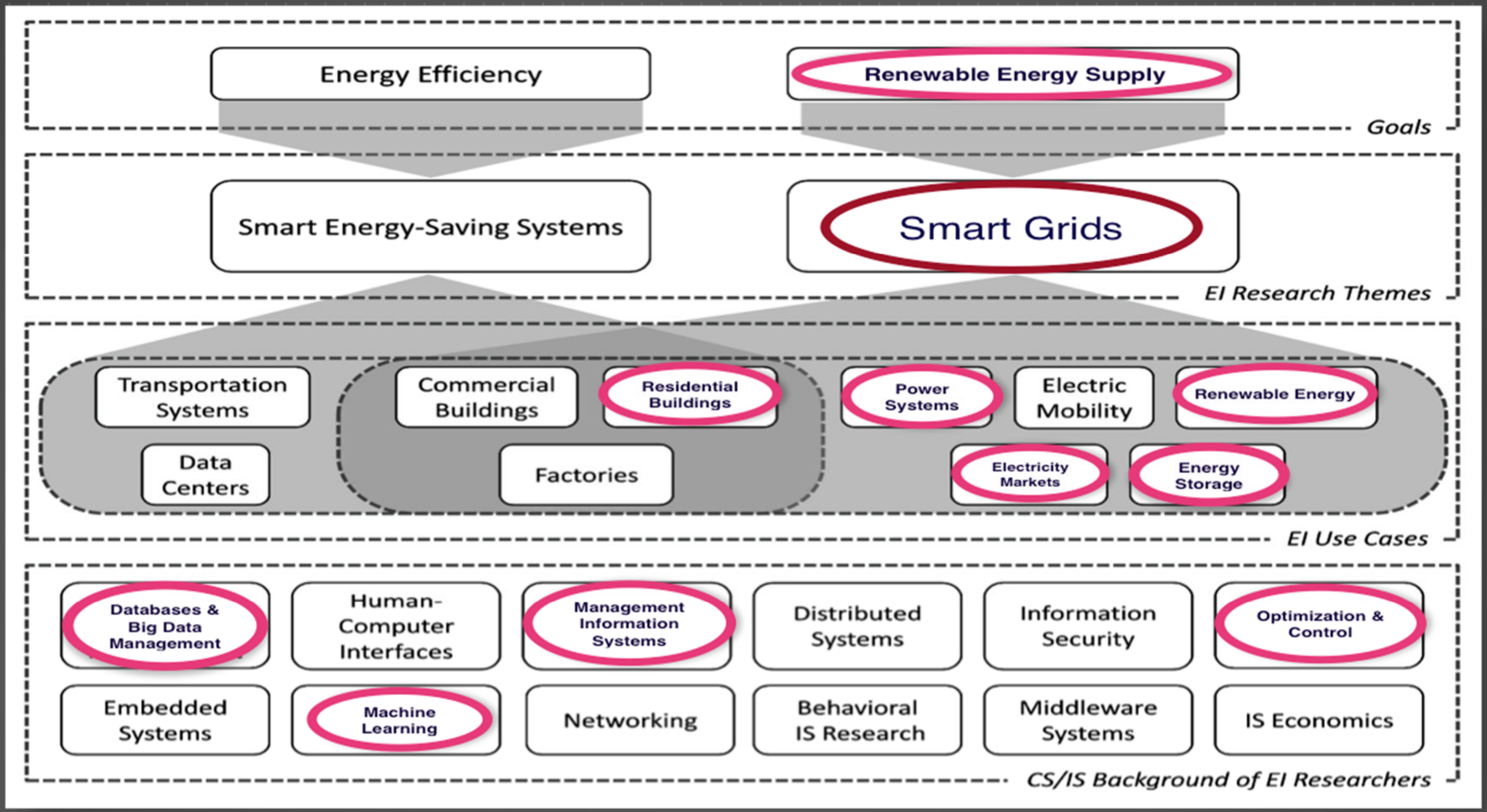
LOCATION ANALYTICS FOR SMART GRID RELIABILITY

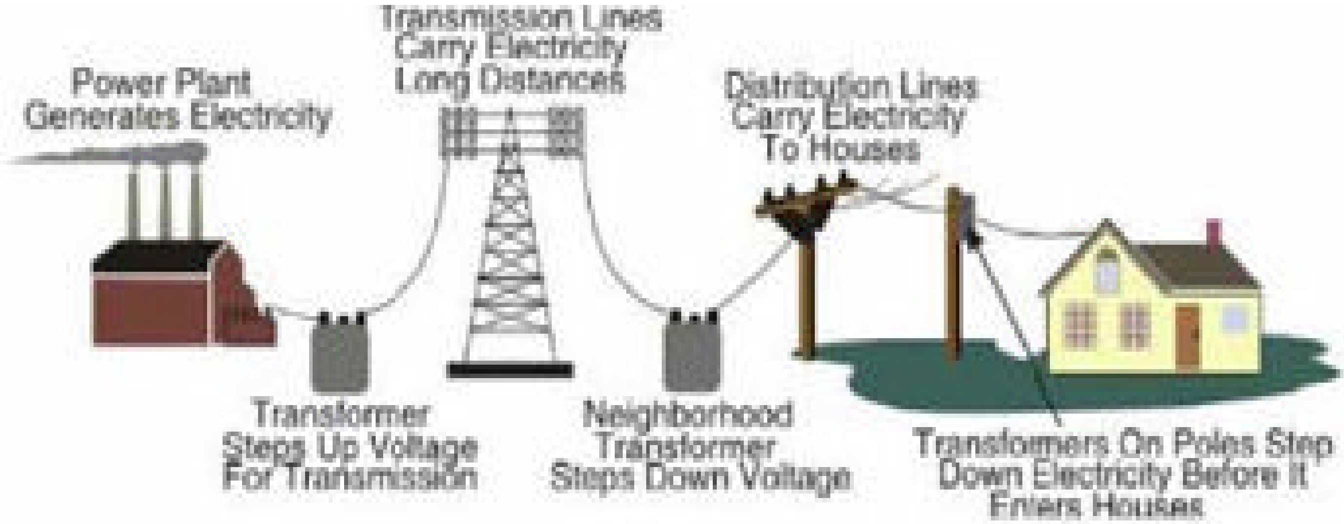
Vivian Sultan, PhD
Claremont Graduate University
The Center for Information Systems & Technology (CISAT)
130 E. 9th Street, ACB - 217
Claremont, CA 91711
Email: vivian.sultan@cgu.edu
Phone: (818) 419-4666

ENERGY INFORMATICS RESEARCH (GOEBEL ET AL. 2014)



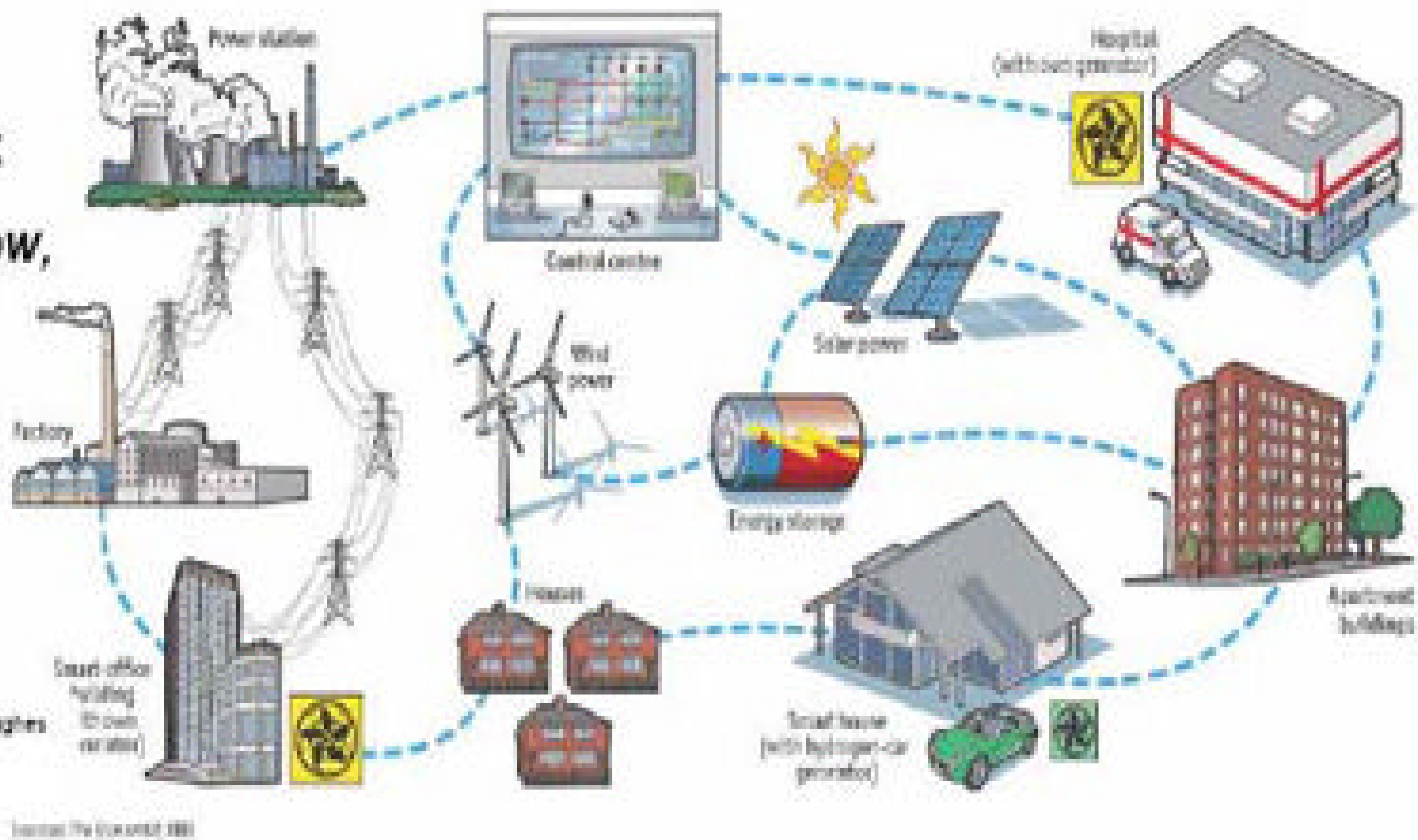
Before Smart Grid:

One-way power flow, simple interactions



After Smart Grid:

Two-way power flow, multi-stakeholder interactions



Adapted from EPRI Presentation by Joe Hughes
NIST Standards Workshop
April 28, 2009

Smart Grid Reliability

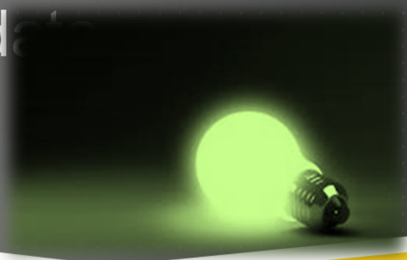
Reliability: the degree to which the performances of the elements of the electric system result in power being delivered to consumers within accepted standards and in the amount desired - Measured by outage indices

- The economic cost of power interruptions to U.S. electricity consumers is $79 billion annually in damages and lost economic activity
- Power outages can be especially tragic when it comes to life-support systems in places like hospitals and nursing homes or in facilities such as in airports, train stations, and traffic control

Goal & Research Direction

The objective is to advance Smart Grid reliability through the use of location analytics - a class of tools for seizing, storing, analyzing, and demonstrating data in relation to its position on the Earth's surface

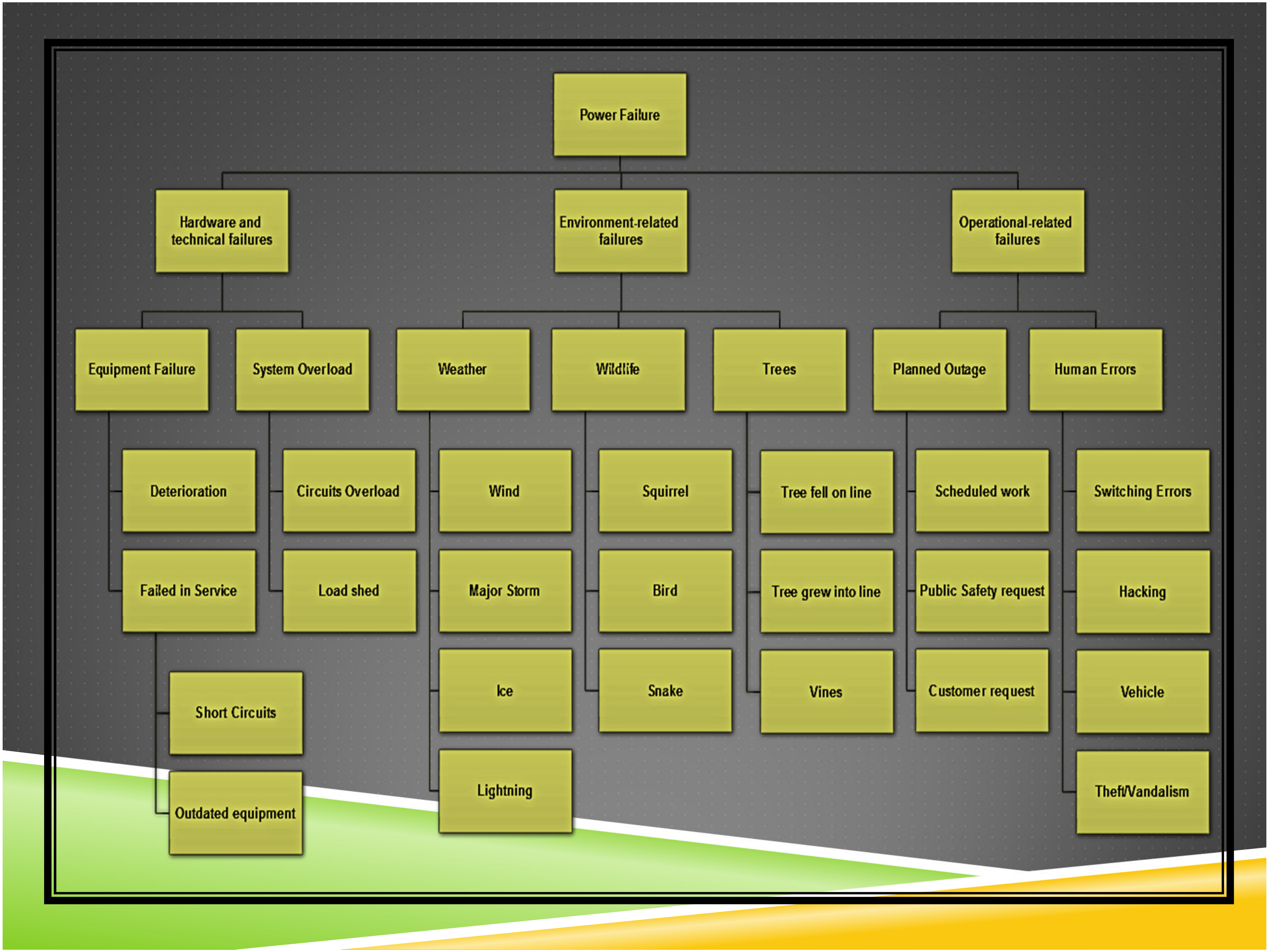
- ✓ GIS fostered a new approach to forecasting and data analytics
- ✓ GIS applications include recognizing site locations, mapping topographies and also developing analytical models to forecast events
- ✓ GIS is not limited to any specific field, only restricted by the availability of geospatial d



Goal & Research Direction

This research is concerned with Smart Grid reliability, specifically the reliability of the distribution system

- Since distribution systems account for up to 90 % of all customer reliability problems, improving distribution reliability is the key to improving customer reliability problems
- Main research question "How may location analytics be used to enhance Smart Grid reliability research?"



Power Failure
Hardware and technical failures
Environment-related failures
Operational-related failures
Equipment Failure
System Overload
Weather
Wildlife
Trees
Planned Outage
Human Errors
Deterioration
Failed in Service
Short Circuits
Outdated equipment
Circuits Overload
Load shed
Wind
Major Storm
Ice
Lightning
Squirrel
Bird
Snake
Tree fell on line
Tree grew into line
Vines
Scheduled work
Public Safety request
Customer request
Switching Errors
Hacking
Vehicle
Theft/Vandalism

DATA SELECTION AND ACQUISITION

The Electric Power Research Institute (EPRI's) Data Repository is the primary datasets utilized to conduct this analysis

- ✓ Access to datasets was provided as part of EPRI's Data mining initiative, an initiative that provides a test bed for data exploration and innovation and seek to solve the top challenges faced by the utility industry
- ✓ The data sets include data from advanced metering systems, supervisory control and data acquisition (SCADA) systems, geospatial information systems (GIS), outage management systems (OMS), distribution management systems (DMS), asset management systems, work management systems, customer information systems, and intelligent electronic device databases

WEATHER DATA

- ✓ Georgia Spatial Data Infrastructure (GaSDI) and the Georgia GIS Clearinghouse is the data source for the monthly temperature and precipitation data

Search Results

Records 1-50 of 52 — 1 next >>

Click the Access icon to download data. To preview, click the Title.

Access	Extent	Title	Year	Scale
FREE	Georgia	Average April Maximum Temperatures : 1960-1991	1999	250,000
FREE	Georgia	Average April Mean Temperatures : 1960-1991	1999	250,000
FREE	Georgia	Average April Minimum Temperatures : 1960-1991	1999	250,000
FREE	Georgia	Average April Precipitation : 1960-1991	1999	250,000
FREE	Georgia	Average August Maximum Temperatures : 1960-1991	1999	250,000
FREE	Georgia	Average August Mean Temperatures : 1960-1991	1999	250,000
FREE	Georgia	Average August Minimum Temperatures : 1960-1991	1999	250,000
FREE	Georgia	Average August Precipitation : 1960-1991	1999	250,000
FREE	Georgia	Average December Maximum Temperatures : 1960-1991	1999	250,000
FREE	Georgia	Average December Mean Temperatures : 1960-1991	1999	250,000
FREE	Georgia	Average December Minimum Temperatures : 1960-1991	1999	250,000
FREE	Georgia	Average December Precipitation : 1960-1991	1999	250,000
FREE	Georgia	Average February Maximum Temperatures : 1960-1991	1999	250,000
FREE	Georgia	Average February Mean Temperatures : 1960-1991	1999	250,000
FREE	Georgia	Average February Minimum Temperatures : 1960-1991	1999	250,000
FREE	Georgia	Average February Precipitation : 1960-1991	1999	250,000
FREE	Georgia	Average January Maximum Temperatures : 1960-1991	1999	250,000
FREE	Georgia	Average January Mean Temperatures : 1960-1991	1999	250,000

- ✓ The National Oceanic and Atmospheric administration website (NOAA) is the data source for the storm events and storm details

TOOLS USED FOR THE ANALYSIS

- ✓ ArcGIS is a scalable and secure software-as-a-service program hosted by the Environmental Systems Research Institute (Esri)
- ✓ GeoDa is a free software package that conducts spatial data analysis, geo-visualization, spatial autocorrelation, and spatial modeling.
- ✓ SPSS is a the standard and most widely used software package for complex statistical analysis

METHODOLOGY

Step 1: Loaded data files from EPRI's Data Repository along with weather data to ArcGIS

- ✓ Created a folder (geodata set) and set up local projection to use Georgia projection system.
- ✓ Imported the data files and basemaps (counties, tracks, roads, etc.) into the geodata set
- ✓ Imported 6 map layers from NOAA, 48 weather shapefiles from GaSDI and the Georgia GIS Clearinghouse into a geodatabase

METHODOLOGY– *CONT'D*

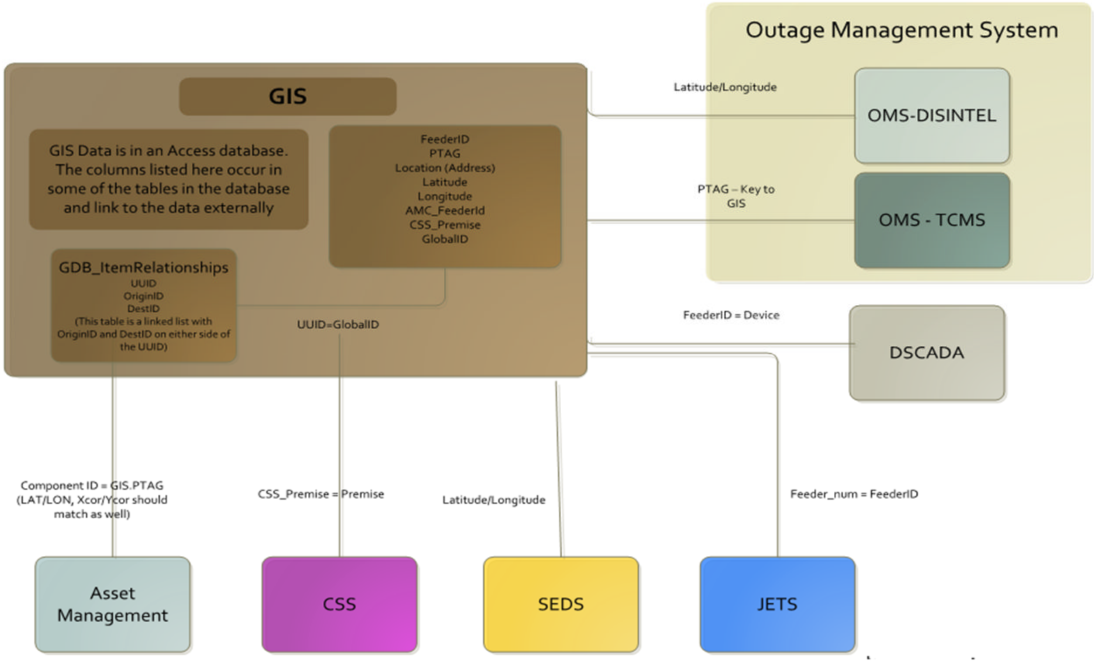
Step 2: Ran initial power outage events data exploration analyses in excel and GeoDa software.

Step 3: Merged and related various data files from EPRI's data repository in ArcGIS

- ✓ Merged outage events layers 2013, 2014, 2015 into one combined layer for the three years and linked to customers called and customers interrupted data layers
- ✓ Related the forestry data and the Asset Management data with the combined events layer

METHODOLOGY– *CONT'D*

Overview of how data files are related in the GIS system



Source: EPRI's Data Repository

METHODOLOGY– *CONT'D*

Step 4: Changed the projection of all maps to WGS 1984 projection system.

Step 5: Cleaned the outage events map layer

- ✓ Started with 80,839 total records in the outage events map layer attribute table
- ✓ Ended with 76,848 total records

Step 6: Defined and created a study area for throughout project.

METHODOLOGY– *CONT'D*

Step 7: Created a separate dummy variable for each cause of outage and Joined tables

Step 8: Created new map layer for tree caused events by selection from the combined events layer

- ✓ Wrote a query to select all the events under cause (Wind/Tree, Limb on Line, Tree Fell on line, Tree Grew Into Line, Vines)
- ✓ Exported data into the geodatabase
- ✓ Named new map layer "Right Of Way Outage Events"

METHODOLOGY– *CONT'D*

Step 9: Repeated the previous step to create additional map layers for weather related outage events, equipment failure, and System overload events.

- ✓ Weather related outage events (events under cause category Wind/Tree, Wind, Ice, Major Storm, Lightning)
- ✓ Equipment failure (events under cause category Failed in Service, Deterioration)
- ✓ System overload (events under cause category Thermal overload, Overload, Load shed)

METHODOLOGY– *CONT'D*

Step 10: Used the average nearest neighbor tool to find the average distance between outage events and if events are likely to cluster in certain areas

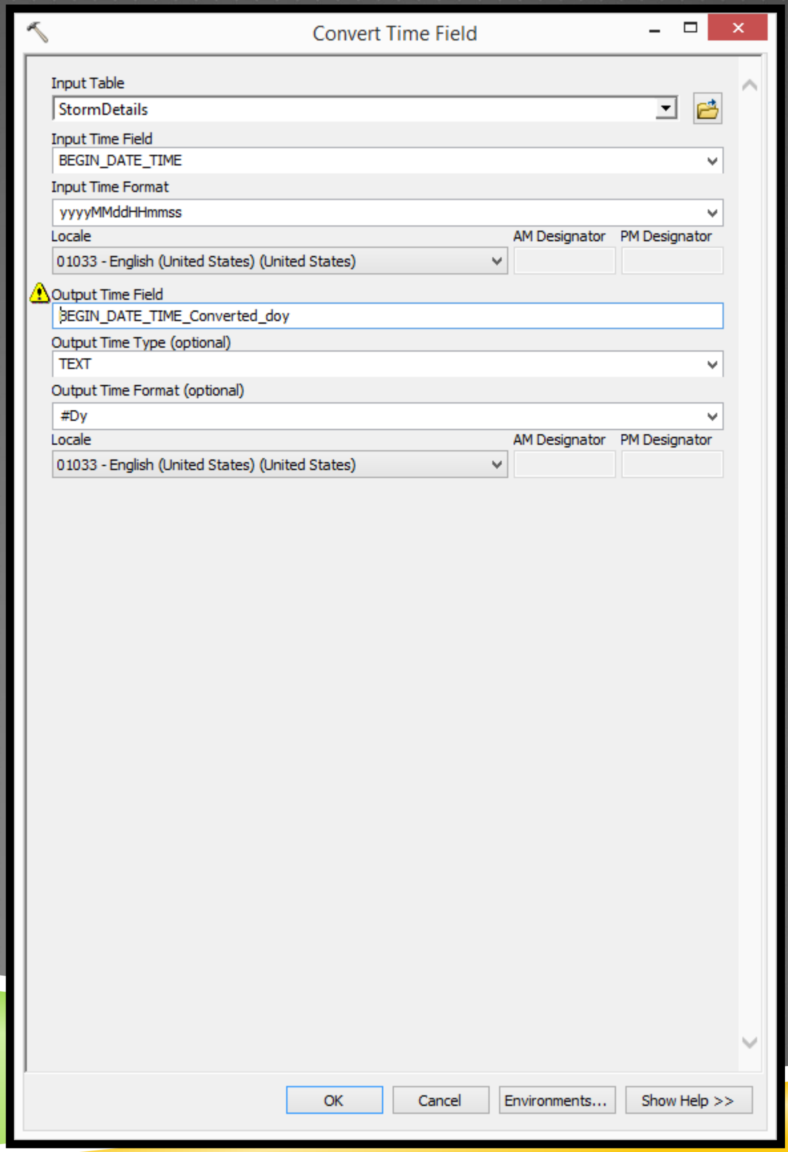
Step 11: Calculated transformers age and joined to the transformer table in ArcGIS

Step 12: Used the Convert time field / data management tool in ArcMap to convert outage event time to day of year.

- ✓ Repeated the same step for the storm events on storm details map layer.

METHODOLOGY– *CONT'D*

Convert time field (data management) tool to convert event time to day of year



METHODOLOGY– *CONT'D*

Table

StormDetails

MAGNI	FLOOD_C	CATEGORY	TOR_F	TOR_LE	TOR_WI	TOR_OT	TOR_OT	TOR_OTH	TOR_O	BEGIN_	BEGIN	BEGIN_LOC	END_RAN	END_A	END_LOC	BEGIN_LAT	BEGIN_LON	END_LAT	END_LON	EPISODE_NARRATIVE	EVENT_NARRATIVE	DATA_S	BEGIN_DATE_TIME	year2	day_year_id *
EG	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	1	E	COVINGTON	1	E	COVINGT	33.6	-83.86	33.6	-83.86	Marginal Risk (SPC) day produced rather wides	Numerous trees and powerlines down	CSV	146	2015	146_2015
EG	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	1	NW	SARGENT	1	NW	SARGENT	33.44	-84.88	33.44	-84.88	Marginal Risk (SPC) day yielded several severe t	Several trees down northwest of Ne	CSV	151	2015	151_2015
EG	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	2	S	TYRONE	2	S	TYRONE	33.4458	-84.6008	33.4458	-84.6008	Strong afternoon heating and a very moist airma	An NWS survey team determined that	CSV	175	2015	175_2015
<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	2	W	PALMETTO	2	W	PALMETT	33.5196	-84.705	33.5196	-84.705	A stationary frontal boundary across North Geo	A report of quarter sized hail 2 miles	CSV	154	2015	154_2015
EG	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	2	E	ROSCOE	2	E	ROSCOE	33.4986	-84.7835	33.4986	-84.7835	A stationary frontal boundary across North Geo	An off-duty NWS employee reported s	CSV	154	2015	154_2015
<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	1	N	NEWNAN	1	N	NEWNAN	33.3807	-84.7997	33.3807	-84.7997	A stationary frontal boundary across North Geo	The Coweta County Emergency Mana	CSV	154	2015	154_2015
<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	2	ENE	MC BRIDE	2	ENE	MC BRIDE	33.3965	-84.7493	33.3965	-84.7493	A stationary frontal boundary across North Geo	A report of dime to golf ball sized hail a	CSV	154	2015	154_2015
<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	1	N	RAYMOND	1	N	RAYMON	33.34	-84.72	33.34	-84.72	A stationary frontal boundary across North Geo	The public reported quarter sized hail	CSV	154	2015	154_2015
EG	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	0	SW	WILLIAMSO	1	ENE	WILLIAMS	33.1757	-84.3736	33.1845	-84.3587	A weak cold front and a strong upper-level shor	The Pike County Emergency Manager r	CSV	160	2015	160_2015
<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	1	NNW	MORROW	1	NNW	MORROW	33.5926	-84.3395	33.5926	-84.3395	A weak cold front and a strong upper-level shor	A trained spotter reported leaves shre	CSV	160	2015	160_2015
<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	1	E	EAST PT	1	E	EAST PT	33.68	-84.44	33.68	-84.44	Strong afternoon heating and a very moist airma	The Fulton County Emergency Manage	CSV	175	2015	175_2015
EG	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	1	SE	RED OAK	2	SE	RED OAK	33.6032	-84.4843	33.6044	-84.4739	Despite a persistent upper-level ridge over the r	An Atlanta television news station rep	CSV	169	2015	169_2015
EG	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	1	E	VAUGHN	1	E	VAUGHN	33.28	-84.39	33.28	-84.39	Strong afternoon heating and a very moist airma	The Spalding County 911 Center report	CSV	175	2015	175_2015
<Null>	Heavy Rain	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	1	S	WELCOME	1	S	WELCOME	33.3823	-84.8819	33.3837	-84.8779	Marginal Risk (SPC) day yielded several severe t	Several inches of rain in a short period	CSV	151	2015	151_2015
EG	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	0	S	JERSEY	1	NNE	SOCIAL CI	33.7154	-83.7993	33.6577	-83.7172	A weak cold front and a strong upper-level shor	The Walton County 911 Center reporte	CSV	160	2015	160_2015
EG	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	0	NE	SARGENT	3	NNE	MC COLLU	33.4326	-84.8678	33.4865	-84.6792	Despite a persistent upper-level ridge over the r	The Coweta County 911 Center report	CSV	169	2015	169_2015
EG	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	1	SW	MAGNET	1	SW	MAGNET	33.5566	-84.039	33.5566	-84.039	Despite a persistent upper-level ridge over the r	The Rockdale County 911 Center repor	CSV	169	2015	169_2015
EG	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	1	ESE	FAIRVIEW	1	W	HUB JCT	33.5932	-83.9378	33.5971	-83.7694	Despite a persistent upper-level ridge over the r	The Newton County 911 Center report	CSV	169	2015	169_2015
EG	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	2	SSW	ATLANTA	3	ENE	ATLANTA	33.738	-84.4176	33.7891	-84.3503	A slow moving cold front combined with an upp	Reports of trees blown down on Ralp	CSV	222	2015	222_2015
EG	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	1	S	JACKSON	1	S	JACKSON	33.29	-83.97	33.29	-83.97	A slow moving cold front combined with an upp	The Butts County Emergency Manager	CSV	222	2015	222_2015
EG	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	2	N	STARRS MIL	2	N	STARRS	33.3657	-84.5205	33.3657	-84.5205	A weak upper-level trough combined with abun	A NWS employee reported one pine tr	CSV	229	2015	229_2015
EG	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	1	SE	WALNUT GR	0	WNW	GOOD HO	33.7207	-83.8394	33.7808	-83.6224	A weak upper-level trough combined with abun	The Walton County 911 Center reporte	CSV	229	2015	229_2015
<Null>	Heavy Rain	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	4	NW	CONSTITUTI	1	W	CONSTITU	33.71	-84.4	33.68	-84.36	A strong surface low associated with a deep u	The stage height at a USGS stream ga	CSV	4	2015	4_2015
<Null>	Heavy Rain	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	1	N	CONSTITUTI	0	N	CONSTITU	33.7	-84.35	33.68	-84.35	A strong surface low associated with a deep u	The upper reaches of Shoal Creek nea	CSV	4	2015	4_2015
EG	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	1	N	MORELAND	1	N	MORELAN	33.29	-84.77	33.29	-84.77	Marginal Risk (SPC) day produced rather wides	Trees and powerlines down along Ro	CSV	146	2015	146_2015
EG	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	1	ESE	YATES	1	ESE	YATES	33.46	-84.88	33.46	-84.88	Marginal Risk (SPC) day produced rather wides	Trees down along Robinson Road and	CSV	146	2015	146_2015
EG	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	0	N	SENOIA	0	N	SENOIA	33.3	-84.55	33.3	-84.55	Marginal Risk (SPC) day produced rather wides	Multiple trees down at the intersection	CSV	146	2015	146_2015
EG	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	1	NE	SHAKE RAG	1	NE	SHAKE R	33.43	-84.56	33.43	-84.56	Marginal Risk (SPC) day produced rather wides	Trees down blocking road at Clear Spr	CSV	146	2015	146_2015
EG	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	4	SW	LOVEJOY	4	SW	LOVEJOY	33.39	-84.38	33.39	-84.38	Marginal Risk (SPC) day produced rather wides	Trees down across southern Clayton	CSV	146	2015	146_2015
EG	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	3	WSW	FLIPPEN	3	WSW	FLIPPEN	33.46	-84.23	33.46	-84.23	Marginal Risk (SPC) day produced rather wides	A large tree was blown down at the in	CSV	146	2015	146_2015
<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	3	SW	WHITESBUR	3	SW	WHITESBU	33.45	-84.95	33.45	-84.95	A series of moderate short waves swept acros	The public reported nickel sized hail ne	CSV	90	2015	90_2015
<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	2	ESE	MC BRIDE	2	ESE	MC BRIDE	33.37	-84.75	33.37	-84.75	A series of moderate short waves swept acros	A NWS employee reported dime sized	CSV	90	2015	90_2015
<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	0	N	NEWNAN	0	N	NEWNAN	33.37	-84.8	33.37	-84.8	A series of moderate short waves swept acros	A report of quarter size hail in Newna	CSV	90	2015	90_2015
<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	1	WNW	SHARPSBUR	1	WNW	SHARPSB	33.3407	-84.6694	33.3407	-84.6694	A series of moderate short waves swept acros	WSB TV reported nickel to quarter siz	CSV	90	2015	90_2015
<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	0	N	SENOIA	0	N	SENOIA	33.3	-84.55	33.3	-84.55	A series of moderate short waves swept acros	The public reported quarter to half doll	CSV	90	2015	90_2015
<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	1	SW	NEWNAN	1	SW	NEWNAN	33.36	-84.81	33.36	-84.81	A series of moderate short waves swept acros	The public reported ping pong ball size	CSV	90	2015	90_2015
<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	0	N	TYRONE	1	NNE	SHAKE R	33.47	-84.6	33.4341	-84.5641	A series of moderate short waves swept acros	Amateur radio operators reported quar	CSV	90	2015	90_2015
<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	1	SE	NEWNAN	1	SE	NEWNAN	33.36	-84.79	33.36	-84.79	Marginal Risk (SPC) day produced rather wides	Lightning hit a natural gas line and cau	CSV	146	2015	146_2015
EG	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	1	S	FLIPPEN	6	NE	OLA	33.4657	-84.1802	33.4761	-83.9713	A slow moving cold front along with a moderatel	The Henry County Emergency Manage	CSV	218	2015	218_2015
EG	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	1	ESE	STEWART	0	SE	JERUSALE	33.4135	-83.8532	33.5194	-83.7292	A slow moving cold front along with a moderatel	The Newton County 911 Center report	CSV	218	2015	218_2015
EG	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	3	SE	ATLANTA	5	ENE	BOLTON	33.7426	-84.3659	33.8371	-84.3915	A weak cold front and a strong upper-level shor	The Fulton County Emergency Manage	CSV	160	2015	160_2015
EG	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	1	N	(ATL)ATLAN	1	N	(ATL)ATL	33.66	-84.43	33.66	-84.43	Strong afternoon heating and a very moist airma	The Georgia DOT reported a tree blow	CSV	175	2015	175_2015
MG	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	1	S	ATLANTA H	1	S	ATLANTA	33.64	-84.43	33.64	-84.43	Strong afternoon heating and a very moist airma	The ASOS at Atlanta Hartsfield-Jackso	CSV	175	2015	175_2015

(0 out of 195 Selected)

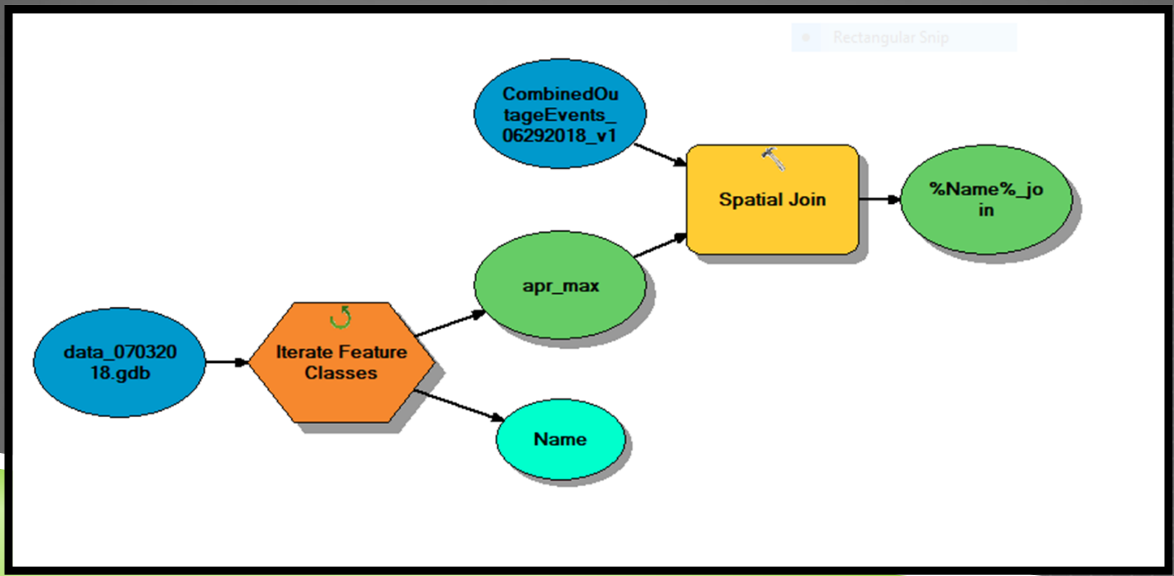
StormDetails

Storm Details attribute table with additional columns to show the day of the year and the year for the event

METHODOLOGY– *CONT'D*

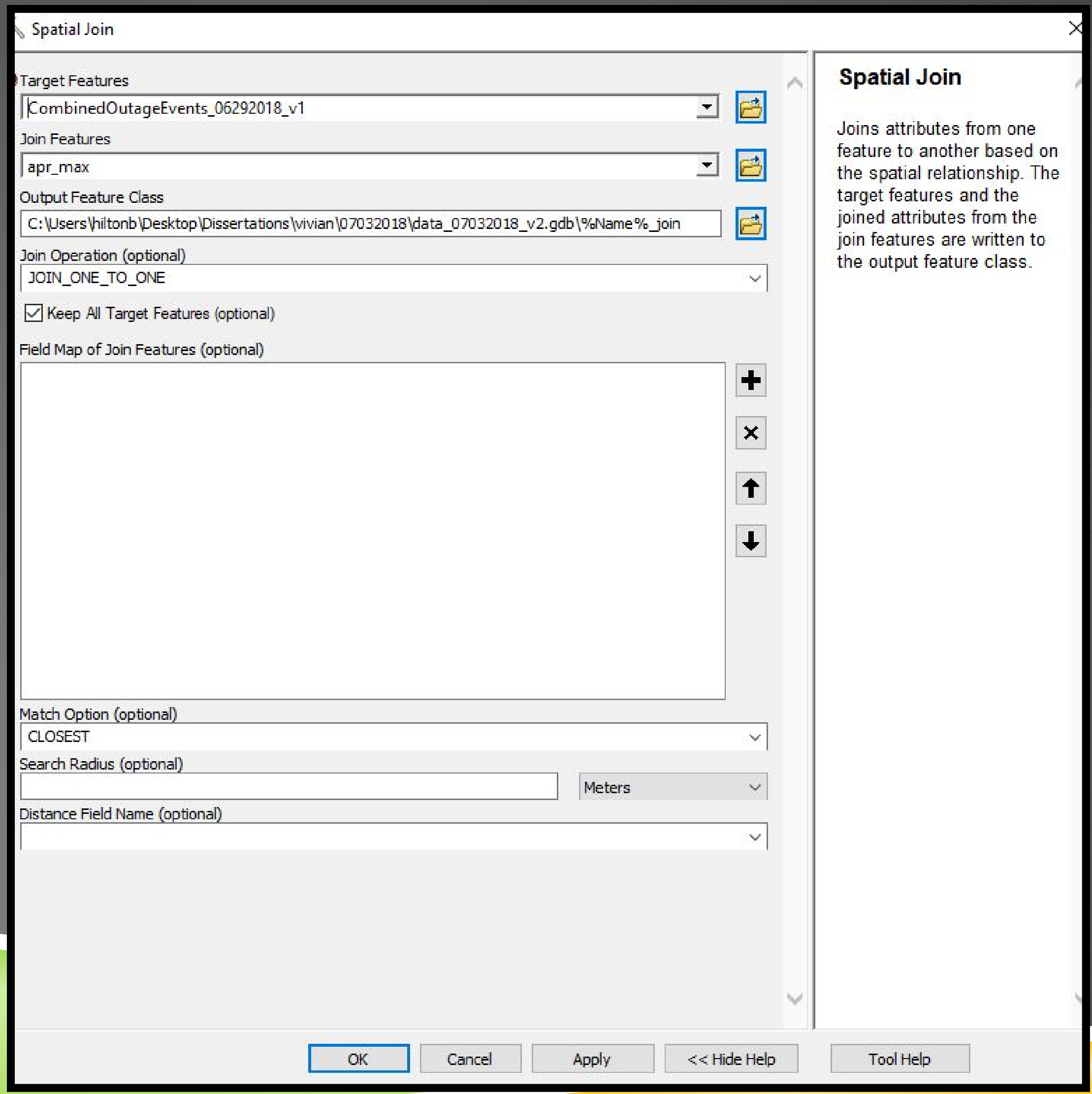
Step 13: Using ArcMap modelBuilder tool, three models were designed to spatially join the 48 map layers of weather data with the outage map layer.

✓ Model 1 to spatially join the outage events with the weather data.



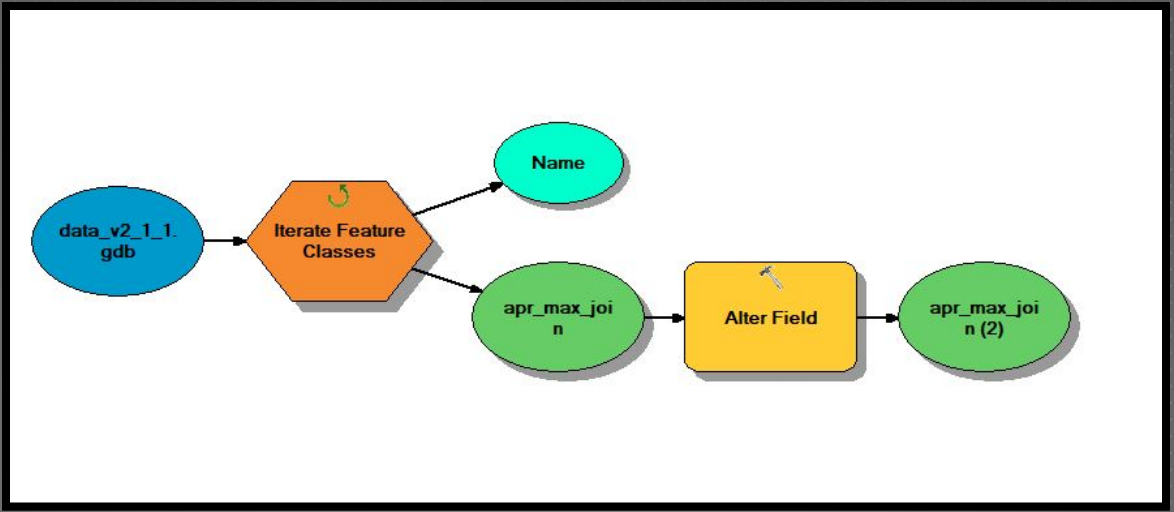
METHODOLOGY– *CONT'D*

Spatial join tool to join the outage events with the closest contour data from the weather file



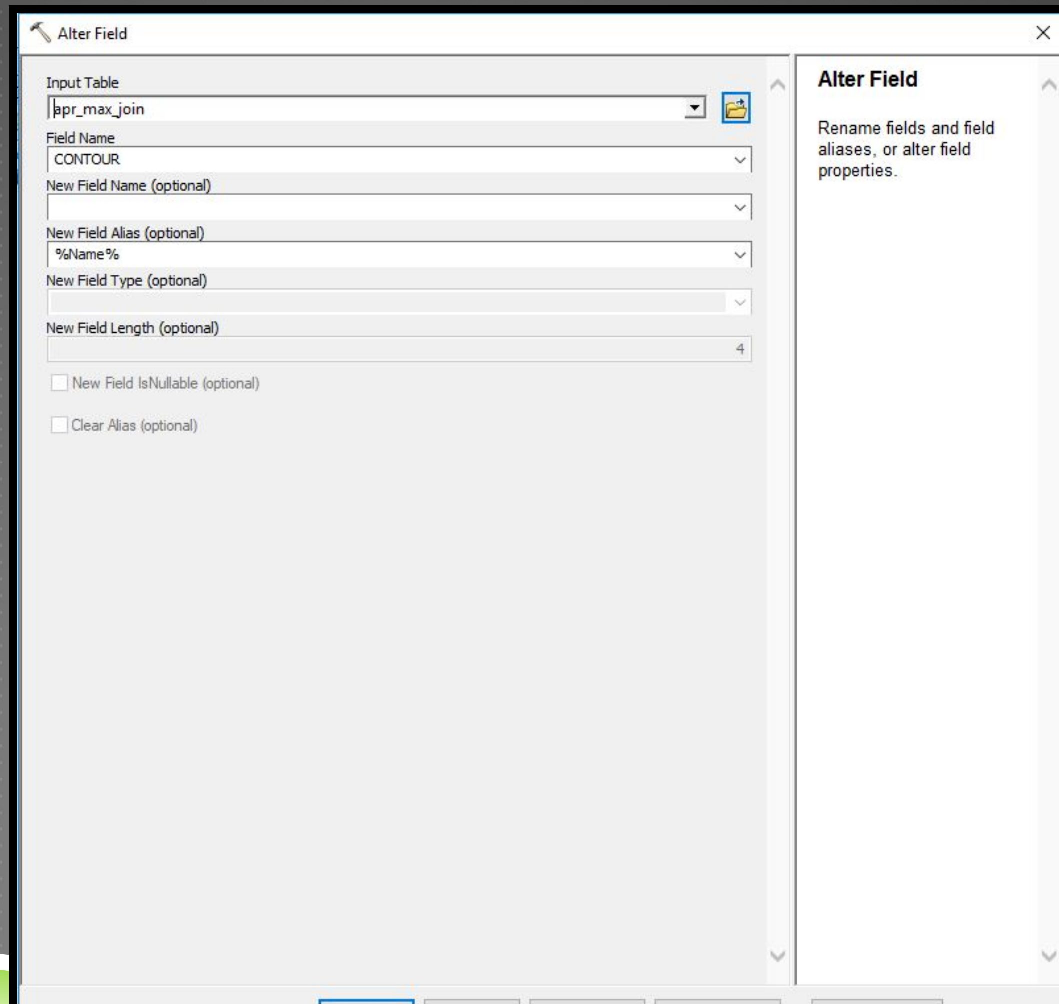
METHODOLOGY– *CONT'D*

Model 2 to rename the output field (contour field) from model 1 using the alter tool to reflect the month and the type of weather data.



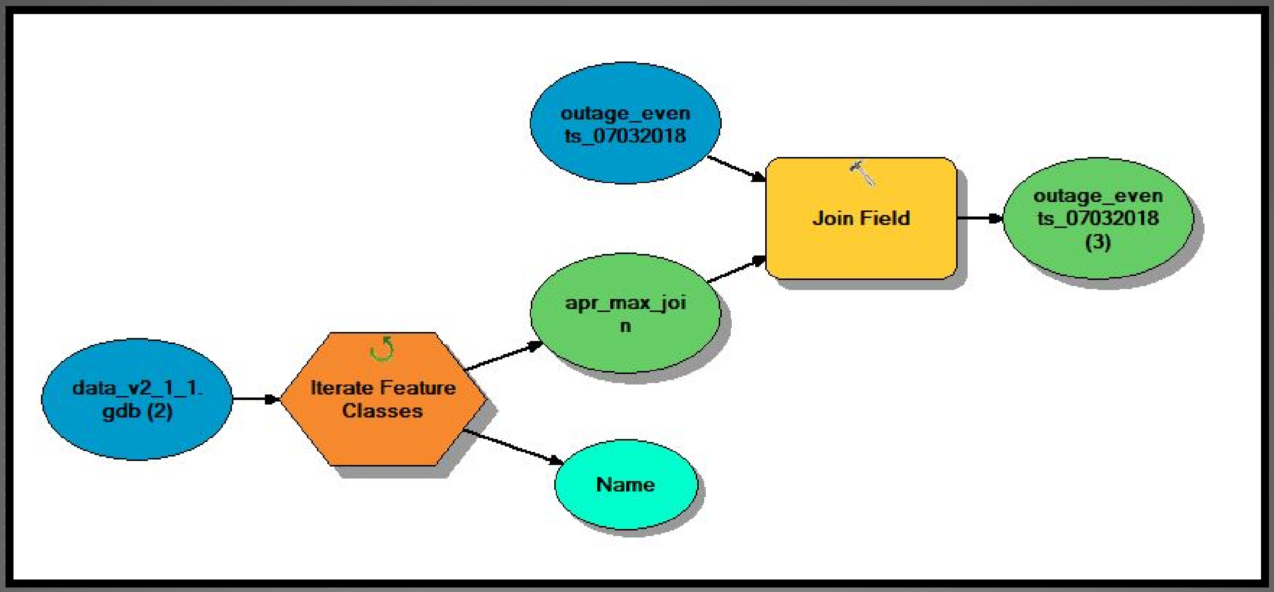
METHODOLOGY– *CONT'D*

The alter tool to rename the contour field to reflect the month and the type of weather data



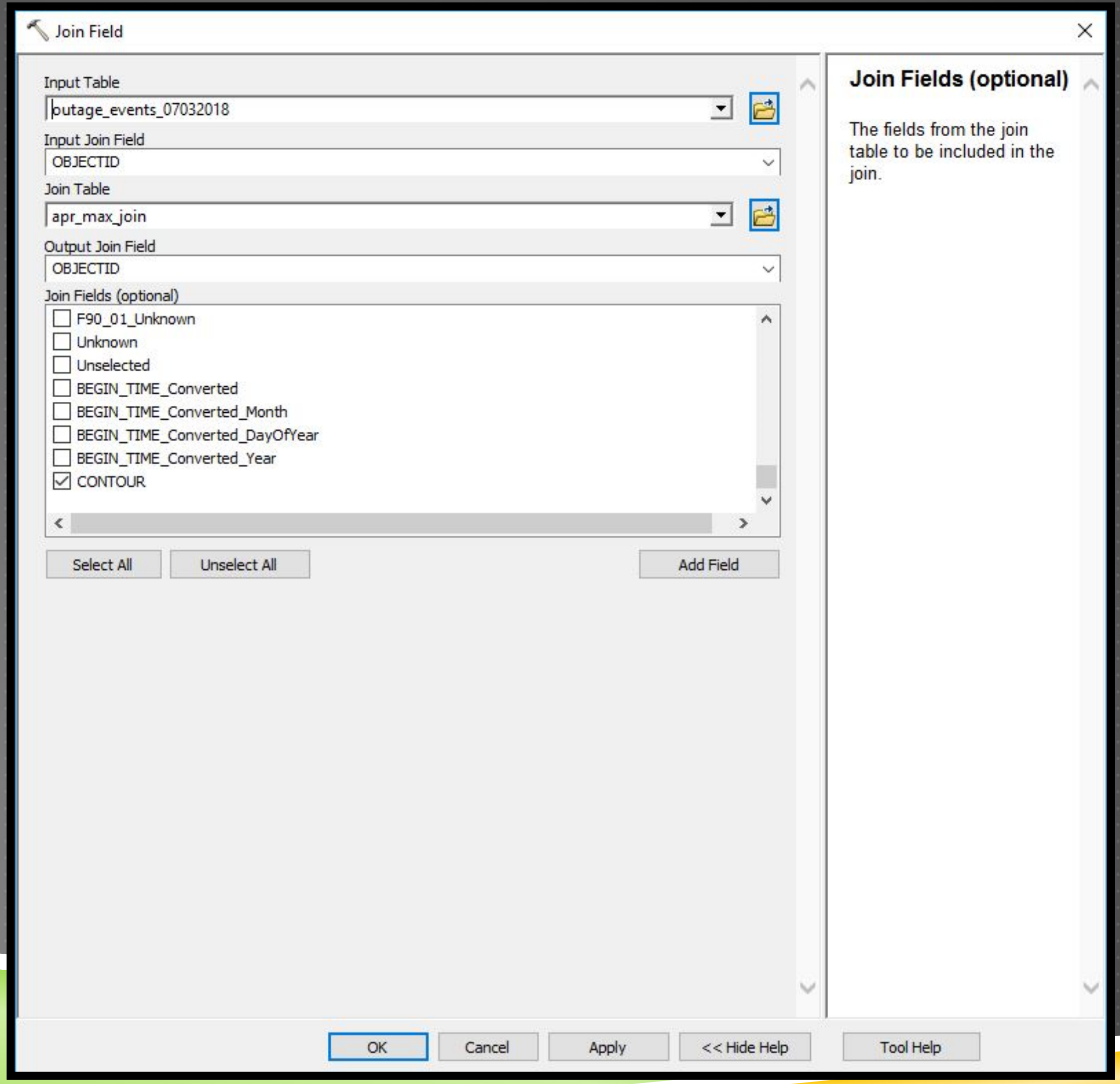
METHODOLOGY– *CONT'D*

Model 3 used the join field tool to join the outage events data with the 48 fields of weather data.



METHODOLOGY– *CONT'D*

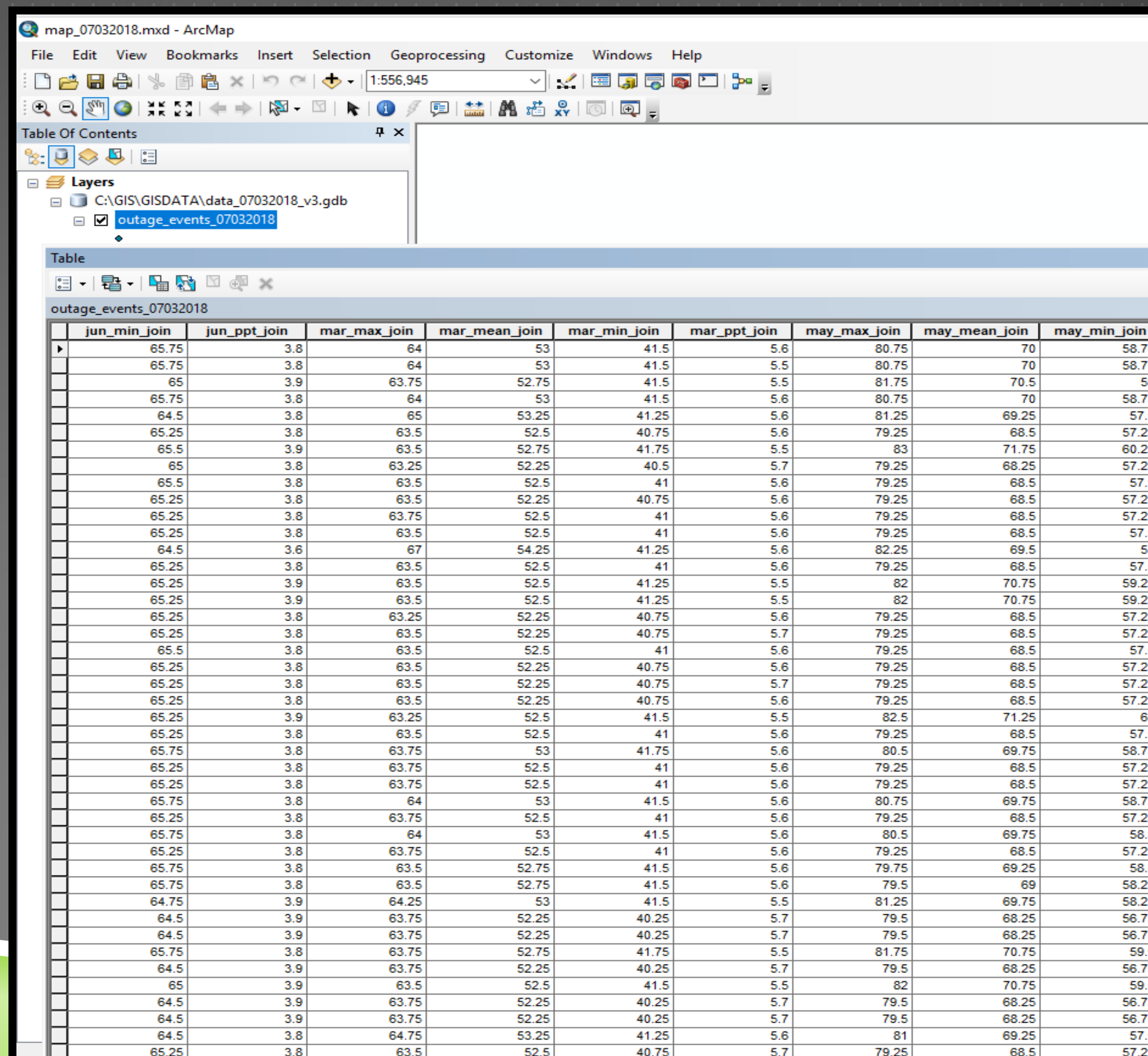
The join field tool to join the outage events data with the 48 fields of weather data



METHODOLOGY– *CONT'D*

The Outage events attribute table with the additional 48 columns of weather data

(Monthly Max, Min, Average Temperature and Precipitation).



jun_min_join	jun_ppt_join	mar_max_join	mar_mean_join	mar_min_join	mar_ppt_join	may_max_join	may_mean_join	may_min_join
65.75	3.8	64	53	41.5	5.6	80.75	70	58.75
65.75	3.8	64	53	41.5	5.5	80.75	70	58.75
65	3.9	63.75	52.75	41.5	5.5	81.75	70.5	59
65.75	3.8	64	53	41.5	5.6	80.75	70	58.75
64.5	3.8	65	53.25	41.25	5.6	81.25	69.25	57.5
65.25	3.8	63.5	52.5	40.75	5.6	79.25	68.5	57.25
65.5	3.9	63.5	52.75	41.75	5.5	83	71.75	60.25
65	3.8	63.25	52.25	40.5	5.7	79.25	68.25	57.25
65.5	3.8	63.5	52.5	41	5.6	79.25	68.5	57.5
65.25	3.8	63.5	52.25	40.75	5.6	79.25	68.5	57.25
65.25	3.8	63.75	52.5	41	5.6	79.25	68.5	57.25
65.25	3.8	63.5	52.5	41	5.6	79.25	68.5	57.5
64.5	3.6	67	54.25	41.25	5.6	82.25	69.5	57
65.25	3.8	63.5	52.5	41	5.6	79.25	68.5	57.5
65.25	3.9	63.5	52.5	41.25	5.5	82	70.75	59.25
65.25	3.9	63.5	52.5	41.25	5.5	82	70.75	59.25
65.25	3.8	63.25	52.25	40.75	5.6	79.25	68.5	57.25
65.25	3.8	63.5	52.25	40.75	5.7	79.25	68.5	57.25
65.5	3.8	63.5	52.5	41	5.6	79.25	68.5	57.5
65.25	3.8	63.5	52.25	40.75	5.6	79.25	68.5	57.25
65.25	3.8	63.5	52.25	40.75	5.7	79.25	68.5	57.25
65.25	3.8	63.5	52.25	40.75	5.6	79.25	68.5	57.25
65.25	3.9	63.25	52.5	41.5	5.5	82.5	71.25	60
65.25	3.8	63.5	52.5	41	5.6	79.25	68.5	57.5
65.75	3.8	63.75	53	41.75	5.6	80.5	69.75	58.75
65.25	3.8	63.75	52.5	41	5.6	79.25	68.5	57.25
65.25	3.8	63.75	52.5	41	5.6	79.25	68.5	57.25
65.75	3.8	64	53	41.5	5.6	80.75	69.75	58.75
65.25	3.8	63.75	52.5	41	5.6	79.25	68.5	57.25
65.75	3.8	64	53	41.5	5.6	80.5	69.75	58.5
65.25	3.8	63.75	52.5	41	5.6	79.25	68.5	57.25
65.75	3.8	63.5	52.75	41.5	5.6	79.75	69.25	58.5
65.75	3.8	63.5	52.75	41.5	5.6	79.5	69	58.25
64.75	3.9	64.25	53	41.5	5.5	81.25	69.75	58.25
64.5	3.9	63.75	52.25	40.25	5.7	79.5	68.25	56.75
64.5	3.9	63.75	52.25	40.25	5.7	79.5	68.25	56.75
65.75	3.8	63.75	52.75	41.75	5.5	81.75	70.75	59.5
64.5	3.9	63.75	52.25	40.25	5.7	79.5	68.25	56.75
65	3.9	63.5	52.5	41.5	5.5	82	70.75	59.5
64.5	3.9	63.75	52.25	40.25	5.7	79.5	68.25	56.75
64.5	3.9	63.75	52.25	40.25	5.7	79.5	68.25	56.75
64.5	3.8	64.75	53.25	41.25	5.6	81	69.25	57.5
65.25	3.8	63.5	52.5	40.75	5.7	79.25	68.5	57.25

METHODOLOGY– *CONT'D*

Step 14: Used the Merged and related additional data files in ArcGIS

- ✓ Added four additional columns to the outage map attribute table to show the weather data for each outage event.
- ✓ Joined by date the storm events with the outage events.
- ✓ Joined the storm events details with the outage events.
- ✓ Joined the outage events with the forestry file.

METHODOLOGY– *CONT'D*

Step 14: Used the Merged and related additional data files in ArcGIS

- ✓ Added a field "Adjusted_TransfAge" and a field "Adjusted_PoleAge - Used Field Calculator to calculate the difference between the outage event year and the year the equipment was installed or modified.
- ✓ Added columns to show "Forestry Expected Pruning Man Hours", "Average Climbing Tree Pruning Miles", "Actual Pruning Man Hours/Circuit Mileage".

METHODOLOGY– *CONT'D*

Step 15: Conducted exploration and correlation analysis In SPSS - Prior to statistical analyses, the following steps were taken to prepare the data:

- ✓ For variables forestry expected pruning man hours, average climbing tree pruning miles, and actual pruning man hours / circuit mile , a value of zero (0) was input for missing data.
- ✓ Values for transformer age was substituted for missing data on pole age.

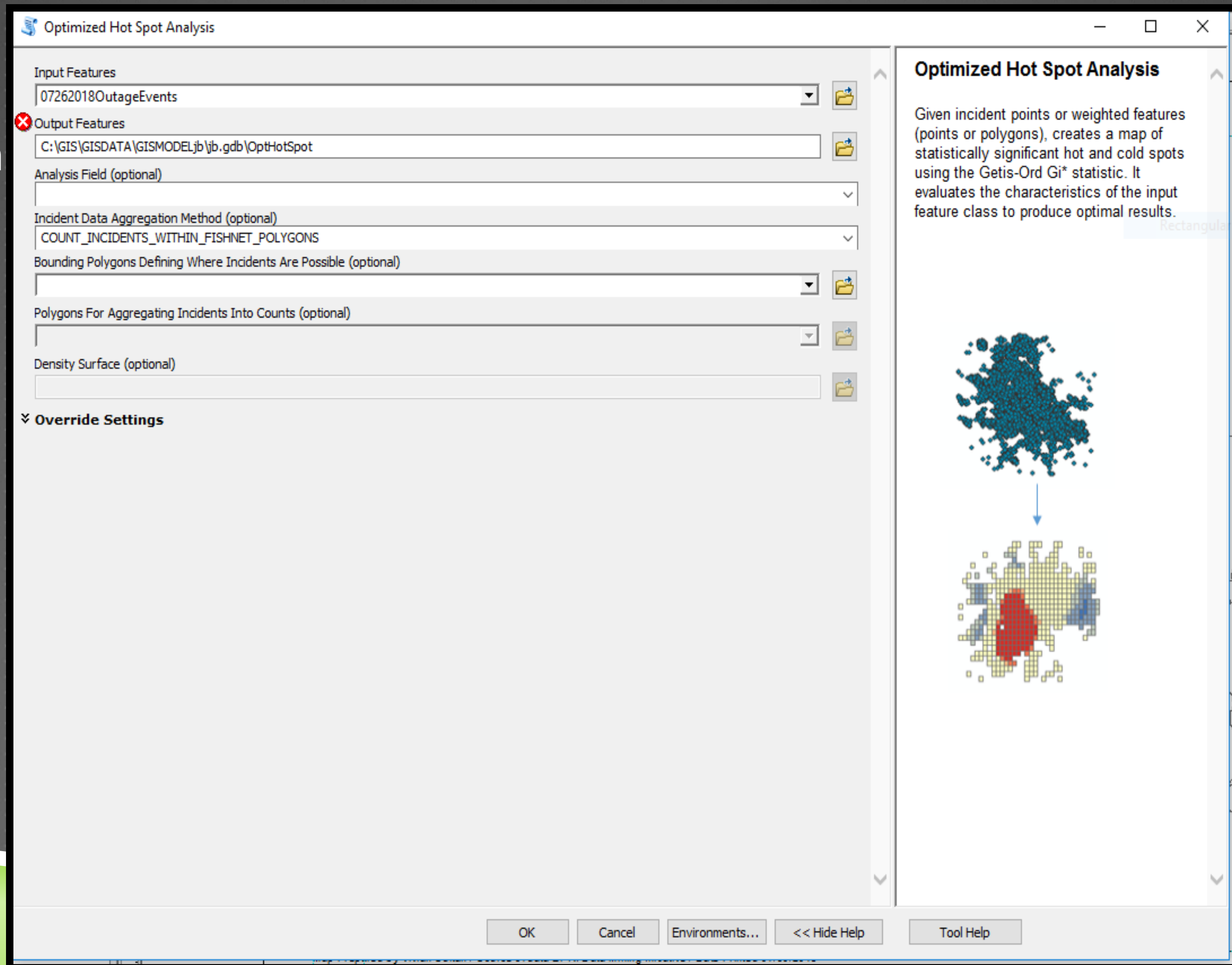
METHODOLOGY– *CONT'D*

Step 16: Ran Optimized hotspot analysis In ArcGIS

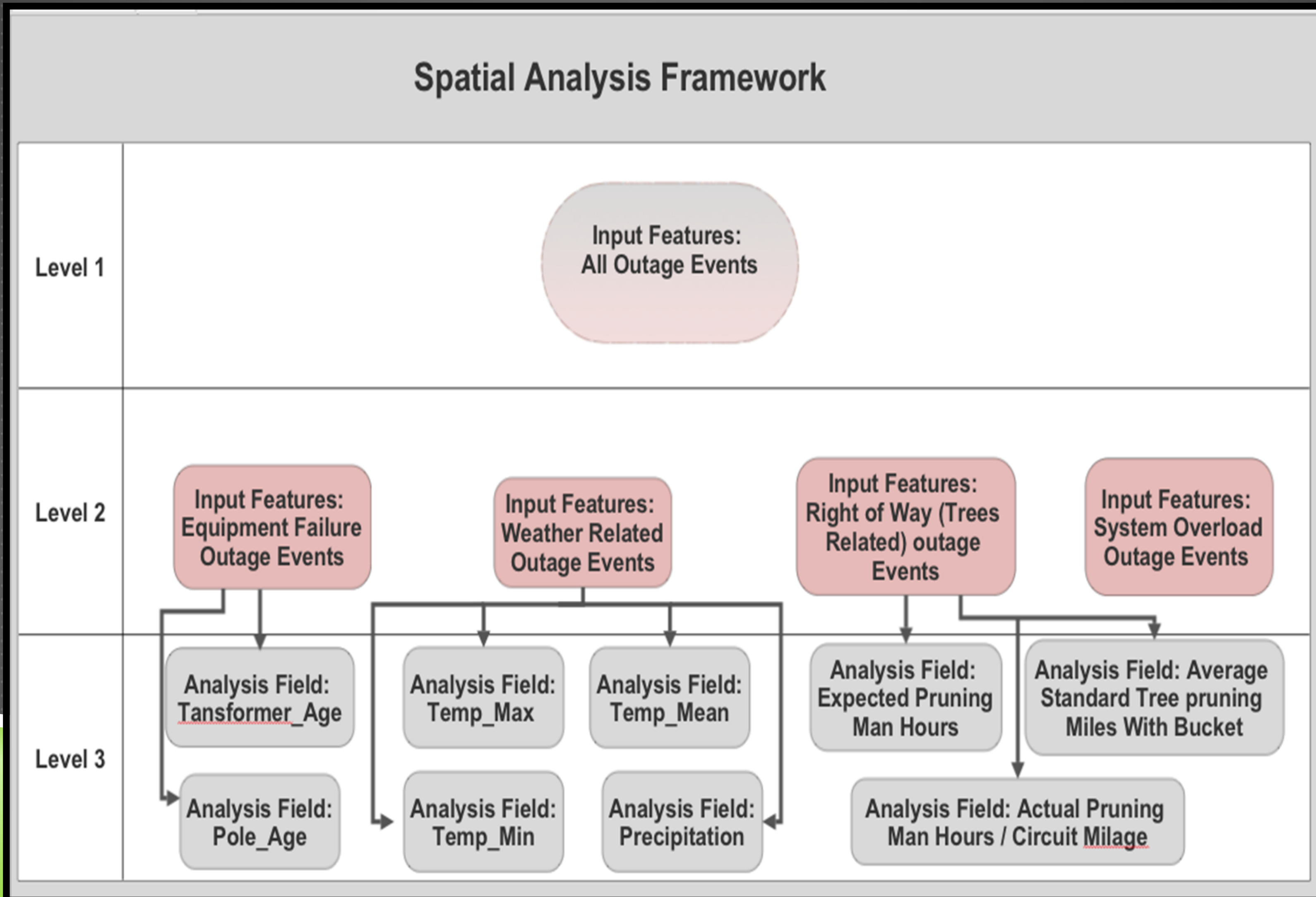
- ✓ When the Input Feature is power outage events data and you do not identify an Analysis Field, the tool will aggregate the power outage events and the outage events counts will serve as the values to be analyzed. - one level of analysis.
- ✓ Another level of analysis is when you provide an Analysis field.

METHODOLOGY– *CONT'D*

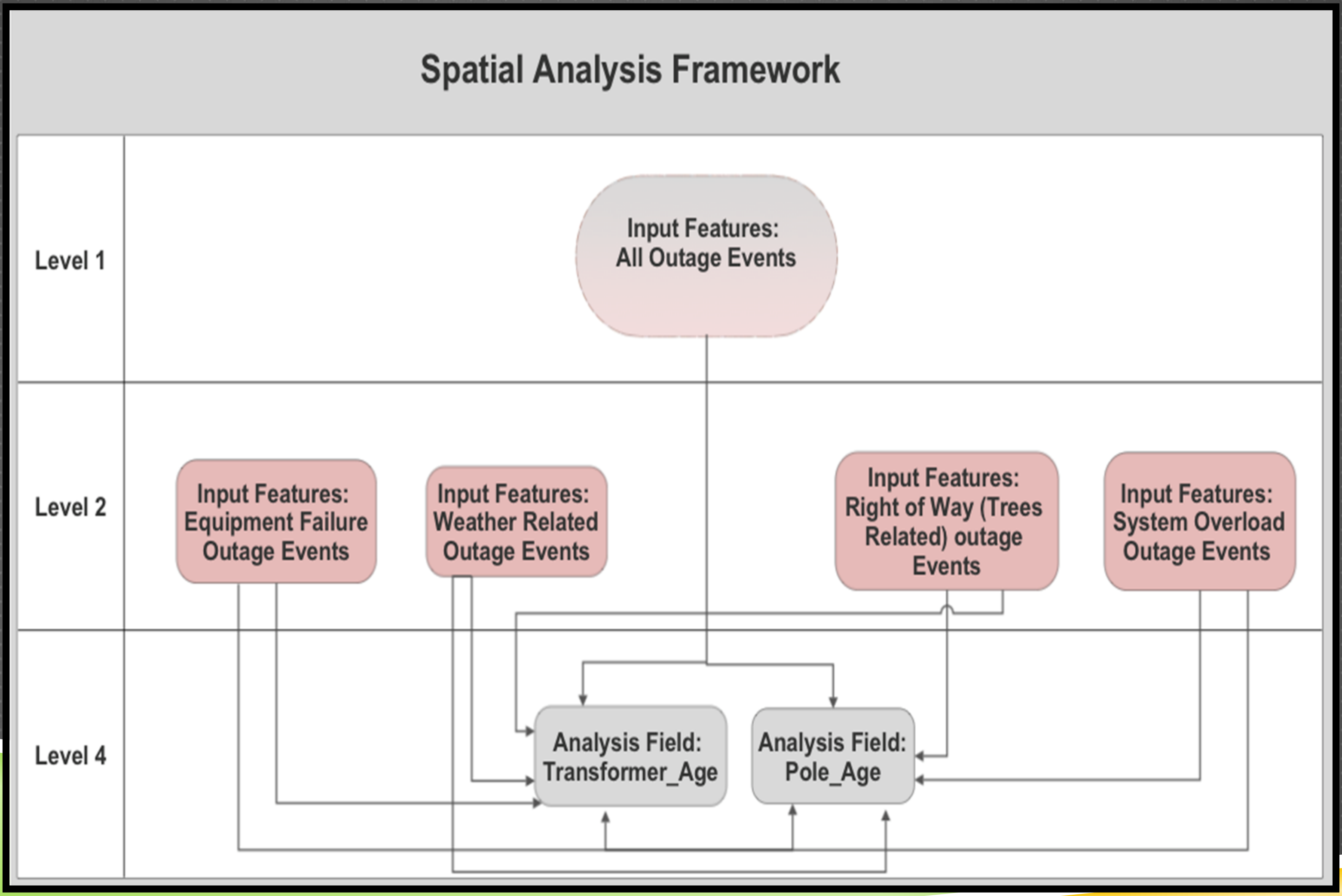
Optimized hotspot analysis In ArcGIS



METHODOLOGY– *CONT'D*



METHODOLOGY– *CONT'D*

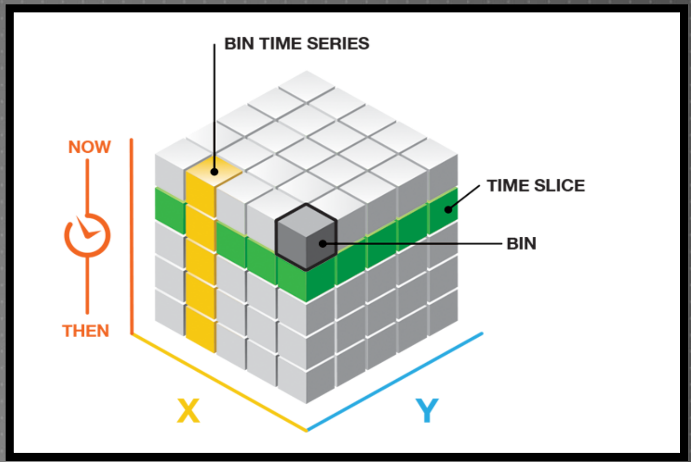


METHODOLOGY– *CONT'D*

Step 17: Ran Emerging Hot Spot Analysis In ArcGIS - Two Steps processes

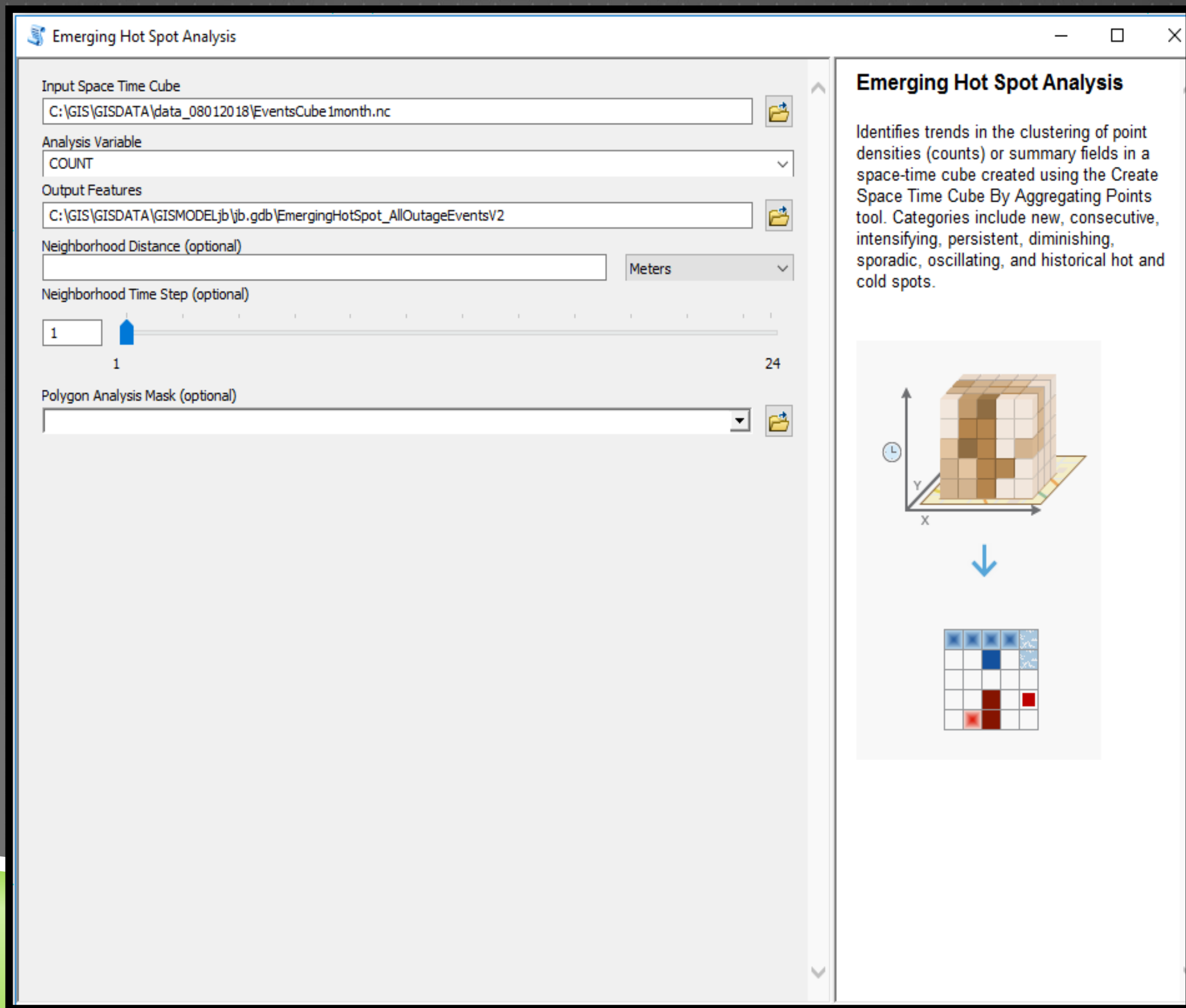
- ✓ Create Space Time Cube By Aggregating Points.
- ✓ Run the Emerging Hot Spot analysis.

This tool aggregates point Input Features into space-time bins



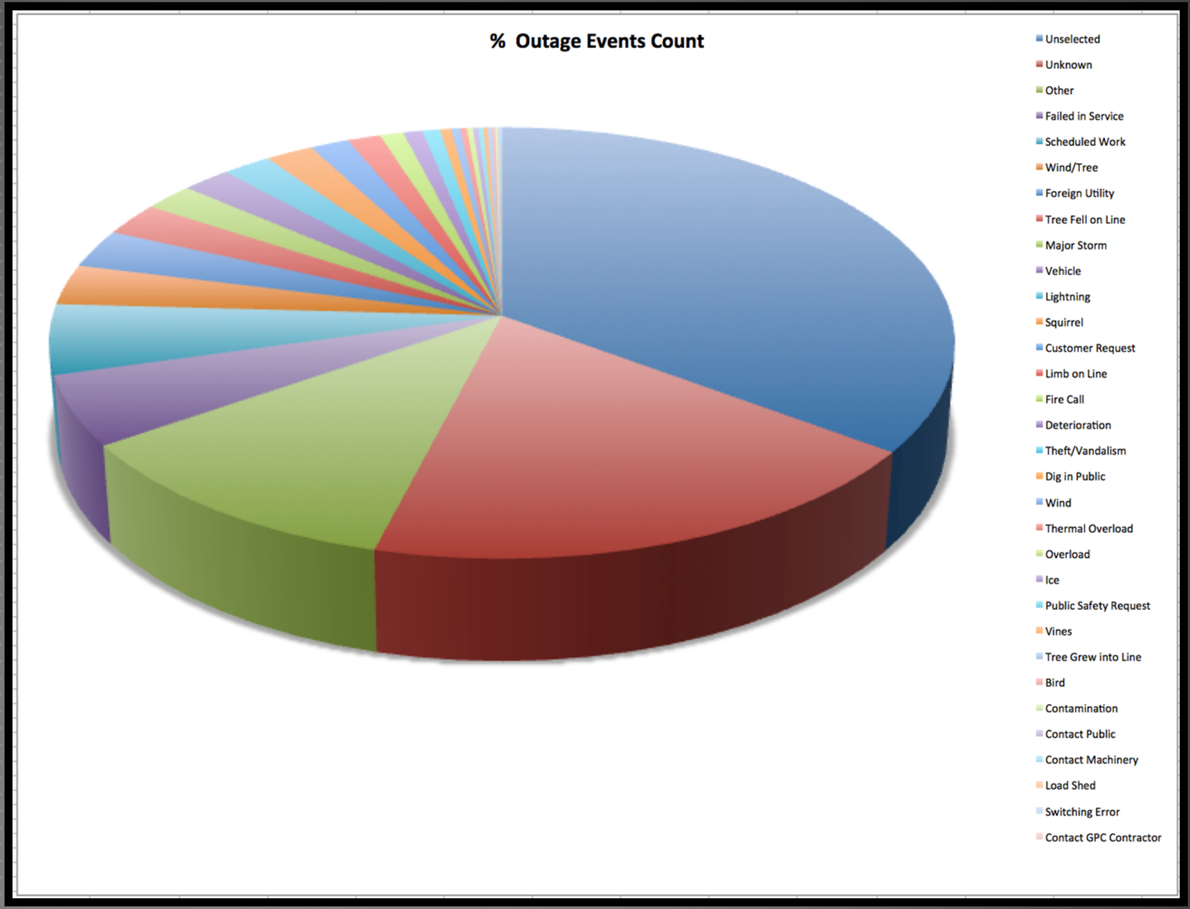
METHODOLOGY– *CONT'D*

Emerging Hot Spot Analysis In ArcGIS



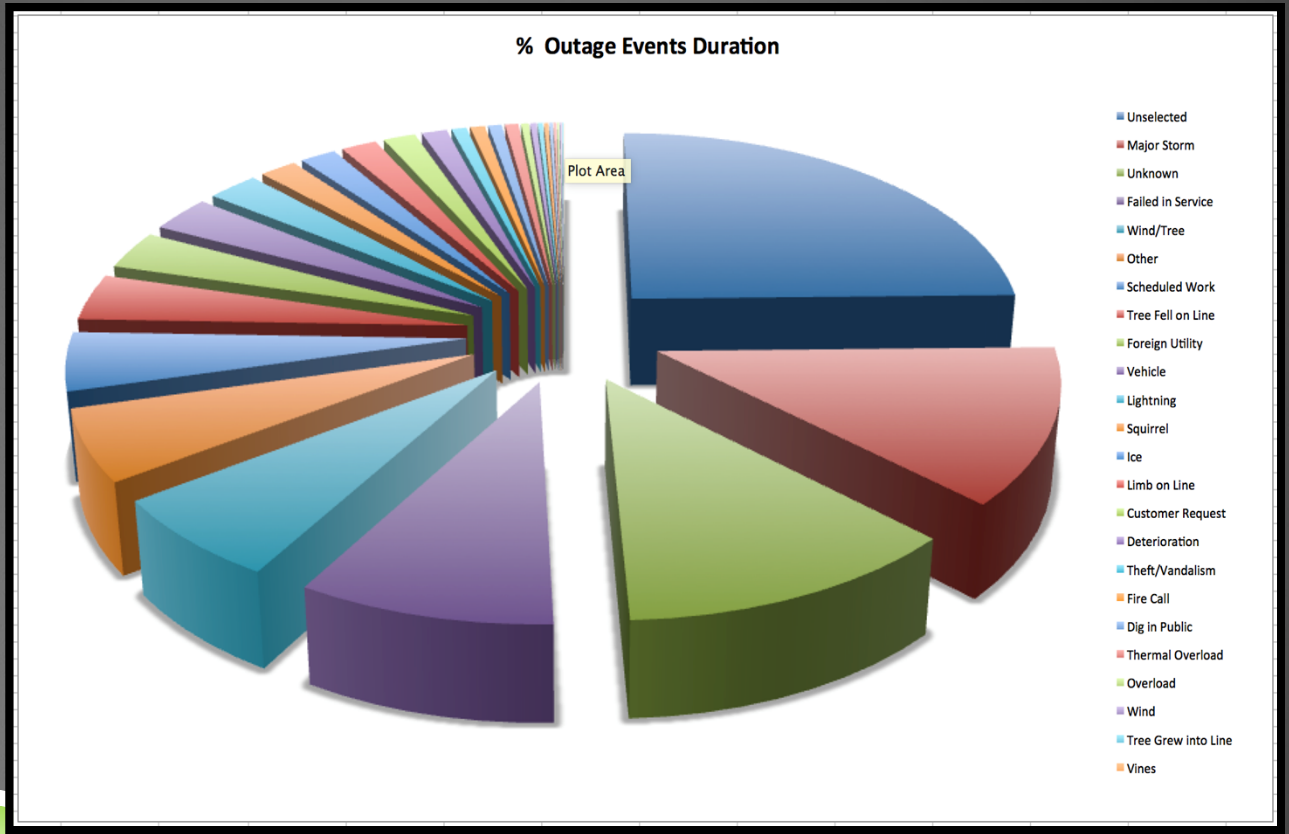
ANALYSES AND FINDING

Reported Power Outage Events Percent Count by Cause



ANALYSES AND FINDING

Reported Power Outage Duration by Cause



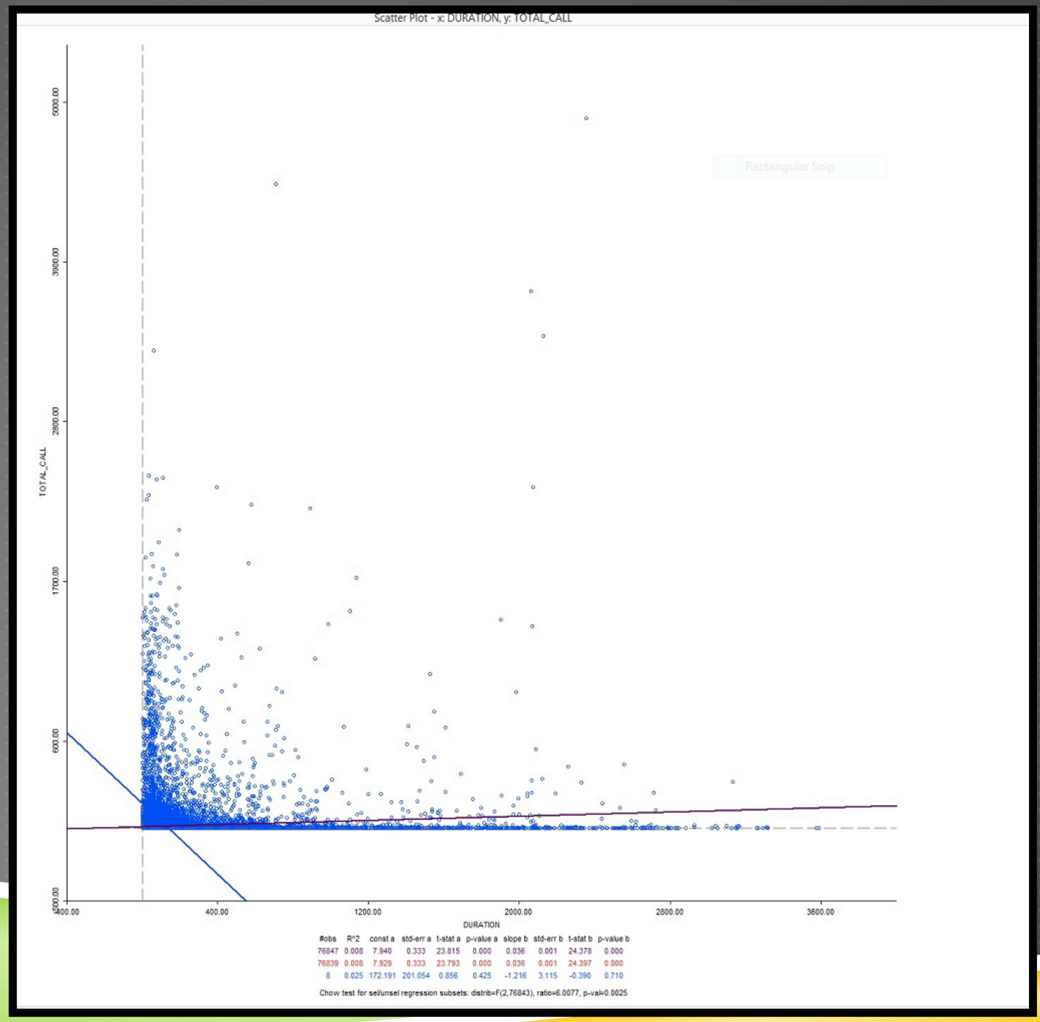
ANALYSES AND FINDING

Underscored Power Outage Cause Category

Outage Cause Category	Percent Of Outage Events Count	Percent Of Total Outage Events Duration
Failed in Service	5.26%	8.99%
Deterioration	0.77%	1.20%
Wind/Tree	3.03%	6.67%
Wind	0.36%	0.30%
Ice	0.21%	1.70%
Major Storm	2.04%	12.53%
Lightning	1.96%	2.44%
Limb on Line	1.34%	1.69%
Tree Fell on Line	2.47%	3.76%
Tree Grew into Line	0.18%	0.23%
Thermal Overload	0.26%	0.63%
Overload	0.25%	0.36%
Load Shed	0.01%	0.01%
Total Cause Contribution	18.13%	40.51%

ANALYSES AND FINDING

Scatter Plot of the duration and total calls of the outage events



ANALYSES AND FINDING

Descriptive Statistics

Percentages and Frequencies, Study Variables

	Frequency	Percent
Storm event		
Yes	59078	76.9%
No	17769	23.1%
Forestry management		
Yes	47175	61.4%
No	29672	38.6%
n	76847	100.0%

ANALYSES AND FINDING

Descriptive Statistics

Means and Standard Deviations, Study Variables

Variable	M	SD	Min	Max
Outage event duration	89.15	204.81	0	3589
Outage event customer calls	11.18	85.07	0	4888
Temperature (mean)	62.52	13.72	40.25	80.75
Precipitation	4.29	0.66	2.8	5.8000002
Forestry expected pruning man hours	858.01	882.24	0	3300
Average standard tree pruning miles with bucket	6.63	6.48	0	20.4898
Average mechanical tree pruning miles	3.00	2.94	0	9.2784
Average climbing tree pruning miles	0.75	0.73	0	2.3196
Actual pruning man hours / circuit mile	42.18	36.80	0	157
Transformer age	4.50	1.86	3	8
Pole age	23.90	16.76	3	93

Note: n=76847.

ANALYSES AND FINDING

Correlation Results

Variables	1		2		3		4		5		6		7	
1	1.00													
2	0.09	**	1.00											
3	0.08	**	0.01		1.00									
4	-0.13	**	0.01		0.14	**	1.00							
5	0.08	**	0.00		-0.06	**	-0.37	**	1.00					
6	0.01		-0.02	**	-0.01		0.00		-0.03	**	1.00			
7	0.01	**	0.00		0.00		0.00		-0.02	**	0.77	**	1.00	
8	0.01	**	0.00		0.00		0.00		-0.02	**	0.81	**	0.96	**
9	0.01	**	0.00		0.00		0.00		-0.02	**	0.81	**	0.96	**
10	0.01	**	0.00		0.00		0.00		-0.02	**	0.81	**	0.96	**
11	0.01	*	-0.01	**	-0.01		-0.01	**	-0.02	**	0.91	**	0.85	**
12	0.01	*	0.01	**	0.01	**	0.00		0.02	**	-0.13	**	-0.11	**
13	0.02	**	-0.01	**	0.02	**	-0.01	**	0.03	**	0.02	**	0.04	**

NOTE: * < p .05; ** < p .01, two-tailed tests.

Key to the correlation table:

1. Outage event duration
2. Outage event customer calls
3. Storm event (1=yes)
4. Temperature (mean)
5. Precipitation
6. Forestry management (1=yes)
7. Forestry expected pruning man hours
8. Average standard tree pruning miles with bucket
9. Average mechanical tree pruning miles
10. Average climbing tree pruning miles
11. Actual pruning man hours / circuit mile
12. Transformer age
13. Pole age

ANALYSES AND FINDING

Correlation Results

Variables	8		9		10		11		12		13
1											
2											
3											
4											
5											
6											
7											
8	1.00										
9	1.00		1.00								
10	1.00	**	1.00		1.00						
11	0.79	**	0.79	**	0.79	**	1.00				
12	-0.12	**	-0.12	**	-0.12	**	-0.11	**	1.00		
13	0.03	**	0.03	**	0.03	**	0.03	**	-0.03	**	1.00

NOTE: * < p .05; ** < p .01, two-tailed tests.

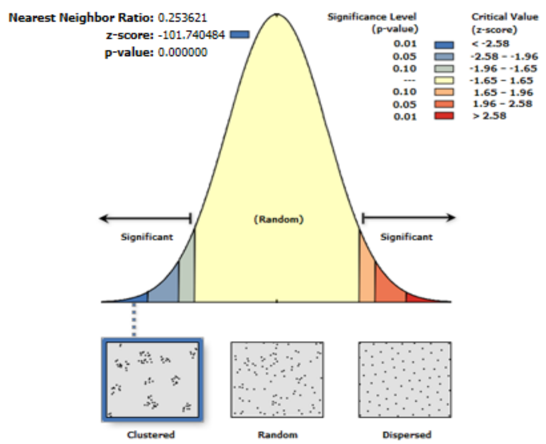
Key to the correlation table:

1. Outage event duration
2. Outage event customer calls
3. Storm event (1=yes)
4. Temperature (mean)
5. Precipitation
6. Forestry management (1=yes)
7. Forestry expected pruning man hours
8. Average standard tree pruning miles with bucket
9. Average mechanical tree pruning miles
10. Average climbing tree pruning miles
11. Actual pruning man hours / circuit mile
12. Transformer age
13. Pole age

ANALYSES AND FINDING

Spatial Pattern Analysis in ArcGIS

Average Nearest Neighbor Summary



Given the z-score of -101.740484148, there is a less than 1% likelihood that this clustered pattern could be the result of random chance.

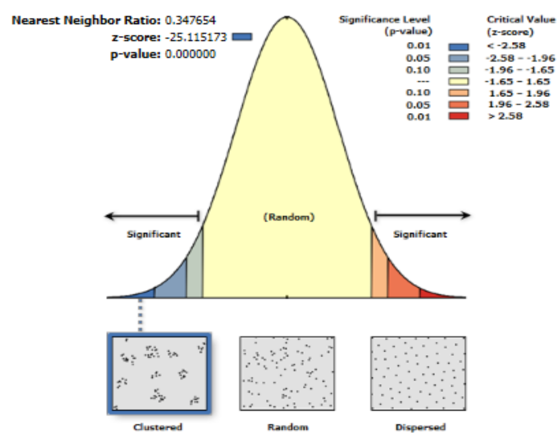
Average Nearest Neighbor Summary

Observed Mean Distance:	171.6770 Meters
Expected Mean Distance:	676.9035 Meters
Nearest Neighbor Ratio:	0.253621
z-score:	-101.740484
p-value:	0.000000

Dataset Information

Input Feature Class:	WeatherRelatedOutageEvents
Distance Method:	EUCLIDEAN
Study Area:	9305093128.852377

Average Nearest Neighbor Summary



Given the z-score of -25.1151732534, there is a less than 1% likelihood that this clustered pattern could be the result of random chance.

Average Nearest Neighbor Summary

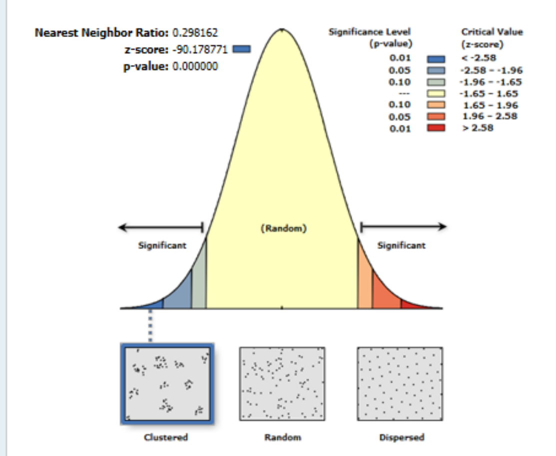
Observed Mean Distance:	727.5412 Meters
Expected Mean Distance:	2092.7144 Meters
Nearest Neighbor Ratio:	0.347654
z-score:	-25.115173
p-value:	0.000000

Dataset Information

Input Feature Class:	SystemOverloadOutageEvents
Distance Method:	EUCLIDEAN
Study Area:	7094714931.245956
Selection Set:	False

ANALYSES AND FINDING

Spatial Pattern Analysis in ArcGIS



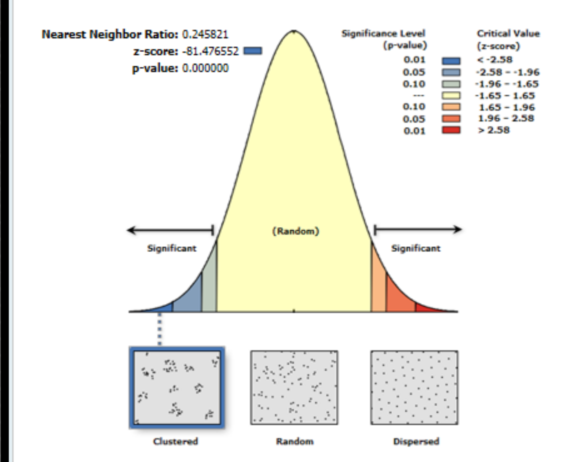
Given the z-score of -90.178771094, there is a less than 1% likelihood that this clustered pattern could be the result of random chance.

Average Nearest Neighbor Summary

Observed Mean Distance:	207.7803 Meters
Expected Mean Distance:	696.8709 Meters
Nearest Neighbor Ratio:	0.298162
z-score:	-90.178771
p-value:	0.000000

Dataset Information

Input Feature Class:	EquipmentFailureEvents
Distance Method:	EUCLIDEAN
Study Area:	8762689918.741295
Selection Set:	False



Given the z-score of -81.476552027, there is a less than 1% likelihood that this clustered pattern could be the result of random chance.

Average Nearest Neighbor Summary

Observed Mean Distance:	210.1276 Meters
Expected Mean Distance:	854.7996 Meters
Nearest Neighbor Ratio:	0.245821
z-score:	-81.476552
p-value:	0.000000

Dataset Information

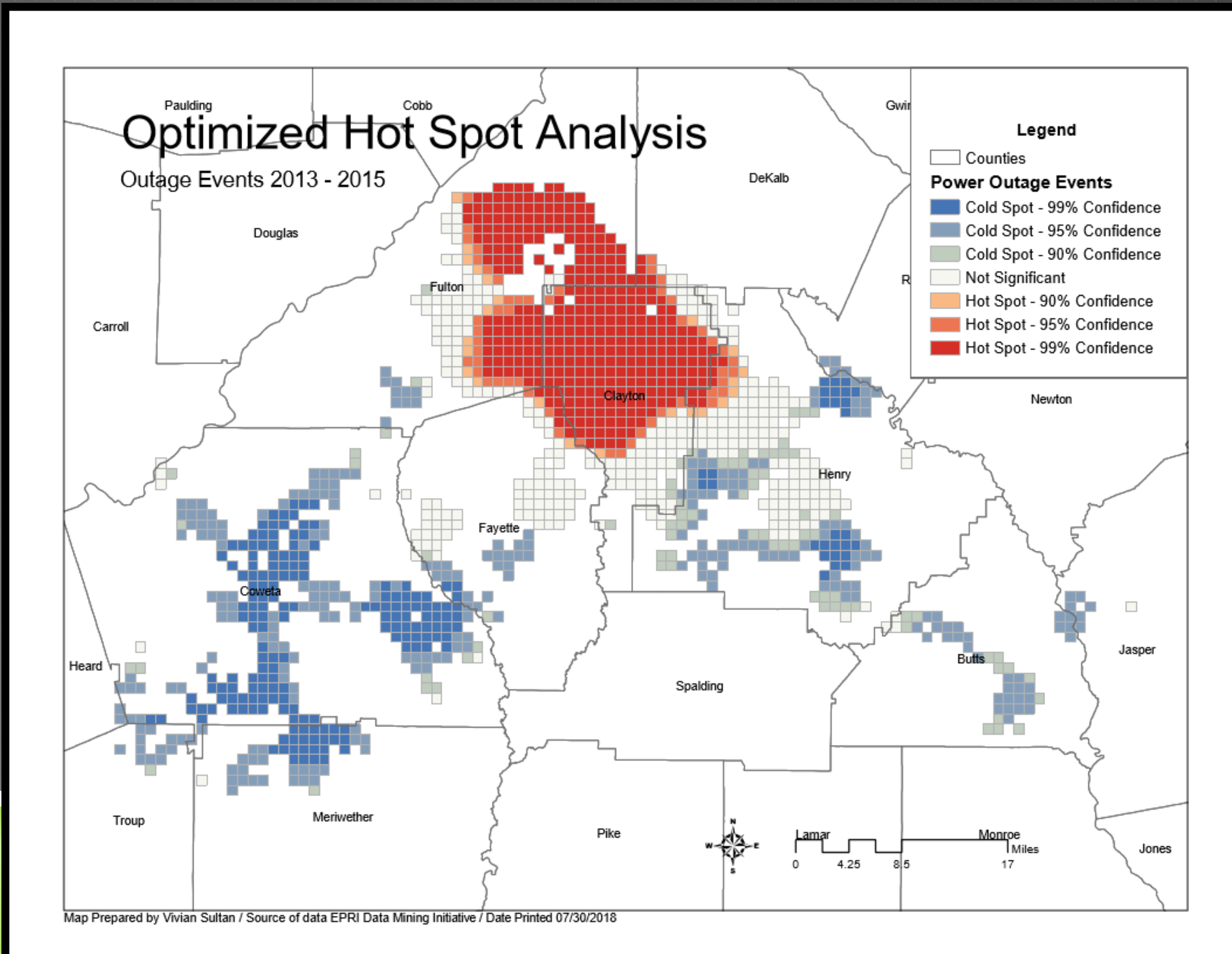
Input Feature Class:	RightOfWayEvents
Distance Method:	EUCLIDEAN
Study Area:	9320583955.110958
Selection Set:	False

ANALYSES AND FINDING

Optimized Hot Spot Analysis Level 1

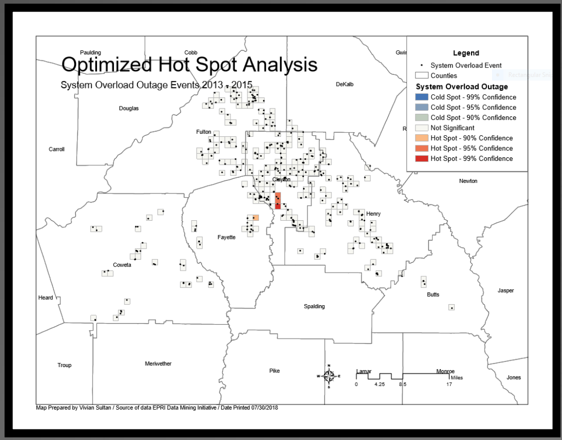
Using a polygon cell size of 1319.0000 Meters
The aggregation process resulted in 1296 weighted polygons.

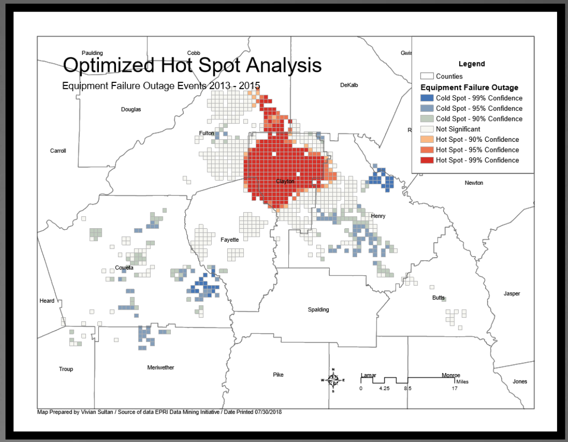
Incident Count Properties:
Min: 1.0000
Max: 598.0000
Mean: 59.2955
Std. Dev.: 81.2320

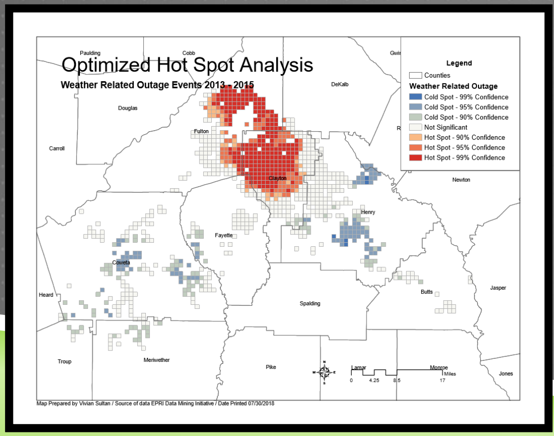


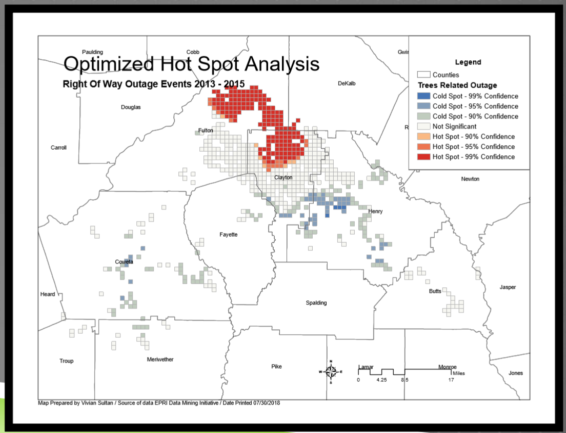
ANALYSES AND FINDING

Optimized Hot Spot Analysis Level 2





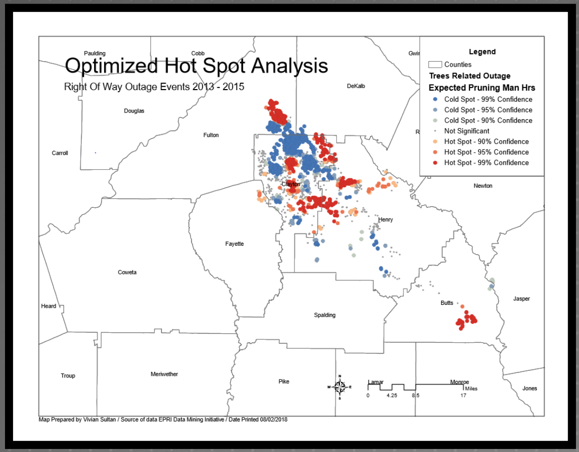


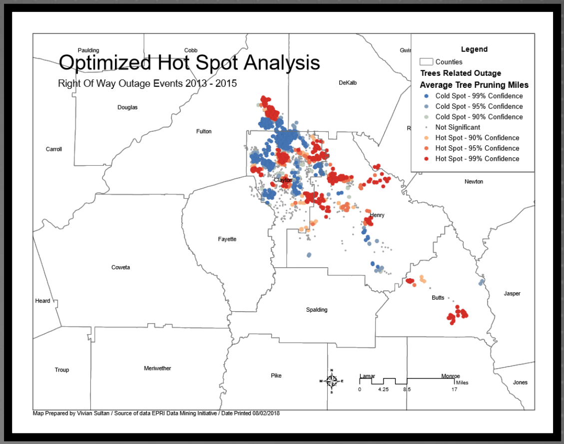


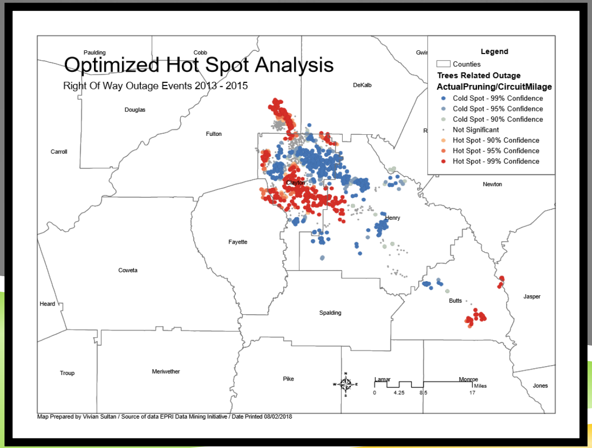
ANALYSES AND FINDING

Optimized Hot Spot Analysis Level 3

Input Features: Right Of Way (Trees Related) Outage Events



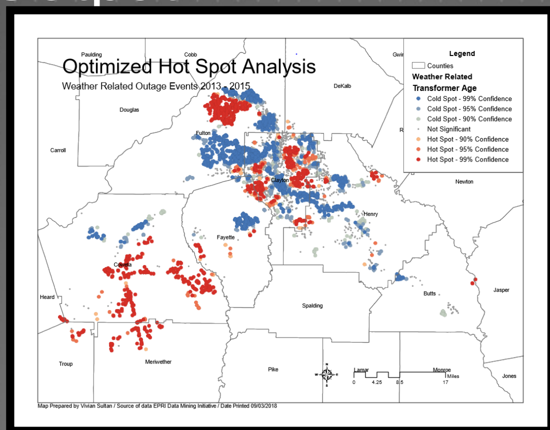


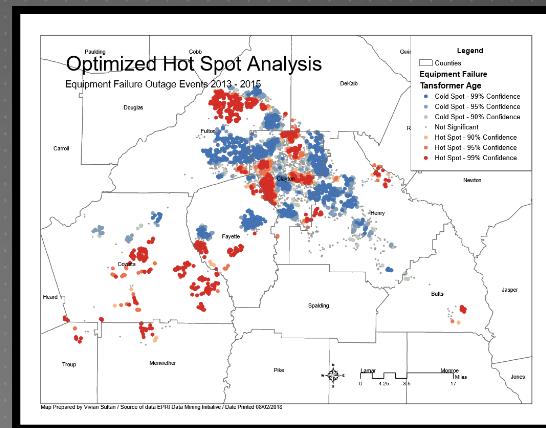


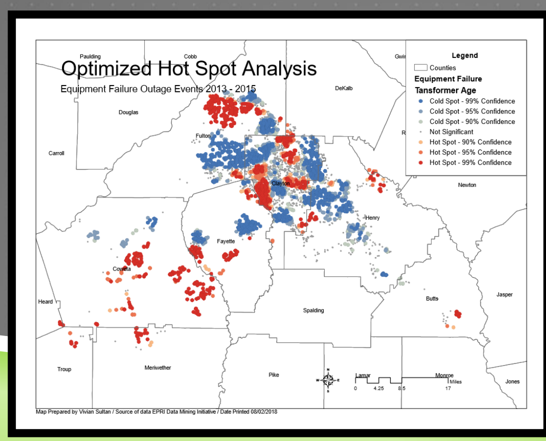
ANALYSES AND FINDING

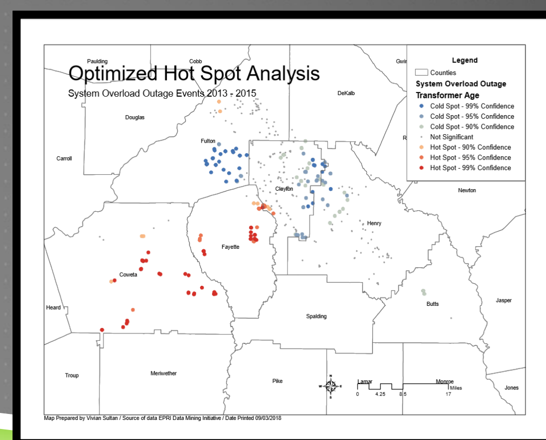
Optimized Hot Spot Analysis Level 4 - Transformer Age Analysis Map Output

Hot spots mainly in Counties where statistically significant clusters of high Transformer Age values can be found









ANALYSES AND FINDING

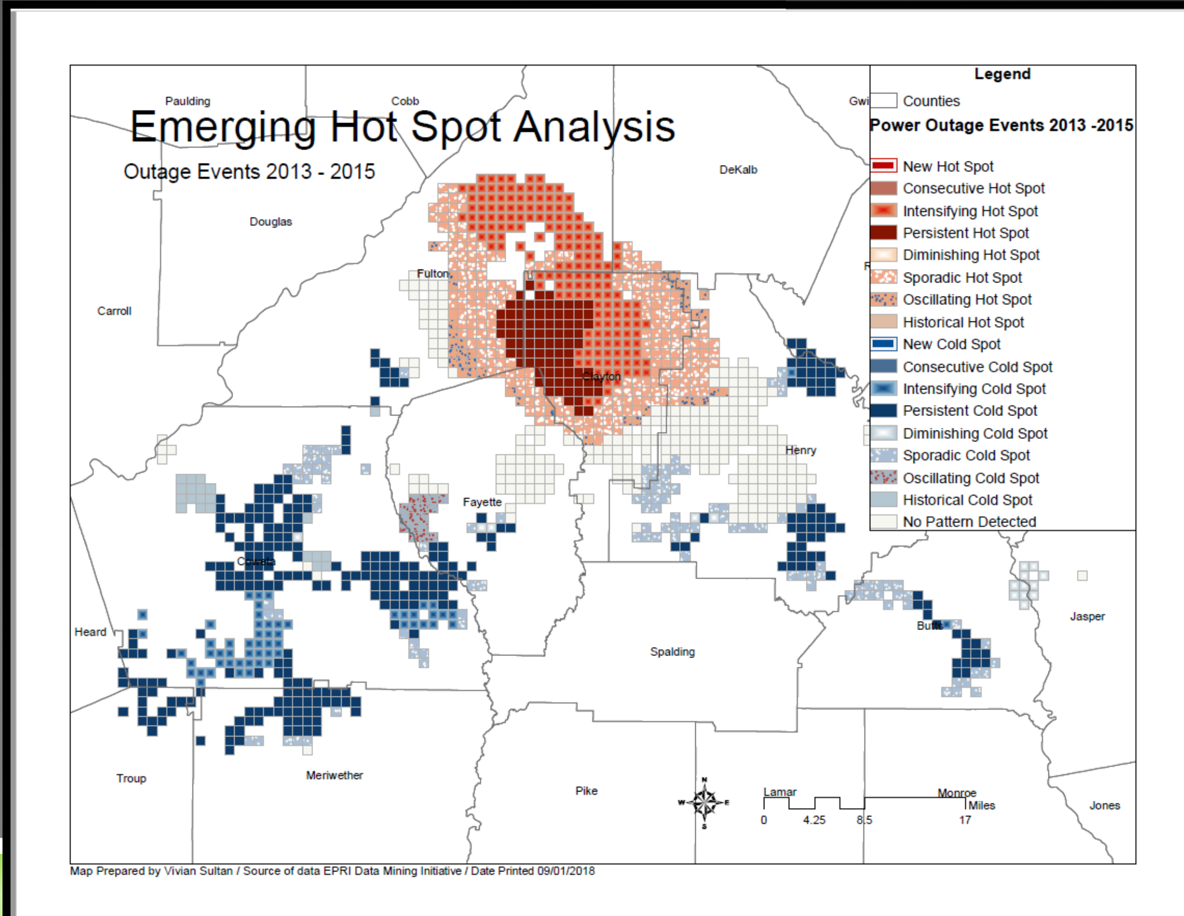
Emerging Hot Spot Analysis Level 1

Time step interval
1 month

Number of space-time bins analyzed
41472

--------- Analysis Summary of Results ---------

	HOT	COLD
New	0	0
Consecutive	0	0
Intensifying	169	57
Persistent	86	298
Diminishing	0	16
Sporadic	227	113
Oscillating	37	17
Historical	0	21



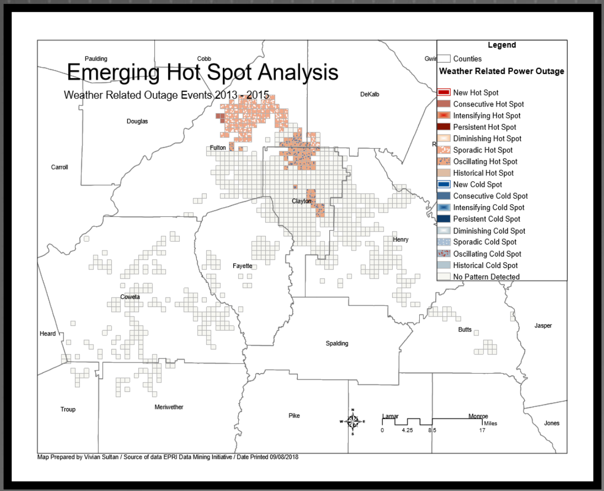
ANALYSES AND FINDING

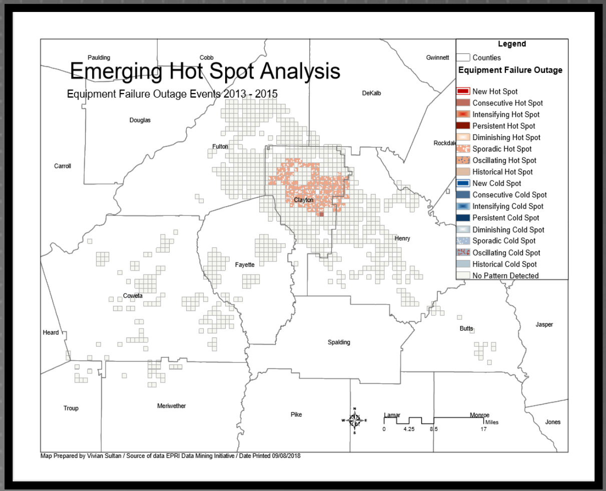
Emerging Hot Spot Pattern Type Definition

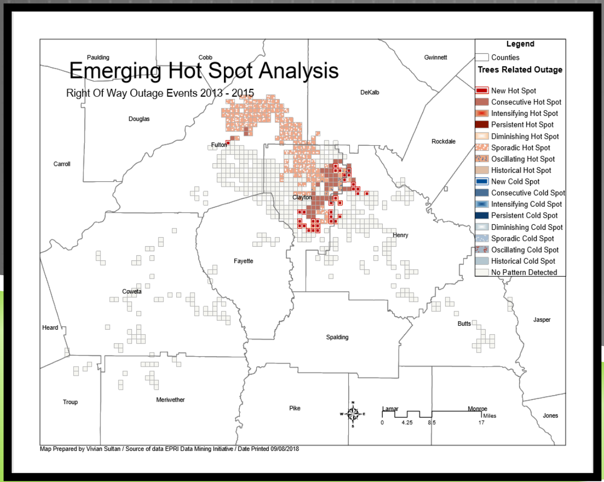
New Hot Spot: A location that is a statistically significant hot spot for the final time step and has never been a statistically significant hot spot before.
Consecutive Hot Spot: A location with a single uninterrupted run of statistically significant hot spot bins in the final time-step intervals. The location has never been a statistically significant hot spot prior to the final hot spot run and less than ninety percent of all bins are statistically significant hot spots.
Intensifying Hot Spot: A location that has been a statistically significant hot spot for ninety percent of the time-step intervals, including the final time step. In addition, the intensity of clustering of high counts in each time step is increasing overall and that increase is statistically significant.
Persistent Hot Spot: A location that has been a statistically significant hot spot for ninety percent of the time-step intervals with no discernible trend indicating an increase or decrease in the intensity of clustering over time.
Diminishing Hot Spot: A location that has been a statistically significant hot spot for ninety percent of the time-step intervals, including the final time step. In addition, the intensity of clustering in each time step is decreasing overall and that decrease is statistically significant.
Sporadic Hot Spot: A location that is an on-again then off-again hot spot. Less than ninety percent of the time-step intervals have been statistically significant hot spots and none of the time-step intervals have been statistically significant cold spots.
Oscillating Hot Spot: A statistically significant hot spot for the final time-step interval that has a history of also being a statistically significant cold spot during a prior time step. Less than ninety percent of the time-step intervals have been statistically significant hot spots.

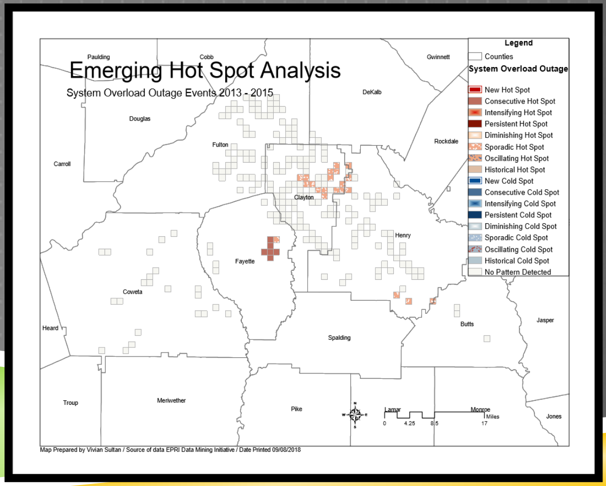
ANALYSES AND FINDING

Emerging Hot Spot Analysis Level 2









ANALYSES AND FINDING

Emerging Hot Spot Analysis Results

- ✓ Right of way (Trees Related) outages has the highest number of locations with hot trends (259 total count of locations)
  - Include the 40 consecutive locations with a single uninterrupted run of statistically significant hot spots - The utility company can use this information to reduce the risk of wildfire and keep customers safe.
- ✓ Weather Related outages (160 locations with hot trends)
  - Considering the availability of weather forecasts, this analysis can help a utility firm prepare should a storm is anticipated.
- ✓ Equipment Failure outage (129 locations with hot trends)
- ✓ System Overload (27 count of locations with hot trends)

Conclusion

GIS offers a solution to analyze the electric grid distribution system. My model provides evidence that GIS can perform the analysis to investigate power failure events and their causes.

GIS can be a main resource of assistance for electronic inspection systems, to lower the duration of customer outages, improve crew response time, and reduce labor and overtime costs.