Pipeline Integrity Management Using Linear Referencing With ArcObjects

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Paper Abstract

A standardized and automated procedure to assess pipeline integrity, in relation to High Consequence Areas (HCA), is achievable using GIS. Applications integrating linear referencing data principles packaged using ArcObjects™ will provide oil companies the means to comply with the Pipeline Safety Act of 2002. This presentation will explore application development issues, linear referencing or route analysis models, and HCA corridor assessment. Programming issues, ArcObject class structures, digital data requirements, and spatial methodology will be discussed. Prototype applications will be demonstrated.

Purpose

The purpose of this paper and subsequent presentation is to briefly introduce and examine how a GIS linear referencing data model can be utilized by pipeline operators to conduct High Consequence Area (HCA) Impact Analysis as part of their Integrity Management Plan (IMP). One of the primary objectives of an IMP is to identify locations along pipelines where a loss of containment could potentially affect HCA sites. Spatial operations available with linear referencing provide the tools to perform such tasks. As part of the presentation two customized ArcGIS applications utilizing linear referencing, will be discussed and demonstrated.

Background

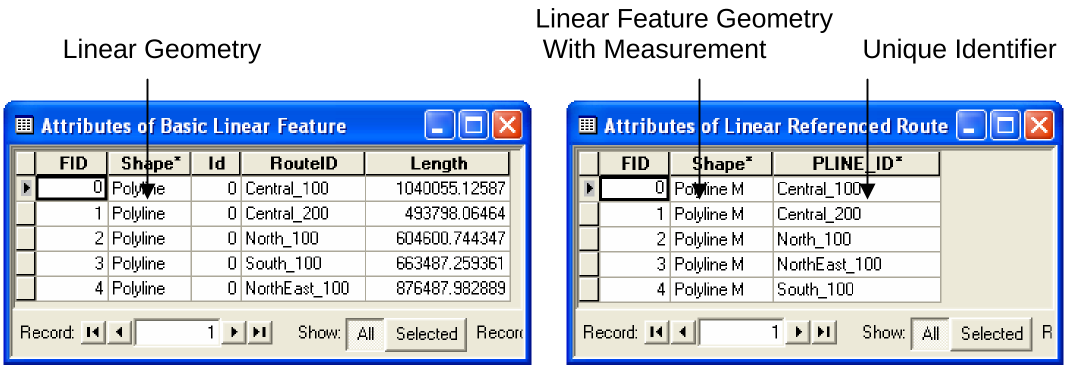
For a number of years BP Pipelines, N.A., a business unit of British Petroleum, has been using GIS technology for mapping and assessment of pipelines. Much of the initial data entry work and mapping was completed by GeoSpatial Services (GSS), a full service GIS consulting arm of Saint Mary's University of Minnesota.

Convinced that thorough HCA Impact Analysis required for regulatory compliance could be achieved using GIS technology, BP staff began working with GSS to design a suite of customized tools. After a number of meetings to conceptualize user requirements and identify the necessary spatial operations, it was decided that GSS would initially develop two applications for the ArcMap™ component of ArcGIS®. The first application would be a HCA Intersect Tool and the second a Cumulative Risk Index Tool. In order to best satisfy the complex requirements and operations of each tool, staff decided to explore some of the spatial capabilities found in the linear referencing data model.

Why use linear referencing for HCA Impact Analysis?

Features such as pipelines have generally been stored as simple linear geometric shapes. Because of the simple geometry, measuring, manipulating, clipping, and calculating individual pipeline segments or the geographic features found along such segments can be a programmatic nightmare. Limitations in the vector storage model requires splits in linear features when attribute changes occur and by default does not store discrete measurement information about each split segment as they relate to the original linear feature.

In order to handle these dynamic linear characteristics ESRI has incorporated a linear referencing data model in ArcGIS. When pipelines are “linear referenced”, a unique identifier is determined and a measurement system is stored within the linear geometry (Figure 1). This provides a means to model relative locations along the pipeline features.



Attributes of Basic Linear Feature

FID	Shape*	Id	RouteID	Length
0	Polyline	0	Central_100	1040055.12587
1	Polyline	0	Central_200	493798.06464
2	Polyline	0	North_100	604600.744347
3	Polyline	0	South_100	663487.259361
4	Polyline	0	NorthEast_100	876487.982889

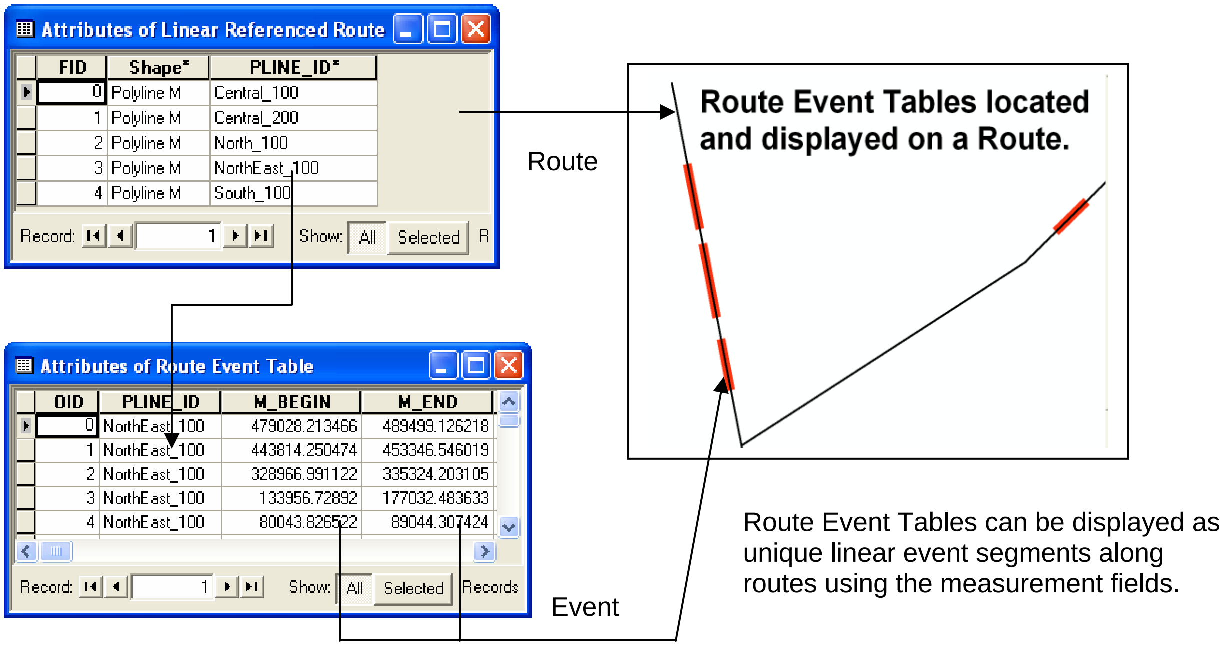
Attributes of Linear Referenced Route

FID	Shape*	PLINE_ID*
0	Polyline M	Central_100
1	Polyline M	Central_200
2	Polyline M	North_100
3	Polyline M	NorthEast_100
4	Polyline M	South_100

Figure 1 - Compares the database structure of a normal linear feature (left) and a linear referenced feature (right).

Once the geometry has been converted, pipelines are then considered “routes” and have expanded spatial capabilities, including the ability to associate and display tabular measurement data. In the linear referencing data model, measurement data tables are referred to or considered Route Event Tables. Each table at a minimum, consists of a route identifier field and a measurement location, either stored in a single field for points or multiple fields for lines (Figure 2).

Once these events have been spatially located on the pipeline features they are considered Route Events and are stored temporary in an ArcMap data frame as Route Event Source layers, available for display and manipulation.



Attributes of Linear Referenced Route

FID	Shape*	PLINE_ID*
0	Polyline M	Central_100
1	Polyline M	Central_200
2	Polyline M	North_100
3	Polyline M	NorthEast_100
4	Polyline M	South_100

Attributes of Route Event Table

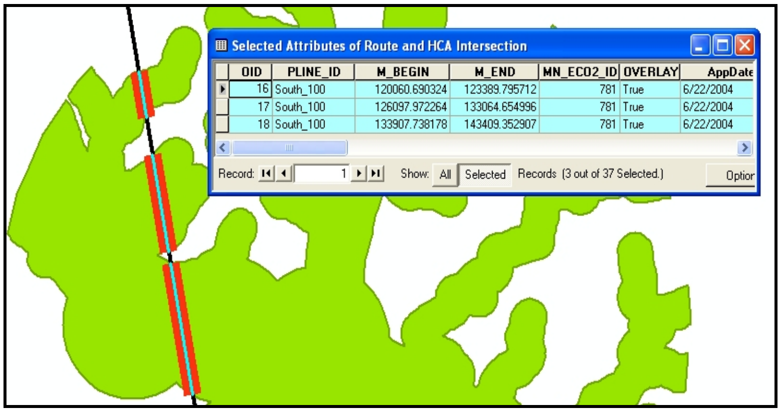
OID	PLINE_ID	M_BEGIN	M_END
0	NorthEast_100	479028.213466	489499.126218
1	NorthEast_100	443814.250474	453346.546019
2	NorthEast_100	328966.991122	335324.203105
3	NorthEast_100	133956.72892	177032.483633
4	NorthEast_100	80043.826522	89044.307424

Route Event Tables located and displayed on a Route.

Route Event Tables can be displayed as unique linear event segments along routes using the measurement fields.

Figure 2 – Illustrates the relationship between Routes and Route Event Tables. In order for this type of table to be associated with route segments, a unique route identifier and two measurement fields are required.

Spatial features adjacent to pipeline segments, such as HCA zones, form a new route event table when intersected with the route. These tables contain important information regarding the entry and exit distances of the pipeline within each HCA, as illustrated in Figure 3.



Selected Attributes of Route and HCA Intersection

OID	PLINE_ID	M_BEGIN	M_END	MN_ECO2_ID	OVERLAY	AppDate
16	South_100	120060.690324	123389.795712	781	True	6/22/2004
17	South_100	126097.972264	133064.654996	781	True	6/22/2004
18	South_100	133907.738178	143409.352907	781	True	6/22/2004

Records (3 out of 37 Selected.)

Figure 3 - shows the intersection of a pipeline route and HCA polygons

There are a number of other important spatial operations available to linear referenced features. These operations can be controlled, customized, and integrated for use with ArcObjects.

ArcObjects and Linear Referencing

ArcObjects are packaged software components (or objects) which make up the development platform for ArcGIS. By accessing these components, the programmer can use or customize a full range of GIS functionality within ArcGIS.

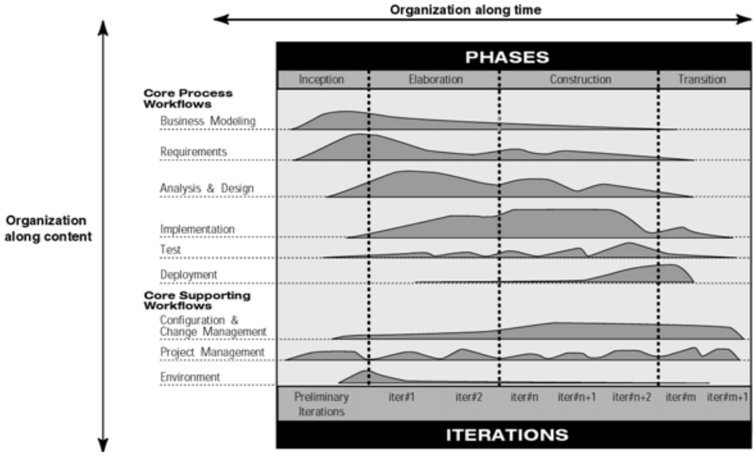
ArcObjects components are accessed within VBA (Visual Basic for Applications), an object-oriented programming language embedded in ArcMap and ArcCatalog. Every element contained in an ArcMap session can be reduced down to a set of components or objects. A thematic layer, geoprocessing operations, symbol sets, an attribute table, and a button, are all accessible using ArcObjects. This includes components for the linear referencing data model and related operations.

GSS staff developed the two HCA applications in VBA using ArcObjects. In order to build the complex array of spatial components, minimize user input error, and satisfy the client specified customization requirements, it was important to approach the development process with a well defined strategy.

Application Design and Development

As part of the application design process, staff organized a development strategy based on the Rational Unified Process (RUP), a proven approach for software development. The RUP approach is structured into a two-dimensional matrix configuration as shown in Figure 4, bound by workflow processes (Y axis), which progress over time or through phases (X axis).

Figure 4 – The Rational Unified Process Diagram.



These phases are divided into four distinct categories consisting of inception, elaboration, construction, and transition phases. Each phase is comprised of specific tasks and/or activities that produce pieces of information, termed artifacts, which are refined through iterations or development cycles.

The process begins with the Inception Phase and can be categorized by fact-finding activities and high-level (generalized) project organization. This phase consists of the following requirements:

- Collect and categorize user requirements
    - Example – Identified specific spatial operations and products.
- Conduct an inventory and assessment of datasets
    - Example – Acquired pipeline and HCA layers.
- Organize a high-level risk assessment
    - Example – Identified obstacles or possible barriers.
- Organize a high-level Project Description

From a design stand point the Inception Phase is the most important essential phase for application development. During this phase the generalized concepts and requirements are refined into a detailed structure. Additional tasks included:

- Create conceptual models
    - Example - Constructed software blueprint using UML (Unified Modeling Language) diagrams.
- Eliminate high-risk elements
    - Example – Identified problems and offer alternative solutions.
- Identify required products
    - Example – Determine what analysis needs to be performed and how it is delivered to the client.

After BP and GSS formed a solid conceptual framework the project moved into the Construction Phase. Requirements of this phase were to:

- Create the applications
    - Example – Design individual procedures (or modules) that could be independently tested and placed within the application.
- Flush out design problems
    - Example – Shapefiles do not support true circles, so we created buffers in a geodatabase.
- Author procedural documentation
    - Example – Construct a user manual.
- Test the application
    - Example – Deliver an ArcMap Document file (MXD) to client for testing.

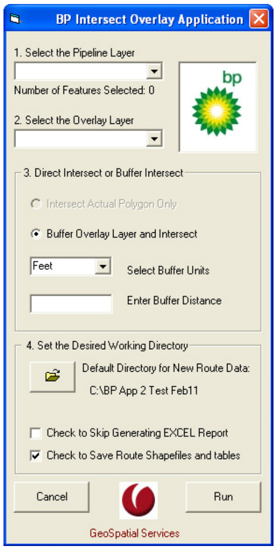
Once the applications were written, the code cleaned up, and the functionality rigorously tested and debugged, we proceeded into the final development stage, the Transition phase. During this phase the final versions of the software was tested by the client, then packaged, and deployed. Required tasks included:

- Incorporate user feedback into the final product
    - Example – After testing the application the user decided that they would like to see a progress bar.
- Modified application and transferred to VB
    - Example – Some VBA functions need to be rewritten before porting into VB and then on to a self-contained package or DLL.
- Create the distributed application
    - Example – Construct a DLL (dynamic link library) from the VB code.
- Delivered Documentation
    - Example – Author the final user's manual.
- Archived VBA, VB, and DLL deliverables
-

The development process for each application took approximately 3 ½ to 4 months, well within budget and approximated delivery date. Each application was packaged in a Visual Basic DLL (Dynamic Link Library) file and delivered to the client. The DLL files were loaded into ArcMap and within minutes staff were able to begin conducting HCA Impact Analysis.

Product Demonstration

The HCA Intersect Tools offer the user the ability to perform both direct (HCA layer) and indirect (HCA buffer) impact analysis. The user selects the pipelines, HCA layers, type of analysis, and required parameters from an easy-to-use GUI window as shown in Figure 5. Specified layers are copied to temporary directories and modified as needed. Selected pipelines layers are converted to “linear referenced” routes and intersected with HCA or buffered HCA layers. A new intersected feature (route event source) is created containing entry (beginning) and exiting (ending) measurements along with additional attribute information from the HCA layer or buffer layer. (Figure 6)



BP Intersect Overlay Application

1. Select the Pipeline Layer

Number of Features Selected: 0

2. Select the Overlay Layer

3. Direct Intersect or Buffer Intersect

○ Intersect Actual Polygon Only

● Buffer Overlay Layer and Intersect

Select Buffer Units: Feet

Enter Buffer Distance

4. Set the Desired Working Directory

Default Directory for New Route Data: C:\BP App 2 Test Feb11

☐ Check to Skip Generating EXCEL Report

☑ Check to Save Route Shapefiles and tables

Figure 5 - Application Interface window

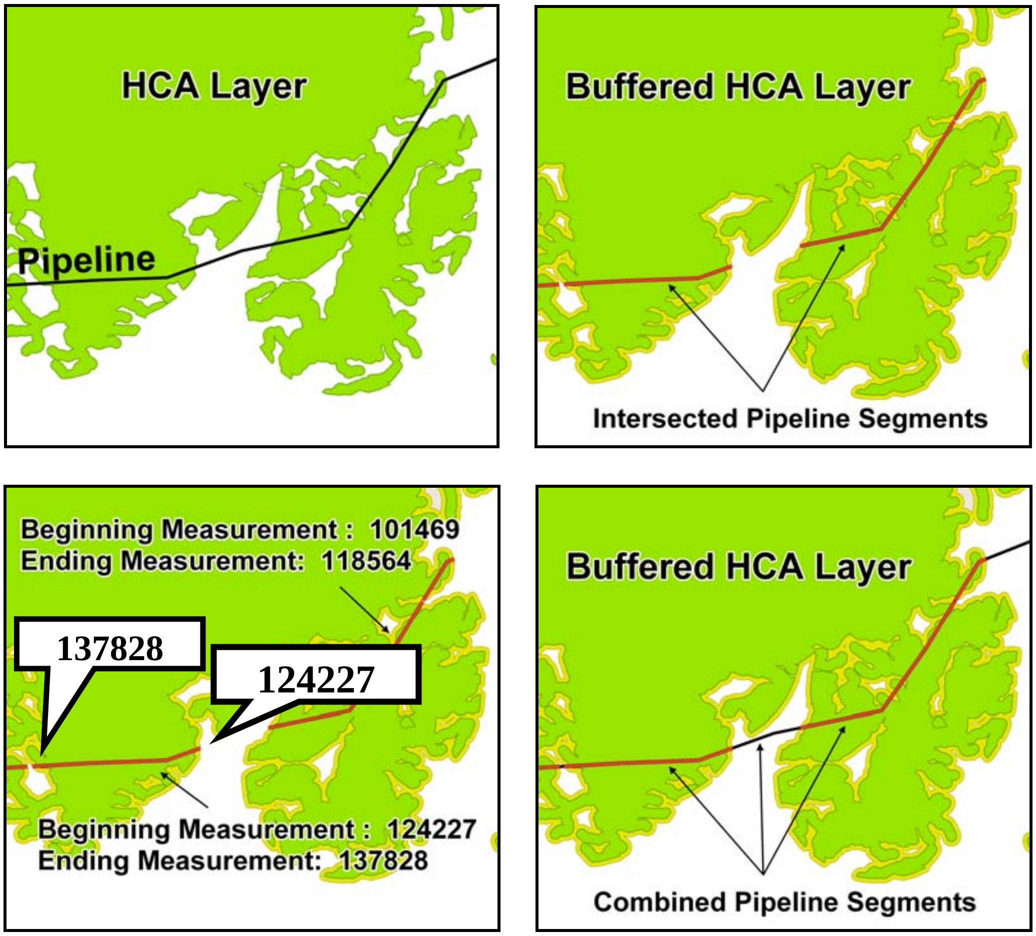
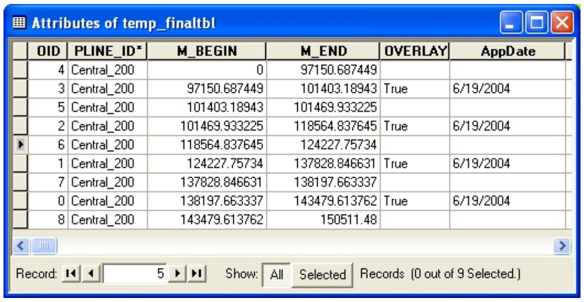


Figure 6 – Illustrates the spatial operations performed in the first application.

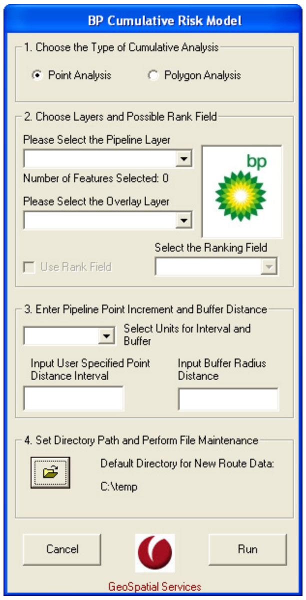
As part of the application deliverables, the client required a tabular assessment of all pipelines. Measurements from the intersected features were combined with original non-intersected pipeline segments, producing an overall pipeline table used for HCA Impact Analysis. (Figure 7)



OID	PLINE_ID*	M_BEGIN	M_END	OVERLAY	AppDate
4	Central_200	0	97150.687449		
3	Central_200	97150.687449	101403.18943	True	6/19/2004
5	Central_200	101403.18943	101469.933225		
2	Central_200	101469.933225	118564.837645	True	6/19/2004
6	Central_200	118564.837645	124227.75734		
1	Central_200	124227.75734	137828.846631	True	6/19/2004
7	Central_200	137828.846631	138197.663337		
0	Central_200	138197.663337	143479.613762	True	6/19/2004
8	Central_200	143479.613762	150511.48		

Figure 7 – One of the tables produced by the application.

The second application, the Cumulative Risk Index Tool, gives the user the ability to generate Potential Impact Circles for counting and identify HCA sites along pipeline segments. The application parameters are set from a GUI interface window (Figure 8). User specified increments are placed along the pipeline and buffered. These buffers or Potential Impact Circles are then used to perform the HCA analysis. (Figure 9 & 10)


BP Cumulative Risk Model

1. Choose the Type of Cumulative Analysis
● Point Analysis ○ Polygon Analysis

2. Choose Layers and Possible Rank Field
Please Select the Pipeline Layer
Number of Features Selected: 0
Please Select the Overlay Layer
Select the Ranking Field
☐ Use Rank Field

3. Enter Pipeline Point Increment and Buffer Distance
Select Units for Interval and Buffer
Input User Specified Point Distance Interval
Input Buffer Radius Distance

4. Set Directory Path and Perform File Maintenance
Default Directory for New Route Data:
C:\temp

Figure 8 – Example of the user interface window for the second application. (above)

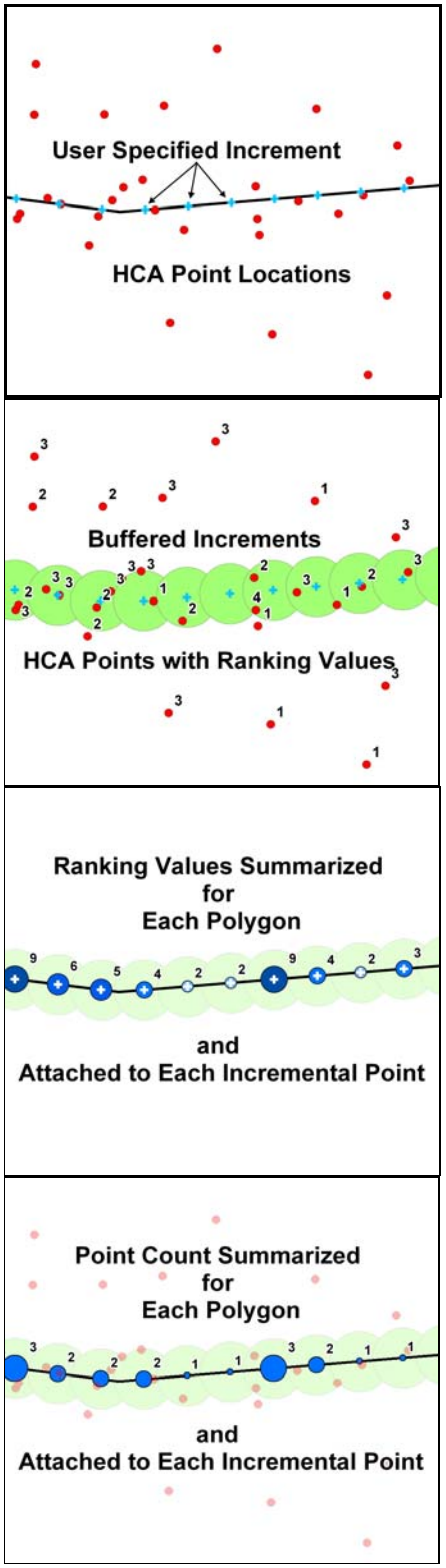
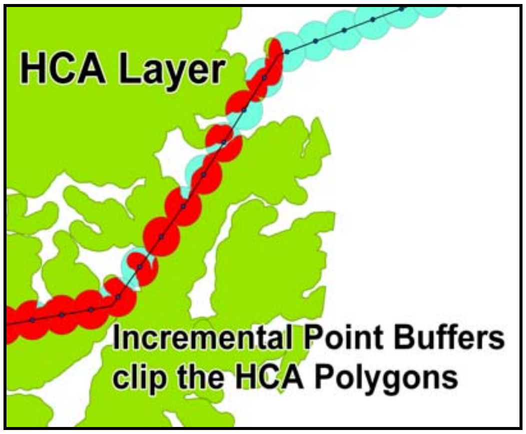


Figure 9 – Illustrates some of the various analytical operations that can be performed on the Potential Impact Circles. (right)

Figure 10 - The Potential Impact Circles can also be used to analyze HCA polygons by clipping and totaling area or calculating percentage of fill for each circle. (below)



Built into both applications are a number of error checking routines, which inspect user input parameters, data layer requirements, and ArcMap environmental settings. These routines, along with additional examples of application functionality, programming issues, and development considerations will be discussed further during the actual conference presentation.

Conclusion

In order to comply with DOT OPS regulations, many pipeline operators are looking to GIS technology for new tool sets to facilitate the implementation of their Integrity Management Plan. As part of the implementation process, operators will be focusing their efforts and resources on conducting HCA Impact Analysis.

This type of analysis can best be performed using the advanced GIS spatial operations found in the linear referencing data model. By taking advantage of the expanded functionality and operations, users are no longer constrained by the inherent limitations of simple linear geometry.

As demonstrated in this paper and subsequent presentation, the expanded functionality available within a GIS can be customized, standardized, and packaged in a user friendly application built with ArcObject components. These applications provide some of the essential tools required by the pipeline community to perform their analysis and ultimately achieve regulatory compliance.

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Please note that all examples of pipelines and HCA have been created solely for this paper and do not represent real GIS data.

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