Cost-distance modelling

Exercise: Planning a new bike path

Contents

Purpose

The aim of this exercise is to prepare the data and build a workflow to plan a new bike path based on a cost distance analysis. The data used are datasets on land use, slope, and wetness.

The method

From raster-based tools a **friction layer** can be produced that cell by cell expresses the relative or absolute costs when establishing a new path or road. The friction layer may be assembled from several layers to accumulate the total establishing costs for a road – for example the **absolute cost** of buying the land unit, the cost of establishing a bike path on different soil types and slope variations. Thus, a friction layer may be based on actual costs from a road engineer's construction perspective. However, the friction values may also be based on 'soft value' estimations in **relative units** to build a friction layer based on land use types, more and less attractive nature/landscape experiences when crossing the landscape et cetera.

When the frictions values are ready, you build a **cost distance surface** from a **point source origin**, and in a final step, you determine the **shortest path** using the **cost path** tool from anywhere on this surface and back to the cost surface's origin.

The principles and tools involved in Cost Surface analysis are described here:

[ArcGIS Pro reference for the Distance Accumulation and Optimal Path tools]

A case study from the Faroe Islands on how to establish the shortest path through an undulating landscape is available here:

[Identifying Least Cost Paths]

A short introduction in Danish on cost distance principles is found in "Bogen om GIS og Geodata" by Thomas Balstrøm, Ole Jacobi & Lars Bodum p. 211-214.

The problem

The problem is to plan for the location of a new 'super bike path' from Farum as an extension of the existing bike path from Copenhagen, see https://supercykelstier.dk/rute/farum-allerroedruten/. The extension shall reach the nearby suburbs at Lillerød/Allerød and/or Birkerød. Actually, in 2020 the bike path from Farum to Lillerød opened, but we would like you to investigate how close your calculations may come to the established bike path.

There are a couple of demands to the new 'super bike path':

- Non-built-up areas are preferred – especially on farmland or within forests,
- It must avoid the crossing of railroads,
- It may coincide with existing roads,
- It shall avoid potential wet areas,
- It shall avoid steep slopes.

Data preparation steps

- Many different data sources are available, but in this exploratory project phase very high-resolution data is not necessary. Concerning ***land use***, a nationwide raster dataset from Danish Centre for Environment and Energy, DCE, is available from 2016 at 10 meter resolution, see [the technical documentation here](). A copy of this dataset is available at **I:\SCIENCE-IGN-CGD-UVMAT\GIS\Geodata\English\5. Land use & Landscape\LandUse2016v2_10m_Basemap-AU-IGN_2017.lyr**

- ***Slopes*** may easily be determined from a digital terrain model. The most recent one at .4 m resolution is publicly available from SDFE (the Agency for Data Supply and Efficiency) and is available from Kortforsyningen, but ready for your use at this location:
  I:\SCIENCE-IGN-CGD-UVMAT\GIS\Geodata\English\3. Elevation\DTM_0.4m_TerrainModellen-SDFE_2020.lyr

- A map of potential ***wet locations*** after heavy rainfalls was produced from the Malstrøm-software that may be downloaded from here: https://github.com/Septima/malstroem/releases/tag/v0.2.0 or here: https://learn.arcgis.com/en/projects/model-bluespots-to-map-flood-risk/ . The method used is documented in Balstrøm & Crawford and a copy of the results for the area of investigation is part of the exercise data.

Copy exercise data

1) Open **Windows File Explorer** and copy the folder ***I:\SCIENCE-IGN-CGD-UVMAT\GIS_course\Exercises\ArcGIS_Pro\Exercise_CostDistance*** to an existing or new folder on your H-drive or another drive. From now on you will work on this copy to obtain write access to the data.

Set up ArcGIS Pro

2) Open ArcGIS Pro and select ‘Start without a template’. Select the Insert menu -> New Map
3) Prepare folder connections:
   Open Windows File Explorer and locate ***I:\SCIENCE-IGN-CGD-UVMAT\GIS\Geodata***, see Figure 1**.**

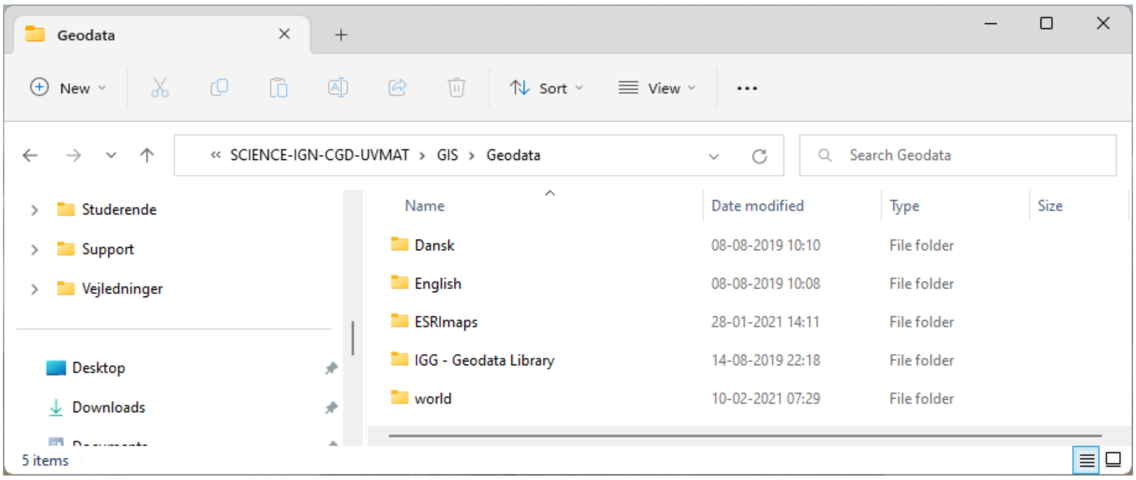

Figure 1 Add Folder Connection to folder on the I-drive

4) Make sure that both File Explorer and ArcGIS Pro are visible on your display. Press the left mouse button on the **English**-folder in File Explorer and drag & drop the folder into the Folders-section in ArcGIS Pro's Catalog pane, see Figure 2. When done, close File Explorer.

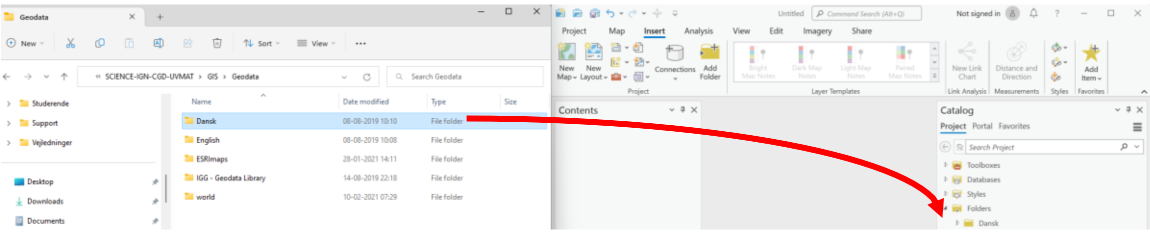

Figure 2 Drag & drop of folder from the I-drive tol ArcGIS Pro's Folders-section.

5) Next, in the Catalog Pane, right-click Folders -> **Add Folder Connections** and create a connection to the copy of the ***Exercise_Distance***-folder you created in step 1).

6) <u>Assign default geodatabase</u>: Create a new file geodatabase, ***Outputs.gdb***, in your **Exercise_Distance** folder. Next, drag and drop ***Outputs.gdb*** to the **Databases** entry. Next, right-click the copied instance of ***Outputs.gdb*** in the Databases section -> **Make Default**. From now on the ***Outputs.gdb*** is the default output location from your geoprocessing tools.

7) Save your setup by entering **Project** in the main menu -> **Save Project** and save the setup in the ***Exercise_Distance***-folder on the H-drive.

Inspect the data sets involved and create new subsets for the area of interest

8) In your folder connections, the necessary shortcuts to your data locations are ready. So, from there add the following datasets to your current map (please notice that the data is in two different folders):

- ***English\5. Land use & Landscape\LandUse2016v2_10m_Basemap-AU-IGN_2017.lyr***
- ***English\3. Elevation\DTM_0.4m_TerrainModel-SDFE_2020.lyr***
- ***Exercise_CostDistance\Inputs.gdb\Bluespots_Extents_40mm***
- ***Exercise_CostDistance\Inputs.gdb\Bluespots***
- ***Exercise_CostDistance\Inputs.gdb\Mask***

9) Change the symbology for the ***Bluespots_Extents_40mm*** layer to blue, and the ***Bluespots*** layer to a deeper blue colour. The bluespots are landscape sinks that are filled during heavy rainfalls. The Bluespot layer shows all sinks when filled to their pour point levels. The ***Bluespots_Extents_40mm*** layer shows their extent after a 40 mm rain event, if no water has infiltrated the soils, yet. Remove the ***Bluespots*** layer and turn off the visibility of the other layer before you continue.

10) Change the ***Mask*** layer, so the interior of the polygon is Hollow (No Color), the outline is red and has a width of 2pt. This mask shows the area of interest. Turn off the ***Bluespot*** layer before you continue.

11) Turn on the nationwide ***Land Use*** map that has 36 classes. It's a raster layer with an extended attribute table. Open the layer's attribute table and notice the Value and AGG_LU_Code fields with LU class numbers and the fields with corresponding labels.

<u>Clip raster:</u>

12) We will now use the **Clip Raster** (Data Management) tool and the ***Mask*** layer to extract data for the area of interest from the Land Use raster:
    - In the **Analysis** tab -> **Tools** search for the **Clip Raster** (Data Management) tool and open it.
    - In the **Input raster** field click the tiny arrow to the right and point to the loaded ***LandUse*** layer.
    - For the **Output Extent** point to the ***Mask*** layer.
    - Notice that the Output Raster Dataset is named automatically and that the path points to your default geodatabase. Meanwhile, just change the output name to ***LUCC*** and press **Run**.

13) The result is loaded as a greytone layer, but enter the layer's **Symbology** -> **Unique Values** -> set **Field1** to **AGG_LU_Name_EN**.

    Before you proceed right-click the nationwide land use layer's name in the TOC and remove it from your map. Also, turn off the visibility of your new ***LUCC*** layer.

14) The ***DTM*** layer is a raster terrain model with a spatial resolution of .4 meters that becomes visible, only, when the layer's upper check box is marked, see Figure 3. Notice that the layer's content is stored in the Image sub-layer. This layer covers the entire Denmark, so it must also be cut to the area of interest.

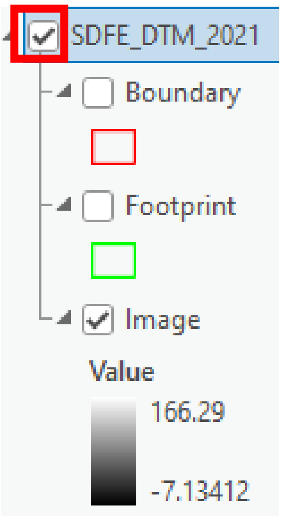

Figure 3 Grouped DTM-layer

15) Unfortunately, it may take up to 20 minutes to extract a subset from the nationwide DTM using the **Clip Raster** or **Extract By Mask** tools, so a subset was extracted for your use. So, get rid of the nationwide DTM by right-clicking its entry in the Table of Contents and select **Remove**. Next, go to your ***Exercise_Distance\Inputs.gdb*** and add the ***DTM*** subset to your current map**.**

16) Now, to match the Land Use map's resolution (and to reduce the computation costs) the ***DTM*** must be resampled to a 10 m cell size:

- In the **Analysis** tab -> **Tools** search for the **Resample** tool and open it.
- In the **Input raster** field point to the ***DTM*** layer,
- Change the **Output Raster Datasets** name to ***DTM_10m***.
- For the **Output Cell Size** point to the ***LUCC*** layer so the cell size becomes 10 meters like that one
- For the **Resampling Technique** select **Nearest** (as this method will not assign new values to the categorical data).
- Click the tool's **Environments** section and for the **Snap Raster** point to ***LUCC*** as well. This ensures that the 10 m cells will be aligned with the ***LUCC*** dataset.
- Press **Run**.

When the new layer is ready, remove the ***DTM*** layer.

17) To create a **slope** raster search for the **Slope** (Spatial Analyst) tool and open it.

- For the **Input raster** point to ***DTM_10m***
- For the **Output Raster** enter: ***Slopes***
- For **Output measurement** select Percent rise and hit **Run**.

18) The ***Bluespots_Extents_40mm*** layer must be converted into a raster with 10 m resolution as well, so search for the **Feature to Raster** tool and open it:

- For the **Input Features** point to the ***Bluespots…*** layer

- For the **Field name** point to the **BluespotID**
- Name the **Output Raster *BluespotsExt40mm_10m***
- Enter the tool's **Environments** section. For the **Cell Size** point to 'Same as the ***LUCC*** raster', and do the same for the point **Snap Raster** to the ***LUCC*** raster and hit **Run**.

19) Remove the ***Bluespot_Extents_40mm*** layer.
20) The converted bluespot… layer has cells coded with a meaningless BluespotID value, so the cells must be changed to having the same value = 1. This is easiest done by the **Con** (Spatial Analyst) tool, so search for it and open it:
    - For the **Input Conditional Raster** point to ***BluespotsExt40mm_10m***,
    - For the **Input True Raster** or **Constant Value** enter 1,
    - Name the **Output Raster** as **Bluespots_raster** and hit Run.

21) Now, clean up the Table of Contents, so the only layers left are the ***Bluespots_Raster***, ***Slope***, ***LUCC*** and the basemap.

Build a model to generate the friction raster, the cost distance surface, and the cost path

Part 1: Create the Friction layer

The next step is to build a model to assemble the friction raster, derive the cost distance raster and calculate the shortest path. Once the model is set up, you may easily change the parameters to check how sensitive the assembled friction values are towards a change of values from the three inputs' values in the ***LUCC***, ***Slopes*** and ***Bluespot_raster***.

22) <u>Change default geodatabase:</u> We want the outputs from now on to be saved in the prepared **Outputs file geodatabase**, so in the Catalog Pane expand the Databases section and check if the ***Outputs.gdb*** is present. If not, drag and drop **CostDistanceAnalysis\Outputs** to the **Databases** entry. Next, right-click the instance of **Outputs.gdb** in the Databases section -> **Make Default**.

23) In the Catalog Pane locate your Default Toolbox, ***Default.atbx***, in the ***Exercise_Distance*** folder. If it cannot be found, right-click the folder's name -> **New Toolbox**. When ready, right-click it and select **New** -> **Model** to open a new empty model that overlaps your current map, but from clicking either tab you may select what becomes active, see Figure 4.

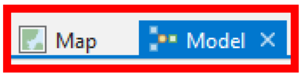

Figure 4 The Map and Model tabs

24) From the TOC drag and drop the ***Bluespots_raster***, ***Slopes*** and ***LUCC*** layers into the model canvas.

25) In the ribbon select **Analysis** -> **Tools**, search for the **Reclassify** (Spatial Analyst) tool. When found drag and drop 3 instances of it to the canvas, see Figure 5 and auto-hide the Geoprocessing window by clicking the tiny arrow down -> **Auto Hide**, see Figure 6.

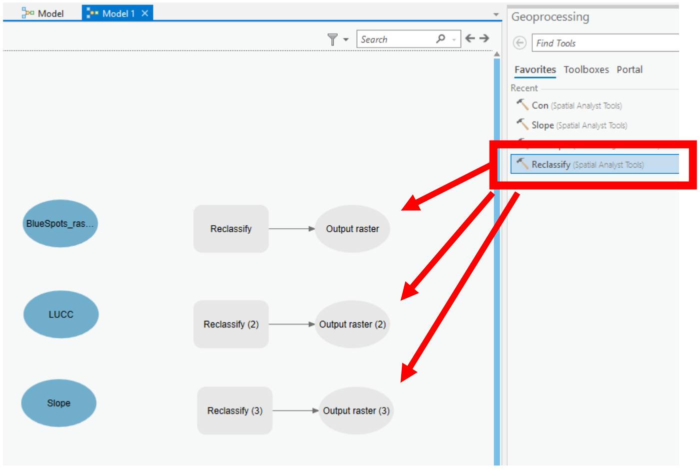

Figure 5 Drag & drop 3 instances of the Reclassify tool into the model

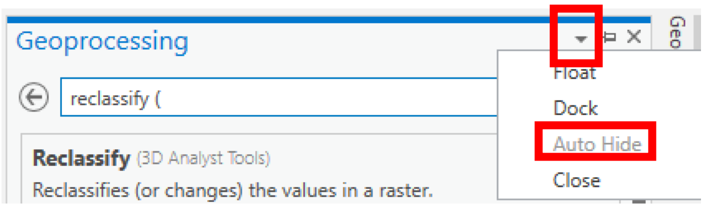

Figure 6 Auto-hide the geoprocessing window

26) Activate the **ModelBuilder** ribbon by clicking the name shown in Figure 7. Also, click the **Auto Layout** button to re-arrange the model's contents.

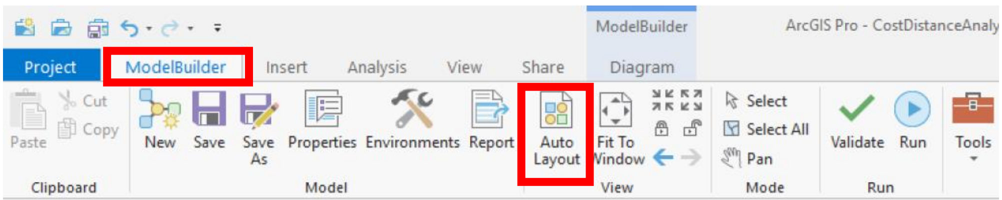

Figure 7 ModelBuilder ribbon.

Drag a rectangle around the 3 input layers and move them to the left of the Reclassify tools, see Figure 8.

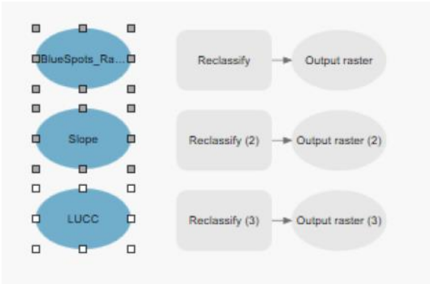

Figure 8 Re-arrange the layers in ModelBuilder

27) Click anywhere next to the selected layer-representations to unselect them. Next, drag a line from inside the layer symbols to each of the reclassify tools and assign them as **Input Rasters**, see Figure 9. When connected most tools are (ideally) ready to be executed when having a yellow colour. However, you must adjust some of the reclassification options in the next steps.

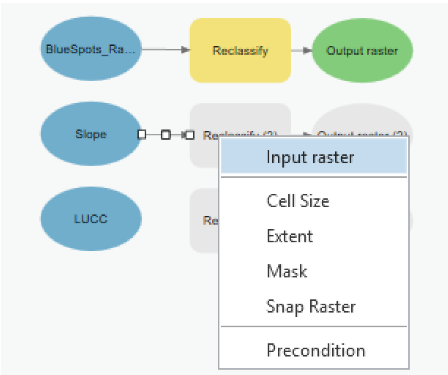

Figure 9 Connectors

28) Double-click the **Reclassify** tool connected to the ***Bluespot_raster***. The tool is used to change the original raster values into friction values. First, press the **Unique** entry, see Figure 10, to change the view so you watch the actual values present in the layer, only. Next, for the 'old' value 1 (representing the only cell value present in the ***Bluespot-raster***), assign the new value **5** and change the **NODATA** value to **0** and hit the -ENTER- button. If not, the last value isn't changed. Name the **Output raster** ***Bluespots_recl*** and press **OK** to close the tool.

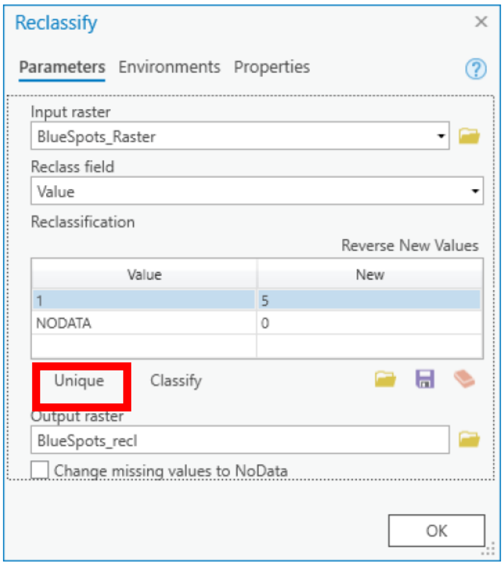

Figure 10 Reclassification

29) Double-click the **Reclassify** tool connected to the ***Slopes*** layer. Click the **Classify** option and enter that you want **6** classes. Next, enter the friction values as shown in Figure 11. You may delete a block of unused rows by marking them and pressing the keyboard's Delete-button. Notice that the **NODATA** value (which means that the cells are impassable) must be entered as uppercase characters. Name the output ***<u>Slopes_recl</u>*** and close the tool.
All entered friction values are relative, and they all relate to the friction value = 1. This means that a cell with a friction value of 5 is 5 times more expensive/harder to pass than a cell with a friction value of 1. All cells not passable are assigned the NODATA value.

Start	End	New
0	2	1
2	4	2
4	6	3
6	8	5
8	10	8
10	1000	999
NODATA	NODATA	NODATA

Figure 11 Slope friction values

30) Double-click the **Reclassify** tool connected to the ***LUCC*** layer. For the **Reclass Field** select **Value** and click the **Unique** option so all old values are listed. Now, assign the new values as shown in Figure 12 and remember to hit -ENTER- to finish the edits. Name the output ***LUCC_recl***.

Value	New
100000	NODATA
100104	NODATA
101000	NODATA
101104	NODATA
102000	NODATA
102104	NODATA
103000	NODATA
103104	NODATA
104000	NODATA
110000	5
110110	5
201000	NODATA
201104	5
300000	5
400000	50
600000	5
600104	NODATA
701000	1
702000	1
703000	1
704000	1
801000	1
801703	1
802000	10
802703	10
901000	NODATA
902000	25
999000	1
NODATA	NODATA

Figure 12 Friction values for the LUCC layer

31) In the **ModelBuilder** ribbon select **Properties** and enter **BikePath** for the model's name and label -> OK. Next, press **Save** in the ModelBuilder ribbon.
32) To combine all 3 friction layers into one go to *the* ModelBuilder ribbon -> Tools -> search for the **Raster Calculator** (Spatial Analyst) tool, drag it into your model, and double-click its name to open it. What you see is a calculator to enter a mathematical expression based on the layers available in the TOC.
33) Double-click the ***Bluespots_recl*** layer name in the calculator's left pane on and notice that it appears in the calculator expression. Next, double-click the '+'-sign in the right pane so it is added to the expression. Double-click the ***Slopes_recl*** layer name, double-click the '+'-sign and double-click the ***LUCC_recl*** layer name. Change the **Output Raster** name to ***Friction*** and press OK.
34) Right-click the **Friction** layer output and select 'Add to Display'. This means that when this layer is ready it will be added to your Map. Also, right-click the ***Bluespots_recl, Slopes_recl*** *and* ***LUCC_recl*** outputs and uncheck their '**Intermediate data**' status, so they are saved to disk. Finally, **Auto-Layout** your model and **save** it.
35) Validate the model's components by clicking the Validate icon. If all components are coloured, the model is ready. If parts of it are grey, you must inspect the tool(s), correct any parameter and re-validate it. Next, press the **Run** icon in the ModelBuilder ribbon to run the entire model, see Figure 13.

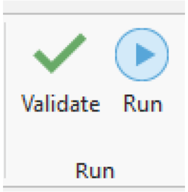

Figure 13 Validate and Run tools

While the model executes, you can watch that the active tool is highlighted in red. You may expand the execution window, also, to inspect the details, see Figure 14. When completed close the execution window – but don't check the 'close on completion' box!

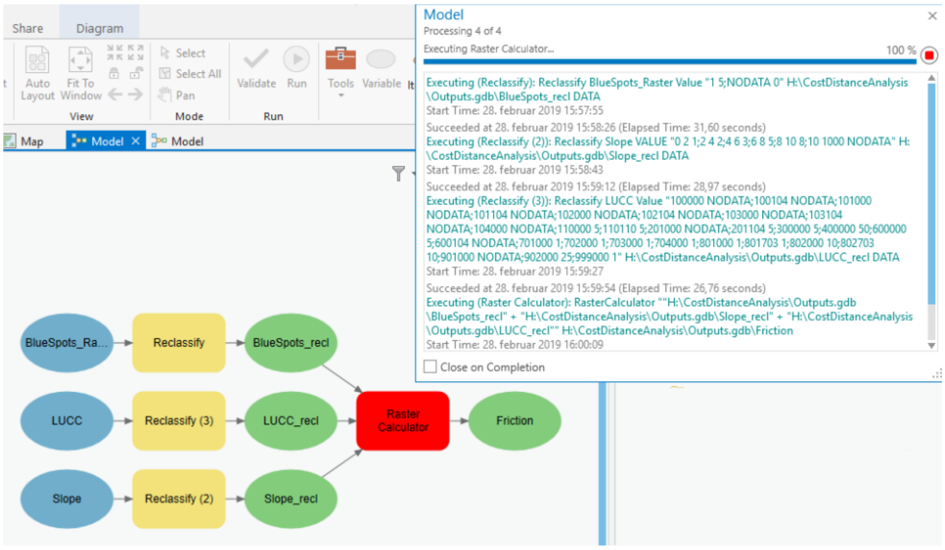

Figure 14

36) Make sure that all layers except the ***Friction*** layer and the basemap are turned off in your map and inspect the Friction layer. You may change the layer, so it is coloured from green over yellow to red. The values should be in the range 2 to 1054. If not, you must correct your model.

Prepare start and end points to serve the cost distance and cost path steps

To prepare start and end points for your new bike route, you must digitize and save the locations in two new separate point feature classes.

37) First, create a **SourcePoint** feature class in your **Inputs.gdb**:

- Right-click the ***Inputs.gdb*** -> **New Feature Class**:
  - Set Name to ***SourcePoint***, Feature Type to **Point** and click **Next** twice,

- Set Current XY Coordinate System to ETRS 1989 UTM Zone 32N (if not available click the Globe with a +-sign  -> Import Coordinate System and point to one of the existing feature classes or rasters in your Inputs.gdb) and click Finish.

38) You may follow the same procedure to create an empty **EndPoint** feature class, but it will be easier to create a copy of the **SourcePoint** feature class and rename it afterwards:
    - Right-click the **SourcePoint** feature class in your ***Inputs.gdb*** and select **Copy**,
    - Right-click the ***Inputs.gdb*** and select **Paste**,
    - Next right-click the new copy named ***SourcePoint_1***, select **Rename,** change its name to ***EndPoint*** and add it (although empty) to your map.

Digitize start and endpoints

The source point must be located at Farum Station close to where the existing bike path from Copenhagen ends:

39) Zoom into Farum Station on your map.
40) In the **Edit**-ribbon select **Create** and in the **Create Features** pop-up menu click the point **Source**. Now digitize Farum Station's location a little north of it but make sure that its location is inside a coloured cell in the Frictions raster and not a NoData cell.
41) In the Map tab click **Explore** and zoom into Allerød Station.
42) In the **Edit**-ribbon -> **Create Features** popup click the **EndPoint** symbol.
43) Digitize Allerød Station's location a little west of it but make sure that its location is inside a coloured cell in the Frictions raster.
44) When done click **Save** in the Edit-ribbon and close the Create Features popup. Finally, nake sure that both layers have symbologies of size 10 pt and in different colours.

Extend your model to generate the friction raster, the cost distance surface and the cost path

Part 2: Create the Cost Distance surface and derive Cost Paths

Now you're ready to add the source point, the end point and the two last tools to your model.

45) Re-activate your **ModelBuilder** window and drop and drag the two-point layer files into the canvas.
46) In the **Analysis** tab -> **Tools**, search for the **Distance Accumulation** tool and drag and drop it into your model's right-hand side. Also, locate the **Optimal Path As Line** tool and drag it into the model's right side.
47) Connect the ***SourcePoint*** layer to the **Distance Accumulation** tool's **'Input raster or feature source data'**. Connect the ***Friction*** output in the model to the **Distance Accumulation** tool as its '**Input Cost Raster**'.
48) Double-click the **Distance Accumulation** tool to open it, assign the name ***CostDistance*** to the **Output Distance Accumulation Raster**. Also, assign the name ***Backlink*** to the '**Out back direction raster**'.

Close the tool, right-click the ***CostDistance*** output, check '**Add to Display**' and uncheck the '**Intermediate data'** status.

49) Connect the ***CostDistance*** output to the **Optimal Path As Line** tool's '**Input Distance Accumulation Raster**'. Also, connect the ***Backlink*** output to the **Optimal Path As Line** tool's '**Input Back Direction Raster**'. Finally, connect the ***EndPoint*** layer to the **Optimal Path As Line** tool's **'Input raster or feature destination data**'.

50) Double-click the **Optimal Path As Line** tool and change the **Output Raster** to ***BikePath*** and verify that it is saved in the ***Outputs.gdb***. Close the tool, right-click the ***BikePath*** output and check '**Add to Display**'.

51) Still, in the model right-click the ***Friction*** and ***Backlink*** outputs and uncheck their '**Intermediate data'** status.

52) In the **ModelBuilder** tab select **AutoLayout**, next **Fit to Window** and save the model that should look like Figure 15.

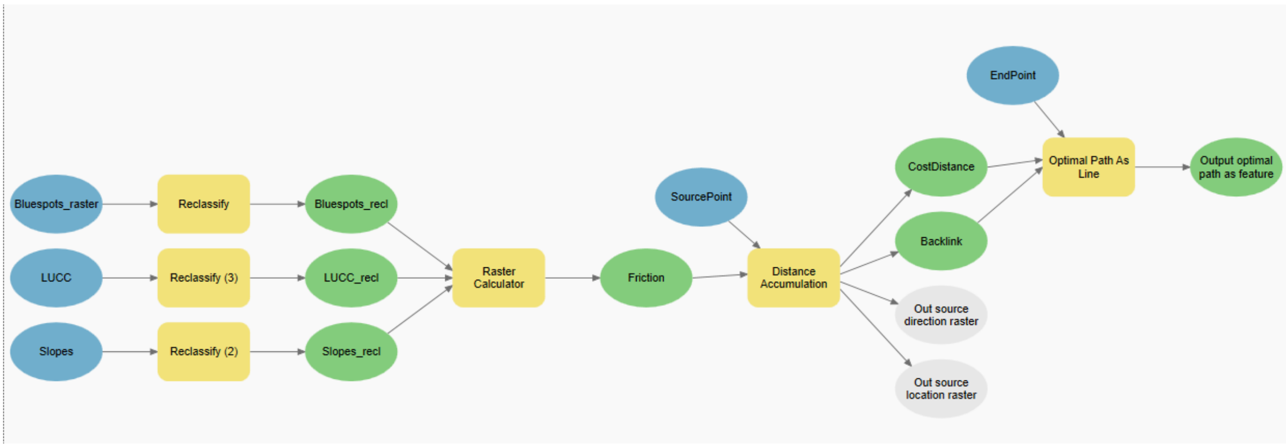

Figure 15 Assembled workflow.

53) When looking at the model's components you'll notice that the already executed components have a shaded offset, and there is no need to re-run them. So, don't re-validate your model before you run the rest of the model by hitting the **Run** tool in the ModelBuilder tab.

Inspect results

Challenge 1: Investigate the path created and evaluate if it makes good sense. Is the path straight or does it have many unwanted bends? If the path is too windy you may consider altering some of the friction values derived from the land use, the slope, or the wet spot layers.

If you make the ***Friction*** layer, the ***Slopes_recl***, ***LUCC_recl*** and ***Bluespots_recl*** layers visible, you may use the **Explore** tool to read out the individual friction values cell by cell:

Enter the **Map** ribbon -> **Explore** -> check '**Visible Layers**', see Figure 16. Click on cells in your map and investigate if some friction values should be changed. When done open your model and change the friction values in the Reclassify tools and re-run the model. Meanwhile: Before you re-run the model, it may be wise to rename the BikePath feature class, so you don't overwrite the old result.

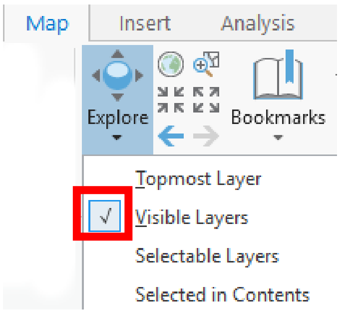

Figure 16 Explore tool

Also, add feature class ***Inputs.gdb\BikePathConstructed2021*** to your map that represents the actual bike path from Farum to Allerød. How does it match your

Challenge 2:

Your modelling is the result of 3 data sets. Which of them do you consider as most reliable and which one(s) as less reliable?

For example, consider the land use layer: Make sure that only that layer and the basemap are visible. Highlight the ***LUCC*** layer in the TOC and notice that the ribbon now shows that this is a **Raster Layer**. In the Appearance group click the Swipe tool, see Figure 17. Next, move your mouse's cursor into the Map, hold down the left mouse button and swipe to drag away parts of the Land Use map.

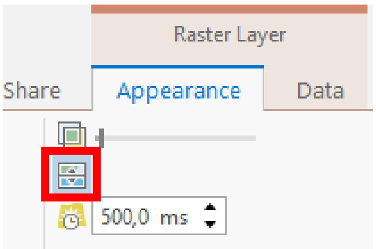

Figure 17 Swipe tool

Do you see any areas not well represented? Try and change the basemap into an orthophoto instead and perform a new swipe. Especially, please notice areas close to railroads. Are they okay? And how about the 'unmapped areas (ikke kortlagt)' that are treated as non-passable (coded as cells with the NODATA value)? Should they in general be treated as passable instead?

Challenge 3: The friction values assigned are based on quick assessments, but they all refer to the same relative scale. The land use layer has indications of potential wet areas (codes 802000 and 802703). So, is it fair to add the bluespot-locations as one more 'wetness'-friction value to already potentially 'wet' locations?

Challenge 4: When looking into the friction values, the ***Slopes_recl*** layer was assigned a friction value of 999 in areas where slopes were > 10%. Is that a reasonable threshold value (or in other words: Would you consider climbing a hill on your bike having a slope > 10%)[1]?

Challenge 5: How may you easily add an extra new super bike path from Farum Station to Birkerød to your result?

Thomas Balstrøm, March 5, 2024.

[1] For your reference Geels bakke near Holte has an average slope of 4.7%. Valby Bakke has an average slope of 4.3%.