance travel time modeling. Path distance modeling will be further discussed in the travel time path distance modeling (Section 5.12).

4. Travel Cost Surface

After the CstSrf and SpdSrf grids have been developed, the SpdSrf is divided by the CstSrf to yield the TrCstSrf. The TrCstSrf has the final travel speed (seconds/meter) at which movement with a cell occurs after accounting for the resistance which was defined in the CstSrf. For ease of interpretation a miles/hour TrCstSrf is also calculated and saved in the output directory (travelCostMph.img). An example miles/hour TrCstSrf for a section of Rocky Mountain National Park is shown in Figure 3.

Figure 3. Travel Cost Surface in Miles/Hour.



5. Travel Time Modeling

Using the TrCstSrf the last step in the TTCSM process is to calculate travel time using either cost distance or path distance least-cost path modeling.

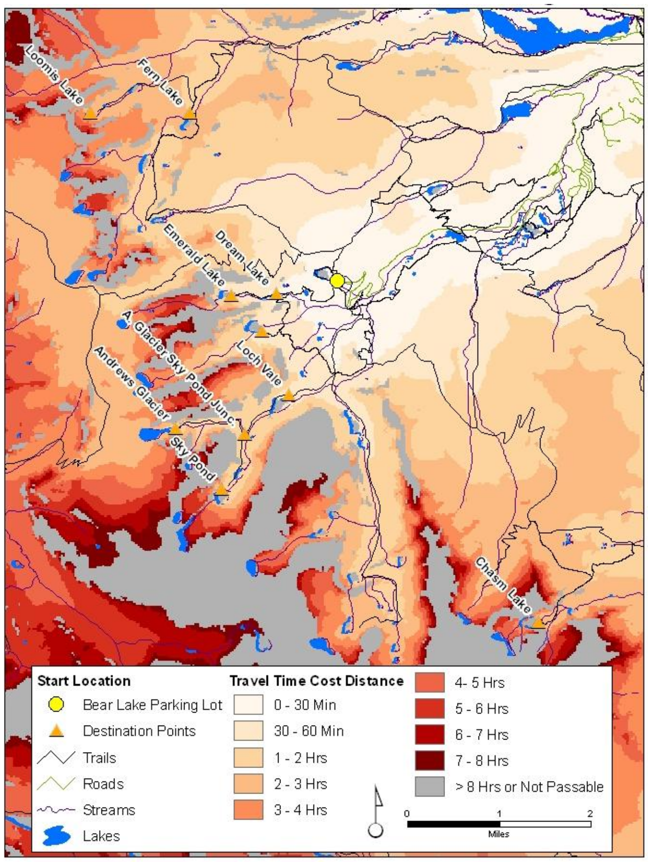
5.1. Cost Distance Modeling

Cost distance modeling calculates travel time using the ArcGIS Cost Distance function (ArcGIS 9.3 Cost Distance). Cost distance calculates the least accumulative cost distance to move from each cell to the nearest source cell. The cost of traveling through a cell is calculated by multiplying the cost per unit distance, as defined by the TrCstSrf (seconds/per meter), times the grid cell resolution and also accounting for diagonal distance when appropriate. In this manner the least accumulative travel cost is calculated from the defined starting location(s) to all other cells within the area of interest.

- If cost distance modeling is desired the "**usePathDistance"** variable (in the TTCSM Master Script) should be left undefined (i.e. usePathDistance = " ").
- Cost distance modeling output is three grid layers (timehours, timemin, and timeseconds) which represent the travel time required to reach each cell within the area of interest in hours, minutes and seconds.

An example travel time cost surface derived using cost distance modeling is shown in Figure 4

Figure 4. Travel times for a TTCSM which used Cost Distance modeling. The grayed area represent locations which have; modeled travel time greater than 8 hours; or are on slopes greater than the defined maximum slope of 40 degrees; or a lake surface.



5.2. Path Distance Modeling

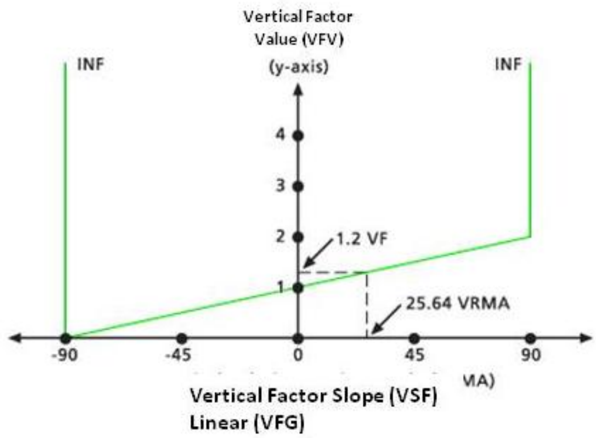
A more complex and potentially more realistic method of calculating travel time distance is to use path distance modeling with the ArcGIS Path Distance function (ArcGIS Path Distance). Path distance modeling allows for the inclusion of additional travel cost factors when calculating travel time distances using least-cost path methods. Path distance calculates the accumulative cost to travel over a cost surface (the TrCstSrf in this case), while also compensating for the actual surface distance that must be traveled in the horizontal and vertical directions as defined by horizontal and vertical factors.

Path distance modeling is used to account for the anisotropic nature of movement based on slope. In other words, it accounts for directional differences in travel speed when traveling upslope versus downslope. While slope is the primary factor in the SpdSrf calculation, these speed calculations are isotropic, in that the calculated speeds are assumed to be the same regardless of slope directionality. Obviously in practice this is usually not the case. In certain situations going down slope might be faster than going upslope and vice versa. Path distance modeling allows users to account for directionally depended (anisotropic) travel speed differences based on slope, which represents the major advantage of using path distance modeling over cost distance modeling.

In the TTCSM, only the vertical factor (VF) option of the path distance function is utilized. Using a DEM as the vertical factor raster, during least-cost path analysis the slope between the origin cell and the adjacent destination cell is calculated. Using this directionally dependent Vertical Factor Slope (VFS), the VFS is graphed on a VF Graph (VFG) in order to define a Vertical Factor Value (VFV). The VFV can be considered a slope correction value which is multiplied on the previously defined TrCstSrf to yield the final slope adjusted TrCstSrf to be used in travel time modeling.

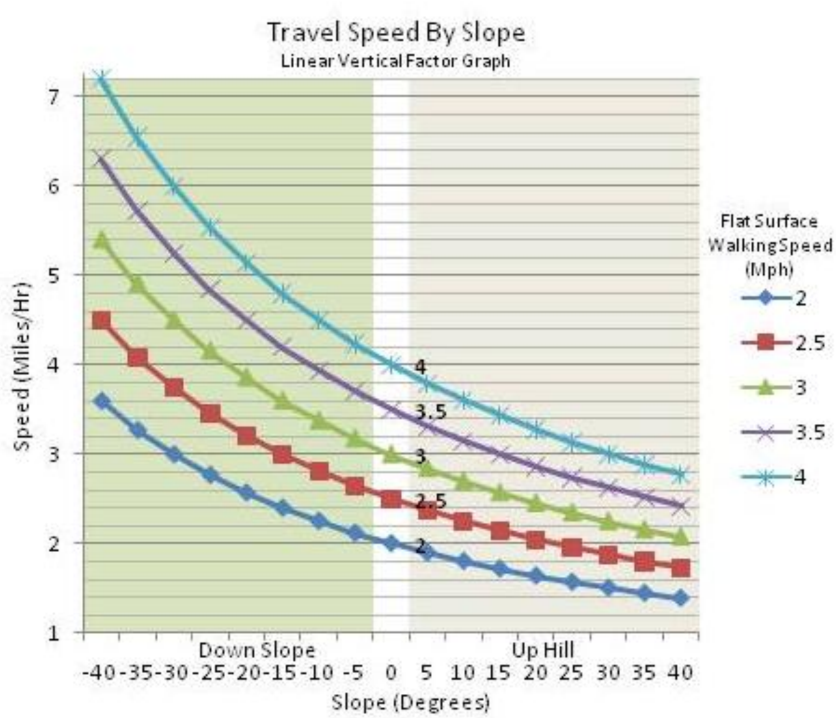
An import step when using path distance modeling is selecting the VFG which meets the needs of your modeling scenario. A “linear” VFG is shown in Figure 4. This VFG has an increasing VFV when travel upslope, and a decreasing VFV when traveling downslope. Thus a “linear” VFG yields a reduced travel speed (i.e. takes more time) when traveling upslope (i.e. uphill) and increased travel speed when traveling down slope (i.e. downhill).

Figure 5. A Linear Vertical Factor Graph (ArcGIS).



To illustrate the influence of slope on travel speed when using path distance modeling, figure 6 graphs travel speed for five common average walking speeds across a range of slopes from -40 to 40 degrees. In this scenario if you had an average flat surface walking speed of 3 miles/hour, when walking uphill and downhill on a 40 degree slope (this is very step) your travel speed in miles/hour would be ~ 2, ~5.4 respectively. In this example the slope correction value (the VFV) was calculated using a "linear" VFG.

Figure 6. Travel speed by slope for five flat surface walking speeds when using path distance modeling with a "linear" VFG.



The ArcGIS path distance tool comes with 9 predefined vertical factor graphs. Additionally there is the option of defining your own VFG using a space delimited ASCII table. Please see Section 9.2 for graphs of the predefined VFG's and an example user defined VFG table.

To use path distance modeling four input variables must be defined in the TTCSM master script:

- **"usePathDistance"** = "yes" if path distance modeling is desired.
- **"vertValueZero**" = "1", this represents the VFV at a VSF value of zero. Usually this will be 1, but this can be changed as desired.
- **verticalGraphType** = " " , The user specified VFG to be used. (i.e. "Linear", "Inverse_Linear", "Table", etc.
- **verticalGraph** = " " , path to the user defined VFG ("Table"), if this option is selected.

For a more in depth discussion on the path distance function go to the ArcGIS Desktop Help interface and type *path distance function*. A comparison of cost distance versus path distance travel time with three different VFG is shown in Table 5.

The TTCSM travel times given in table 5 represent the one-way travel time using the "standard" scenario input layers for CstSrf development (i.e. roads, trails, streams, lakes, and land cover). The modeled starting point was Bear Lake parking lot in Rocky Mountain National Park. For the 10 selected destination locations the majority of one way travel would be upslope, which can be seen by the increased estimated travel time for the path distance calculations. Among the path distance models, the "Inverse Linear" and "Custom Table" VFGs more heavily weight uphill travel then the "Linear" VFG resulting in an increased travel time to reach the destination. The Cost Distance travel time is less than all the path distance estimates because the model doesn't account for difference in travel speed due to slope directionality. The user specific VFG table which was used is shown in appendix Figure 9.

Table 5. Estimated one way travel time for 4 different travel time modeling methods: Cost Distance, and Path Distance with Linear, Inverse Linear, and user specified VFG tables.

	Travel Time (Minutes) By Modeling Method			
Destination	Cost Distance	Path Distance Linear	Path Distance Inverse Linear	Path Distance Custom Table
Dream Lake	26	28	32	36

Emerald Lake	41	44	48	53
Fern Lake	119	120	122	148
Loomis Lake	158	165	183	208
Lake Haiyaha	49	54	63	70
Loch Vale	55	59	69	76
Andrews Lake/Sky Pond Trail Junction	76	81	91	100
Andrews Glacier	104	113	136	147
Sky Pond	107	115	132	147
Chasm Lake	162	173	190	214

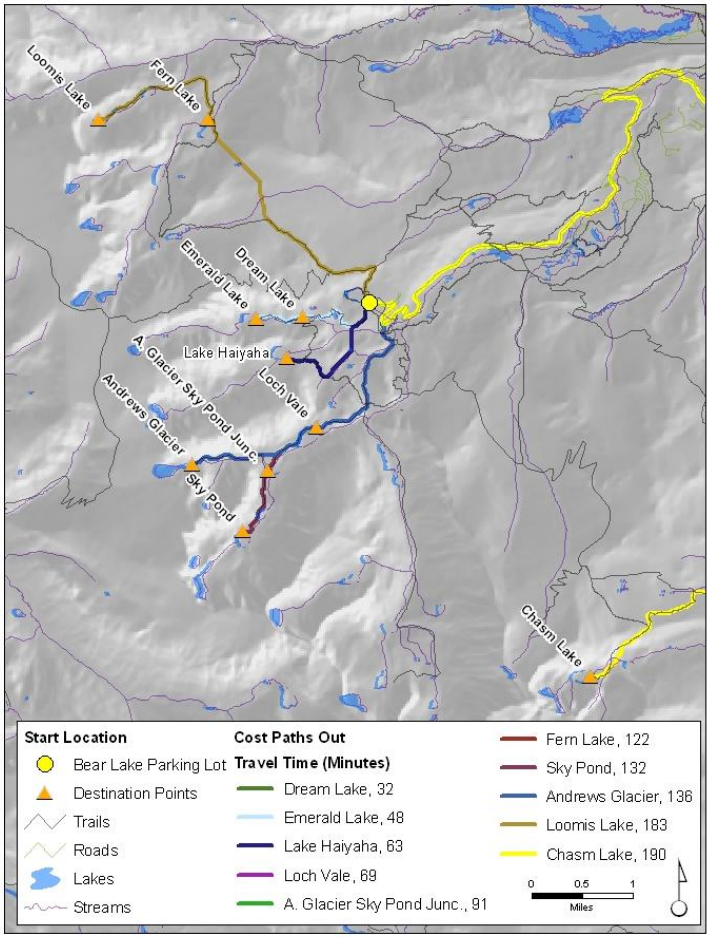
5.3. Travel Time Least Cost Paths

Travel time least cost paths can be derived from the start point to each specified location in the "destinations**"** data layer. In addition to providing the estimated travel time to reach the destination the least cost path spatially shows the modeled path (least cost) which was used.

- The cost path option is defined by the **"**leastCostPath**"** variable. For cost path calculation set to "Yes"; if this is not desired set to "No".
- The directory path to the destinations data layer must be defined using the "destinations**"** variable. The destinations data layer represents the desired locations from which the cost paths will be calculated.

An example least cost path(s) is shown in Figure 7 In this example the least cost path was derived using the inverse linear path distance travel time model.

Figure 7. Travel time least cost paths using an inverse linear path distance travel time model.



5.4. Round Trip Option

The TTCSM can be used to model either one way or round trip (out and back) travel times. Depending upon the terrain in the area of interest, the desired destination, and the mode of travel, travel out and travel back times can be substantially different. As was discussed in the path distance modeling section, if path distance modeling is used then travel speed differences related to upslope versus down slope are incorporated into the time estimate. When path distance modeling is selected, separate travel out and travel back time estimates should be performed in order to account for the time differences associated with each direction of travel. If cost distance modeling is used then the travel out and travel back times will be the same due to the isotropic nature of the model. Table 6 shows travel times for travel out, travel back and total round trip for 10 selected destinations in ROMO, with a starting point of the Bear Lake parking lot.

Table 6. Travel out, travel back and round trip travel time as estimated using an inverse linear path distance travel time model.

	Travel Time (Minutes)		
Destination	**Out Time**	**Back Time**	**Round Trip**
Dream Lake	32	23	55
Emerald Lake	48	37	85
Lake Haiyaha	63	42	105
Loch Vale	69	49	118
A. Glacier Sky Pond Junc.	91	69	160
Fern Lake	122	114	236
Sky Pond	132	94	226
Andrews Glacier	136	91	227
Loomis Lake	183	150	333
Chasm Lake	190	166	356

If round trip travel times are desired the "**timeCalculation**" variable must be set to "RoundTrip". For one way time calculations set to "Oneway".

The **"destinations"** variable directory path must be defined if round trip travel time calculations or cost path analyses are desired.

6. Running TTCSM

6.1. TTCSM Python Script

The TTCSM has been developed in the Python 2.5.1 environment and consists of one master script **npsTTCSM.*py*** and six individual functions which are housed in the npsTTCSMModule.py script. A brief description of each script and function is given in Table 7. It is recommended the TTCSM be run using PythonWin, however these scripts can also be run in the IDLE environment.

Table 7. Scripts and Functions in the TTCSM.

Travel Time Cost Surface Model	
Module Name	**Description**
npsTTCSM.py Script	Master Script defining the model workflow, data input paths and model parameters.
npsTTCSMMOdule.py Script	Script containing the python code which is associated with each of the functions in the TTCSM.
demBasedMS.function	Derives DEM related variables for use in models (i.e. Slope, Max Slope, etc.)
costSurfaceMS.fucntion	Derives the Cost Surface (CstSrf) grid.
speedSurfaceMS.function	Derives the Speed Surface (SpdSrf) grid
travelCost SurfaceMS.function	Derives the travel Cost Surface (TrCSTSrf) grid
travelTimeOutMS.function	Performs the travel time out modeling processes.
travelTimeBackMS.function	Performs the travel time back modeling processes.

6.2. Recommended Workflow

6.2.1. Step 1. Preprocessing required GIS Data

At a minimum, the data layers required to run the TTCSM are listed in Table 8.

Table 8. The required data layers to run the TTCSM.

Data Layer	TTCSM Variable Name	Description
Start Location(s)	**startLocation**	Feature class with the defined starting point(s) and/or linear corridor start locations for travel time calculations.
Roads	**roadsData**	Roads Feature Class, with 'PMTS' and 'Velocity' fields, for the CstSrf and SpdSrf modules respectively.
Trails	**trailsData**	Trails Feature Class, with a 'PMTS' field, for the CstSrf module. Model can be run without trail data, must set 'trail' variable to "no".
Digital Elevation Model	**DEM**	Digital Elevation Model.
CstSrf Table	**costSurfaceTable**	Table used to define the CstSrf factors, the PMTS for each factor, and the overlay logic. Table should be a comma delimited text file.

- It is recommended that at least one of the overlay data layers used in the CstSrf process be continuous across the area of analysis. Having at least one continuous layer will insure that all cells have a defined PMTS (i.e. CstSrf weight) in the CstSrf.

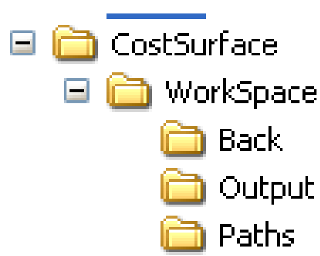
A land cover classification in most situations can be used as the continuous base layer in the CstSrf process; however other data types can be used.

- Every CstSrf feature class layer must a have a ‘PMTS’ field defining the Percent Maximum Travel Speed (PMTS). This ‘PMTS’ field is defined in the CstSrf table by the field variable.
- The Road Network in additional to a ‘PMTS’ field must also have a ‘Velocity’ field defining in miles/hour the travel speed on the respective road.

After the required GIS data layers have been identified and preprocessed, model parameters for the TTCSM python script (ttcsmMasterScript.py) must be defined.

6.2.2. Step 2. Setting up the workspace

When running the TTCSM it is necessary to set up a workspace directory structure. In order to decrease the time needed to run the model it is recommended that the user run the model locally. The workspace directory needs to be setup with three folders: back, output, and path.



- Workspace – will be the root workspace location.
- Back – directory with data created for the TTBack calculations.
- Output - directory with all the final data products.
- Paths – directory with data created for the TTOut calculations.

6.3. Step 3. Setting up the Master Script (ttcsmMasterScript.py)

A screen shot of the three sections within the master script that require manual manipulation prior to running the TTCSM is shown in Figure 8.

Figure 8. ttcsmMasterScript.py variables requiring hard coding.

ttcsmMasterScript.py

```
## Required Data Layers

startLocation= "S:\\ksherrill\\costsurface_test\\test_data\\start_bearlake_pl.shp"
roadsData = "S:\\ksherrill\\costsurface_test\\test_data\\Roads.shp"
trailsData = "S:\\ksherrill\\costsurface_test\\test_data\\Trails.shp"
DEM = "S:\\ksherrill\\costsurface_test\\test_data\\dem"
destinations = "S:\\ksherrill\\costsurface_test\\test_data\\Destination_PointsTwo.shp"
costSurfaceTable = "S:\\ksherrill\\costsurface_test\\workspace\\costSurfaceTable.txt"
workspace = "S:\\ksherrill\\costsurface_test\\workspace\\"
logFileName = workspace + "AA_TTCSM_logfile.txt"


## General Model Parameters
maxSlope = "40"
timeCap = "28800"

##Travel Time Modeling Parameters Cost
usePathDistance = "Yes"
vertValueZero = "1"
verticalGraphType = "Inverse_Linear"
verticalGraph = "S:\\ksherrill\\costsurface_test\\workspace\\vfg_fastdownslope.txt"
timeCalculation = "OutBack"
leastCostPath = "yes"
```

Required Data Layers - Hard Coded Paths

Six data layers, one log file path and the workspace location need to be hard coded within the master script.

startLocation - Path to the feature class with start point(s) for travel time modeling

roadsData - Path to the road network

trailsData - Path to the trail network, note if trail data is not available the “trails” variable in the ttcsmMasterscript can be set to “no”, and the model will run without trails.

DEM - Path to the digital elevation model

Destinations – Path to the destinations data layer

costSurfaceTable - Path to the CstSrf table, which is used in the CstSrf module.

workspace - Path to the TTCSM workspace

logFileName - Path to the TTCSM logfile

6.4. Step 4. Set Model Parameters:

General Model Parameters:

walkingSpeed **–** User specific average flat surface travel speed (miles/hour) prior to accounting for CstSrf factors. Default speed is 3.13 miles/hour.

maxSlope - represents the maximum slope (degrees) which is travelable.

timeCap – the maximum travel time in seconds that will be calculated in travel cost modeling. Any time greater than the defined timeCap will be truncated to the timeCap value.

trails - defines if trails data is being used in the model. If yes set to “yes”, if no set to “no”. This trails variable influences how the speed surface is calculated.

Travel Time Modeling Parameters**:**

usePathDistance – defines if cost distance or path distance modeling will be performed. “yes” for path distance and “ “ for cost distance.

vertValueZero - defines the VFV at a VSF value of zero. Usually this will be 1, see the path distance modeling section 4.1.2.

verticalGraphType – the user specified vertical factor graph to use in path distance modeling. Values can be: "Binary", "Linear", "Sym_linear", "Inverse_Linear", "Sym_Inverse_Linear", "Cos", "Sec", "Cos_Sec", "Sec_Cos", or "Table". See Appendix for further detail.

verticalGraph – path to the user specified vertical factor graph if the verticalGraphType is defined as “table”. Default is “ “ unless the VFG.

timeCalculation – defines if one way “oneway” or round trip “roundtrip” travel time calculations are to be performed.

leastCostPath – defines if travel time least cost paths are to be derived. If yes set to “yes”, if no set to “no”.

6.5. Miscellaneous Information:

- The TTCSM is designed to run in the Python scripting language, on a computer with ArcGIS 9.3 functionality.

- It may be necessary to change Toolbox paths within the npsTTCSM.py and npsTTCSMModule.py scripts to the true paths associated with your computer and ArcGIS set up.

- If you desire to calculate travel times where roads are traveled not using a vehicle but rather via foot travel, then define the road network ‘Velocity’ field with an average foot travel speed in miles/hour (i.e. 3 miles/hour).

6.6. TTCSM Outputs

Final products from the TTCSM are saved in the Workspace\output directory. A list and brief description of final products is given in Table 9.

Table 9. TTCSM output final products.

		Travel Time Method		TTCSM Model Variables	
Output Products/Layers	**Description**	**Cost Distance**	**Path Distance**	**leastCostPath**	**timeCalculation**
costSurface.img	CstSrf grid with the defined percent of maximum travel speed (PMTS) per cell.	x	x	"yes" or "no"	"Oneway" or "Roundtrip"
speedSurface.img	SpdSrf grid with the defined travel speed, (second/per Meter), at which movement within a cell occurs.	x	x	"yes" or "no"	"Oneway" or "Roundtrip"
travelCost.img	TrCstSrf grid, with the final travel speed (seconds/per Meter) after accounting for the resistance as defined by the CstSrf grid.	x	x	"yes" or "no"	"Oneway" or "Roundtrip"
travelCostMph.img	TrCstSrf grid, with the final travel speed in Miles per Hour.	x	x	"yes" or "no"	"Oneway" or "Roundtrip"
timeSecondsOut_"method".img	Time in seconds required to reach each cell within the area of interests as calculated from the start location(s). (travel out).	x	x	"yes" or "no"	"Oneway" or "Roundtrip"
timeMinOut_"method".img	Time in minutes required to reach each cell within the area of interests as calculated from the start location(s). (travel out).	x	x	"yes" or "no"	"Oneway" or "Roundtrip"
timeHoursOut_"method".img	Time in hours required to reach each cell within the area of interests as calculated from the start location(s). (travel out).	x	x	"yes" or "no"	"Oneway" or "Roundtrip"
CostPathsOut_"method".shp	All merged travel time least cost paths and times for travel from start point(s) to destination(s), (travel out).	x	x	"yes"	"Oneway" or "Roundtrip"

CostPathsBack_"method".shp	All merged travel time least cost paths and times for travel from destination(s) to start point(s), (travel back).	x	x	"yes"	"Roundtrip"

7. Acknowledgements

The TTCSM which is described in this standard operating procedure (SOP) document has been a result of iterative model development and refinement from the cumulative efforts among numerous individuals. In addition to the authors listed on this document we would like to acknowledge the contributions of Courtney Hurst, David Pillmore, Billy Schweiger, and Colin Talbert.

8. References

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9. Appendix

9.1. Variable Field Definitions

Variable	Definition	Unit
TTCSM	Travel Time Cost Surface Model	n/a
VFG	Vertical Factor Graph	n/a
VFS	Vertical Factor Slope	n/a
VFV	Vertical Factor Value	n/a
Cost Surface (CstSrf)	Surface defining the amount of travel speed resistance or impedance which is encounter when crossing through a cell.	0 - 100
Speed Surface (SpdSrf)	Surface defining the travel speed at which movement within a cell occurs.	seconds/per meter
Travel Cost Surface (TrCstSrf)	Surface with the final travel speed (seconds/per meter) at which movement with a cell occurs.	seconds/per meter
Travel Time Surface	Surface with the travel time modeling estimated travel time(s).	seconds/minutes/hours
Cost Path	Modeled least cost path(s) to from start point(s) to destination(s).	n/a

9.2. Vertical Factor Graphs

Figure 8. Binary Vertical Factor Graph (ArcGIS).

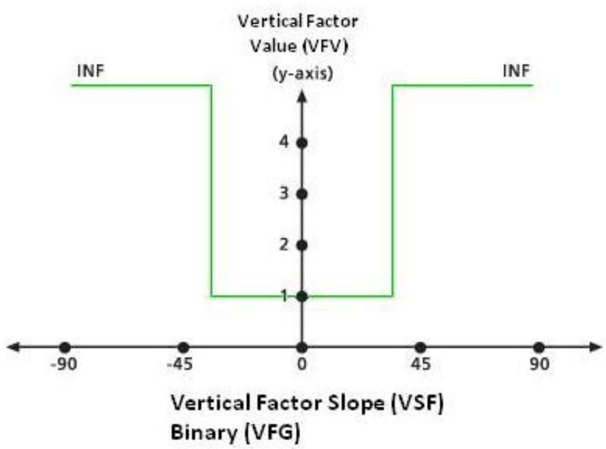


Figure 9. Inverse Linear Vertical Factor Graph (ArcGIS).

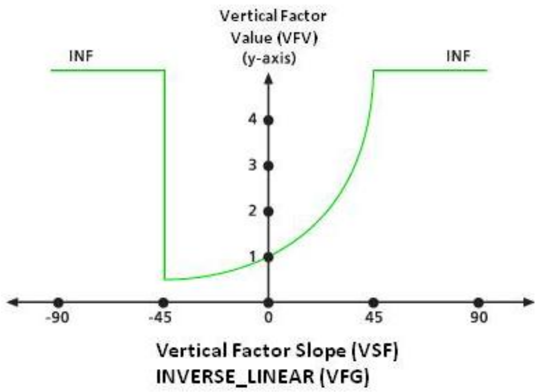


Figure 10. Sym_Linear Vertical Factor Graph (ArcGIS).

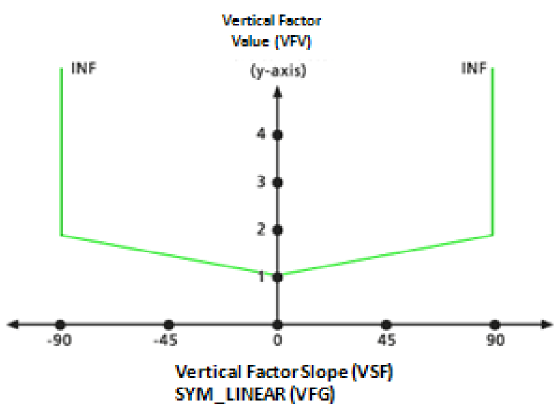


Figure 11. Sym_Inverse_Linear Vertical Factor Graph (ArcGIS).

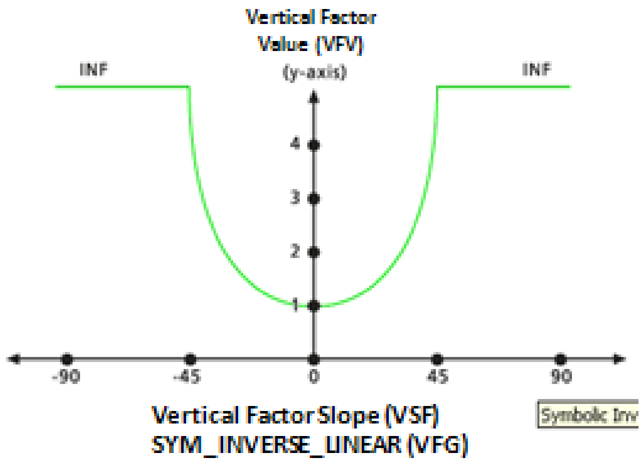


Figure 12. COS Vertical Factor Graph (ArcGIS).

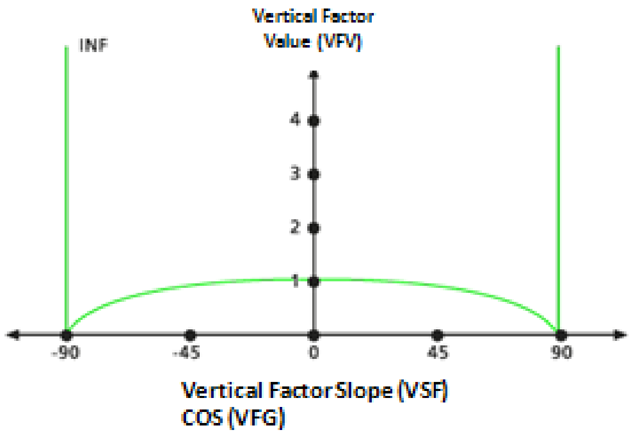


Figure 13. Cos_Sec Vertical Factor Graph (ArcGIS).

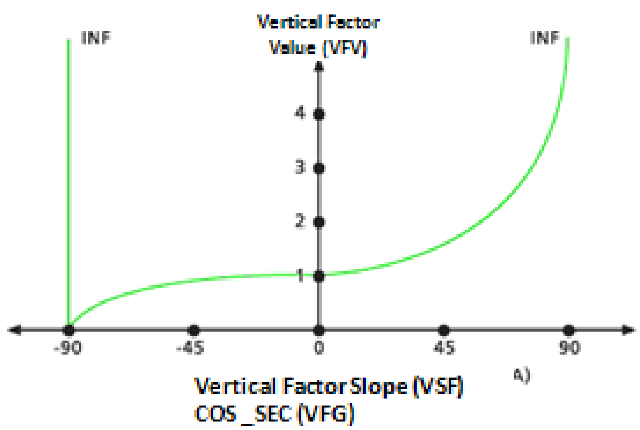


Figure 14. Sec Vertical Factor Graph (ArcGIS).

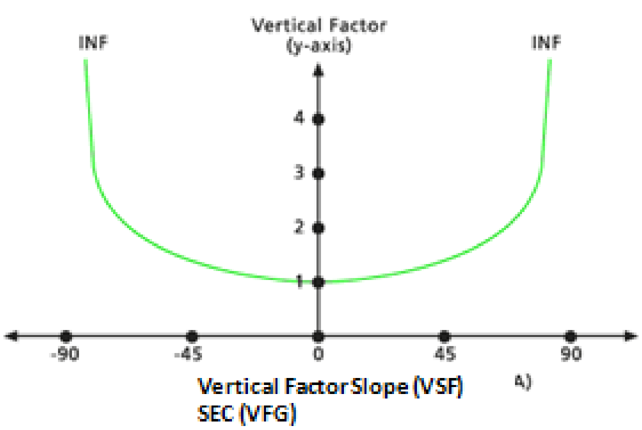


Figure 15. Sec_Cos Vertical Factor Graph (ArcGIS).

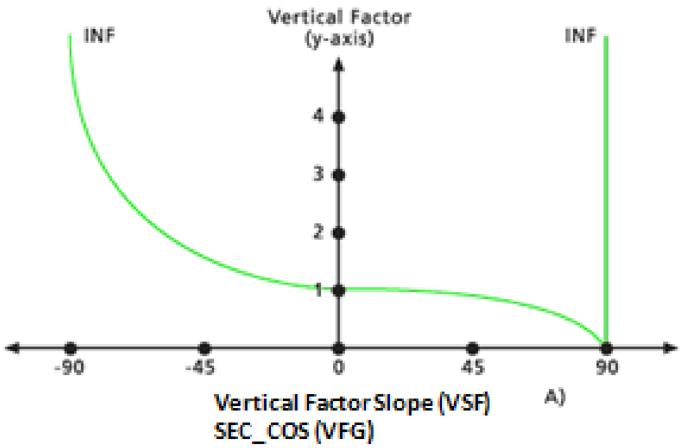
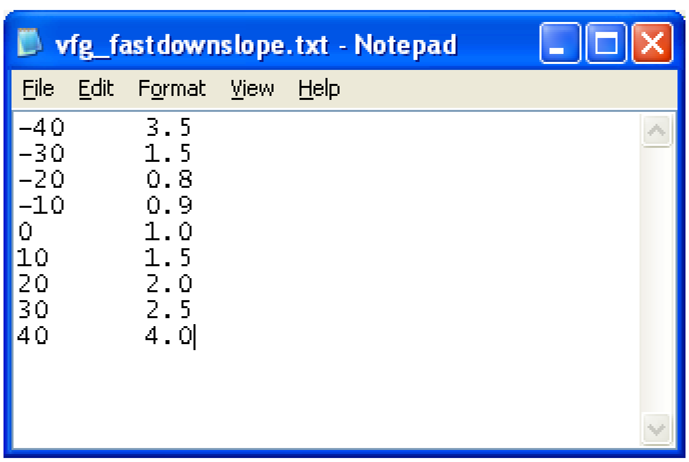


Figure 16. Custom vertical factor graph.

Downslope travel up to -20 degrees would have an increased travel speed. Greater than -20 degrees would experience decreased travel speed. All upslope travel would experience decreased travel speed.




```
-40      3.5
-30      1.5
-20      0.8
-10      0.9
0        1.0
10       1.5
20       2.0
30       2.5
40       4.0
```