Linear Referencing in ArcGIS*

Managers of artifacts with long linear structures (e.g., highways, pipelines, railroads) are generally unconcerned with the precise two-dimensional geographic coordinates of the entity they deal with. A locomotive is pretty well locked onto the railroad's linear structure-unlike, say, an airplane, which can operate in three dimensions. As a result, many of the coordinate systems that have grown up around linear structures are different from those we have been talking about up to now. Terms like road miles, river miles, and rail miles are in common use in those industries. The average citizen who uses the Interstate Highway System will probably be familiar with the tiny green signs with numbers on them that indicate the number of miles from some origin-frequently a state border.

We are in the habit of representing linear structures with lines drawn between junction points (e.g., nodes). (Of course, these structures are portrayed on a two-dimensional field, but the smallest part of each such line is one-dimensional [a vector], so we call them one-dimensional, or linear.) The problem with simply representing such a structure-let's take a highway, for example-from intersection to intersection is related to attributes. The requirement, so far in your studies, is that for any GIS feature (whether point, line, or polygon), it must be homogeneous in all its attributes. For example, all of a given cadastral polygon is owned by one entity, the taxes are paid on all of it or none of it, and so on. If different attributes apply to two different parts of the feature, then you need two features (e.g., if different people own different parts of a piece of land, then you need more polygons).

Imagine that you have a stretch of highway that is 2 miles long between intersections A and B with other roadways. Among the attributes you want to store for this length of road are speed limit, pavement type, pavement quality, political jurisdiction, and number of lanes. The difficulty is that the speed limit changes four times and the road goes from four lanes down to two and then back to four. It crosses a county boundary. Part of it is blacktop and part concrete. And repairs have taken place on different segments of the road at different times. To represent this "traditionally" in ArcGIS, we would have to have a plethora of features. Every time an attribute changed (e.g., the speed limit changed from 55 to 45), a new feature would have to be declared. So the single-line feature or arc that represented the 2 miles between intersections might have to tum into dozens of short features. The complications created then- for example, how would you find the distance from A to B?-are considerable.

The invention that turned out to make attribute representation tractable for such linear features is called "linear referencing." The fundamental idea is that you can have several sets of attribution information that accompanies a single linear feature. What makes this possible is the concept described earlier in this section: The thing that fixes the point at which a change takes place is a number-a distance-that is related to the origin of the feature, in the style of, say, road miles.

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To recap, linear referencing lets you store geographic information without explicit x-y coordinates. Instead, a measure (distance) along a linear feature is provided (which is itself, of course, defined by x-y coordinates). Linear referencing is a mechanism that allows you to associate multiple sets of attributes to portions of linear features.

One way to view linear referencing is "features within features." As such, some new terminology and tools are necessary to understand and operate linear referencing. We address those in the Step-by-Step section that follows.

Linear Referencing assignment

The first concept to grasp is that of a "route." A route is a linear feature, probably made up of several or many other linear features, that has a unique identifier and has a measurement system stored with its geometry.

Experimenting within Linear Features

1. Start ArcCatalog. In the Catalog Tree find the "**Linear_Referencing**" data file you downloaded for this assignment.

2. Navigate to the following data layer: ***\Linear_Referencing\Pitt.mdb\PITT_Roads_Routes***

   In the "**PITI_Roads_Routes**" layer preview the Geography of "**Just_Roads**". Using the Identify tool, click on a few features. You will notice that you that you get some standard information (e.g., feature name) and also at least the possibility of a route identifier (called "**ROUTE1**"), a beginning mile point, and an ending mile point. Look at the attribute table of "**Just_Roads.**" Review the number of road segments – ensure you scroll down to the end of the table, since initially ArcCatalog will display only the first 2,000 records.

   How many road segments are there in total? **______**.

3. In the Catalog Tree, click "**All_Routes**". Switch back to the Geography display, which thins out a lot compared to "**Just_Roads**". These are road features that have been combined and designated as "***routes,***" all under the name of "**ROUTE1**". Each route is composed of sets of features from "**Just_Roads**".

4. Again use **Identify** tool. Notice that you get completely different results from previously. The shape is still polyline. But usually the **Shape_Length** is way longer. When you click on a feature, the line that flashed is usually lengthy and composed of many of the features you saw before. Look at the table.

How many routes are there in total? ______.

5. Lastly, display "**Some_Routes**" from the Catalog Tree. "**Some_Routes**" is a subset of "**All_Routes**" that we will use for demonstration purposes.

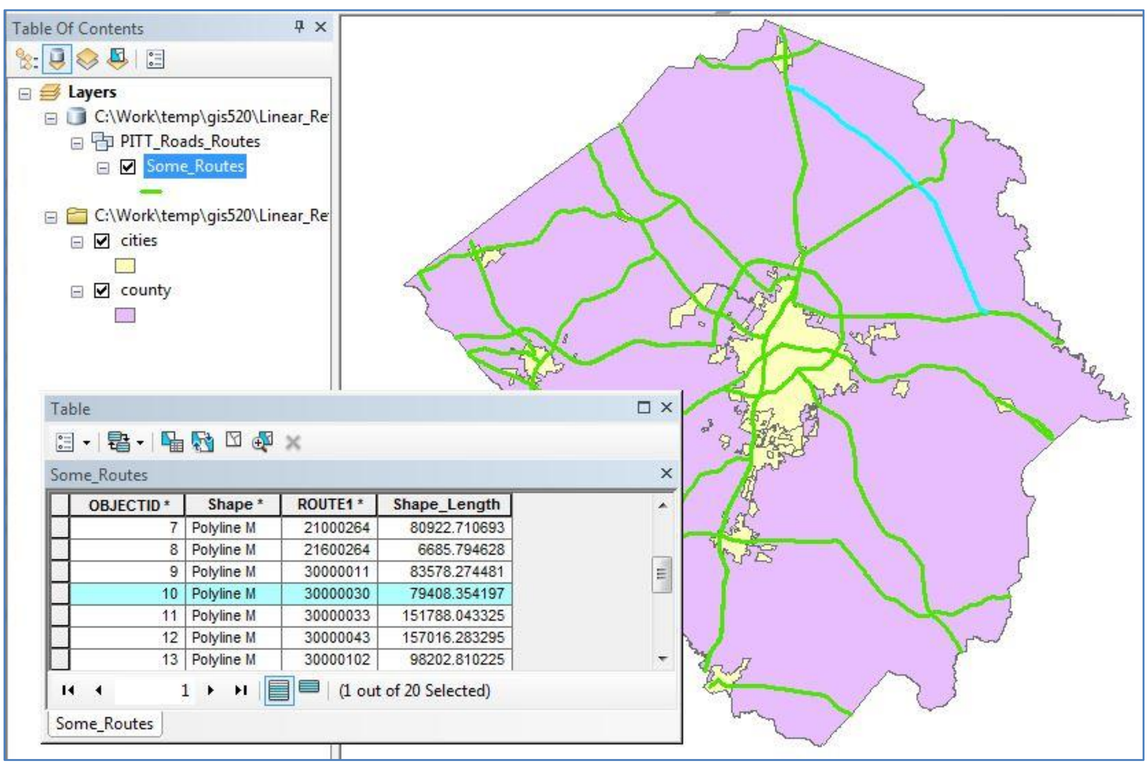
   How many of "**Some_Routes**" are there in total? ______.

From the preceding steps, you can see that routes are features. But they are features with remarkable, complex, and useful characteristics, as you will see from the steps that follow.

6. Start **ArcMap**. Add two data sets from the **Linear_Referencing** folder: (1) **County** and (2) **Cities**. Make sure that **Cities** is at the top of the Table of Contents.

   From the ***Pitt.mdb*** > ***PITT_Roads_Routes*** layer, add "**Some_Routes**". Make the line feature **bright green**, with a width of **2**.

7. Open the "**Some_Routes**" attribute table. Find the route 30000030. Select it in the table and note its location in the northeast quadrant of the map. As shown in the figure below:



You have identified **Some_Routes** as **a feature**. Next you will identify it as **a route**, but you have to add a button to a toolbar to do it.

8. Choose ***Customize*** > ***Customize Mode*** > ***Commands tab***. In the Categories list find "**Linear Referencing**". From under "Commands" list, drag "**Identify Route Locations**" to the **Menu Tools toolbar**, where it becomes a button. Close the Customize window.

9. Make the "**Identify Route Locations**" tool active and click on the selected route.

   What are the Minimum and Maximum values of the Measure of the route? **______**(min), **______**(max).

   Of how many **Parts** does the route consist? **______**.

   Click on different points of the selected route so you can determine, based on the Measure value, in which direction (northwest or southeast) the Measure **increases**? **______**.

   Dismiss the **Identify Route Location Results** window.

Suppose you know that a call box has malfunctioned at measure 3.35 and you want to find that point on the map.

10. Click ***Find*** *(the binoculars)* **>** ***Linear Referencing***. For **Route Reference**, pick "**Some_Routes**". The Route Identifier is, as always, "**ROUTE1**". **Load Routes**. Pick the route that you have been working with: **30000030**. The "**Type**" should be **Point**. Put in the Location **3.35** and press **Find**. Information about the route should appear in the bottom panel of the window.

11. Click the route information in the bottom panel of the Find dialog window to highlight the text. Right-click the highlighted text. Now perform the following from the context menu that appears on the right-click:

    Select "**Flash Route**" to flash the route location that was found.

    Select "**Draw Route Location**".

    Select "**Label Route Location**". Click the **Select Elements** pointer and place it over the route label; click once and pause. Drag the label around, noting that it is a call-out box tied to a location you just indicated. Press **Delete** to remove the box. Next, select the drawn location by dragging a box around it; delete the drawn location. Close the Find window. Minimize the table.

12. Add the table "**accident.dbf**" as data from the **Linear_Referencing** folder. Open the table.

    How many accidents are recorded? **______**.

    With ***Table Options*** **>** ***Select By Attributes***, select the **ROUTE1** records with **30000030**.

    Your SQL expression should resemble: "ROUTE1" = 30000030

    NOTE: You may have noticed that sometimes a field name in a query is enclosed in square brackets and sometimes in double quotes. It depends on what database management system is in use for the layer or table.

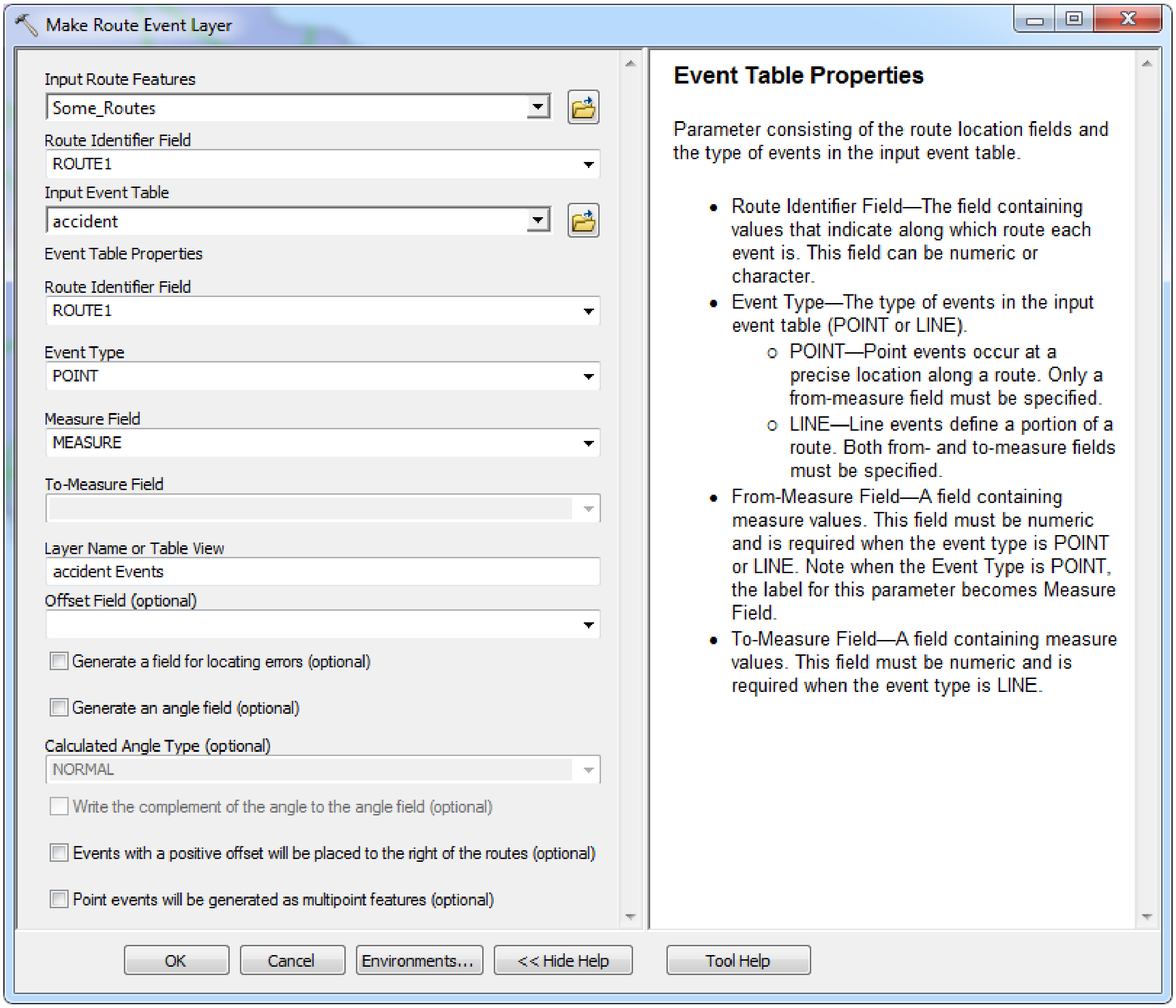
Show the selected records. How many are there? **______**.

In the table, right-click the gray box to the left of any record and click the **Identify** item that comes up from the drop-down list. Note that the record contains a **MEASURE** field that indicates the position along the route where the accident occurred. Lots of other data about the accident is also recorded. Close the **Identify Results** window.

13. Move the table around so you can see the map, and particularly Route 30000030. Notice that no points along the route where these accidents occurred are shown. That's because the table is just that: a table. To see the locations of the accidents, you can use **the table to make a layer.** (This layer will exist only in memory and will go away once you close ArcMap, unless you save the map, in which it is saved [only with the map]. Of course, you may specifically save it as a layer file by right clicking and choosing save as LayerFile.)

14. Make a route event layer for the "accident" events:
Show All Records in the table. Under **Table Options**, choose **Clear Selection**. Close the table. From the file menu, choose "***Customize > Customize Mode > Commands tab > Linear Referencing Tools*** " drag the "**Make Route Event Layer**" tool to the tools menu.

Click on "**Make Route Event Layer**" tool and select the "**Show Help**" and the bottom of the window to review the parameter fields. Next set up the window so it looks like the figure below and click OK:



15. Examine the map. Now you see the accidents depicted in the table that have been calculated from the layer called "**Accident Events**". Next click the **Source tab** from the Layer Properties and examine the source.

> NOTE: For reasons whose logic or history escapes the author points or segments within a route are termed "events".

16. Open the "**Accident Events**" attribute table. Again use "**Select By Attributes**" to select Route 30000030. Show only selected records. Resize and rearrange the table so you can see the map. Notice that the accidents on our favorite route are highlighted. Sort the **MEASURE** attribute values, smallest to largest. Click the gray box to the left of the record with **MEASURE** value **7.23**. The record should turn yellow. The point on the map should also turn yellow. Display All Records. Choose ***Clear Selected Features***. Dismiss the table.

17. Add and open the **pavement.dbf** table.

How many different pavement events are there? ______.

Select those pavement events in Route 30000030. How many events are there? ______.

Notice that there is a beginning mile point and an ending mile point field. Show selected records. Sort **BEGIN_MP** is ascending order. That should also put **END_MP** in ascending order. The segments connect but do not overlap. Display All Records. Clear all selections.

18. Make a route event layer for the "pavement" events:
Using the Make Route Event Layer tool, make a layer from the "**Pavement.dbf**" table. This time, of course, the event table should be "**pavement**" and Event Type is **Line** for a line event. The **From-Measure Field** should be **BEGIN_MP** and the **To-Measure Field** should be **END_MP**. As before, the route identifier field is **ROUTE1**. Click **OK**.

19. Turn off "**Some_Routes**". Make the **Pavement Events** layer **bright red**. Open the attribute table. Using **Select by Attributes**, select those **pavement events** on Route 30000030 and show selected records. Click the gray box to the left of the record that runs from mile point 4 to mile point 7; the record will turn yellow (the line on the map should also turn yellow). Zoom in and look at it on the map. Examine the **RATING** attribute, which is a value from 0 to 100, indicating the quality of the roadway.

What is the range of **RATING** values for all selected records? High ______. Low ______.

20. Show all records and clear selection. Minimize the **Attributes Of Pavement Events** window. Close the "**Some_Routes**" table. Save the map document as **Pitt_Routes**.

Intersecting Route Events

Just as you could combine a set of polygons with another set of polygons to create a third set of polygons with appropriate (geo)graphic and attribute information, you can also combine the graphic and linearly referenced attributes of routes.

Suppose someone has suggested that there is a **correlation between auto accidents and road conditions on Route 30000030**. You want to combine the accident data with road condition data.

21. If necessary, start ArcMap with "**Pitt_Routes,**" as saved in the previous step.

22. Open the attribute table of Some_Routes.

What is the Shape_Length of 30000030? ______.

Close the table.

The length of a route, considered as a feature, is, of course, in the units of the coordinate system. But, as you noted previously, the event measures are in miles. Just for the sake of confidence, let's compare one against the other.

23. Restore the attribute table of Pavement Events. Select 30000030. Display Selected Records.

Nowhere in the table is the length of each segment, but we can fix that, since we have the beginning and ending mile point number. With this few records (six), you could easily verify that there are no overlaps (a requirement for valid segmented data) and determine the total length in miles covered by the segments. But let's add a field to the table whose value is the segment length.

24. Under Table **Options** in the table, bring up the **Add Field** window. Call the new field "**Seg_Len**". Make its type **Float**. Set the **precision** (the number of digits possible) at **6**. Set the **scale** (the number of digits to the right of the decimal) at **2**. Click **OK**.

25. Right-click on the field name **Seg_Len** and click **Field Calculator**. Ignore the warning.

The segment length is calculated as the beginning mile point minus the ending mile point. Because this number might be negative, we will take its absolute value.

26. Calculate **Seg_Len** as **Abs([BEGIN_MP] - [END_MP])**. The calculation will take place only for selected records. Click **OK**. By looking at the table, verify that **Seg_Len** does indeed contain the positive difference between the beginning and ending points.

27. Run **Statistics** on **Seg_Len**.

    What is the Sum? ______.

    Divide the length of the route in feet that you found previously (step #22) by the number of feet in a mile (5280).

    The result should be reassuring: ______.

28. Using **Table Options > Select By Attributes,** and for Method: "**Select from current selection"**, obtain those segments of 30000030 that have **RATING >75**.

    How many total miles are in these segments? ______.

29. Clear Selections. Using a similar method, select segments of 30000030, and then **RATING <= 75**.

    How many total miles are in these segments? ______.

The intersection of point events and line events has a lot in common with its polygonal counterpart. The graphic result will consist of those points and segments that occupy common space. The attribute table will reflect both event tables. We will do the intersection for all route segments and all accident event points. (There are certainly more efficient ways to do this, as far as number of calculations is concerned, but this is the most straightforward.)

The process will be to intersect the accident and pavement event layers to produce **a new event table,** consisting of records of pavement event segments where the segments contain accidents. Then this table will be made into a (temporary) event layer and displayed.

30. Display All Records of Pavement Events. Clear Selected Records. Close that table. Open Arc Toolbox. In "**Linear Referencing Tools**", right-click on "**Overlay Route Events**" and select **Open**.

31. In the **Overlay Route Events** window, for the **Input Event Table,** select **Pavement Events**.

> NOTE: The next four text boxes may populate automatically however please check that all parameters are specified correctly. If you are unsure of the correct parameters to use please click the "**Show Help**" option at the bottom of the **Overlay Route Events** window.

For the **Overlay Event Table**, pick **Accident Events** in the same way.

32. Change the name of the default output table name (i.e. "**Output Event Table**") to "**Accidents_and_Pavements**". Click **OK**. You may have to wait a bit, since thousands of point events are being matched up with hundreds of segments. Close the window when the job is completed.

What you have now is an attribute table named "**Accidents_and_Pavement**". To see the graphics, you must make a layer. You did this before with the **Tools menu**. Since you have ArcToolbox open, you may use the tool there.

33. Make a route event layer for the "Accidents and Pavements" events:
In "**Linear Referencing Tools**", right-click on "**Make Route Events Layer**" and open the tool. In the "**Input Route Features**" text box, take the only choice offered: "**Some_Routes**". The Route Identifier field is, of course, "**ROUTE1**". The **Input Event Table**, from the drop-down menu, should be "**Accidents_and_Pavement**". Again, the **Route Identifier** field is "**ROUTE1**".

> NOTE: Again the fields in the window may populate automatically for you however please check that all parameters are specified correctly. If you are unsure of the correct parameters to use please click the "**Show Help**" option at the bottom of should be filled in for you.

Click **OK**.

34. Hide ArcToolbox. Turn off "**Accident Events"** and **"Pavement Events**". Open the "**Accidents_and_Pavements Event"** layer attribute table. Select the records in route 30000030.

How many accidents in total occurred on the selected route? ______.

Show only these records.

35. Right-click on the gray box to the left of any record. Notice the large number of fields and values in the **Identify Results** box. Dismiss the **Identify results** window. Next select accidents that occurred on the stretch of road with rating <= 75. Under **Table Options**, click "**Select By Attributes**". In that window, under Method, pick "**Select from current selection**". For the SQL expression, use **RATING <= 75**. Click Apply.

36. How many accidents occurred on the stretch of road where the rating is less than or equal to 75? ______.

    From your previous calculation in step #29, how many miles were involved in segments with rating <=75? ______.

37. By using subtraction, determine the number of accidents that occurred on segments with a RATING > 75. ______. (i.e., total number of accidents that occurred in route 30000030 – accidents that occurred on the stretch of route 30000030 where the rating is less than or equal to 75).

    From a previous step (#28), copy the length of road with rating >75: ______.

    Finally, calculate the **number of accidents per mile** for both, the stretch of the route with rating > 75 and the stretch of route with rating <= 75. Based on accidents per mile, a) what is your conclusion as to whether the condition of the road was related to the number of accidents and b) why do you think so?
    ____.

What's Not Covered Here

As with many applications we have covered in this course, we have barely scratched the surface. There is the issue of calibrating routes. And, as with everything we do, editing is also a major issue. To make use of linear referencing, you should refer to ESRI's publication *Linear Referencing in ArcGIS*, which exists as a paper manual available from ESRI or as a PDF file from Adobe Systems Incorporated. This file may also be available in the documents included in your installation of ArcGIS Desktop. Please check the folder named ESRI_Library\ArcGIS_Desktop. In addition to a Quick Start Tutorial (from which this assignment has been adapted), other topics covered include Creating Route Data, Displaying and Querying Routes and Events, Editing Routes, and Creating and Editing Event Data.

Please answer the following with brief sentences.

38. What is a route event? And, give examples of events used in this assignment.

39. Just as polygons can contain lines, linear route events can contain:

40. **What it means to intersect route events? Which route events were intersected in the assignment?**

41. Intersecting route events produces a table, which, in order to have its geographies displayed, must be converted to what?