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Informing Post-Disaster Restoration through Modeling Interdependent Agriculture and Transportation Networks: Data Work

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DISCLAIMER

Project Description

Agriculture is a critical part of the U.S. economy both domestically and in terms of international exports. While disruptions due to weather can affect any sector, agriculture is unique in its time sensitivity for planting and harvesting. Additionally, agriculture is interdependent on other sectors, particularly transportation to get seed and fertilizers to fields at appropriate times and in getting products that may spoil to market efficiently. At present, available tools and models do not appropriately address the interdependencies and interactions that occur between agriculture and transportation infrastructure systems during times of disruption as well as the importance of restoration of these systems post-event.

A multi-institutional collaborative project between the University of Arkansas and Vanderbilt University sought to develop optimized models which determine how to effectively use transportation and coordinated restoration efforts to make agricultural supply chains more resilient through combined mathematical modeling approaches with visualization and simulation using geographic information systems (GIS) for the state of Arkansas as a case study example. Vanderbilt University team members provided support on the project throughout, but it was primarily focused on data acquisition, management (formatting and cleaning), analysis, and visualization across both the agriculture and transportation sectors to support the mathematical models. Vanderbilt's team utilized publicly available GIS data to represent components across the agricultural supply chain, the multimodal transportation network, and other critical infrastructure to provide a foundation for the modeling efforts of the University of Arkansas team members. The Vanderbilt team also investigated historic disruptive events to inform scenarios for analysis by the team with considerations for potential impacts and network routing needs to inform optimization of restoration the transportation system for minimized impacts to agricultural production.

This report provides an overview of the data and information that were utilized by the collaborative project team toward evaluation of the multi-modal transportation network in Arkansas and connections to agricultural applications. Here, we present the story of the "data work" as part of that project with regards to data sources, considerations for project and modeling usage, and processing. In the Results section, we present some key takeaways from the data work. Then, the Impacts and Benefits of Implementation are discussed briefly followed by Recommendations and Conclusions. For the full report on the collaborative project including the modeling analysis and outcomes, please see the companion report "Informing Post-Disaster Restoration through Modeling Interdependent Agriculture and Transportation Networks" by Nurre, et al. (2021).

Case Study Background

Due to geographic proximity, foundational knowledge from prior work, prevalence of agriculture in the state, and potential for multimodal transportation analysis (Figure 1), it was determined that the state of Arkansas would serve as the case study area. Arkansas is home to multiple agricultural products such as cotton, rice, and forestry that could be modeled and considered in the study (Figure 2). Upon review and considerations of agricultural product distribution across the state, potential need for multimodal transportation connectivity, and overall impacts to the state's economy and livelihoods, rice was identified as the crop of focus. It is estimated that 60% of the rice produced in Arkansas is exported, lending to the need to consider potential mitigation of disruptive events on production as well as transport to market (Arkansas Farm Bureau, 2021). Historic flooding and other disruptive events were taken into consideration as well as seasonality of when those events tend to occur for both modeling and determination if the team should focus on goods flowing to the fields (inputs to crop production) or away from the fields (outputs from crop production). For the purposes of this project, fertilizer delivery from New Orleans to rice farms in Arkansas was identified as an essential commodity flow subject to disruption and utilized in modeling efforts and became the focus of the project. Of note is that the methodology and modeling approach used in the full report (Nurre, et al. 2021) could be applied to other crops using similar, relevant data as inputs to the model(s).

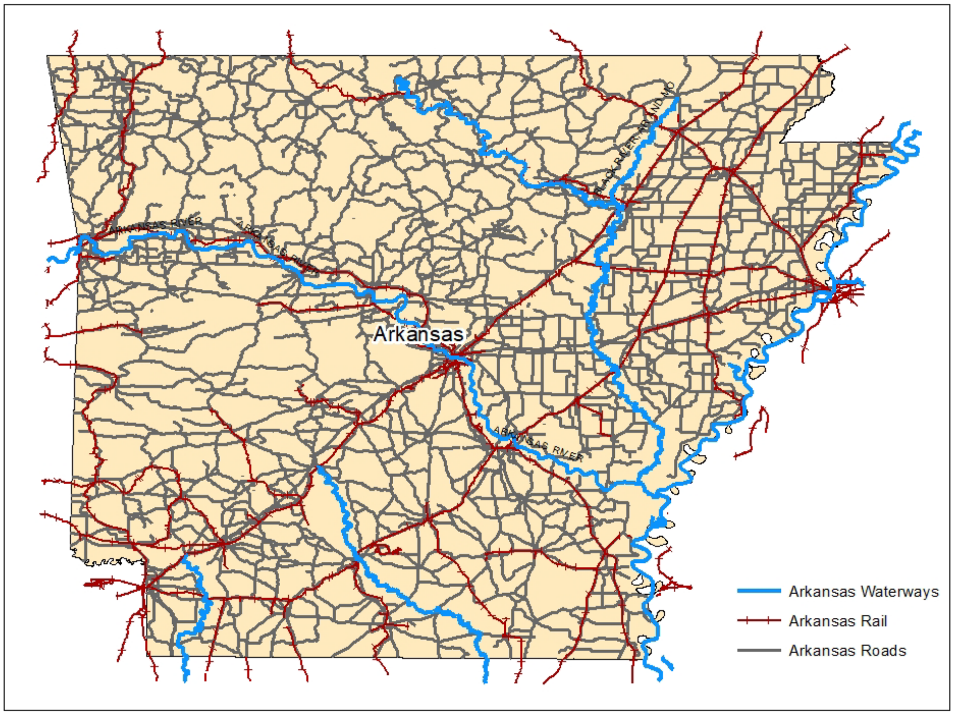


Figure 1: Arkansas Multi-modal Transportation Networks

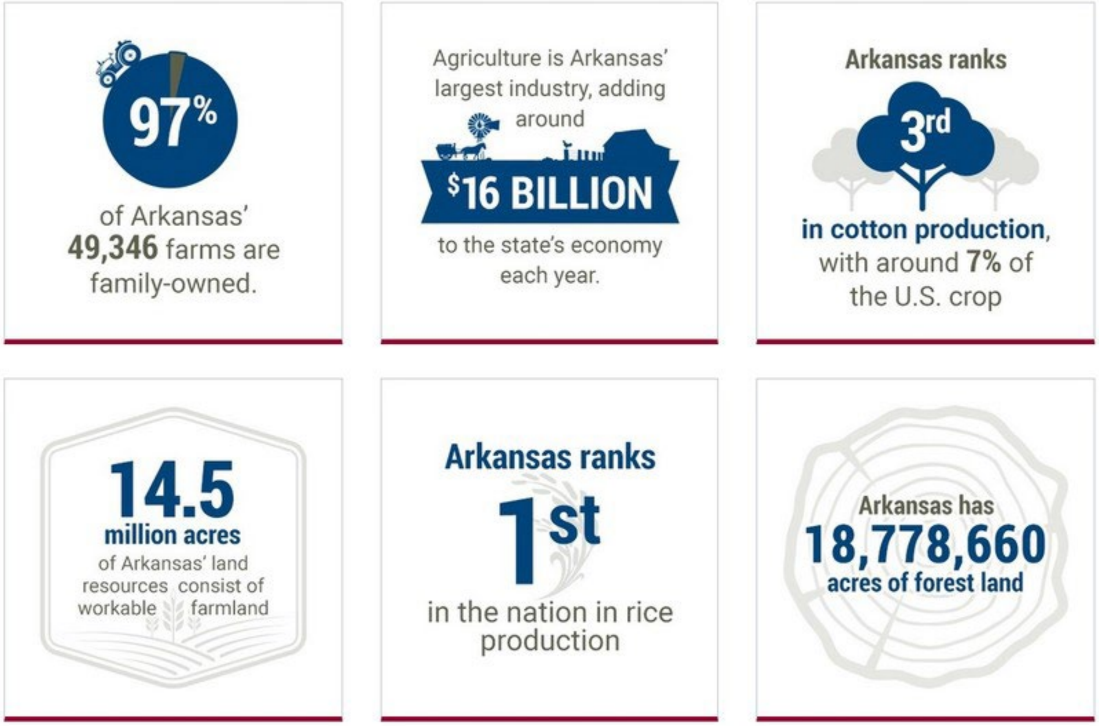


Figure 2: Agricultural facts for the state of Arkansas (Source: Arkansas Farm Bureau, 2021)

Methodological Approach

The overall study applied a network-based optimization model to describe relationships and connections between the agriculture and the transportation sectors for consideration during and following disruption scenarios within the state of Arkansas. The infrastructure systems are subject disruption by natural hazards such as floods, ice storms, and droughts that can degrade, temporarily impede, or even close portions of the transportation network, resulting in potentially reduced agricultural production and challenges in moving products to market. Considerations were given as to whether the analysis should consider moving inputs to the field (e.g., seed and/or fertilizers) at the beginning of the growing season(s) or moving products away from fields to market. After much consideration and debate among the project team, it was decided to focus on fertilizer movements from the Gulf Coast Area to rice fields. In the sections that follow, the data utilized and efforts to transform it into both data and information to support modeling efforts is discussed. Processing included projecting data layers into the same or compatible coordinate systems, cleaning duplicate points and arcs, connecting arcs and nodes that were disconnected or hanging, and overall quality control to ensure that the modeling would run smoothly. Appendix A provides a summary of the coordinate systems of key spatial data layers and the projections used.

Multimodal Transportation Network

The data for road, rail and waterway networks, and some data for intermodal nodes were obtained from the most recent versions of US Census Bureau's TIGER/Line Shapefiles ("TIGER/Line Shapefiles," n.d.). These were mapped and processed for project use using ESRI's ArcGIS software and

Python (Figure 3). The multimodal transportation network includes the three primary freight transportation modes: road, rail, and water. Trucks, trains, and barges are used as the transporting entities for each mode, respectively. The data utilized and processing/model preparation considerations are discussed below for each mode.

Roads

For model simplicity, roads with the designation representing state highways and interstates (i.e., I and U codes in the RTTYP format according to the Census Bureau code lists) were used to capture the roads most likely to be used for transportation of fertilizer which also results in a simplified network. The project team acknowledges that local and secondary roads are needed to move from field to highway/interstate, but this was also a proof-of-concept project and some simplifications were made with that purpose in mind.

Major roads were also mapped for surrounding states (i.e., Louisiana, Mississippi, Tennessee) that connect the supply node (i.e., New Orleans) to road nodes in the case study area. By doing so, commodities could move to demand nodes (agricultural areas) using various routes, so they do not rely solely on the Mississippi River or other waterways and/or rail. This allows for true consideration of multi-modal transportation to get commodities to/from the fields. After cleaning and processing, the road network was comprised of 660 arcs and 114 nodes. This represents the consolidated and simplified road network. Each road node was assigned a unique identification number starting at 0 and ending at 9000 using the ArcGIS Editor tool for use in modeling efforts.

Speed limits for the roads were also collected as well as other data such as average annual daily traffic (AADT) to help provide context and limits on the arcs for modeling. This information was added to the base spatial data using the Join tool in ArcGIS. Figure 3 shows the resulting distribution of speed limits for roads in the state of Arkansas. Each arc or segment has an associated traversal time and a capacity that limits the number of containers moved on the arc per unit time. In addition, there are transshipment nodes (nodes along roadways that do not connect to another roadway or mode) that serve as intermediate points and have neither supply nor demand, and intermodal nodes which are a subset of transshipment nodes.

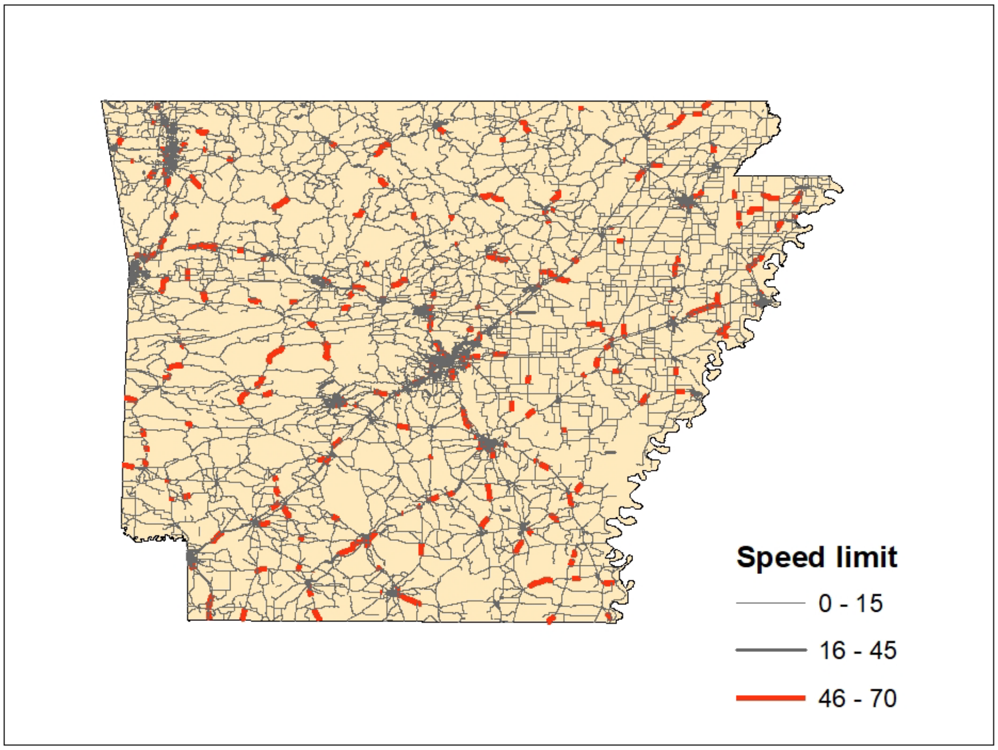


Figure 3: Speed limit designations on Arkansas roadways.

Rail

Similar to the road network, rail data was obtained from US TIGER/Line Files ("TIGER/Line Shapefiles," n.d.). When mapping the data, it consisted of a high number of arcs and nodes that represent abandoned rail yards and segments. Because these arcs and nodes are not currently being used, we removed them from our dataset. In addition, we grouped the arcs and nodes that belong to the railyards together to reduce the complexity of the network. The visual observation of the simplified network showed that there were a few disjoint components that were either eradicated or linked to the rest of the rail network after providing reasonable justifications. As a result, the number of arcs and nodes amounted to 620 and 179, respectively. Rail nodes were assigned IDs of 30001 to 35000 for model use.

Waterways

The Arkansas River connects with the Mississippi River in Southeast Arkansas. The McClellan-Kerr Arkansas River Navigation System (MKARNS) runs through Arkansas to Catoosa, Oklahoma. The MKARNS is designated a Marine Highway 40 Corridor (M-40). The river has ports in Pine Bluff, Little Rock, and Fort Smith. The river is 445 miles long, 308 of which are in Arkansas. The width of the river is 250 feet. There are 18 locks along the river, with 13 in Arkansas. Each lock chamber is 110 feet wide x 600 feetlong and has capacity for 8 barges and a towboat (2017 Inland Waterway Fact Sheet). Navigable waterway data and port locations were obtained from the US Army Corps of Engineers US TIGER/Line Files ("TIGER/Line Shapefiles," n.d.). For representation of the Arkansas river in modeling, we divided the waterway using nodes at locks and dams (Figure 4). This allowed us to create disruption scenarios based on the historical operational data of these locks.

The navigable waterway network outside the state of Arkansas to reach New Orleans comprises three primary components: the Red River, the Ouachita River, and the Mississippi River. Efforts were made to quality check and use the best available information from the two sources to arrive at a complete data set. To simplify the water network beyond Arkansas that provided potential linkages to the New Orleans source node, we combined the arcs and intersected them at the supply node in New Orleans. Therefore, we have three routes to move commodities out of the supply node to the water nodes in Arkansas. In the final water network, there were 128 arcs and 36 nodes. The labels for water nodes ranged from 40000 to 45000 for modeling purposes.

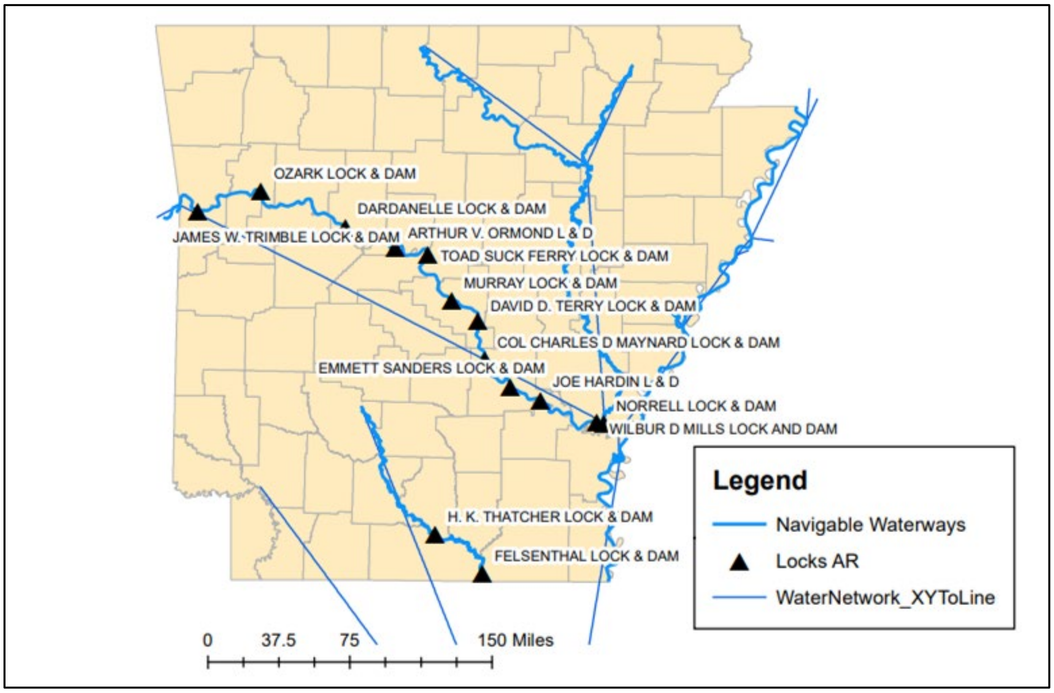


Figure 4: Navigable Waterways and Locks in Arkansas

Time of travel along the inland waterways to key locations in Arkansas was also gathered using US Army Corps of Engineers LPMS data. Consideration was given to different disruptions and the resulting operating restrictions that are imposed due to water levels and other waterway conditions in guidance documents called Waterway Action Plans. In Table 1, travel times under different scenarios of restrictions between multiple points along the waterway are presented. In some river flow conditions, tow boats moving barges may be limited to only moving during daylight hours and no nighttime movements. Additional restrictions may be placed on the number of barges in the tow (T) configuration or horsepower (H) used.

Table 1: Example travel time (minutes) on Arkansas River to Key Points under Various Restrictions

	No Restrictions	Daylight Only	T/H Restrictions	Daylight Only T/H restrictions
Mississippi River to David D. Terry (DTD)	1743.7	3487.4	2190.2	4380.4
DTD to James W. Trim	2216.4	5340.8	3124.4	6248.8

Intermodal Nodes

Intermodal nodes are used to enable switching from one transportation mode to another (as may be done in a disruptive event), and they also enable storing inventory (e.g., grain elevators, ports/harbors, etc.). The original data for intermodal nodes consisted of 496 nodes. By creating a visualization of these nodes using ArcGIS, we observed that many intermodal nodes appeared redundant. For example, intermodal nodes of similar types (e.g., from the rail to the road modes) are located close to each other. We selected a reasonable subset of the intermodal nodes by calculating the distance from each intermodal node to the mode-specific node. The intermodal node was retained if it was within seven miles from at least two mode-specific nodes. Otherwise, it was removed. As a result, 123 intermodal nodes met this criterion and were included in the transportation network. For these nodes, we assigned numbers ranging from 70000 to 75000 using the Editor tool.

Then, while retaining this data set, we used ArcGIS to identify locations where all three modes of transportation came within close proximity to each other or at least two modes intersected. Using the Select by Location tool and others, we identified locations where the three modes were in proximity within a search radius of both 100 meters or 500 meters under the assumption that a transfer of containers from one mode to the other may be feasible within these distances in a disruption scenario where cargo may need to be transferred from one mode to another. In Figure 5, the multimodal nodes locations identified for each search distance are shown. Figure 6 presents a close-up view of an area where all three modes converge at one location.

Additional Linkages

For modeling to work effectively, all links and nodes needed to be connected. Therefore, for some of the locations where two modes of transportation intersected and another was in close proximity for an intermodal "node" to exist, a connecting intermodal link was created to the nearest point on the non-intersecting mode. An example of this is provided in Figure 7.

Connections between the agriculture sector and the transportation system are modeled at the demand nodes, which represent agricultural production sites (i.e., crop fields). In a similar approach to the linkages created to ensure connectivity at intermodal nodes, linkages to demand nodes were made from the nearest (typically roadway) transportation link/node.

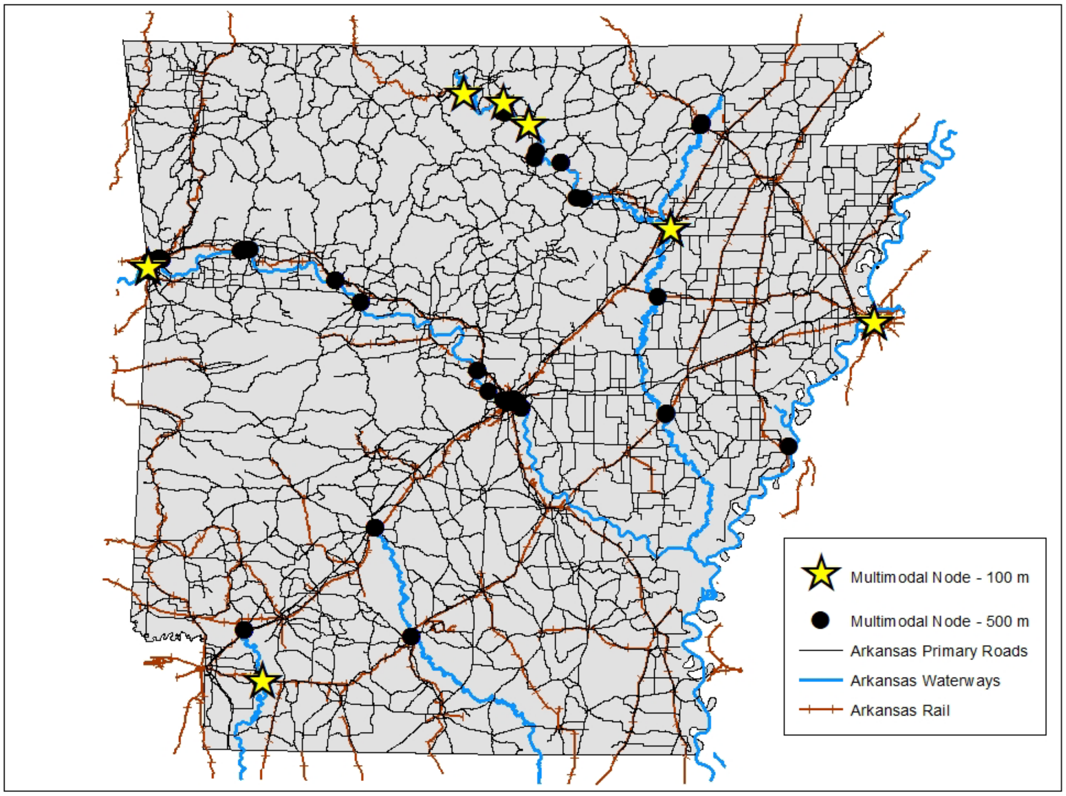


Figure 5: Multimodal nodes identified as locations where all three modes of transportation come within either a 100m radius and/or a 500m radius.

Figure 6: Example of an intermodal node location with all three modes of transportation converging.

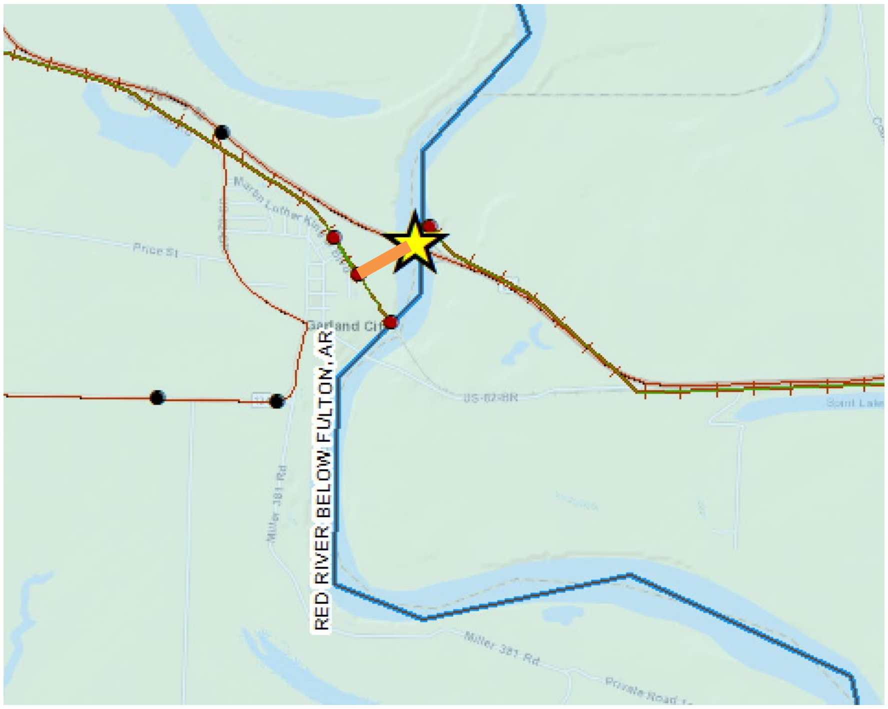


Figure 7: Example of a new intermodal link (thick orange line) to connect rail to the intermodal node (star).

From GIS to Model Inputs

For each transportation spatial data set, the underlying database file in ArcGIS was extracted and converted to a Microsoft Excel spreadsheet that had unique identifiers for each arc or node using the notations mentioned above (e.g., 30000s for rail, 40000s for waterway). For each, arc, the beginning and ending nodes (or beginning and ending latitude and longitude) were identified and listed in a spreadsheet. Appendix C provides samples of the waterway and rail network data with beginning and ending locations. In some cases, additional smoothing of the arcs was performed for modeling to simplify the network and improve simulation run times.

Network Routing Considerations

In this research, we considered a single supply node only for the fertilizer to simplify the modeling. Additional more supply nodes could be created and connected to the existing network in future modeling efforts and research explorations. A location near New Orleans was selected as the supply node since many nitrogen fertilizer production sites and distribution centers are located around it. Using an approach similar to above, the supply node was connected to the waterway network by creating a link in ArcGIS. The supply node was labeled as 80000 and was set with sufficient supply of fertilizer to satisfy all demands.

Based on realistic accounts, the team understood that fertilizer is predominantly shipped on the waterways, then rail, then roads in an undisrupted environment. However, during the initial testing of the optimization model, while all three modes were utilized in routing form the source in New Orleans, the water mode was the least preferred mode of all, because the barges have the slowest transit time. For example, trains could make multiple trips and carry the same number of containers in the same time that a barge can make one trip. However, it has been documented that barge transportation is efficient due to fuel cost and economies of scale (Kruse, J. 2019). To reflect the realistic nature of the transportation network, a penalty per unit distance was developed for each transporting mode reflecting efficiencies of the modes. Using this approach, water was prioritized to become the preferred mode of transportation, next was rail, and last was road.

Agricultural Data

Estimating Fertilizer Demands

Using rice as the agricultural crop of choice for this project, the team investigated and obtained data on locations of rice crops using USDA's Crop Scape and or Land Use/Land Cover data from US Geological Service. Additional information was obtained from the state of Arkansas. Locations for relevant collection points for agricultural products such as grain elevators and rice mills and distributors were obtained from use of various data sources.

Estimates of the demand for fertilizer based upon field size was generated by using the land use data to find the number of 'points' that are closest to each grain elevator in Arkansas. Each point of the land use represents a 30 x 30 m area, so the number of points was then converted to acreage for each grain elevator. Aggregation of the potential crop production and fields that would be served by the grain elevators under different scenarios (estimated by team members from the University of Arkansas) for the grain elevators using a 10,000 m distance radius around them. Grain elevators were considered part of a hub and spoke representation for collectively representing a large area of farms in a simplified modeling environment. While grain elevators are used in getting agricultural products to market, here, we used them inversely as potential dissemination points for fertilizer to be distributed out to fields for modeling purposes. This was done to alleviate the need to route to each individual farm/field. Due to the number of grain elevators representing aggregated farm areas, centralized "demand nodes" were identified/located to "serve" multiple grain elevators. Last-mile transportation arcs were created to connect to demand nodes to the nearest roadway link or node.

Overall, the interactions between the agriculture sector and the transportation system were modeled at the demand nodes, which represented agricultural production sites that require as input the commodity that is being transported through the network. This is discussed in a later section.

In total, 37 demand nodes were created/identified in the network (Figure 9). Each demand node in ArcGIS has underlying data representing the total acreage served, the number of rice elevators, and its geocoordinate. We connected each demand node to its closest road node. This means that the demand nodes can only be accessible by trucks. Each demand node was assigned a unique identification number that starts at 90000.

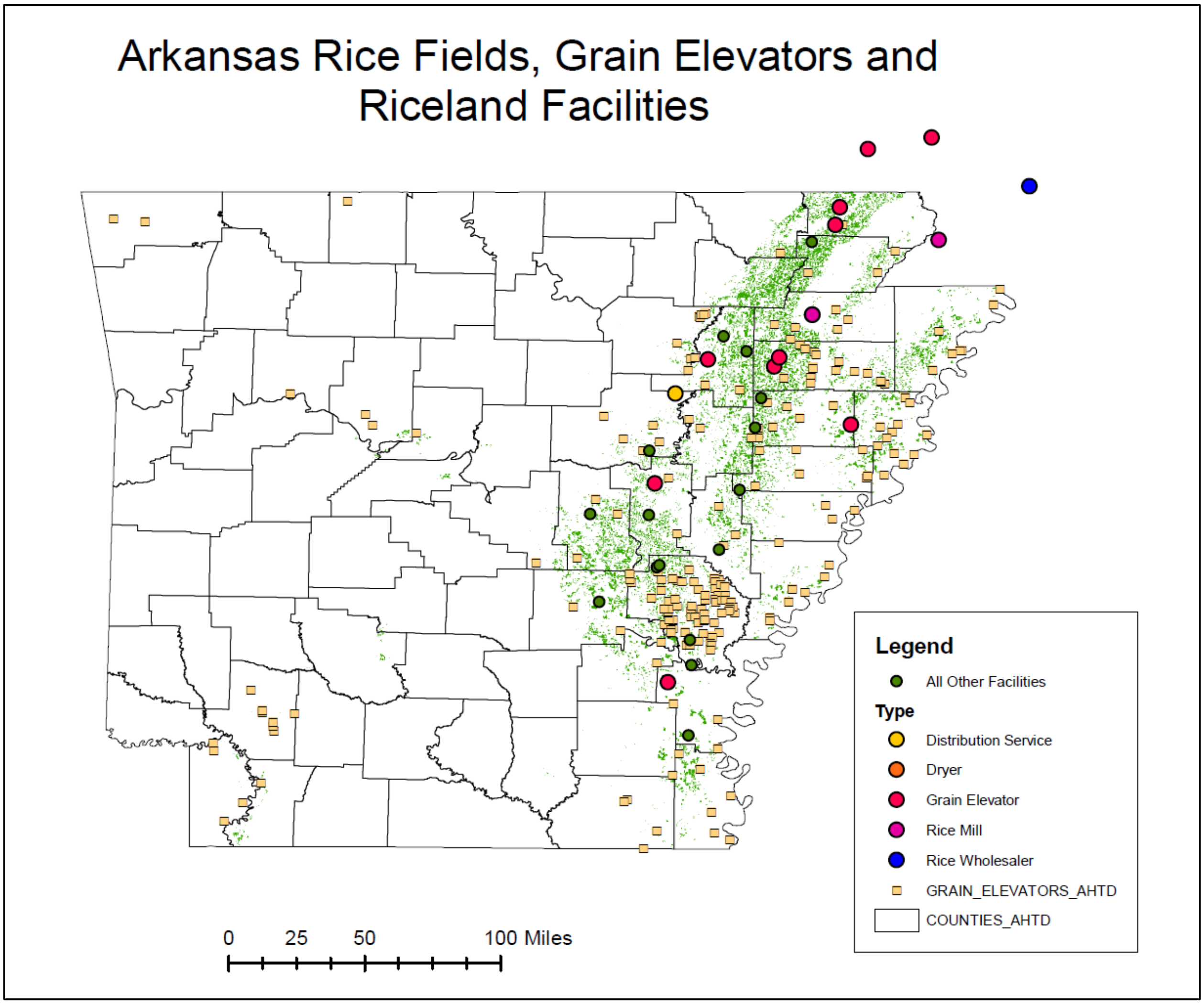


Figure 8: Agricultural Sector Infrastructure Locations

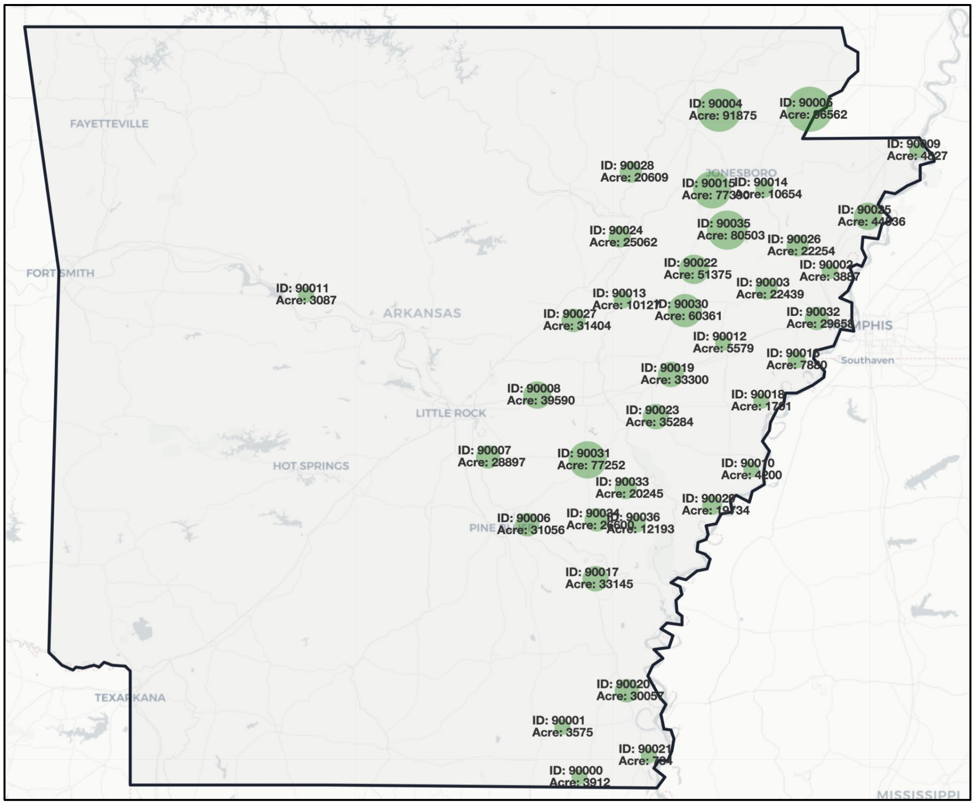


Figure 9: Demand nodes with the node identification number (top) and total acreage (bottom).

Disruption Scenarios

Disruptions scenarios were created for both land and water based upon historical data.

To create the scenarios for land disruption, we gathered geographical data for highways closed due to flooding events for 2011 (a year of significant flooding in the region) and 2016-2019 from the Arkansas Department of Transportation (DOT). A map showing roadway closures due to flooding or "high water" as termed by the Arkansas DOT is presented in Figure 10. In order to align the obtained data with the defined network, several zones/areas with a high risk of flooding were created using ArcGIS. A *density-based spatial clustering of applications with noise* (DBSCAN) algorithm was used to identify clusters that were then used to construct the aforementioned zones. Given a set of points, DBSCAN groups together points that are close in Euclidean distance (high-density regions) and marks the outliers in the low-density regions (Ester et al., 1996). The DBSCAN algorithm is available to use in the sklearn package in Python ("sklearn DBSCAN," n.d.).

Given each cluster of the closed road nodes for each year, a polygon was constructed by calculating an alpha shape using the software. The alpha shapes approach is often used for shape reconstruction from a dense unorganized set of points. A convex hull is an alpha shape when the alpha-parameter is equal to zero. The alpha-parameter can be manipulated to tighten or loosen the fit around the points, which creates a concave hull. In this research, we set the alpha parameter to 3. A Python API is used to aid in the generation of alpha shapes (Bellock, n.d.). By plotting the flooding zones of multiple years, we can see several overlapped areas where traffic is closed most frequently. The end result was the creation of three disruption levels (i.e., levels 1, 2, 3 representing the areas with low, medium, high impact due to the flooding, respectively) (Figure 11). All arcs that intersect the zones can be assumed to be affected by flooding zones (Table 2). Note that some demand nodes are located within these areas; thus, we can see how the disruption levels and their duration will impact the yield in the result section.

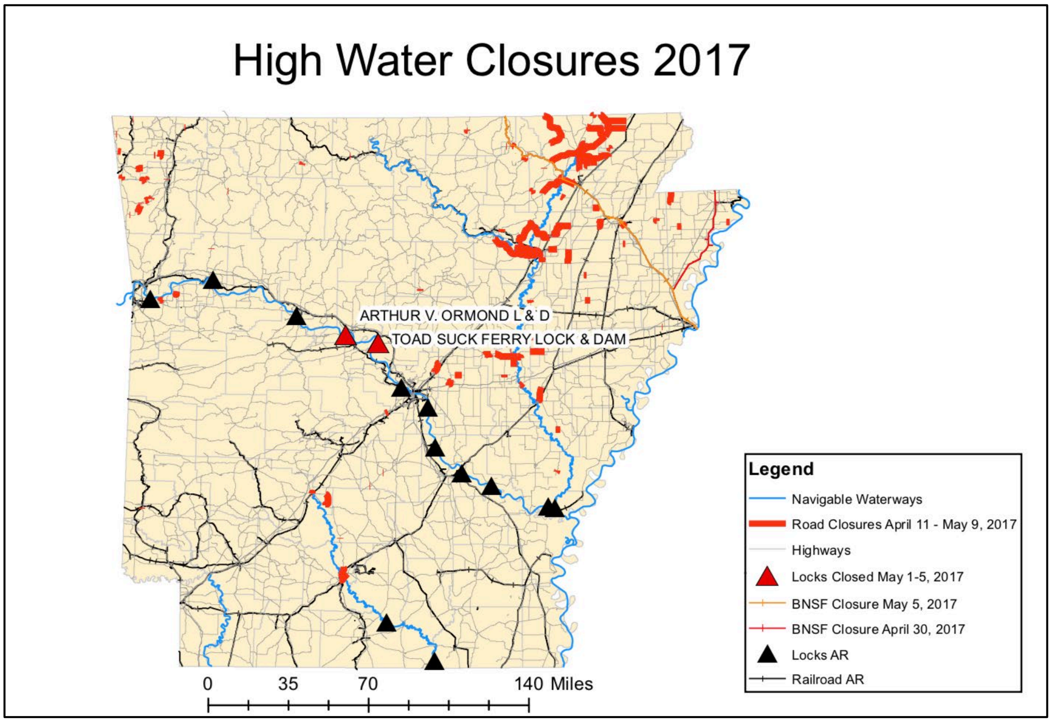


Figure 10: Road closures due to high water based on information from Arkansas DOT.

Disruption scenarios for the waterways were developed using data was extracted from historical lock closures due to flooding for the years of 2015 and 2016 using data from the Inland Rivers, Ports and Terminals, Inc. (IRPT) organization. IRPT is a nationwide trade association composed of ports, terminals, users and suppliers of the U.S. Inland Waterway system and they track and send out notifications of closures to members of the inland waterway community. The data specifies closing and reopening dates for locks in Arkansas's navigable waterway system. Depending on the operational level of each lock, the incident arcs associated with the lock share the same operation level.

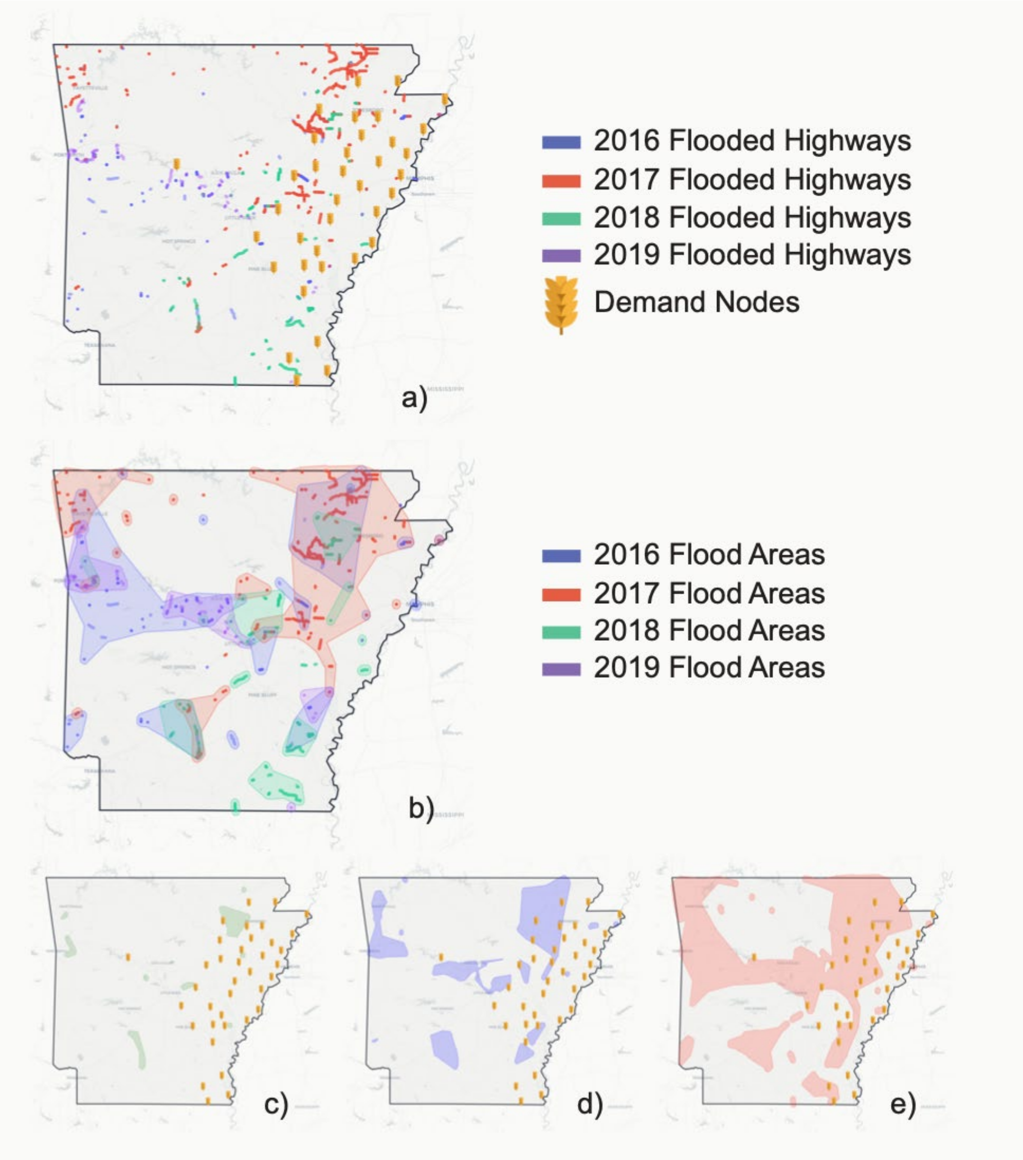


Figure 11: a) Closed highways in 2016-2019, b) flood zones created, c) areas with level 1 risk, d) areas with level 2 risk, e) areas with level 3 risk. Note that there are several demand nodes located inside the flood areas.

Table 2: Summary of the number of transportation system arcs disrupted by each disruption scenario considered.

Disruption Scenario	Number of Disrupted Arcs
Land - Level 1	69
Land - Level 2	357
Land - Level 3	694
Water	36

Iterative and Involved Process

The primary goal was to gather and process data from various sources to facilitate modeling of this cross-sector intermodal system representing three transportation modes and the agricultural sector for optimization analysis. The entire process was collaborative and iterative across the University of Arkansas and Vanderbilt team members with data needs being discussed for the model and data availability and limitations being considered.

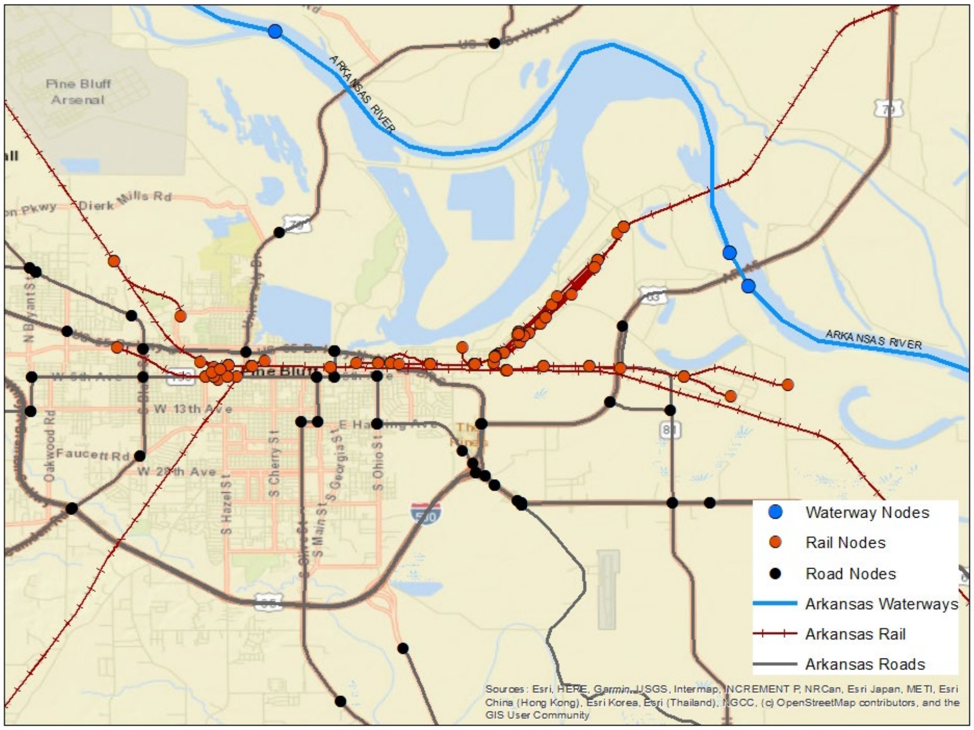
Additional information about the modeling efforts and some of the simplification that was required to convert the "real world" infrastructure assets and associate data into data and information that would work for modeling is discussed in the other report mentioned previously in this report. This report is only supplementary to the report by Nurre et al. 2021 to tell the behind-the-scenes data work story. Truly capturing all the considerations and wrangling of data to get to what was needed for the final project modeling and analysis over years of work would not be feasible. Therefore, this report is intended to help other researchers learn from our process for future research applications.

Results and Discussions

Transportation Network Data Issues

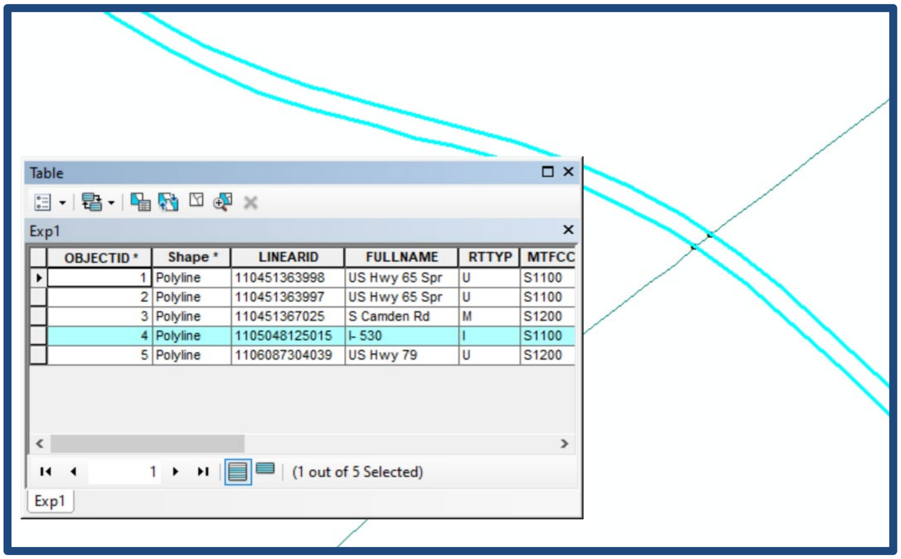
Based on realistic accounts, the team understood that fertilizer is predominantly shipped on the waterways, then rail, then roads in an undisrupted environment. However, during the initial testing of the optimization model, while all three modes were utilized in routing form the source in New Orleans, the water mode was the least preferred mode of all, because the barges have the slowest transit time. For example, trains could make multiple trips and carry the same number of containers in the same time that a barge can make one trip. However, it has been documented that barge transportation is efficient due to fuel cost and economies of scale (Kruse, J. 2019). To reflect the realistic nature of the transportation network, a penalty per unit distance was developed for each transporting mode reflecting efficiencies of the modes. Using this approach, water was prioritized to become the preferred mode of transportation, next was rail, and last was road.

For modeling purposes, the multi-modal transportation network needed to "flow" properly. As we began transferring the transportation network data into formats that were usable for modeling purposes (i.e., numbering the arcs and nodes with consistent IDs, etc.), it became apparent that there was data wrangling needed (i.e., cleaning and processing). Appendix B provides visual examples and explanations for a sample of issues with the roadway network that required attention. As a result, a laborious task was undertaken with ArcGIS tools employed to remove redundancies, ensure that arcs connected to nodes, and simplify/smooth the data. In some cases, aerial imagery was used to check data and more frequently identifying problem areas due to network routing errors or geoprocessing analysis was done. Figure 12, shows a localized view of the three modes with arcs and nodes that required cleaning for modeling purposes. Figure 13 shows an instance where in the database, only one roadway is listed, but spatially, there are two arcs that extend for a large distance that would create problems in routing along the roadway. The arc was "folded" over at a point and then continued in parallel to itself. This had to be cleaned by splitting it into two separate arcs/roadways using the Editor tool.



Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community

Figure 12: Example of three transportation modes in one area with links and nodes identified from the raw GIS data.



OBJECTID *	Shape *	LINEARID	FULLNAME	RTTYP	MTFCC
1	Polyline	110451363998	US Hwy 65 Spr	U	S1100
2	Polyline	110451363997	US Hwy 65 Spr	U	S1100
3	Polyline	110451367025	S Camden Rd	M	S1200
4	Polyline	1105048125015	I- 530	I	S1100
5	Polyline	1106087304039	US Hwy 79	U	S1200

(1 out of 5 Selected)

Figure 13: The roadway highlighted/selected in the attribute table appears on the map as two separate roads. This had to be resolved to avoid model routing errors.

Impacts/Benefits of Implementation

The results demonstrate that publicly available data can be utilized to develop a multi-modal transportation network that connects to other sectors for modeling and simulation of demands and disruptive events. Care should be given to not just take data at surface value and consider "how" it will be utilized and what connections are appropriate within/across modes and with other sectors.

From the overall project, there is great benefit for decision support and development of response scenarios to improve post-disaster restoration of transportation infrastructure to meet demands of other sectors. Along those lines, potential coordination among state and federal transportation entities (e.g., state DOTs, U.S. Army Corps of Engineers) and other sectors could improve production of agricultural products and resilience for the state and other areas. Here, we demonstrate how data can be used to inform modeling efforts that can lead to coordinated restoration damaged transportation waterways and roads resulting in improved agricultural yields. The research demonstrates the need for data and information coordination, interdisciplinary research, systems thinking, continued support for publicly available data sets to inform decisions, and understanding of how transportation impacts other interdependent infrastructure systems.

Recommendations and Conclusions

In the overall project, we investigated the potential for disruptions to the multimodal transportation network to result in delayed delivery of fertilizer to rice farms in Arkansas, thereby causing reduced harvest yields. The modeling would not have been realistic nor possible without foundational data to help create the multimodal transportation network, identify multi-modal connections, identify potential nodes for demand based upon spatial data of rice farm locations. Using historic event data to inform potential disruptive scenarios allows for the research to be grounded in “real-world”, understandable information to help inform decision makers and modeling efforts.

Throughout the process, we identified several limitations that may prompt future research. All modeling efforts were based upon data which was found to have errors, nuances, and issues that required some modifications, cleaning, or judgement. Improved data quality and accessibility could allow for improved modeling results. It is well known that in modeling outputs are only as good as the inputs. Due to time and resource constraints, we could not collect localized data to ensure accuracy, nor could we validate all of the data (arcs, nodes, etc.) for the entire state and surrounding areas. Additionally, modeling required simplification of some data to improve simulation time and processing. However, the results obtained are at a granularity that allows for decision support and planning.

Overall, the full project (data management and modeling) was a rewarding interdisciplinary experience with all learning some from the others’ expertise. Often, optimization modeling may be based upon hypothetical situations and data. This project allowed for data to be utilized in a way to inform the modeling and analysis that has great potential to inform future cross-sector planning and coordination for disaster response activities, infrastructure investment to improve resilience and economic security for both the state and its farmers.

It is recommended that similar analysis be conducted for other agricultural products within the state of Arkansas and replicated in other states. Future research should also consider the potential for prioritized restoration of transportation infrastructure post-disaster to benefit other sectors and supply chains similarly such as municipal water/wastewater treatment and health care facilities. Such research may find that there are truly some “critical” arcs and nodes that serve multiple sectors and would lead to improved outcomes if hardened or prioritized for restoration post-disaster.

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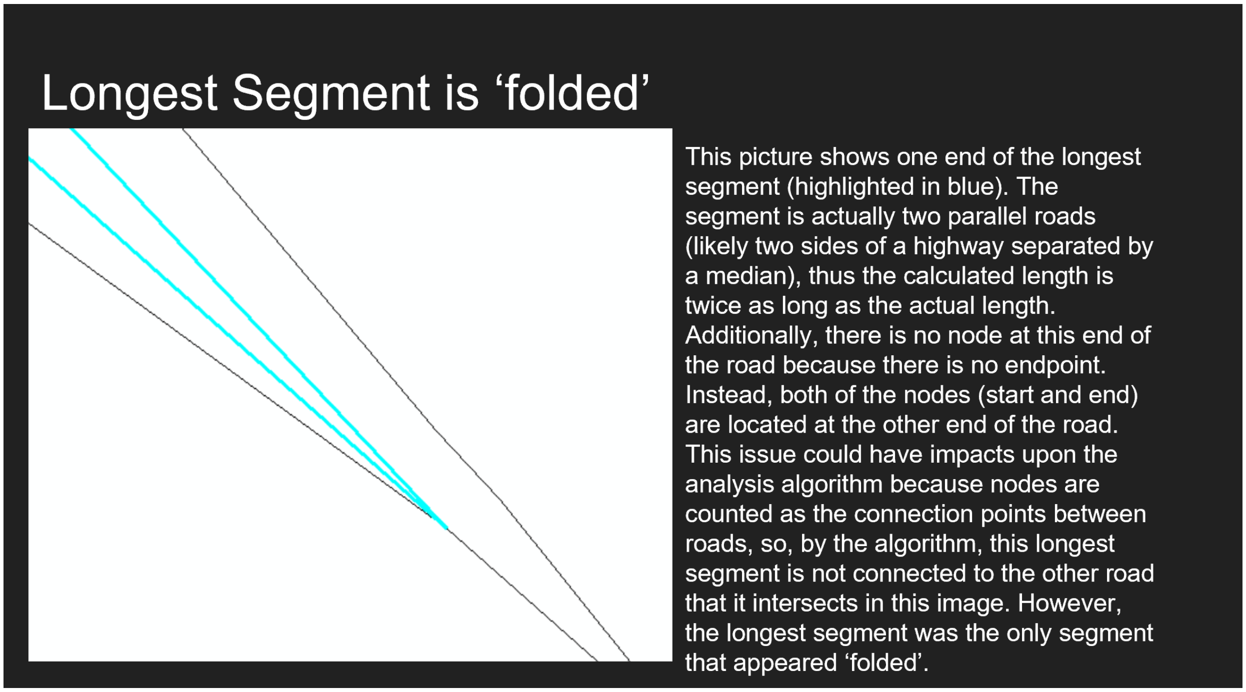
Appendices

Appendix A –Spatial Data File Coordinate System Work

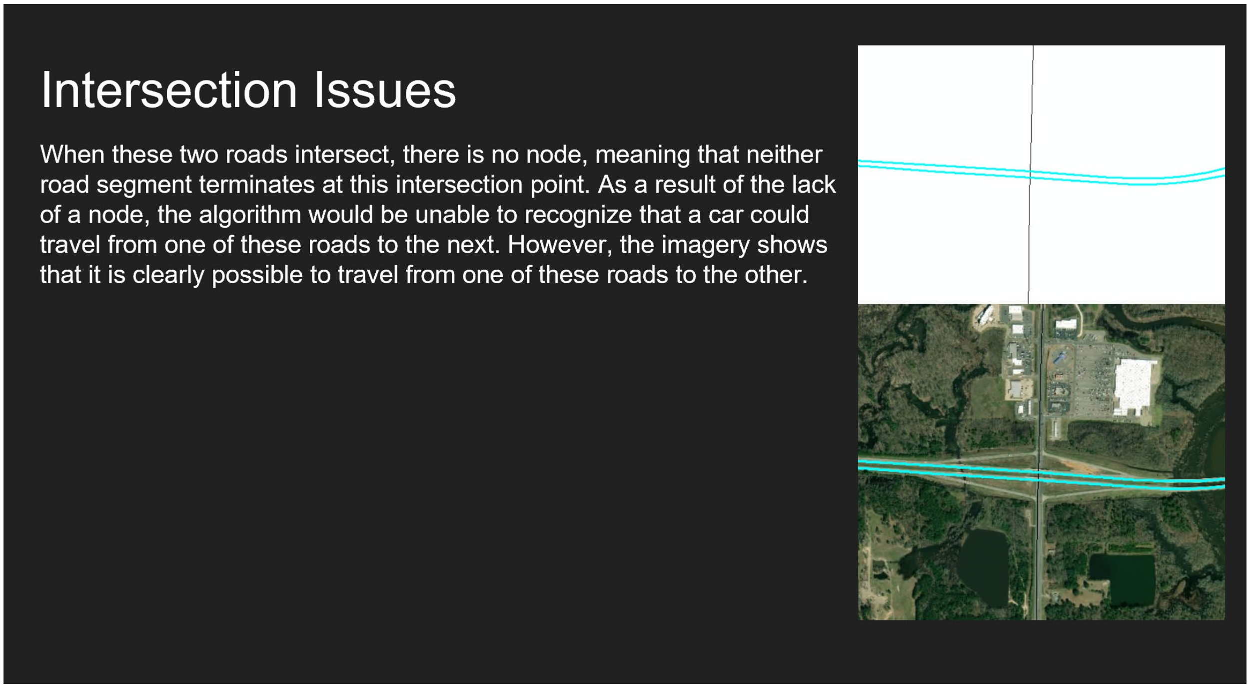
Layer Name	Layer Geographic Coordinate System	Layer Projected Coordinate System	Data Frame Coordinate System	Data Frame Geographic Coordinate System	Projection
ArkansasStateBoundary_Buffer	GCS_WGS_1984	NA	GCS_WGS_1984	NA	NA
Intermodal_Freight_Facilities	GCS_WGS_1984	NA	GCS_WGS_1984	NA	NA
Polylines (appears empty)	GCS_WGS_1984	WGS_1984_Web_Mercator_Auxiliary_Sphere	WGS_1984_Web_Mercator_Auxiliary_Sphere	GCS_WGS_1984	Mercator_Auxiliary_Sphere
Railroads_FeatureVerticesToP	GCS_South_American_1969	South_America_Albers_Equal_Area_Conic	South_America_Albers_Equal_Area_Conic	GCS_South_American_1969	Albers
Railroads_SplitLine	GCS_South_American_1969	South_America_Albers_Equal_Area_Conic	South_America_Albers_Equal_Area_Conic	GCS_South_American_1969	Albers
RailVertices	GCS_South_American_1969	South_America_Albers_Equal_Area_Conic	South_America_Albers_Equal_Area_Conic	GCS_South_American_1969	Albers
RailVertices_Dissolve	GCS_South_American_1969	South_America_Albers_Equal_Area_Conic	South_America_Albers_Equal_Area_Conic	GCS_South_American_1969	Albers
RasterT_img1	GCS_North_American_1983	Albers_Conical_Equal_Area	Albers_Conical_Equal_Area	GCS_North_American_1983	Albers
RasterT_img2	GCS_North_American_1983	Albers_Conical_Equal_Area	Albers_Conical_Equal_Area	GCS_North_American_1983	Albers
RasterT_Majorit1					
RasterT_Majorit2					
RasterT_Nibble_1	GCS_North_American_1983	Albers_Conical_Equal_Area	Albers_Conical_Equal_Area	GCS_North_American_1983	Albers
RasterT_Nibble_1_SimplifyPol	GCS_North_American_1983	Albers_Conical_Equal_Area	Albers_Conical_Equal_Area	GCS_North_American_1983	Albers
RasterT_Nibble_1_SimplifyPol_Pnt					
RasterT_Nibble_1_SimplifyPol1					
RasterT_tif1					
RasterT_tif2					
Roads_Clip	GCS_South_American_1969	South_America_Albers_Equal_Area_Conic	South_America_Albers_Equal_Area_Conic	GCS_South_American_1969	Albers
Roads_CopyRows_XYTableToPoint					
Roads_Dissolve	GCS_South_American_1969	South_America_Albers_Equal_Area_Conic	South_America_Albers_Equal_Area_Conic	GCS_South_American_1969	Albers
Roads_Dissolve_By_Signs	GCS_South_American_1969	South_America_Albers_Equal_Area_Conic	South_America_Albers_Equal_Area_Conic	GCS_South_American_1969	Albers
Roads_FeatureVerticesToPoint	GCS_South_American_1969	South_America_Albers_Equal_Area_Conic	South_America_Albers_Equal_Area_Conic	GCS_South_American_1969	Albers
Roads_FeatureVerticesToPoint1	GCS_South_American_1969	South_America_Albers_Equal_Area_Conic	South_America_Albers_Equal_Area_Conic	GCS_South_American_1969	Albers
RoadsVertices	GCS_South_American_1969	South_America_Albers_Equal_Area_Conic	South_America_Albers_Equal_Area_Conic	GCS_South_American_1969	Albers
RoadsVertices_Dissolve					
Routes_CreateRoutes					
Waterways	GCS_South_American_1969	South_America_Albers_Equal_Area_Conic	South_America_Albers_Equal_Area_Conic	GCS_South_American_1969	Albers
Waterways_Clip	GCS_South_American_1969	South_America_Albers_Equal_Area_Conic	South_America_Albers_Equal_Area_Conic	GCS_South_American_1969	Albers
Waterways_FeatureVerticesToP	GCS_South_American_1969	South_America_Albers_Equal_Area_Conic	South_America_Albers_Equal_Area_Conic	GCS_South_American_1969	Albers
Waterways_FeatureVerticesToP2	GCS_South_American_1969	South_America_Albers_Equal_Area_Conic	South_America_Albers_Equal_Area_Conic	GCS_South_American_1969	Albers
WaterwaysVertices	GCS_South_American_1969	South_America_Albers_Equal_Area_Conic	South_America_Albers_Equal_Area_Conic	GCS_South_American_1969	Albers

Appendix B – Transportation System Data Issue Examples



Longest Segment is ‘folded’

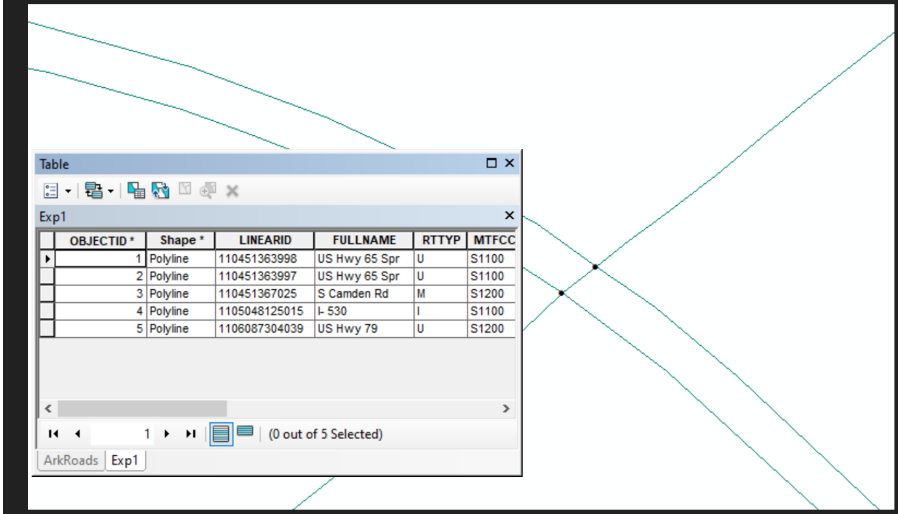
This picture shows one end of the longest segment (highlighted in blue). The segment is actually two parallel roads (likely two sides of a highway separated by a median), thus the calculated length is twice as long as the actual length. Additionally, there is no node at this end of the road because there is no endpoint. Instead, both of the nodes (start and end) are located at the other end of the road. This issue could have impacts upon the analysis algorithm because nodes are counted as the connection points between roads, so, by the algorithm, this longest segment is not connected to the other road that it intersects in this image. However, the longest segment was the only segment that appeared ‘folded’.



Intersection Issues

When these two roads intersect, there is no node, meaning that neither road segment terminates at this intersection point. As a result of the lack of a node, the algorithm would be unable to recognize that a car could travel from one of these roads to the next. However, the imagery shows that it is clearly possible to travel from one of these roads to the other.

Overlap Issue

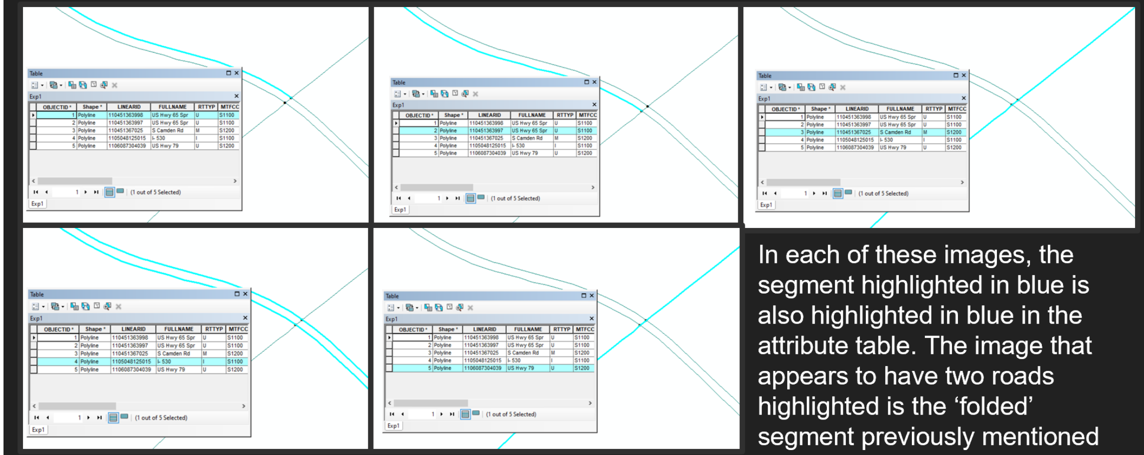


OBJECTID *	Shape *	LINEARID	FULLNAME	RTTYP	MTFCC
1	Polyline	110451363998	US Hwy 65 Spr	U	S1100
2	Polyline	110451363997	US Hwy 65 Spr	U	S1100
3	Polyline	110451367025	S Camden Rd	M	S1200
4	Polyline	1105048125015	I- 530	I	S1100
5	Polyline	1106087304039	US Hwy 79	U	S1200

(0 out of 5 Selected)

This image shows that there are five different road segments in the image. If each segment were to terminate at the nodes shown, however, there would have to be seven segments. The following slides show that there are really two road segments shown in this picture and the rest is just overlap.

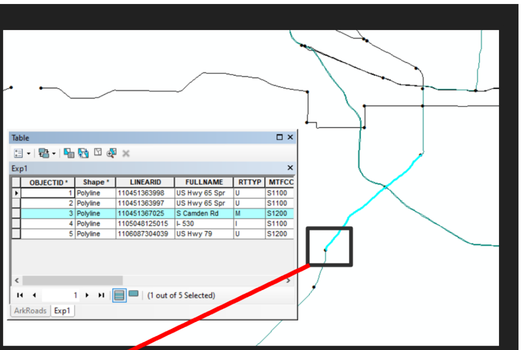
Overlap Issue - 5 Segments Independently



In each of these images, the segment highlighted in blue is also highlighted in blue in the attribute table. The image that appears to have two roads highlighted is the 'folded' segment previously mentioned

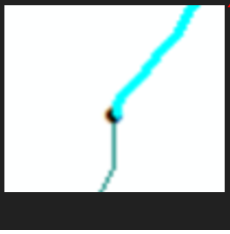
Overlap Issue

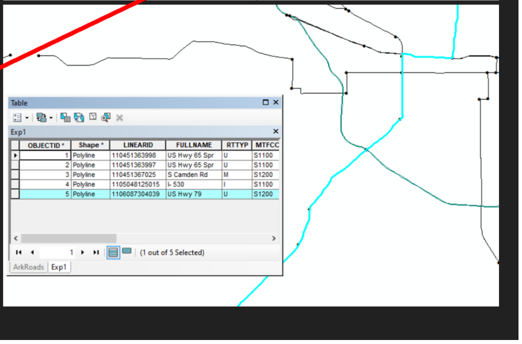
The road segment in the upper right picture is completely overlapped by the segment in the lower right picture. This overlap results in clutter and potential confusion for the algorithm as there are two routes that are actually the same routes. Additionally, the overlap sometimes results in random nodes in the middle of long segments that are the endpoints of the overlapped segments. These random nodes often don't connect to any other road segments, as shown by the box in the upper image.



OBJECTID *	Shape *	LINEARID	FULLNAME	RTTYP	MTFCC
1	Polyline	110451363998	US Hwy 65 Spr	U	S1100
2	Polyline	110451363997	US Hwy 65 Spr	U	S1100
3	Polyline	110451367025	S Camden Rd	M	S1200
4	Polyline	1105048125015	I- 530	I	S1100
5	Polyline	1106087304039	US Hwy 79	U	S1200

(1 out of 5 Selected)





OBJECTID *	Shape *	LINEARID	FULLNAME	RTTYP	MTFCC
1	Polyline	110451363998	US Hwy 65 Spr	U	S1100
2	Polyline	110451363997	US Hwy 65 Spr	U	S1100
3	Polyline	110451367025	S Camden Rd	M	S1200
4	Polyline	1105048125015	I- 530	I	S1100
5	Polyline	1106087304039	US Hwy 79	U	S1200

(1 out of 5 Selected)

Appendix C – Sample Transportation Network Data Extracted for Modeling

Water Network Arcs

FID	ID	X_Start	Y_Start	X_End	Y_End
0	2001	-94.451303	35.338564	-94.433824	35.38834
1	2002	-90.172327	35.052754	-90.177934	35.075144
2	2003	-90.083384	35.106164	-90.177934	35.075144
3	2004	-90.061974	35.181764	-90.177934	35.075144
4	2005	-89.890292	35.164161	-90.061974	35.181764
5	2006	-89.641114	35.905793	-90.061974	35.181764
6	2007	-89.557539	36.048566	-89.641114	35.905793
7	2008	-91.123721	33.824555	-91.071219	33.775936
8	2009	-91.185064	34.017784	-91.079714	33.953214
9	2010	-91.079714	33.953214	-91.071219	33.775936
10	2011	-90.583124	34.514174	-91.079714	33.953214
11	2012	-90.583224	34.521854	-90.583124	34.514174
12	2013	-90.589214	34.624644	-90.583124	34.514174
13	2014	-90.670134	34.719914	-90.589214	34.624644
14	2015	-90.969634	36.256253	-91.321934	35.639603
15	2016	-94.611379	35.309553	-94.433824	35.38834
16	2017	-93.817064	33.6123	-91.6015	31.0476
17	2018	-91.321934	35.639603	-91.185064	34.017784
18	2019	-91.321934	35.639603	-92.561631	36.37195
19	2020	-90.177934	35.075144	-90.589214	34.624644
20	2021	-93.047784	34.124744	-91.6015	31.0476
21	2022	-89.641114	35.905793	-89.619209	36.112335
22	2023	-94.433824	35.38834	-91.185064	34.017784
23	2024	-91.071219	33.775936	-91.6015	31.0476

Water Nodes

FID	ID	ORIG_FID	X_pos	Y_pos
0	2001	0	-94.45130319	35.33856368
1	2001	0	-94.4338242	35.38833967
2	2002	1	-90.17232738	35.05275356
3	2002	1	-90.17793438	35.07514356
4	2003	2	-90.0833844	35.10616355
5	2004	3	-90.0619744	35.18176353
6	2005	4	-89.89029234	35.1641609
7	2006	5	-89.64111448	35.90579337
8	2007	6	-89.55753935	36.04856585
9	2008	7	-91.12372118	33.82455484
10	2008	7	-91.0712192	33.77593585
11	2009	8	-91.18506416	34.01778381
12	2009	8	-91.07971419	33.95321382
13	2011	10	-90.5831243	34.51417368
14	2012	11	-90.58322429	34.52185368
15	2013	12	-90.58921429	34.62464366
16	2014	13	-90.67013426	34.71991365
17	2015	14	-90.96963408	36.25625336
18	2015	14	-91.32193402	35.63960349
19	2016	15	-94.61137909	35.30955322
20	2017	16	-93.81706447	33.61229999
21	2017	16	-91.6015	31.0476
22	2019	18	-92.56163064	36.3719504
23	2021	20	-93.04778364	34.12474386
24	2022	21	-89.6192095	36.11233506

Rail Nodes

FID	ID	ORIG_FID	X_pos	Y_pos
0	1001	0	-92.83946828	34.37660102
1	1001	0	-92.82774328	34.35170427
2	1002	1	-92.72716909	34.38270932
3	1002	1	-92.71935728	34.38245602
4	1003	2	-92.22162139	34.77377966
5	1003	2	-92.21208882	34.77610618
6	1004	3	-91.66550629	35.23388702
7	1004	3	-91.59591729	35.29117402
8	1005	4	-94.17503321	36.05329108
9	1005	4	-94.18178743	36.05527344
10	1006	5	-94.12484729	36.194999
11	1006	5	-94.10977629	36.188159
12	1007	6	-94.11637036	36.3425684
13	1007	6	-94.19136629	36.364132
14	1008	7	-93.04710502	34.49557878
15	1008	7	-93.05129126	34.50517102
16	1009	8	-93.01860595	34.50276754
17	1009	8	-93.021514	34.51088504
18	1010	9	-93.00485228	34.50032002
19	1011	10	-92.98505028	34.50104301
20	1012	11	-92.81324228	34.43832502
21	1012	11	-92.81070694	34.42666794
22	1013	12	-92.24655064	34.75914522
23	1013	12	-92.22639279	34.75887612
24	1014	13	-92.21557885	34.7632463
25	1015	14	-90.65342328	34.52254853
26	1015	14	-90.64484424	34.51545653
27	1016	15	-90.65322629	34.51405503
28	1017	16	-91.97749827	33.13685202
29	1017	16	-91.97735327	33.12573102
30	1018	17	-91.97163422	33.14674132

Rail Arcs

FID	ID	X_Start	Y_Start	X_End	Y_End
0	1001	-92.839468	34.376601	-92.827743	34.351704
1	1002	-92.727169	34.382709	-92.719357	34.382456
2	1003	-92.221621	34.77378	-92.212089	34.776106
3	1004	-91.665506	35.233887	-91.595917	35.291174
4	1005	-94.175033	36.053291	-94.181787	36.055273
5	1006	-94.124847	36.194999	-94.109776	36.188159
6	1007	-94.11637	36.342568	-94.191366	36.364132
7	1008	-93.047105	34.495579	-93.051291	34.505171
8	1009	-93.018606	34.502768	-93.021514	34.510885
9	1010	-93.004852	34.50032	-93.018606	34.502768
10	1011	-92.98505	34.501043	-93.004852	34.50032
11	1012	-92.813242	34.438325	-92.810707	34.426668
12	1013	-92.246551	34.759145	-92.226393	34.758876
13	1014	-92.226393	34.758876	-92.215579	34.763246
14	1015	-90.653423	34.522549	-90.644844	34.515457
15	1016	-90.644844	34.515457	-90.653226	34.514055
16	1017	-91.977498	33.136852	-91.977353	33.125731
17	1018	-91.971634	33.146741	-91.977498	33.136852
18	1019	-91.96523	33.199255	-91.971634	33.146741
19	1020	-91.961096	33.245903	-91.96523	33.199255
20	1021	-91.792126	33.627182	-91.793296	33.579356
21	1022	-91.135144	36.159041	-91.147254	36.154179
22	1023	-90.649405	35.819426	-90.668801	35.834633
23	1024	-90.509242	35.67621	-90.503154	35.672971
24	1025	-90.190843	35.203754	-90.186195	35.176808
25	1026	-90.186195	35.176808	-90.170801	35.134916
26	1027	-90.095848	35.143314	-90.190843	35.203754
27	1028	-90.073835	35.129346	-90.095848	35.143314
28	1029	-94.340096	34.029695	-94.334395	34.035947
29	1030	-92.727169	33.670565	-92.720945	33.670891
30	1031	-92.720945	33.670891	-92.72377	33.664444