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GEOG 596B - MGIS Capstone Project Final Report

Decision Support Tool for Planning Infrastructure Improvement

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Elsit Mandal

Advisor: Dr. Jan Oliver Wallgrun

Abstract

Highway bridges with vertical clearance limitations, weight restrictions or roundabouts act as barriers to oversize overweight (OSOW) truck traffic. This project involves the development of an ArcGIS Decision Support Tool Set to assist in planning the allocation of funding for transportation infrastructure improvements. The tool set developed includes scripts to analyze and visualize OSOW data and to select candidate bridges for improvement or replacement based on their spatial location in the context of OSOW traffic demand. The tools are Python scripts that use the ArcGIS network analyst extension to determine the shortest path without and with barriers. A routable network and the restricted bridges as a point feature class are required to perform the analysis along with the origin-destination (OD) pairs representing OSOW traffic demand.

Disclaimer

The contents of this report reflect the views of the author who is responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the views or the policies of KDOT or the State of Kansas. This report does not constitute a standard, specification or regulation.

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1. Introduction

Transportation costs include fuel costs, vehicle operating costs and travel time costs. Travel times are affected by posted speed limits, traffic congestion and length of chosen routes. In the case of oversize or overweight (OSOW) trucks, the presence of load posted bridges, load restricted bridges, vertical clearance limited bridges or roundabouts cause the trucks to take alternate routes to complete the traffic demand. These alternate routes may not be the best in terms of vehicle operating cost or other transportation costs. Transportation planners need to know the traffic demand and should be able to run 'what if' scenarios to determine benefit cost ratios to make decisions to improve the transportation infrastructure. The tool set developed in this project includes scripts to analyze and visualize OSOW data and to select candidate bridges for improvement or replacement based on their spatial location in the context of OSOW traffic demand. The tools are Python scripts that use the ArcGIS network analyst extension to determine shortest path without and with barriers. A routable network and the restricted bridges as a point feature class are required to perform the analysis along with the origin-destination (OD) pairs representing OSOW traffic demand.

2. Background

Kansas has the advantage of being in the heartland and thus is a hub (Figure 2.1) of freight accessibility [5]. In Kansas, trucks having more than 14 feet height or weighing more than 40 T gross vehicle weight (GVW), or length > 120 FT or width > 8 FT 6 IN are required to obtain a permit to use the highways.

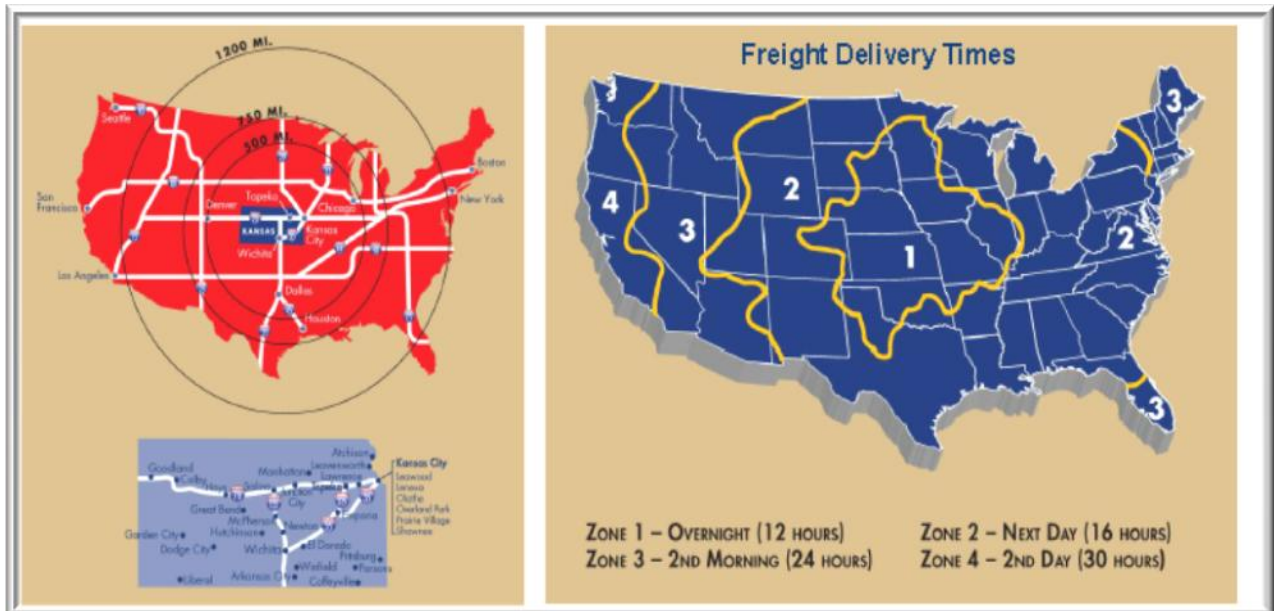


Figure 2.1. Freight Delivery Times from Kansas [5]

(Credit: Kansas Freight Advisory Committee)

KTRIPS (Kansas Truck Routing Intelligent Permitting System) [20] was implemented in 2014 to issue permits and routing for OSOW trucks on the state's highways. Improving or replacing the bridges to provide more vertical clearance is costly for the State. But trucks taking alternate routes is costly to the truck industry in terms of lost time and additional mileage travelled on alternate routes. It is costly in terms of lost revenue for the State. The primary and secondary freight corridors of significance (Figure 2.2), which are also the major highways that the OSOW traffic uses, are identified by the Kansas Freight Advisory Committee based on traffic patterns.



Figure 2.2. Freight Corridors of Significance

Along with the Interstate Routes, there are also several US Routes (U69, U81, U83 and others) identified as primary corridors. Figure 2.3 shows bridges on the highway network that are load posted, load restricted or vertical clearance limited.



Figure 2.3. Load Posted, Load Restricted or Vertical Clearance Limited Bridges

3. Literature Review

3.1 Decision Support Systems (DSS) and Tools

Any software program or programs that helps decision makers to analyze complex problems and arrive at solutions can be referred to as Decision Support System (DSS). Decision Support Systems (DSS) were in existence before GIS software technologies were developed. With the development of GIS, there has been much growth in the field of spatial decision support systems (SDSS) which incorporate location data into the decision-making process. Some examples are: Rodrigues, Simao & Antunes developed a GIS based multi-criteria Spatial Decision Support System for planning urban infrastructure [13]; Kang, Srivastava, Fulton, Owsley & Yoo developed a GIS-based poultry litter transport management system using ArcGIS and network analyst extension [14]. Higgins [16] explored the use of a state- wide analysis model from TransCAD along with TREDIS to estimate the economic impact from transportation investments. From the literature, it becomes apparent that transportation problems are complex and there are several specialized DSS specific to transportation infrastructure planning and evaluation. These systems are intended to be used by specialists who have expertise in those subject areas. However, with increased availability and capabilities of general GIS software, there is greater location awareness in organizations. Decision makers and managers demand user friendly and easy to use spatial analysis tools to gain insight, before more complex infrastructure planning studies are undertaken.

3.2 OSOW Truck Traffic Studies

Russell & Landman [22] studied Kansas State system highways to identify freight corridors that do not limit OSOW vehicles or that limit loads to varying degrees. This study was done in 2012 before KTRIPS was implemented. They recommended that additional studies are desirable to explore eliminating or managing all restrictions for OSOW loads and developing cost-benefit

ratios. Prozzi J. et al [23] conducted research on OSOW load traffic issues to prioritize research needs. Analysis of the OSOW data is very important to establish policies or to plan for infrastructure improvements.

4. Motivation

Government agencies responsible for maintaining transportation infrastructure utilize some form of GIS software to manage the roadway network and inventory data. ArcGIS is the most widely deployed GIS software in government organizations. KDOT needed a tool that can be used to analyze data from the KTRIPS system and assist in infrastructure improvement decisions. An ArcGIS tool will fit the needs because of the availability of several concurrent licenses in the organization and also due to the ease of customization with Python coding for ArcGIS. The ArcGIS Network Analyst extension has several tools that utilize routable networks to solve driving time/cost minimization problems, which could be used for analyzing barrier scenarios for a given traffic demand.

Other GIS software that provide decision support for project planning and infrastructure investments are AASHTOWare Bridge Management software (BrM) and TRANSCAD (by Caliper Corp.) [2]. BrM is a specialized software for bridge management, which has some GIS functionalities including ability to access googlemaps within the system. It does not provide routing based analytic capabilities. TransCAD is a specialized transportation planning GIS software that has routing and travel demand forecasting capabilities. TransCAD has been in use for many years. However, it is not as widely deployed as ArcGIS in organizations. Some customization using GISDK (GIS Developer's Kit) would be needed in TransCAD to solve this specific problem because automated tools do not exist. TransCAD Standard version for single user license with nationwide **HERE** data (routable network data) costs \$15,000. ArcGIS is much cheaper with Enterprise licensing.

5. Goals

The goals of this project include development of a user-friendly ArcGIS tool that supports analysis and visualization of OSOW truck traffic and prioritization of bridge infrastructure improvement scenarios. The proposed tool requires a routable network dataset, origin-destination pair features(OD pairs) and point barrier feature data sets. The point barriers in this project are restricted bridges having vertical clearance limitations, weight restrictions or roundabouts. The barrier feature data set also may contain the cost of improving the restrictions for each one of the bridges. Even though the idea for this project was originated from KDOT's need to analyze project scenarios with respect to improving restricted bridges on Kansas Highways to accommodate oversize/overweight trucks, the tool could be used on any routable network, OD pairs and point barriers.

6. User Requirements

A prototype of the tool, that creates prioritized list of bridges, was presented at an internal meeting at KDOT to solicit inputs from the anticipated users from the Bureau of Transportation Planning and Bridge Management (Bureau of Structures and Geotechnical Services) of KDOT. Five people attended the presentation, three from Transportation Planning, and one from Bureau of structures. The attendees provided inputs and suggestions. It became clear that the users also needed some tools to analyze the available KTRIPS data to gain insight into the OSOW traffic demand and patterns. The Statewide planning unit in the Bureau of Transportation Planning is responsible for conducting analysis for infrastructure investment studies with input from other Bureaus and stakeholders.

7. Analysis & Classification of OSOW Data

Each year about 75,000 OSOW truck permits are issued from KTRIPS. Data from KTRIPS is available as route geometry and truck/load size (Length, Width and Height) and weight characteristics. Table 7.1 shows the summary of OSOW data from KTRIPS for 2014 and 2015. The weights are classified into three groups 40-60 T, 60-75 T and > 75 T. OSOW loads are not allowed on load posted bridges. The restricted bridges do not allow OSOW loads that are greater than 60 T. Weights > 75 T are called superloads.

Tonnage	Truck height OR Load Height	Total of Year 2014 & 2015 counts	Percent Count	*Barrier Bridges
< 60 T	<=14 FT	83,371	56.3	P
< 60 T	> 14 FT AND <=18 FT	23,564	15.9	P/V
< 60 T	> 18 FT	402	0.3	P/V
60 T-75 T	<=14 FT	13,150	8.9	P/R
60 T-75 T	> 14 FT AND <=18 FT	11,591	7.8	P/R/V
60 T-75 T	> 18 FT	36	0.0	P/R/V
> 75 T	<=14 FT	3,681	2.5	P/R
> 75 T	> 14 FT AND <=18 FT	11,923	8.1	P/R/V
> 75 T	> 18 FT	353	0.2	P/R/V
TOTAL		148,071		
	*P	Posted		
	*P/R	Posted OR Restricted		
	*P/R/V	Posted OR Restricted OR Limited Vertical Clearance		

Table 7.1. Summary Classification of KTRIPS Data for 2 Years

Figure 7.1. shows the OD pairs that are derived from KTRIPS route geometry data for one month.

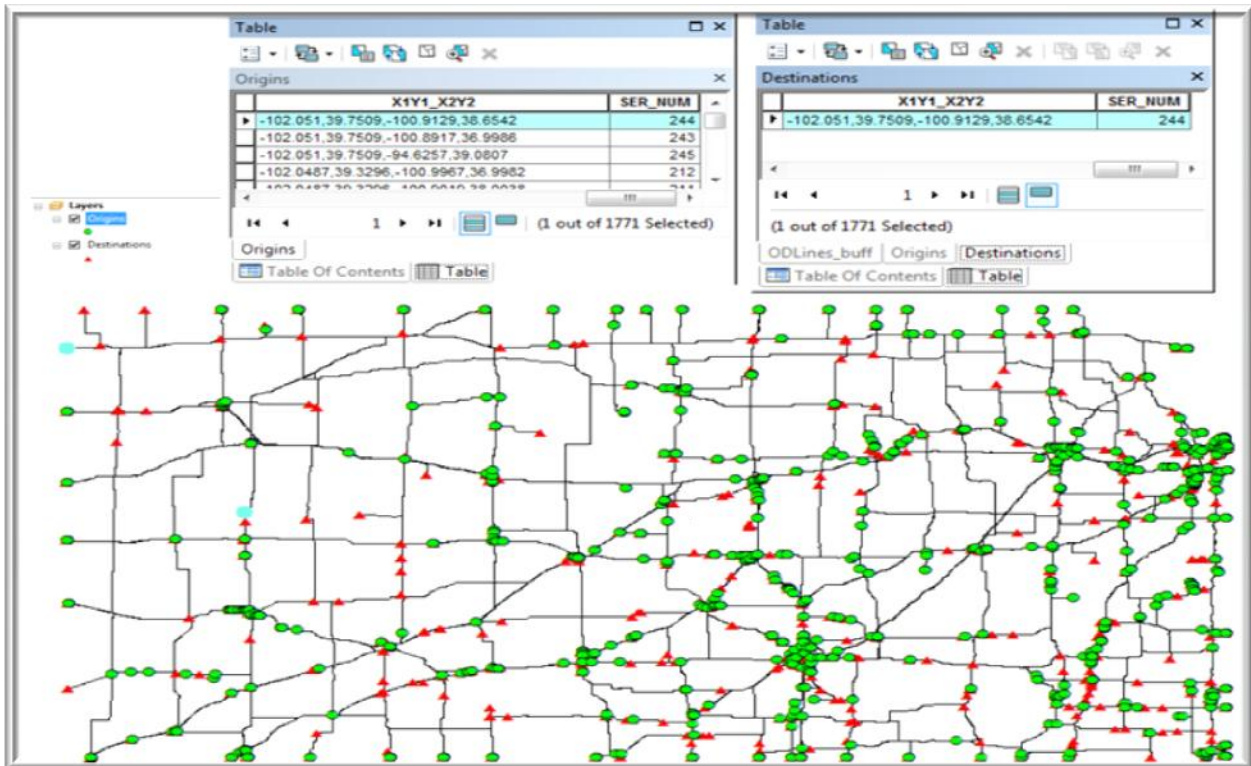


Figure 7.1. Analysis of OSOW Data: Origin and Destination (OD) Pairs

This dataset needed to be further grouped based on origin-destination (OD) pair locations and frequency of occurrence for further insight. The computation time was of major concern as it took on an average 6 sec. to solve an OD pair when all street segments were used in routing, and took 3 sec. when only state highway segments were used. Also, it was expected that many of the OD pairs would be duplicates although the frequency of occurrence will reduce when we consider the truck load characteristics such as weight and size.

To reduce the number of OD pairs to be analyzed, the OD pairs were consolidated by taking 2 decimal approximations of the latitude and longitude [25]. Also, OD pairs having frequency > 4 were taken for analysis. With this grouping strategy, the number of OD pairs analyzed is 3914 which accounts for 60% of all OSOW traffic as shown in Table 7.2.

Grouping Categories		
40-60T, 60-75T, > 75 T	Weight Class	Load Class Definitions/Bridge Restrictions
<85 FT, > 85 FT	Length Class	Roundabout Restrictions
HEIGHT	N/A	Vertical Clearance Restrictions

2 Year Frequency	Number of OD Pairs, 2 DECIMAL APPROX. LAT, LONG	Total	Percent of Total
> 4	3914	88910	60%
4	1302	5208	4%
3	2405	7215	5%
2	6780	13560	9%
1	33178	33178	22%
		148071	

Table 7.2. Summary Classification Used for Analysis

8. Methodology & Approach

8.1 Methodology

The development of the tool using the network analyst extension requires a network dataset and OD pairs representing traffic demand. ESRI StreetMaps (routable network data) [21] is used as the network dataset. The network dataset properties are shown in Fig. 8.1.1. DrivingTime and Length are assigned as cost parameters. Length is assigned as impedance attribute and DrivingTime is assigned as accumulate_attribute in Network Analyst's 'RouteSolver' properties.

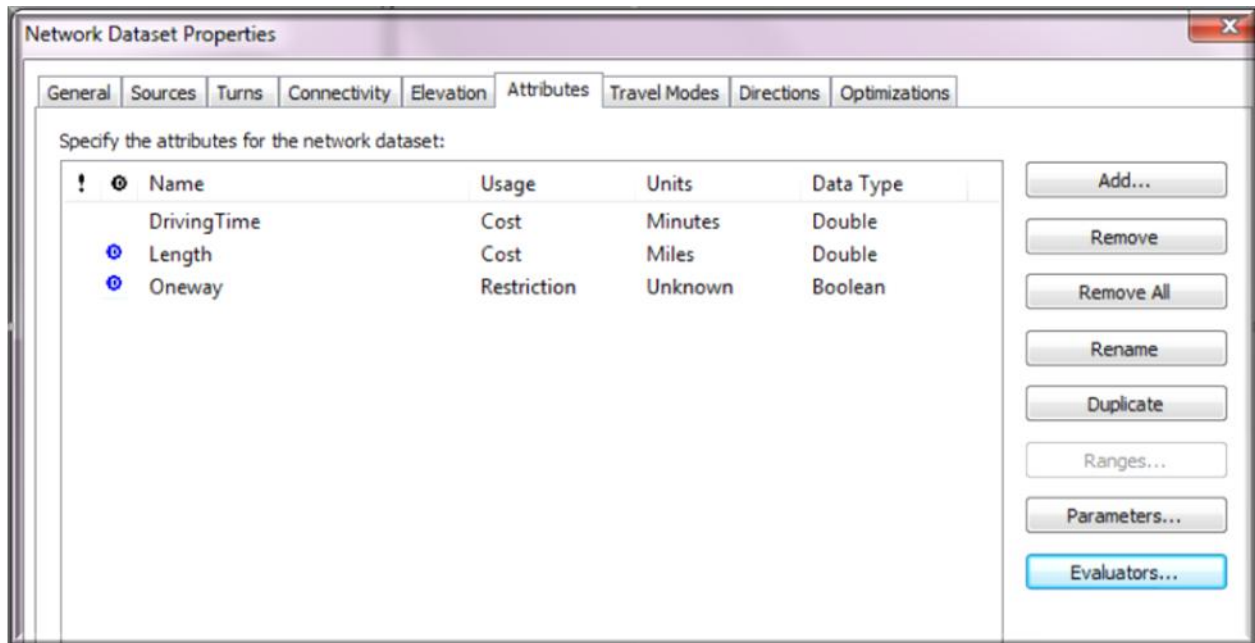


Figure 8.1.1. Network Dataset Properties

KTRIPS freight data consists of the spatial geometry of the route traversed by the permitted trucks, truck size, permit type and other attributes. Figure 8.1.2 shows a sample of such route shape attributes that shows the unique ID for the permit data (PRMT_ID_LE) and truck /load dimensions. Bridges that do not have enough vertical clearance or weight restrictions were considered point barriers in the route Length or DrivingTime calculation process. The bridge attributes including vertical clearances and spatial location on the roadway network are available from the AASHTOWare BrM (formerly PONTIS) database.

	SourceFile	PRMT_ID_LE	Tonnage	WidthFt	HeightFt	LengthFt
▶	KTRIPSRoutes_01_2014.shp	19772_1	119	11.92	14	124
	KTRIPSRoutes_01_2014.shp	19831_1	105	11.5	15.5	107
	KTRIPSRoutes_01_2014.shp	19995_1	77	12.5	14	89.92
	KTRIPSRoutes_01_2014.shp	20011_1	109	11.92	14	114
	KTRIPSRoutes_01_2014.shp	20102_1	63	12	13.5	137
	KTRIPSRoutes_01_2014.shp	20106_1	120	10.42	13.92	129.75
	KTRIPSRoutes_01_2014.shp	20215_1	98	13	15.5	103.67
	KTRIPSRoutes_01_2014.shp	20347_1	81	10.17	13.17	72.17
	KTRIPSRoutes_01_2014.shp	20374_1	120	15	15.67	174
	KTRIPSRoutes_01_2014.shp	20375_1	124	15	15.67	180

Figure 8.1.2. KTRIPS Route Shapes Attribute Table

From the KTRIPS routes, those with travel length > 20 miles are taken for deriving OD pairs and only those with frequency of occurrence > 4 in the 2 year data set were considered for analysis. This strategy to reduce the number of OD pairs for analysis was necessary because of the computation time issues.

The methodology used and the steps performed by the developed tools are listed below.

1. Create Input data for the Tools:
 - a. Create network dataset (using ArcMap or ArcCatalog) with ESRI StreetMap data,
 - b. Create the Origin-Destination (OD) Pairs point feature class with the truck weight, height and width from KTRIPS data. These are obtained from the start and end points of the permitted truck routes. The creation of OD Pairs is done by the developed tool as described in section 9.1. The OD pairs also have an attribute **FREQ** representing the frequency of occurrence. A field called 'SER_NUM' was assigned to the OD pairs to uniquely identify them (Fig.8.1.3)

Origins_Grouped						
SER_NUM *	HeightFt	XY_XY_2	FREQ	Tonnage_class	Length_class	
1	14	-94.61,38.94,-102.05,39.33	1966	LESS_OREQ_60	NO_RNDABT_RESTR	
2	14	-97.34,37,-97.61,40	1718	LESS_OREQ_60	NO_RNDABT_RESTR	
3	14	-100.89,37,-100.57,40	1252	LESS_OREQ_60	NO_RNDABT_RESTR	
4	14	-94.61,38.94,-97.34,37	1080	LESS_OREQ_60	NO_RNDABT_RESTR	
5	14	-102.05,39.33,-94.61,38.94	1040	LESS_OREQ_60	NO_RNDABT_RESTR	
6	14	-97.61,40,-97.34,37	1007	LESS_OREQ_60	NO_RNDABT_RESTR	
7	14	-94.61,38.94,-101,37	982	LESS_OREQ_60	NO_RNDABT_RESTR	
8	14	-100.57,40,-100.89,37	867	LESS_OREQ_60	NO_RNDABT_RESTR	
9	14	-97.34,37,-102.05,39.33	749	LESS_OREQ_60	NO_RNDABT_RESTR	
10	14	-97.61,40,-97.4,37	730	LESS_OREQ_60	NO_RNDABT_RESTR	

Figure 8.1.3. Origins and Destinations Grouped Based on Location and Load Dimensions

c. Create a Bridges point feature class having vertical clearance or weight restriction attributes data (Fig. 8.1.4)

BRIDGE_POTENTIAL_BARRIERS						
Shape *	CLEARANCE	Counter	ExtraMiles	Posted	GroupNum	Ti
Point	14.22	0	0	N	0	
Point	14.17	0	0	N	0	
Point	14.19	0	0	N	0	
Point	14.9	0	0	N	0	
Point	14.98	0	0	N	0	
Point	14.75	0	0	N	0	
Point	15	0	0	N	0	
Point	14.83	0	0	N	0	
Point	15	0	0	N	0	
Point	14.58	0	0	N	0	

Figure 8.1.4. Bridge Attributes for Point Barriers

- Determine the shortest path geometry for all the OD Pairs using network analyst's Route Solver. Travel length from the RouteSolver is used as cost in the analysis. This is done by the tools as described in section 9.2.
- The travel lengths are calculated when there are no barriers and also when all barriers are applied. The tools dynamically determine which of the bridges act as barriers for each of the OD pairs by comparing the truck size (from attributes available in the Origins

feature class) to the bridge attributes. The bridge feature class also assigned additional attributes named **ExtraMiles** and **Counter**. **ExtraMiles** is for keeping the accumulated extra miles travelled due to presence of barriers (Fig.8.1.4). **Counter** is for tracking the number of OD pairs whose shortest path geometries intersected with the bridge when the bridge acted as a barrier for the OD pair. For example, if an OD pair's shortest path length is 320 miles and the best route with barriers is 350 miles then the additional miles travelled (**FREQ***30 miles) is assigned (in the **ExtraMiles** field) to each one of the barrier bridges spatially intersecting with the shortest path geometry. The **FREQ** value is assigned in the **Counter** field.

When all OD pairs are analyzed, the bridges having the most accumulated **ExtraMiles** are considered as candidates for improvement. The order of this initial priority index may change depending on the order in which the barriers are removed (such as improving vertical clearance or replacing a bridge). due to the fact that the extra miles travelled may change after one or more barriers are removed.,

4. After the initial priority list is established from step 3, travel length is determined by removing each barrier or barrier groups one at a time. (Bridges between network junctions will be grouped. Bridges on the first level of interconnected segments also may be grouped). Calculate the total saved miles at each instance of barrier removal. The best scenario will be the one with most saved miles.
5. Assign a priority index based on results of step 4.

8.2.Approach

The approach taken in this project is to utilize a network dataset and ArcGIS network analyst module to create a tool that would give a list of most beneficial locations to make investment for

improving infrastructure. The network dataset was created using ESRI StreetMaps North America Dataset. The network dataset is a roadway network segmented at intersecting roadways. These segments are called edges and the intersection points are called junctions. The routable network is created from the roadway features that has the following attributes: Segment length, one-way indicator (will indicate whether the segment is one-way or two-way and the direction of travel), F_Elev (holds begin vertex point elevation level:0 for ground level, 1 for next level), T_Elev (holds ending vertex point elevation level), Speed and hierarchy (hierarchy indicators: primary-1, secondary-2, local-3 etc.; for example, Interstate routes will be assigned primary). The segment length and speed are used to calculate the driving time on each segment. Turning delays are not included because specific data are not available. Global turn delays are applied while creating the network dataset. The main highways were selected using the attribute query SHIELD_CL in(1,2,3) OR ROAD_CL=3 OR ROADCLASS in (1,2,3). This query selected 106,595 segments (out of 699,196 segments within Kansas State Boundary) including many off-state system segments. The selected segments were exported to a file geodatabase and then off-State system segments were removed as much as possible manually. After creating the network dataset, 'Dissolve' is applied to further reduce the number of network edges and junctions

9. The Developed Python Script Tools

There are four tools in the developed Python toolbox as shown in Figure 9.1, for use in the decision making process for infrastructure improvement to support OSOW traffic.

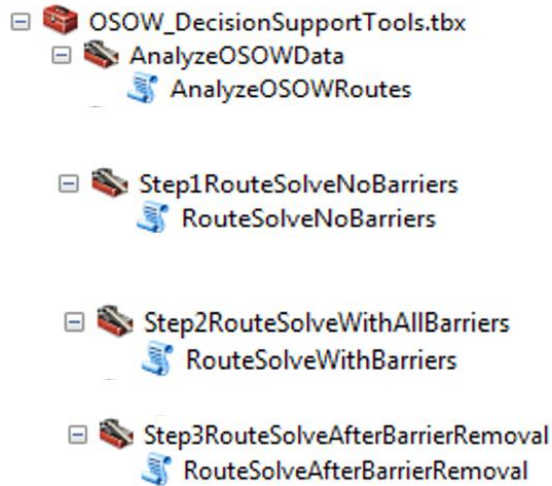


Figure 9.1 Python Script Tool Set

9.1 The OSOW Data Analysis Tool

The **AnalyzeOSOWData** tool takes the KTRIPS route shapes as input and creates the OD pairs and OD Lines frequency. It also takes the state boundary polygon as input and classifies OD Lines into Interstate, Inbound, Outbound or Intrastate traffic. The traffic classification is based on a buffered state boundary polygon with a buffer distance of 0.5 miles inward, to determine if the origin or destination point is within the buffered polygon.

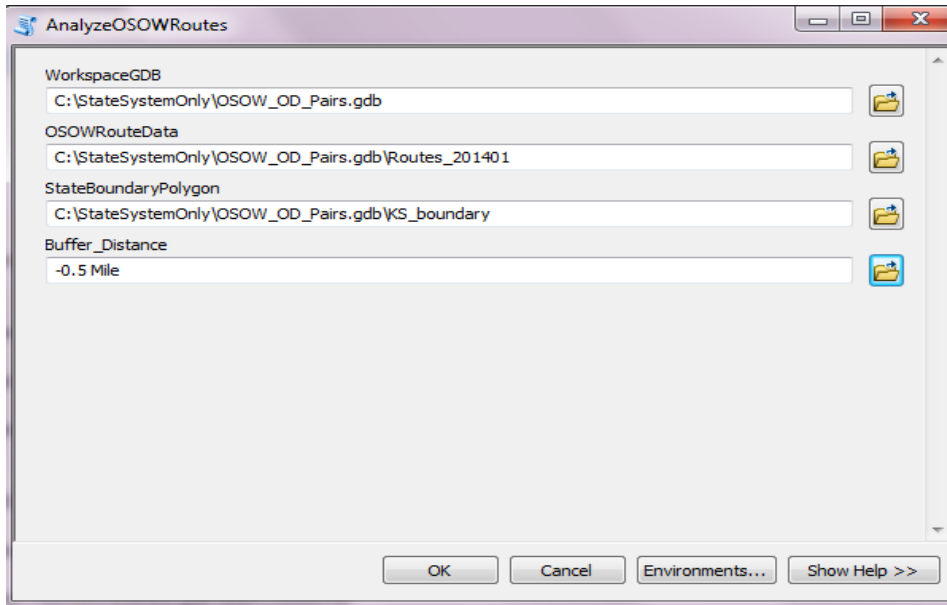


Figure 9.1.1 Tool Interface - Analyze OSOW Routes

Fig.9.1.1 shows the user interface and Fig.9.1.2 shows OD Lines frequency of Inbound OSOW traffic computed by the tool for the KTRIPS 2014 and 2015 data.

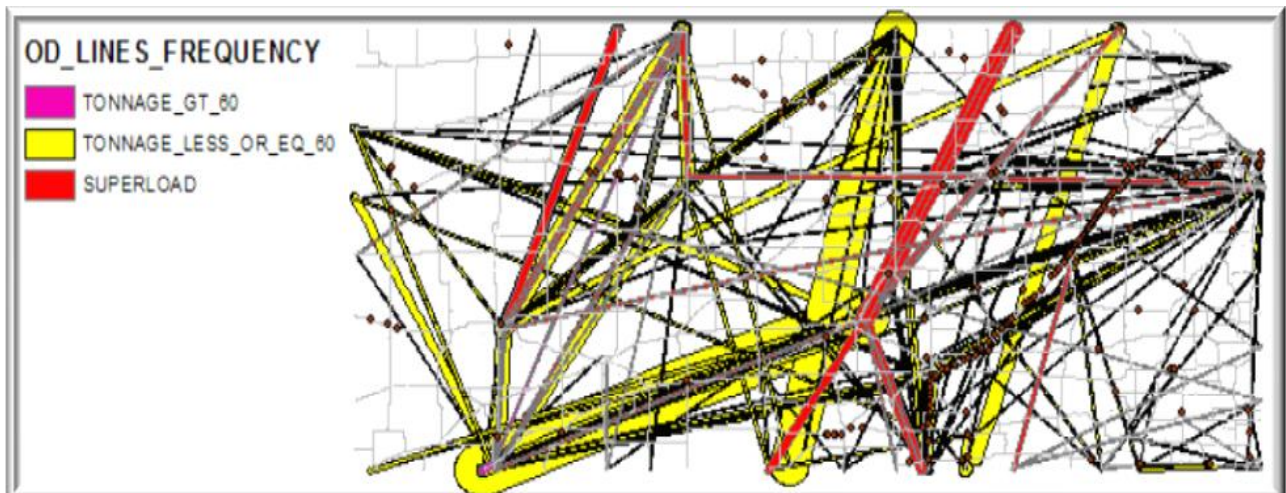


Figure 9.1.2 Frequency Analysis Output - OD Lines Frequency Polygon

9.2 Tool Set for Prioritization of Bridges

The prioritization is done in a 3-step process. In the first step, the shortest path geometry and length of the route for all the OD pairs are determined by the '**Step1RouteSolveNoBarriers**' tool. This tool takes NetworkDataSet, Origins and Destinations point feature classes, as input parameters and outputs the shortest path route feature class.

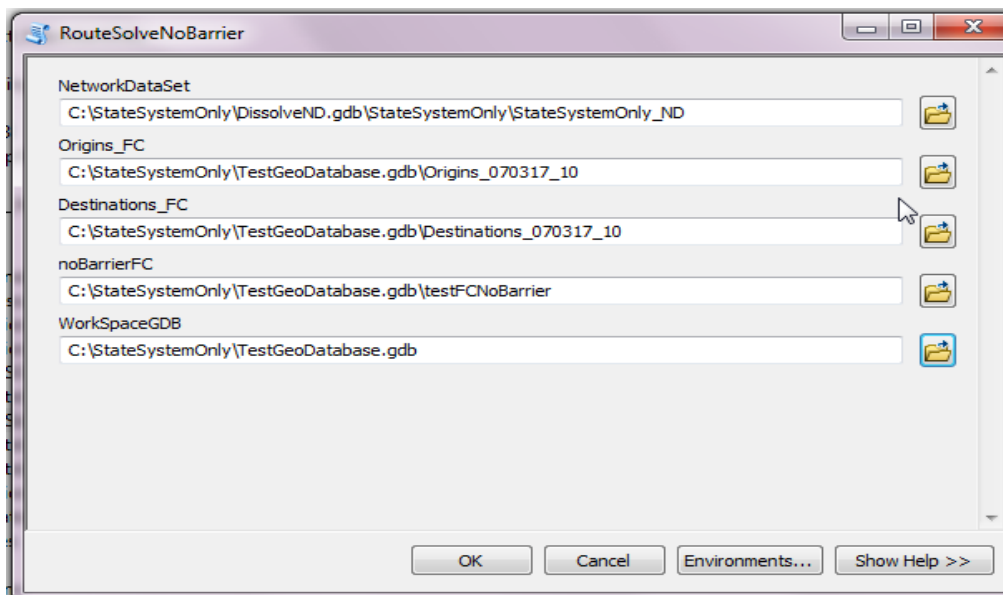


Figure 9.2.1 Tool Interface-Step 1 Route Solve with No barriers

In the second step, **Step2RouteSolveWithAllBarriers** performs a shortest route analysis with all barriers. NetworkDataSet, Origins, Destinations and barrier bridges point feature classes, Shortest Path Route from Step1 are input parameters and Best Route feature class is output parameter. The tool updates the **ExtraMiles** and **Counter** fields of barrier bridges. The results from this tool are the best route geometries for all OD pairs that had at least one barrier and the bridges get updated with the accumulated values of 'ExtraMiles' and 'Counter' fields. Top priority bridges are those with largest values of accumulated ExtraMiles.

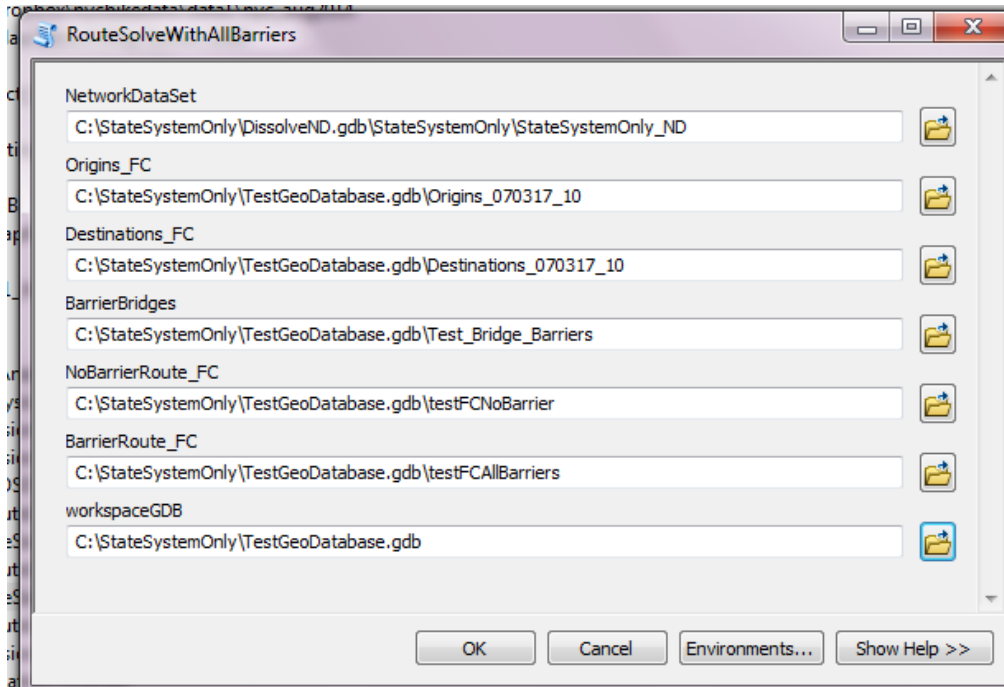


Figure 9.2.2 Tool Interface-Step 2 Route Solve with All barriers

In the third step, the user manually removes barrier bridges from top of the list in the barrier feature class and updates it. (Note the discussion on removal of barriers in section 9.3). With this new barrier feature class, **Step3RouteSolveAfterBarrierRemoval** is run. NetworkDataSet, Origins, Destinations and barrier bridges after removing priority barriers, Shortest Path Route from Step1 are input parameters and Best Route feature class is output parameter. This tool is very similar to the step2 tool, except for some custom output and calculation of saved miles due to removal of barriers.

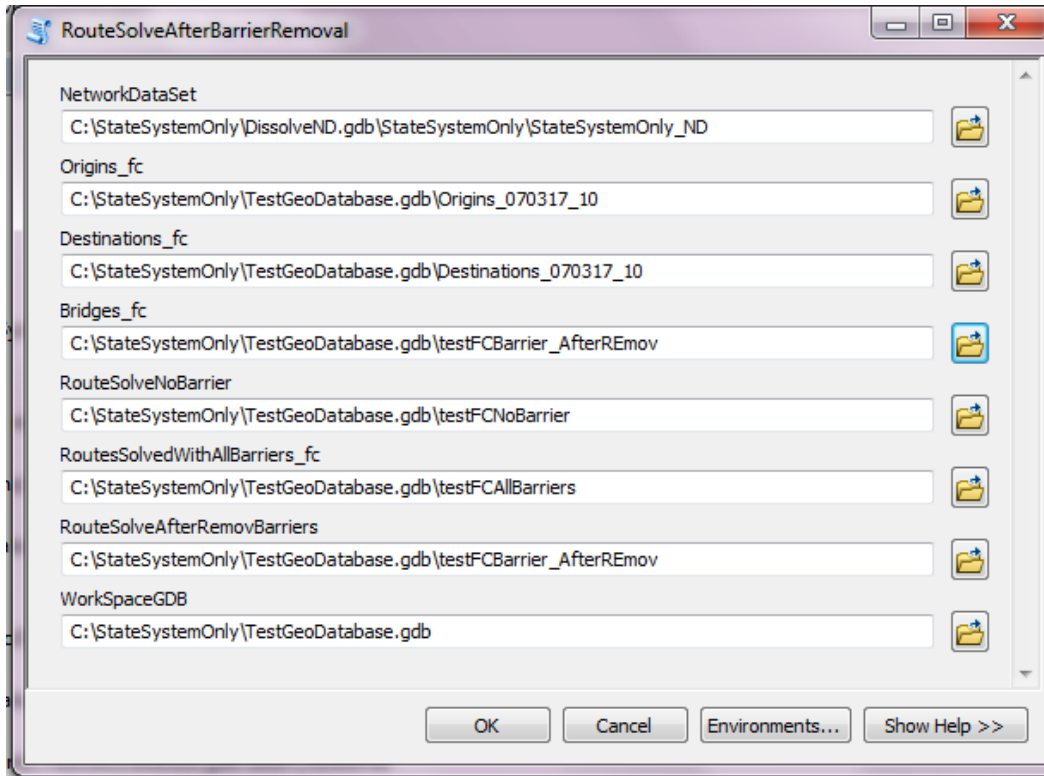


Figure 9.2.3 Tool Interface-Step 3 Route Solve After Priority Barriers Removal

9.3. Barrier Grouping in Removal of Barriers

The users of the tools have to determine the sequence of barrier removals based on the initial priority list produced by the tools. If there are restricted bridges (barriers) between interchanges, then they should be grouped, because the traffic can flow through the segment between the interchanges only when all the barriers are removed. This means that when various barrier removal scenarios are analyzed, these grouped barriers may be removed together for finding the reduction/savings in extra miles travelled. For example, the barriers B1, B2 and B3 in Figure 9.3.1 should be treated as one group. Other possible grouping scenarios may also be considered such as grouping bridges on major freight corridor segments or by considering segments of roadways by route hierarchy (primary, secondary or local). The testing of the grouping strategies has not been done in this project.

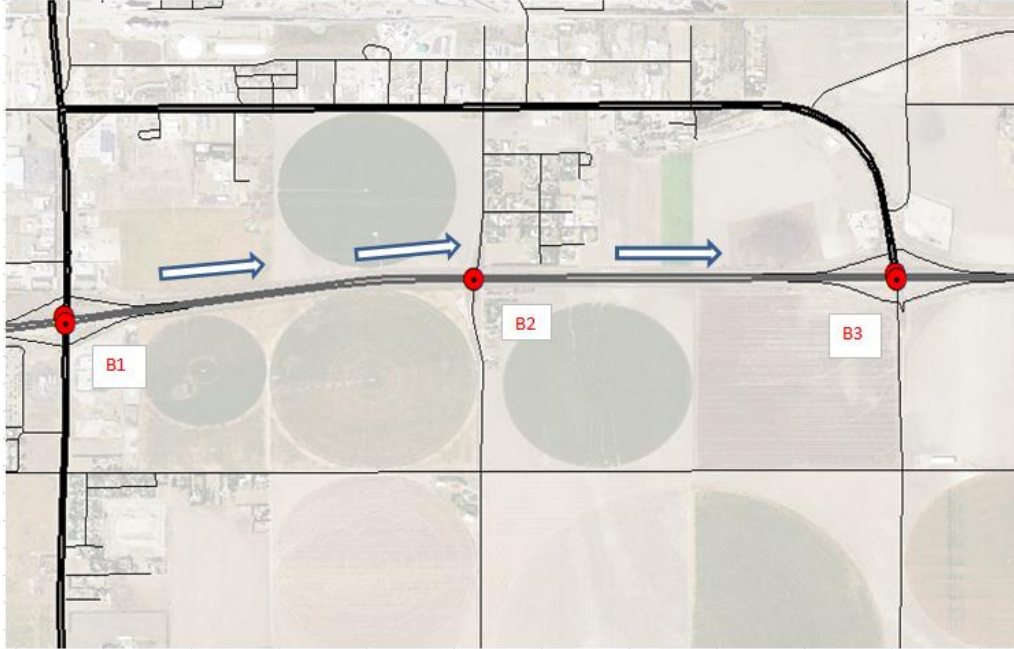


Figure 9.3.1. Barrier Grouping between Interchanges

10. Tool Test Runs & Discussion of Results

Testing of tools was done initially with a set of 10 sample OD pairs and all barrier bridges. The Step1 and Step2 tools were run and the attribute values (*ExtraMiles* and *Counter* fields) of the barrier bridges were reviewed. It was determined that the tools worked as expected in assigning the values. After that, one of the barriers from top of the list was removed and the Step3 tool was run. The results were as expected.

The tools were then run on a large Origin-Destination dataset derived by the Tool from KTRIPS 2014 and 2015 OSOW data. There were 3894 OD pairs. 263 barrier points, were applied, which is a subset of all barrier bridges on the state highway system, in the test. 3749 shortest path routes were solved for the no-barriers case. About 3.7% of all OD pairs did not solve. Possible reasons are that the network dataset may be missing some segments or the search tolerance of

30 meters did not locate them to the street segments. 904 routes (25%) were solved with all barriers. which means that 25% of all OD pairs had at least one barrier on its shortest path.

Shape *	CLEARANCE	Counter	ExtraMiles	Posted	GroupNum
Point	999	6140	48998	P	0
Point	999	1493	30422	R	0
Point	999	1575	14478	R	0
Point	14.57	799	11836	N	0
Point	14.57	799	11836	N	0
Point	14.93	784	11651	N	0
Point	14.93	784	11651	N	0
Point	999	400	11068	P	0
Point	14.25	393	9524	N	0
Point	14.25	393	9524	N	0
Point	999	447	8857	P	0
Point	14.17	400	7933	N	0
Point	14.25	367	7363	N	0

Figure 10.1a. Priorized List of Barriers from Step2 of the Process

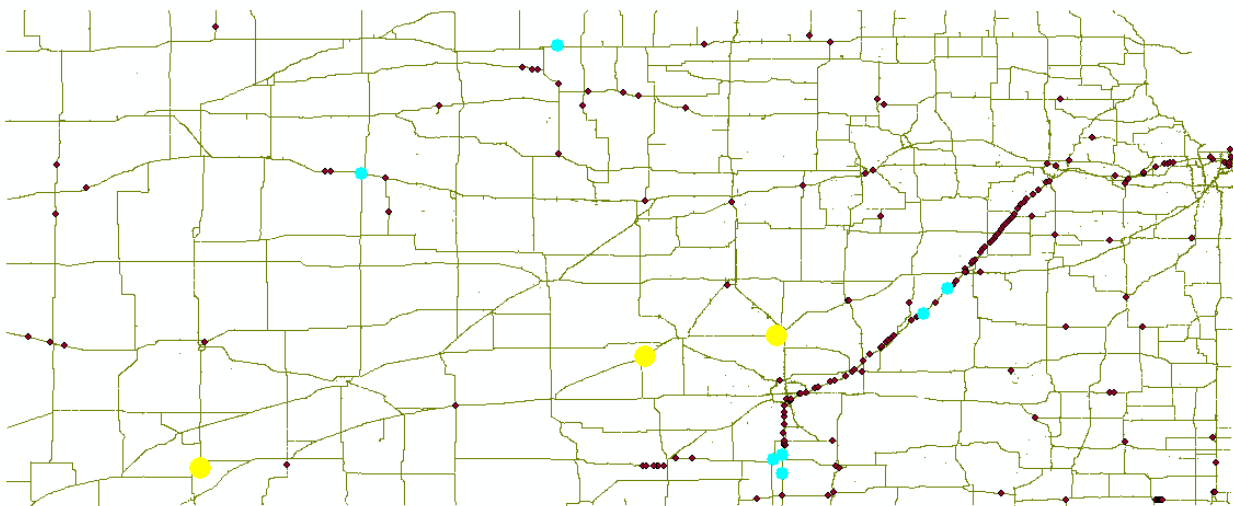


Figure 10.1b. Location of Barriers from Step2 of the Process

After solving with all barriers, 3 of the barriers from the top of the priority list (Figure 10.1 a & b) were removed and the 3rd step of the process was run. 644 routes (17%) were solved. This step runs only on OD pairs that had barriers in the 2nd step. This means that 8% of routes did

not have any barriers after the 3 barriers were removed, or in other words, these 3 barriers were the only barriers on 8% of the routes on their shortest path. In this step, the priority list is updated. It is observed that some of priority orders have been changed for the remaining barriers due to the removal of the 3 barriers in step2. This is expected because the *ExtraMiles* travelled would have changed for some of the OD pairs due to the removal of barriers. Fig 10.2 a and Fig. 10.2 b show the list of bridges and the locations of the priority bridges from the step3 process.

OBJECTID	Shape *	CLEARANCE	Counter	ExtraMiles	Posted	G
214	Point	999	400	11072.954239	P	
40	Point	14.25	393	9424.50044	N	
65	Point	14.25	393	9424.50044	N	

Figure 10.2 a. Priorized List of Barriers from Step2 of the Process

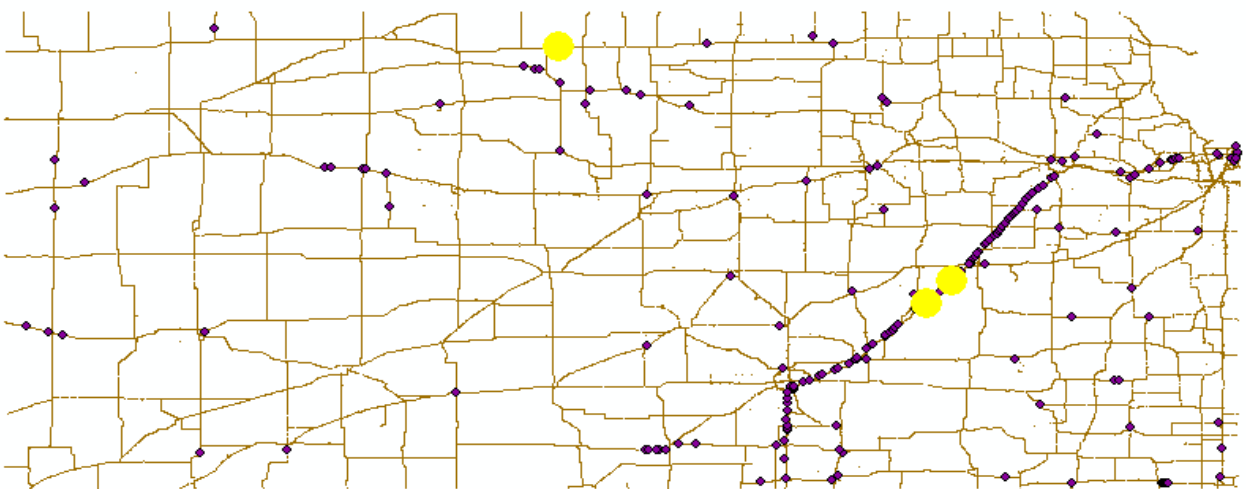


Figure 10.2 b. Location of Barriers from Step2 of the Process

11. Conclusions & Outlook

11.1 Conclusions

For completing this project, it was required that a routable network dataset and point barrier feature class are available for analysis tool development and testing. KDOT currently does not have a routable network. Bridges are kept in a Bridge management database (BrM). Therefore, development and testing of the tools was done by extracting state highway system segments from the ESRI Streetmap dataset. Using lat, long values of bridges in the BrM, a point feature class was created and snapped to the network dataset and barrier points assigned on divided highways. Posted bridges, load restricted bridges, roundabouts and vertical clearance ≤ 15 ft bridges were included in the barrier feature class. KTRIPS data from 2014 and 2015 were used by the tool to derive OD pairs.

From running the tools with the above data sets, it is concluded that the tools provide insight for planning purposes by providing spatial data analysis/visualization capabilities for the OSOW truck traffic data from KTRIPS. It creates an initial list of prioritized bridges for consideration in creating a final list of improvement projects. The set of tools makes it possible to validate or evaluate the initial priority list by analyzing different barrier removal scenarios. The tools are provided for download on [GitHub](https://github.com/ekmandal/CapstoneProjectTools) at URL:<https://github.com/ekmandal/CapstoneProjectTools>

This project was exploratory in nature because of the complexity of the problem. It would have been greatly useful to establish some test cases to check the scripts. Also, some version control measures would have been helpful. The routable network still needs more review to make sure that there are no missing street segments. The barrier bridges also need to be verified that they are snapped to appropriate street segments.

11.2 Further Work

Further work is necessary to fully analyze and interpret the results produced by the Prioritization Tool for the effects of the applied methodology. It is desirable to run the tool on different datasets for further evaluation of results. Even though significant patterns may not be observed for these loads, monthly/seasonal patterns can be easily analyzed because of the availability of the tools developed in this project. Computation time has been a major issue for analysis, so it would be helpful to further explore ways to reduce computation time.

There are many other investigations possibly be conducted as future work

1. Investigate the effects of grouping bridges in barrier removal scenarios.
2. Explore different methods of applying cost of barrier such as dividing the additional miles travelled by the total number of barriers when assigning **ExtraMiles** and see how that affects the priority list.
3. Using ton-miles Instead of miles in assigning **ExtraMiles** to account for the effect of over-weight trucks for the additional miles travelled.
4. Generate cost-benefit ratios for various barrier removal scenarios using the cost of bridge replacement from FHWA's National Bridge Inventory (NBI) System Tables [18] for replacing bridges or using costs of improving vertical clearances as completed by the Kansas Turnpike Authority (KTA) [24] would be desirable.
5. Explore consolidating origin and destination points based on hot spot analysis

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