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Building a Sustainable GIS Framework for Supporting a Tribal Transportation Problem

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BUILDING A SUSTAINABLE GIS FRAMEWORK FOR SUPPORTING A TRIBAL TRANSPORTATION PROBLEM

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ABSTRACT

Due to the recent oil boom, the Fort Berthold Reservation has experienced a dramatic increase in highway and local traffic. To support energy transportation and provide safe roads, the reservation needs cost-efficient and effective transportation planning for present and future needs. A quality road network for the reservation is crucial for transportation operations and management. This study will demonstrate how to integrate multiple road networks to provide comprehensive digital roads using public sources and provide guides to perform a quality control (QC) assessment before delivering data and using these data for geospatial analysis. This paper will also provide the fundamental concepts for quality assurance (QA) and QC. Thus, tribal geographic information system (GIS) professionals working with other reservations will gain second-hand experience configuring quality checks and processes for automation and running the automated data checks. With the integrated road networks, the tribal transportation agency can develop bike line management, conduct ambulance service coverage analysis, develop a program of asset management, and plan road maintenance and rehabilitation. The authors recommend that the agency develop a linear referencing system (LRS) on the proposed road network to adopt efficient asset management and version control.

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1. INTRODUCTION

Fort Berthold Reservation is located in the heart of North Dakota's oil development region. The reservation is home to the three affiliated tribes, the Mandan, Hidatsa, and Arikara, also referred to as the MHA Nation (Mandan, Hidatsa, and Arikara Nation, 2014). The Missouri River, including Lake Sakagawea, flows through the middle of the reservation (Figure 1). Because of the recent oil boom, the region has experienced dramatic increases in highway and local roadway traffic. To support energy transportation and safe travel, the MHA Nation needs cost-efficient and effective transportation planning for current and future needs. A quality road network for the MHA Nation is crucial for transportation management. The nation uses the TIGER® Network for tribal transportation network modeling. The TIGER® network has comprehensive links, and all segments are connected. However, that does not mean the network is appropriate to use for transportation planning and traffic routing. The TIGER® network does not provide road classification and surface type with details such as pavement type, travel speed, and the number of lanes, which are crucial for transportation planning. North Dakota statewide road networks are not fully connected, resulting in difficulty in generating routes.

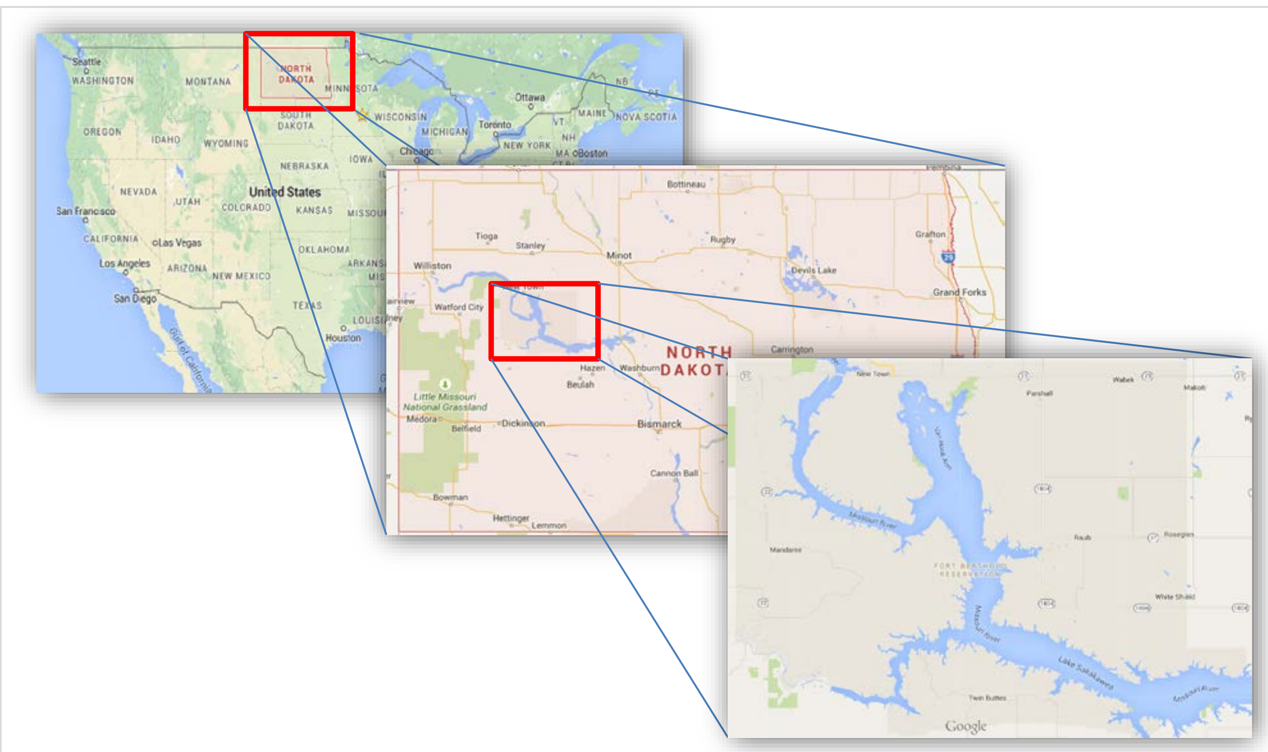


Figure 1.1 Geographic location of Fort Berthold Indian Reservation (MHA nation)

he objectives of this study are to: (1) integrate road networks to provide comprehensive road network using multiple public sources, and (2) provide guides to perform a quality control (QC) assessment before delivering data and using these data for geospatial analysis. This paper will also provide the fundamental concepts for quality assurance (QA) and QC. Thus, tribal GIS professionals working with other reservations will gain second-hand experience configuring quality checks and processes for automation and running the automated data checks.

2. LITERATURE REVIEW

Peng (2005) stated that having different data sources requires data conversion and/or integration. The conversion process needs sophisticated design to avoid mistakes. A conflation cannot be automatically conducted without planning and quality operations. Thus, transportation planners and tribal agencies seek a reliable and best possible standard framework. The conflation processes will be classified by matching criteria and categorization problems. The conflation is categorized into vertical, horizontal, and temporal processes (Ruiz, et al., 2011). This research focuses on geometric and topological conflations for one dimensional road networks.

Tribal roads in South Dakota and North Dakota are evaluated for crash analysis (Qin, et al., 2013). The research found that the attributes of federal ownership representing BIA and tribal roads were separate from rural local roads maintained by South Dakota. They also found that tribal roads in North Dakota are not alienated from state local roads. A safety toolkit proposed a network screening process from a safety perspective (Federal Highway Administration, 2014). The network screening for the toolkit includes all collected roads and intersections.

Choi et al. (Choi, et al., 2014) demonstrated the process of merging two different public road networks with Tiger road networks and North Dakota road networks. However, the study failed to provide a systematic framework for the validation and reviewing process. Douglas Benson (Benson, 2010) provided and tested Indian Reservation Roads (IRR) data in highway performance monitoring systems (HPMS) for use in national highway planning studies such as high economics requirement systems for states (HERS-ST) (Federal Highway Administration, 1991). The Upper Great Plains Transportation Institute included tribal roads for a statewide transportation planning model (Upper Great Plains Transportation Institute, 2014; Upper Great Plains Transportation Institute, 2016)

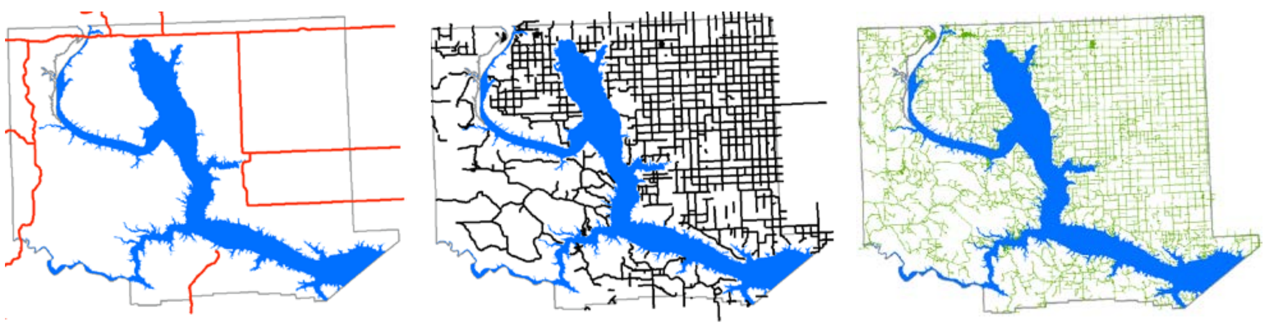
The Wisconsin Department of Transportation also showed a way of integrating multiple sources of state routes and local roads. The two road networks merged were maintained by linear referencing systems (LRS), including link identification and office for state roads and node identification for local roads (Graettinger, et al., 2009). Hallmark et al. (Hallmark, et al., 2003) addressed several issues related to a process of integration of spatial point features with LRS. The issues include offset errors and wrong segment match and pointing locations.

3. METHODOLOGY

3.1 Data Sources and Description

3.1.1 Data Sources

This study uses public sources available through the North Dakota Department of Transportation (NDDOT), U.S. Census Bureau, and MHA Nation[1]. The transportation networks of state and federal highways are available from NDGIS Hub (Figure 3.1a). Local roads, including county, township, and city roads, are obtained from NDGIS Hub (Figure 3.1b). These data sets were created and provided by NDDOT and distributed through the state GIS portal. The authors received a data set of street networks from MHA, which originates from the U.S. Census Bureau's TIGER® network (Figure 3.1c). The links in Figure 3 are extracted from the original sources using tribal land boundary lines. Some roads segments are shown outside of the boundary because all segments that intersect with tribal land were selected. Without clipping the segments using the land polygon, this study includes the origin segments for analysis.



a) State & Federal (SF) Lines b) Local Lines c) TIGER® lines

Figure 3.1 Sources and shapes of the lines

Table 3.1 provides a description of the link files. State and federal (SF) lines and local lines provide 16 and 1,619 segments, respectively, resulting in 1,635 segments throughout the region (Table 3.1). The average length of NDDOT's local lines is 1,619 meters. The TIGER network provides 11,852 segments, and average length of the network is 379 meters. A comparison of the networks indicates that the TIGER network has more links and is denser than the others. The advantages of using the SF Lines are as follows:

- It is compatible with RIMS (road inventory management systems).
- It is used as a base map for LRSs.
- Federal funds are allocated based on the SF lines within the tribal land.

The SF lines are not appropriately aligned with the local roads and show longer segments with an average length of 22,107 meters (Table 3.1). NDDOT's local lines provide ample information including surface type, direction, and through traffic, which are helpful for local and township road maintenance. The SF lines and local lines would be linked to traffic counters across the state.

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[1] Three affiliated tribes of Madan, Hidatsa, and Arikara

Table 3.1 Description of the roads

	NDDOT			US Census Bureau/MHA
	State & Federal (SF) Lines	Local Lines	Total	TIGER[a]
Counts	16	1,619	1,635	11,852
Minimum (meter)	1,512.59	1.17	1.17	0.66
Maximum (meter)	47,956.26	33,735.62	47,956.26	7,574.61
Sum (meter)	353,721.19	2,239,084.88	2592,806.07	4,501,179.99
Mean (meter)	22,107.57	1,383.00	1,585.81	379.78
Standard Deviation (meter)	13,760.80	1,965.00	3,137.60	459.96
# of Attributes	16	22	37 (37-1)	29

The TIGER lines provide fully connected segments, but some links marked as trails are redundant in terms of maintenance operations and long-range transportation planning. However, the redundant trails can be used for many other applications such as historic archeology and tourism management (Table 3.2).

3.1.2 Spatial Pattern of Links

The standard deviation of local lines with respect to segment length is 1,965 meters (see Table 3.1), while the standard deviation of the TIGER links is 459 meters. Thus, we investigated the spatial pattern of the links by length. The hypothesis is that short segments are mostly located in urban areas, and longer segments are in rural and hilly areas. The analysis created seven groups (K=7) using K-Nearest-Neighbors method as shown in Figure 3.2. The first group's average length is 123.39 meters, representing approximately 6% of the population (see the column Share in Figure 3). Group 5 shows 2.43% of the links (i.e., 0.8429-0.8186=0.0243) with an average length of 2,179 meters.

Table 3.2 Comparison of the networks and sources of defects

Sources of Defects	NDDOT-State & Federal Lines	NDDOT - Local Lines	US Census Bureau-TIGER[a]
Attribute	Pavement type; can be joined with RIMS data based on LRS	Basic information such as surface type, direction, and through traffic	Not appropriate for state and local agencies [b]
Topology	No connectivity to the Local Lines	Poor connectivity	
Segment			Redundancy

[a] Authors received TIGER® file from MHA Nation.
[b] The quality of TIGER® varies from state to state due to different sources of the data and methods.

In addition, we investigated the density of the TIGER links (see Figure 3.3). One of the concerns with TIGER links is that too many short segments will be a barrier for developing quality output during conflation. Figure 3.3 indicates densely populated areas of the TIGER lines. The areas should be carefully reviewed before conducting conflation.

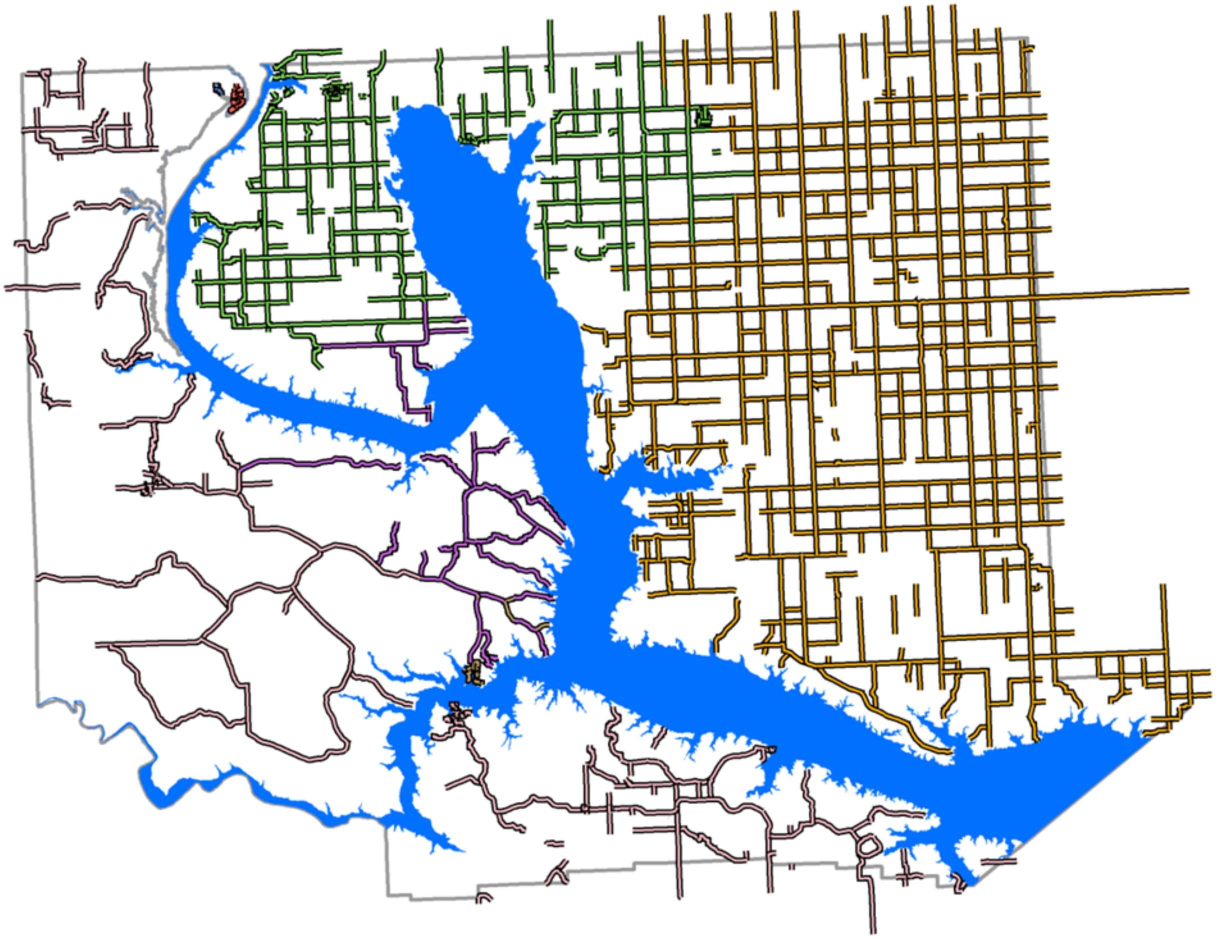
3.2 Issues

3.2.1 Geometry and Attributes

Issues to resolve can be classified into geometry and attributes. Geometry includes redundancy, missing, mismatching, etc. For the inspection, conflation, and review processes, the study uses TIGER® lines as a source feature. In other words, the SF and county lines will be adjusted; the attributes of SF and county lines will be transferred to the TIGER lines.

Figure 3.4a shows redundant links in the TIGER lines. Because the TIGER lines are a source feature, the redundant links should be kept in the source feature by avoiding any activities that remove or erase the redundant links. Most of them are trails with limited access by vehicles. We recommend that those who use the network in the future for the purpose of routing should carefully review the trails before including them to generate shortest paths and routes. Figure 3.4b provides evidence of mismatching of source features and target features. Figure 3.4c provides an example of the missing segments from TIGER lines compared with the SF and county lines. A conspicuous mix of black and red lines in Figure 3.4c overlap the TIGER lines. The missing segments are categorized into those missing a partial segment and those missing a whole segment. Partially missing segments can be ignored or can be extended later, while the whole segment missing should be copied from other sources. Therefore, we focus on 3.4b and 3.4c.

To identify issues and concerns, a team will host a brainstorming session with the data sets. Each member will review the data sets and share his/her findings. The findings should be summarized, and the team then determines importance and priority for each issue and concern. Minor issues can be ignored while focusing on crucial issues. However, the impact of changes and updates should be also discussed.



Group	Mean	Std. Dev.	Min	Max	Share
1	123.3957	120.2682	11.4551	494.5562	0.0599
2	238.1618	372.3506	3.1930	2197.4534	0.2722
3	596.1560	638.0636	0.0000	3348.8588	0.4155
4	1279.9885	664.8104	22.9163	6620.9459	0.8186
5	2179.1274	1554.8661	67.9634	6862.1243	0.8429
6	277.1882	267.2806	1.1760	1038.4620	0.1287
7	1195.8442	1364.7712	1.9583	8060.4759	0.9998
Total	1036.9108	952.4971	0.0000	8060.4759	1.0000

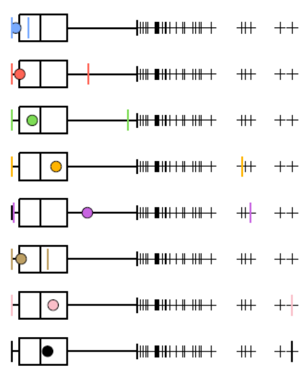


Figure 3.2 Groups of county lines by length (Group Analysis)

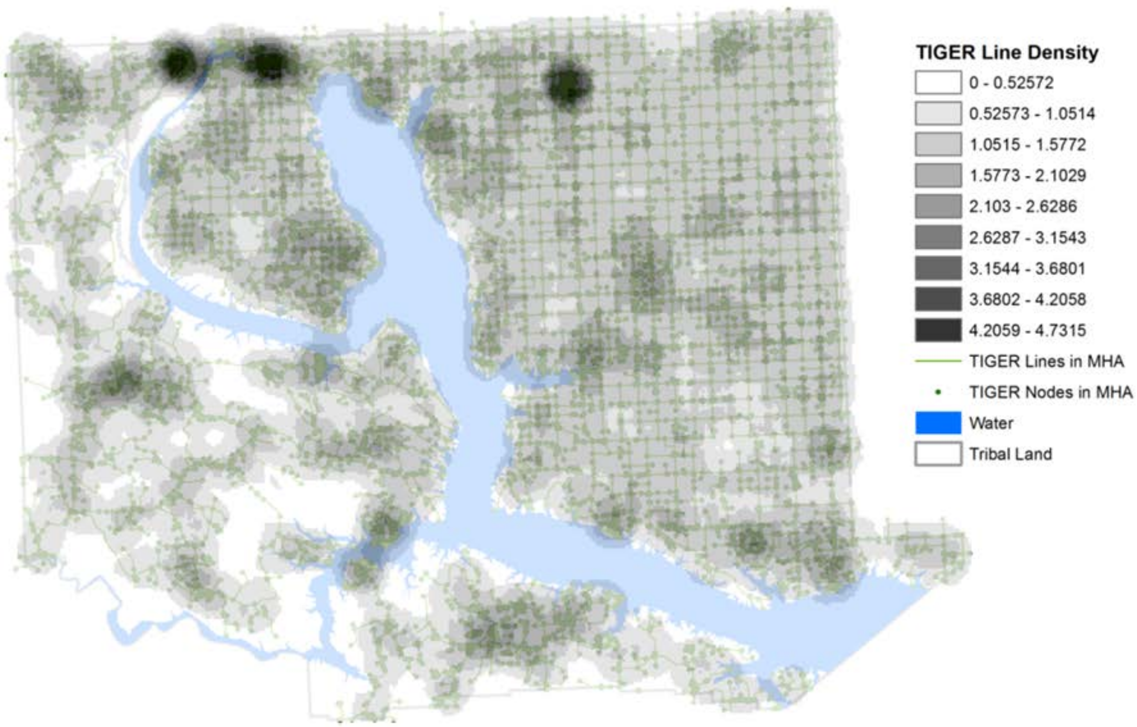
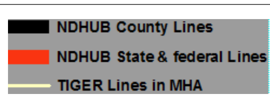


Figure 3.3 TIGER line density in MHA nation (Line Density)

a) Redundancy b) Malalignment c) Missing



Legend: red – state and federal lines, black-county lines, and yellow – TIGER lines

Figure 3.4 Examples of geometric issues

3.2.2 Workflow

Conflation consists of three phases: comparison, matching, and assessment (see Figure 3.5). Comparison investigates the differences between target features and source features. This study only reviews the attributes. After investigating the attributes, the segments were matched to the closest segments using vertices to transfer the attributes from source features to the target features. Then the features were assessed.

After conflation, data review checks were run for data QC. Data review consists of three phases: review, correct, and verify. The review process determines organization rules and basic check rules. The rules are also grouped into a variety of check rules. Based on the checks, the study updated the road networks. The verification phase ensured the corrections. All the corrections and exceptions were recorded in the data review table.

All the results and processes should be reported through tables or documentations for tracking. In general, the records may be used during quality auditing.

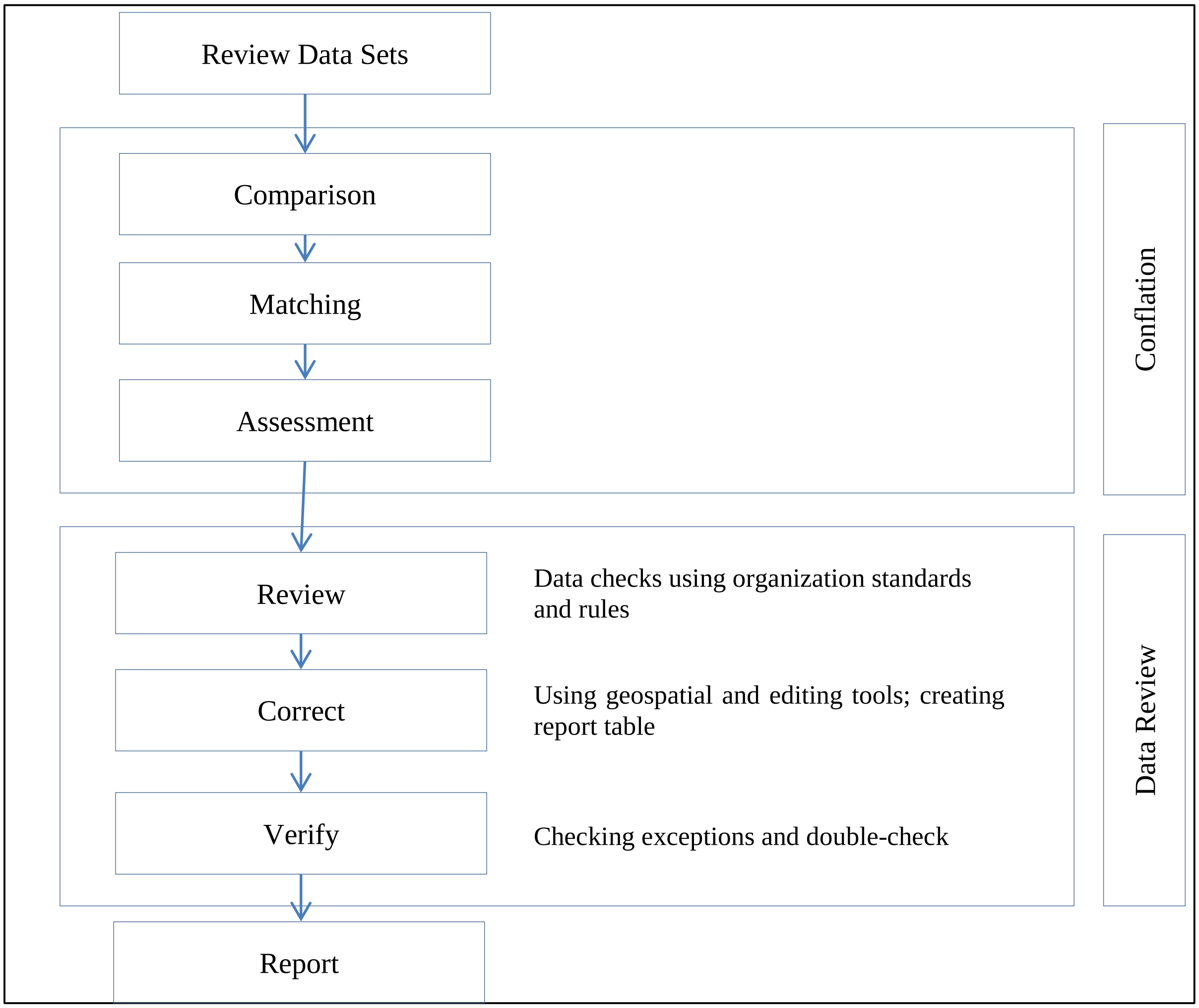


Figure 3.5 Workflow of the project

3.3 Data Conflation

The relationship of the network data sets can be depicted in Figure 3.6. SF lines and county lines are mutually exclusive, while both of them intersect TIGER lines. For that reason, two steps of conflations are expected to establish a set of networks as the intermediary outcomes: (1) TIGER lines and (2) SF lines and county lines. Conflation is a set of procedures that aligns the features of two geographic data layers and then transfers the attributes of one to the others (ESRI Inc., 2015). Then they can be conflated to generate a final complete network. Before merging SF lines and county lines, unique identifications are added to the attribute tables for each shapefile for tracking later. During the merging of SF and county lines, all attributes are retained as they were.

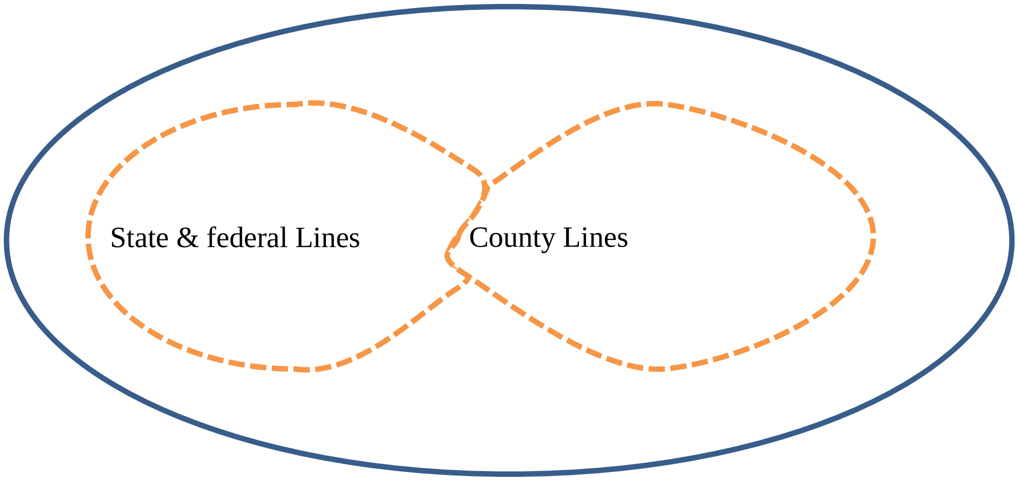


Figure 3.6 Relationship of the network data sets

Before conflation, source networks to be used as a reference network should be of high quality. Preprocessing is a necessary process before conflation. General guidelines for preprocessing are available from (Lee, et al., March 23-27, 2014) as follows:

- Fix invalid geometry
- Validate feature topology
- Remove overshoots and undershoots
- Delete unwanted duplicates
- Break unintended long-running features at intersection
- Exclude irrelevant features from participating in conflation process

The processes can be used with a variety of geoprocessing tools or can be fixed manually.

3.3.1 Match Edge

Figure 3.7a tells us that the bridge links from the TIGER lines are off when compared with an image of a bridge (Four Bear Bridge) and links of SF & county lines. To match two different sources, rubber-sheet links were generated. Figure 3.7b inspects local lines to see the level of detail. In the northwest corner, it appears that SF & county lines and TIGER lines do not align and/or are not even alike. TIGER lines are missing several local lines, which are shown in SF and county lines. Figure 3.7c indicates that the SF and local lines are off from the local lines, while TIGER lines are aligned with the imagery. The lines can be reshaped using force-fitting algorithm for clusters or manually for each (Ubeda & Egenhofer, 1997). Thus, the rubber-sheet links are created to match the corners of the two data sets. Figure 3.7d shows more local lines including trails in TIGER lines. Figures 3.7e and 3.7f generate rubber-sheet links to match local lines.

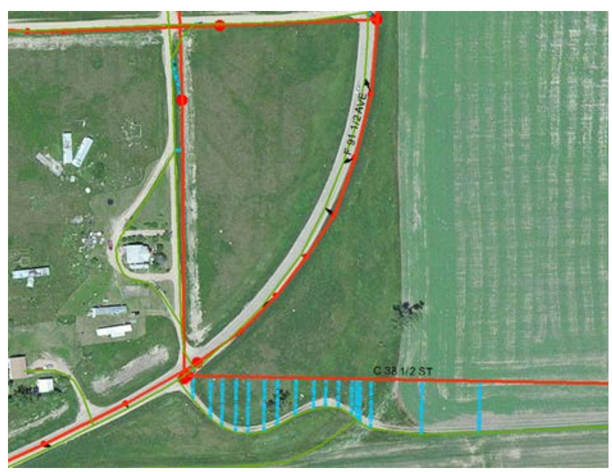
a) SF & County lines (red) and TIGER(green) along a bridge

b) inspecting local lines: missing lines from TIGER and mismatching at the corner. Example of different level of detail.

c) rubbershed links at corner points. State lines (red) should be adjusted. Parcel corner

d) local roads, example of

e) rubbershed links



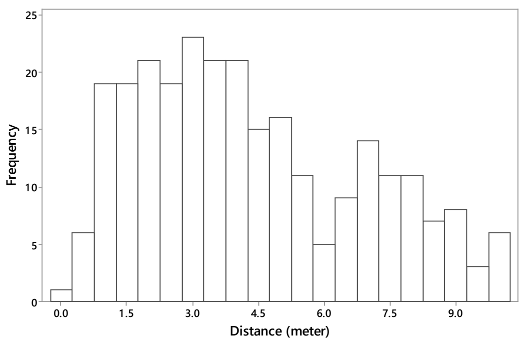
f) rubbershed links

Figure 3.7 Examples of conflation with rubber-sheet links

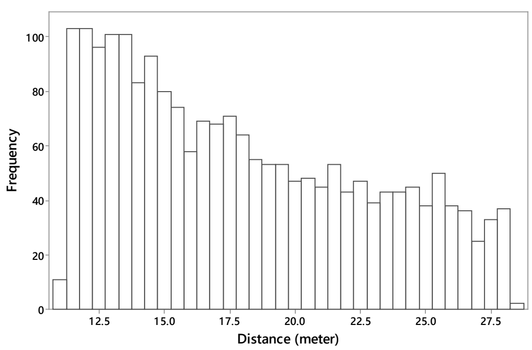
For this study, we believe that TIGER® is spatially more up to date and provides more accurate geometry and shape than SF lines and local lines, while the data set of SF lines provides attributes with greater detail. However, the rubber-sheet links will be sensitive to source-target distance to links.

The comparison of source-target distance distributions is shown in Figure 3.8. The comparison has been done for existing vertices and vertices, which are at least 5 meters away.

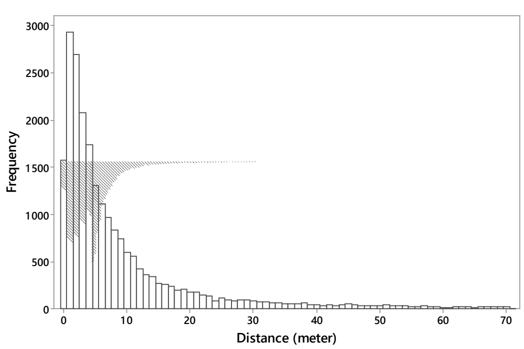
With existing vertices and ends



a) 266 links with maximum of 9.94 meter

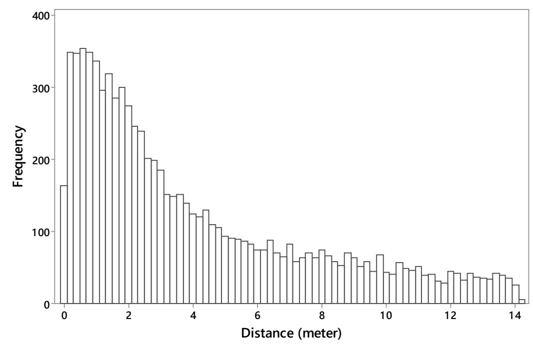


b) 9,946 links with maximum of 28.27 meter

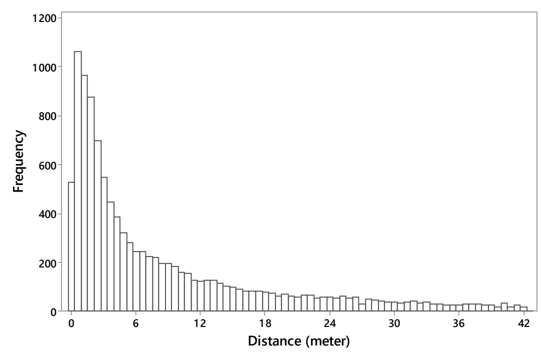


c) 22,035 links with maximum of 70.69 meter

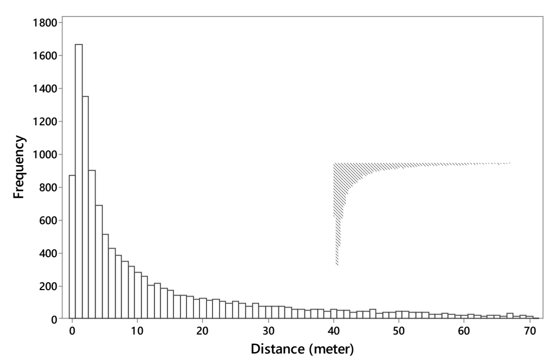
After densifying a feature by adding vertices (20 meters)



d) 8,227 links with maximum of 14.13 meter



e) 10,774 links with maximum of 43.39 meter



f) 11,814 links with maximum of 70.63 meter

Figure 3.8 Source-target distance analysis

The rubber-sheet densely generated near the links densely located comparing with Figure 3.9.

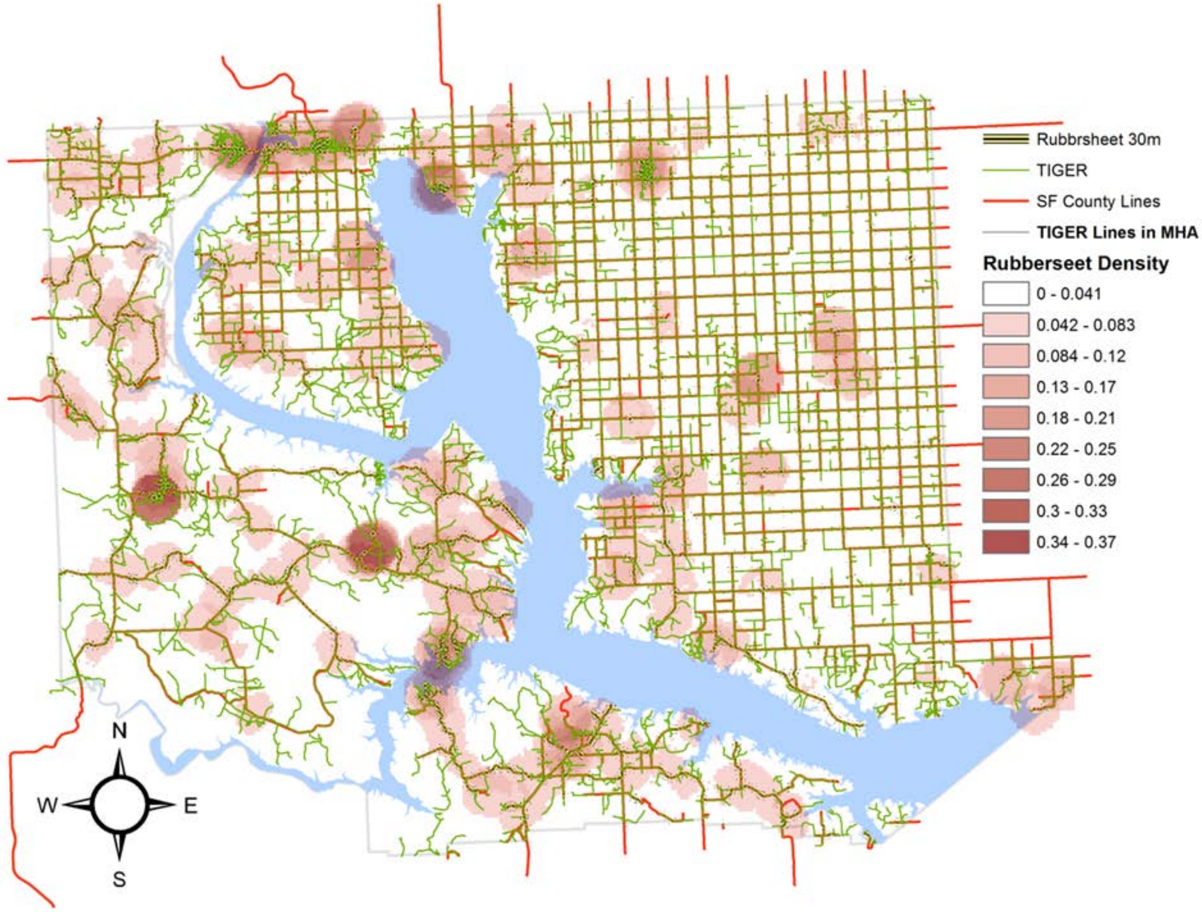


Figure 3.9 Rubber-sheet link density (30 meter density with a densified network)

Considering the length of the links, the kernel density map indicates that many roads of the SF and county lines are off from TIGER lines, especially near the river. The kernel density map generates raster output (areas) using rubber-sheet links as inputs. Kernel density calculates the density of line features in a neighborhood around those features (ESRI Inc., 2015). One square-meter of the search radius produced a smoother, generalized density raster.

Possible uses include finding the density of houses, crime reports, roads, or utility lines influencing a town or wildlife habitat. The population field could be used to weigh some features more heavily than others, depending on their meaning, or to allow one point to represent several observations. For example, one address might represent a condominium with six units, or some crimes might be weighed more severely than others in determining overall crime levels. For example, a line that features a divided highway probably has more impact than a narrow dirt road and a high-tension power line has more impact than a standard electric line.

3.3.2 Spatial adjustment

The goal of this task is to spatially adjust the target features based on source features. The types of changes are detected as follows (ESRI Inc., 2015):

- **S** for spatial, indicating a matched update feature with a spatial change.
- **NC** for no change, indicating a matched update feature with no change.
- **N** for new, indicating an unmatched update feature that is new to the base data.
- **D** for deletion, indicating an unmatched base feature that might need to be deleted from base data.

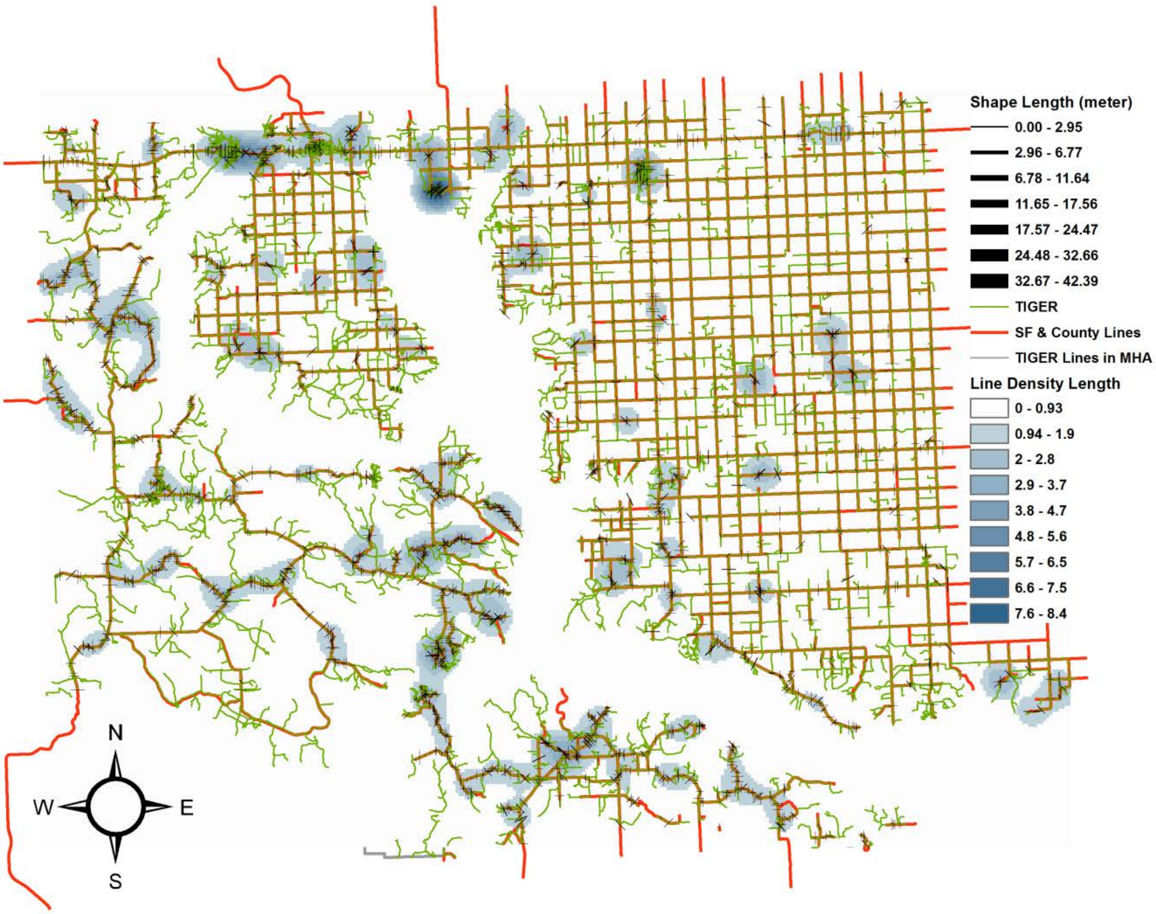


Figure 3.10 Kernel density with regard to shape length (in meters)

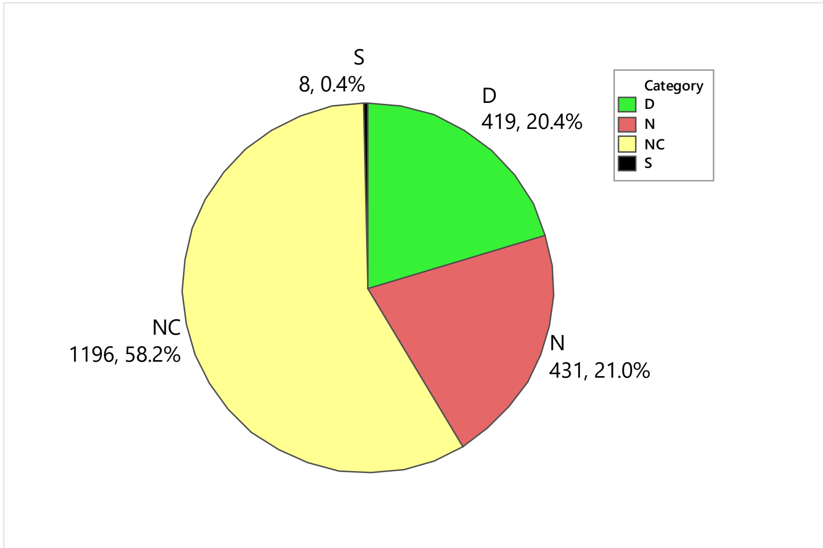
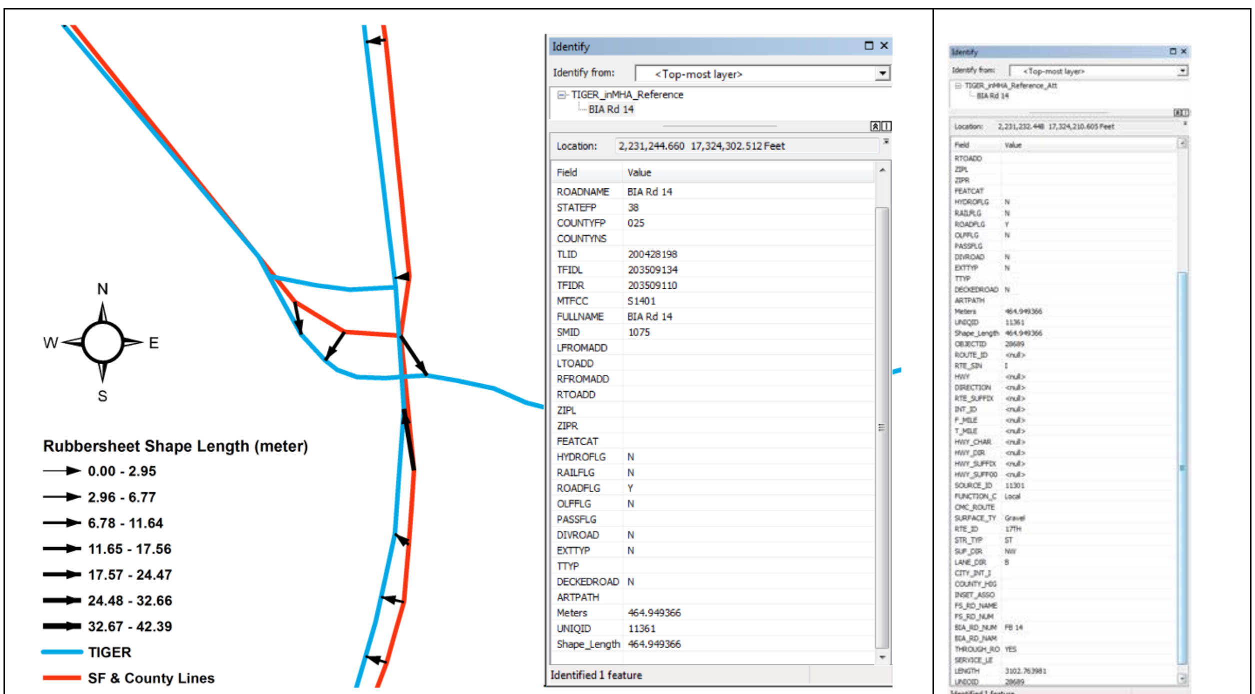


Figure 3.11 Pie chart for change types of detect feature changes

3.3.3 Transfer Attributes

Attributes of SF and county lines are transferred to TIGER links with the rubber-sheet links. Once the links are matched, all the attributes are transferred from sourcing roads to destination roads without any filtering process. For example, Figure 3.12a shows a prior-attribute table in TIGER. Figure 3.12b shows final output with new attributes transferred from SF and county lines.



a) before transferring attributes of ST & county lines | b) after

Figure 3.12 Attribute conflation

This process appears to be straightforward when the links from two different sources match in a one-to-one (1:1) relationship. However, in many cases during a QA/QC process, one-to-many (1:m) or many-to-one (m:1) relationships are found between TIGER lines and SF and county lines. Figure 3.13 illustrates this relationship.

Figure 3.13 shows images of segments from two different data sources: the source features of TIGER® lines (in blue) and the target features of SF & county lines (in red). The target segments of A, B, and C are part of TIGER® lines, and the source links of D and E are from SF & county lines. Attributes of Segment E can be transferred to Segments A and B with a 1:*m* relationship, while Segment D can be transferred to Segments C and A with an *m*:1 relationship. A question associated with Segment A is, which source attributes from either D or E will be transferred to the target links? ArcGIS transfers the attributes from Link D to Link C as the rubber-sheet link between D and C indicates, not from E to C.

In total, 4,433 segments were updated with additional attributes from the SF and county lines. Now that the attributes from D and E are transferred to A and B, respectively, the integrated attribute table should be cleaned by appropriate processes such as deleting, switching, and adding. After doing so, the final attributes are shown in Table 3.3.

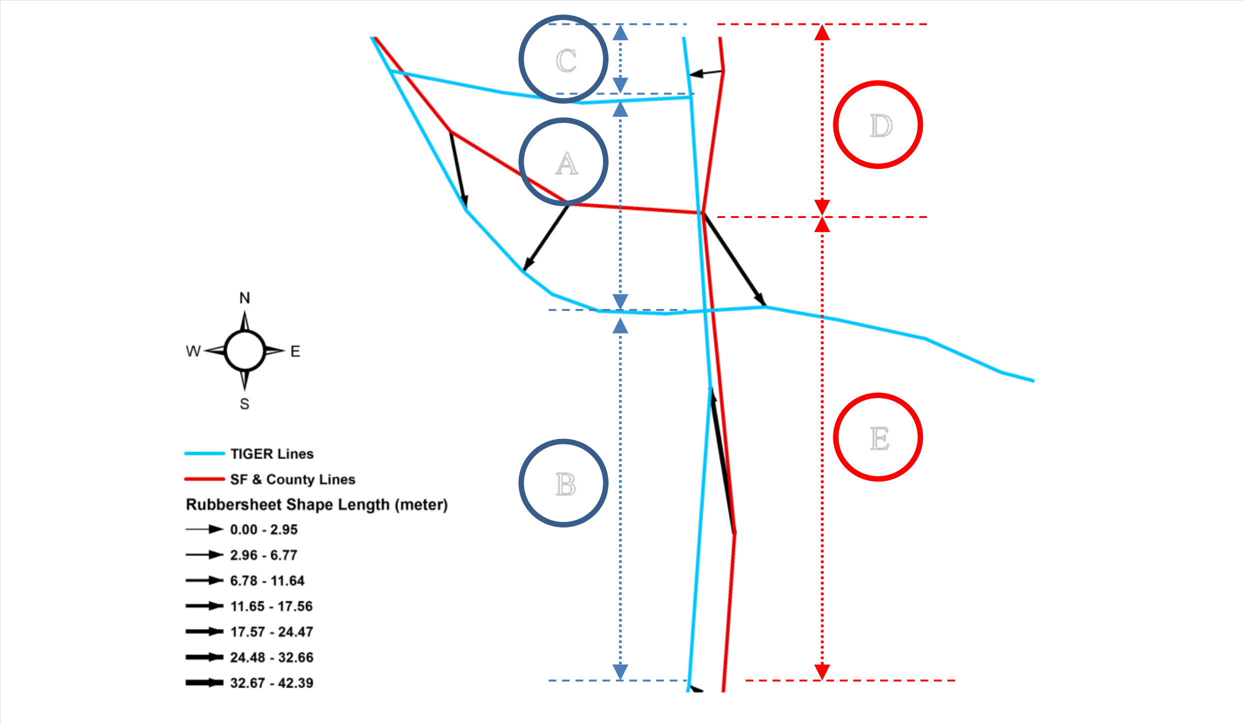


Figure 3.13 Behavior of attribute transfer

Table 3.3 Table integration

Name	Original Source	Action	Description
Object ID	ArcGIS	No Change	Unique object ID automatically created by ArcGIS
Shape	ArcGIS	No Change	Polyline
Roadname	TIGER	No Change	
STATEFP	TIGER	No Change	State FIPS
COUNTYFP	TIGER	No Change	County FIPS
COUNTYN	TIGER	No Change	

Name	Original Source	Action	Description
TLID	TIGER	No Change	
TFIDL	TIGER	No Change	
TFIDR	TIGER	No Change	
MTFCC	TIGER	No Change	
FULLNAME	TIGER	No Change	
SMID	TIGER	No Change	
LFROMAD	TIGER	No Change	
LTOADD	TIGER	No Change	
RFROMAD	TIGER	No Change	
RTOADD	TIGER	No Change	
ZIPL	TIGER	No Change	
ZIPR	TIGER	No Change	
FEATCAT	TIGER	No Change	
HYDROFL	TIGER	No Change	
RAILFLG	TIGER	No Change	
ROADFL	TIGER	No Change	
OLFFLG	TIGER	No Change	
PASSFLG	TIGER	No Change	
DIVROAD	TIGER	No Change	
EXTTYP	TIGER	No Change	
TTYP	TIGER	No Change	
DECKEDROA	TIGER	No Change	
ARTPATH	TIGER	No Change	
UNIQIDT		New	Unique identification transferred from the original TIGER®
UNIQIDS		New	Unique ID related to the State Federal and County Lines, which is transferred
ROUTE_ID	State and Federal		Route identification
RTE_SIN	State and Federal		
HWY	State and Federal	delete	
DIRECTION	State and Federal		Direction of a link: N, S, E, W, and etc
RTE_SUFFIX	State and Federal	delete	Route suffix code
INT_ID	State and Federal		
F_MILE	State and Federal		From mile point in LRS
T_MILE	State and Federal		To mile point in LRS
HWY_CHAR	State and Federal	Delete	Highway number
HWY_DIR	State and Federal	Delete	Highway direction
HWY_SUFFIX	State and Federal		
HWY_SUFFIX00	State and Federal		Highway suffix and direction
SOURCE_ID	County Lines		
FUNCTION_C	County Lines		Highway functional classification
CMC_ROUTE	County Lines		Major county route code
SURFACE_TY	County Lines		Surface type
RTE_ID	County Lines	No change	Route identification
STR_TYP	County Lines		
SUF_DIR	County Lines	Combined	Surface direction
LANE_DIR	County Lines	Removed	Lane direction: one way or both. Note: this should be updated by the nation.

Name	Original Source	Action	Description
CITY_INT_I	County Lines		
COUNTY_HIG	County Lines		
INSET_ASSO	County Lines		
FS_RD_NAME	County Lines	No change	Federal state road name
FS_RD_NUM	County Lines	No change	Federal state road number
BIA_RD_NUM	County Lines	No change	Bureau of Indian Affair road number
BIA_RD_NAM	County Lines	No change	Bureau of Indian Affair road name
THROUGH_RO	County Lines		Through road: Yes or No
SERVICE_LE	County Lines		Service level
TRANSATT	SF and County	New	1 if attribute is transferred, otherwise 0
ONEWAY		New	One way direction
ESPEED		New	Estimated speed
PSPEED		New	Posted speed limit
Length	ArcGIS		In unit of meter

MTFCC. The MAF/TIFER Feature Class Code (MTFCC) is a 5-digit code, which describes geographic features. The S group of the features presents several classes of roads (Table 3.4).

Table 3.4 MAF/TIGER feature class code definition for roads (U.S. Census Bureau, 2015)

MTFCC	Feature Class	Superclass	Feature Class Description
S1100	Primary Road	Road/Path Features	Primary roads are generally divided, limited-access highways within the Interstate Highway system or under state management, and are distinguished by the presence of interchanges. These highways are accessible by ramps and may include some toll highways.
S1200	Secondary Road	Road/Path Features	Secondary roads are main arteries, usually in the U.S. Highway, State Highway or County Highway system. These roads have one or more lanes of traffic in each direction, may or may not be divided, and usually have at-grade intersections with many other roads and driveways. They often have both a local name and a route number.
S1400	Local Neighborhood Road, Rural Road, City Street	Road/Path Features	Generally, a paved non-arterial street, road, or byway that usually has a single lane of traffic in each direction. Roads in this feature class may be privately or publicly maintained. Scenic park roads would be included in this feature class, as would (depending on the region of the country) some unpaved roads.
S1500	Vehicular Trail (4WD)	Road/Path Features	An unpaved dirt trail where a four-wheel drive vehicle is required. These vehicular trails are found almost exclusively in very rural areas. Minor, unpaved roads usable by ordinary cars and trucks belong in the S1400 category.
S1630	Ramp	Road/Path Features	A road that allows controlled access from adjacent roads onto a limited access highway, often in the form of a cloverleaf interchange. These roads are un-addressable.

MTFCC	Feature Class	Superclass	Feature Class Description
S1640	Service Drive usually along a limited access highway	Road/Path Features	A road, usually paralleling a limited access highway that provides access to structures along the highway. These roads can be named and may intersect with other roads.
S1710	Walkway/Pedestrian Trail	Road/Path Features	A path that is used for walking, being either too narrow for or legally restricted from vehicular traffic.
S1720	Stairway	Road/Path Features	A pedestrian passageway from one level to another by a series of steps.
S1730	Alley	Road/Path Features	A service road that does not generally have associated addressed structures and is usually unnamed. It is located at the rear of buildings and properties and is used for deliveries.
S1740	Private Road for service vehicles (logging, oil fields, ranches, etc.)	Road/Path Features	A road within private property that is privately maintained for service, extractive, or other purposes. These roads are often unnamed.
S1750	Internal U.S. Census Bureau use	Road/Path Features	Internal U.S. Census Bureau use.
S1780	Parking Lot Road	Road/Path Features	The main travel route for vehicles through a paved parking area.
S1820	Bike Path or Trail	Road/Path Features	A path that is used for manual or small, motorized bicycles, being either too narrow for or legally restricted from vehicular traffic.
S1830	Bridle Path	Road/Path Features	A path that is used for horses, being either too narrow for or legally restricted from vehicular traffic
S2000	Road Median	Road/Path Features	The unpaved area or barrier between the carriageways of a divided road.

The group of S1400 has 9,099 links, which are approximately 3,655 kilometers long. Only one link is found for S1630, which is 639 meters long. In addition to the public roads, 1,515 private roads are included in the data set, which is equivalent to 268 kilometers.

Table 3.5 Number of links and total meters of TIGER links

MTFCC	Count	Total Length (meter)
S1200	564	228,500
S1400	9,099	3,655,485
S1401	450	211,485
S1500	253	136,481
S1630	1	639
S1740	1,515	268,580
Grand Total	11,882	4,501,173

FUNCTION_C. This column provides information on a functional class. The information can be updated based on guidance for the functional classification of highways memorandum in 2008 and an updated version of the guidance in 2013 (U.S. Department of Transportation, 2013). The classifications are:

a. Principal Arterial
   i. Interstate: all routes belonging to the national system (e.g., interstate and defense highways)
   ii. Other freeways and expressways (OF & E): roads providing directional travel lanes divided by physical barrier, limited on and off ramps, and a very limited number of at-grade intersections.
   iii. Other (OPA)
b. Minor Arterial: routes interconnecting and augmenting the principal arterial system, thereby providing intra-community continuity and carrying local bus routes.
c. Collector
   i. Major collector: routes providing intra-county travel with moderate speed.
   ii. Minor collector: to collect traffic from local roads and bring all developed areas within reasonable distance of a collector.
d. Local: to provided direct access to multiple properties

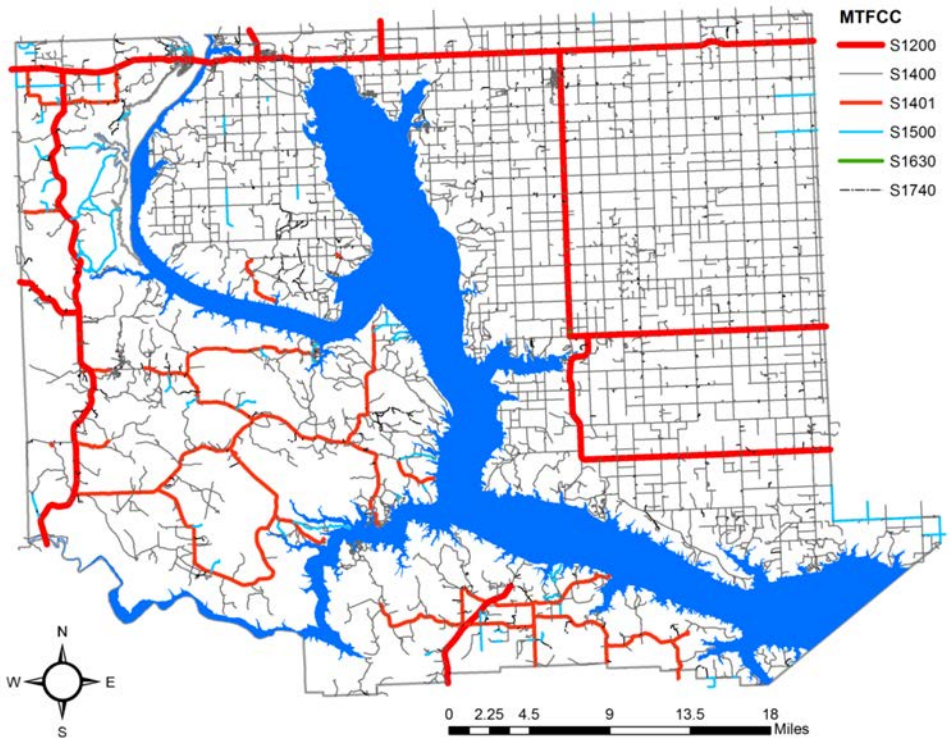


Figure 3.14 MAF/TIGER Feature Class Code (MTFCC)

The classification is shown in Figure 3.15 using hierarchical classification. All roads are grouped into arterial and non-arterial for further explosion.

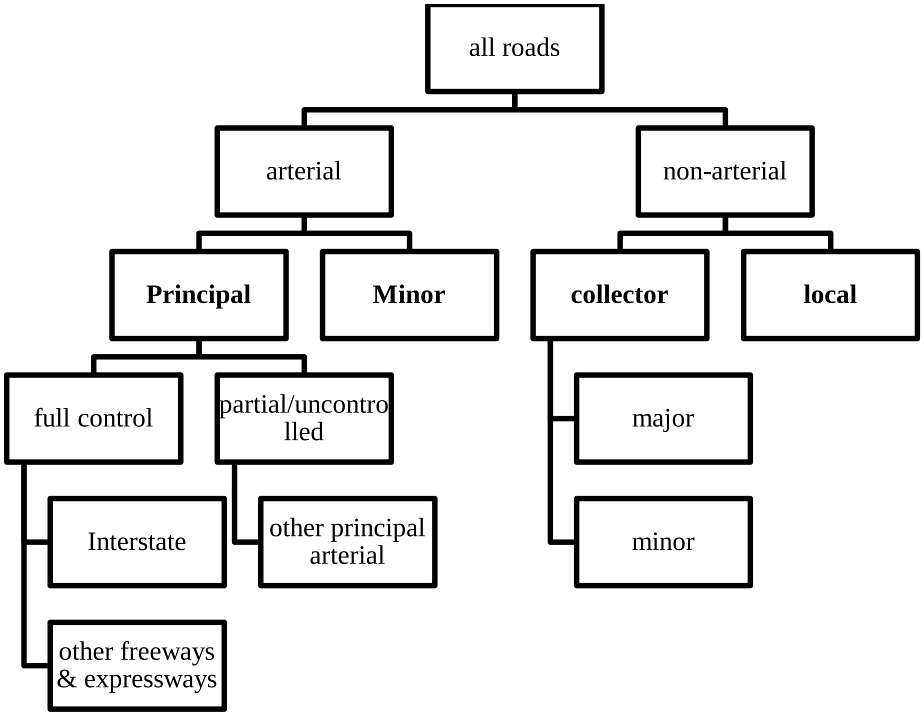


Figure 3.15 Federal Functional Classification decision tree (FHWA and CDM Smith) (U.S. Department of Transportation, 2013).

Based on this guidance, NDDOT should assign functional classifications according to how a corridor functions for the current year. The process of setting functional class follows several rules. For example, if a feature belongs to S1400, the functional class of the feature was set as Local. If a feature is S1200 and is not part of state highway system, it was categorized as Major Collector. If a feature is a member of S1200 and belongs to the state highway system, it was recoded as Minor Arterial. Therefore, the agency should reclassify the corridor accordingly once it has been constructed and reclassified. Missing classifications for the ramp and other non-mainline roadways are assigned the same functional classification as the highest functional classification among the contiguous mainline roadways.

For example, one ramp (a member of S1630) is found in Figure 3.16, and it was coded as the highest classification (i.e., Major Collector). Private roads with a classification code of S1740 were coded as Local. Note that the private roads might be removed before generating routes for transportation planning later. The results are visualized in Figure 3.17.

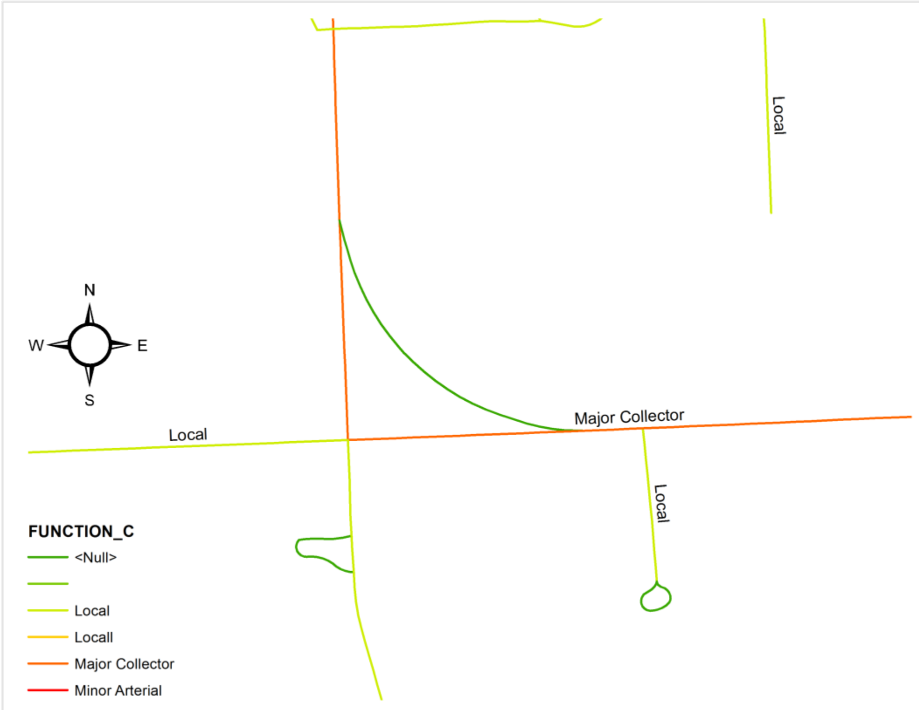


Figure 3.16 Example of ramp (S1630)

HWY_SUFFIX. This represents a highway number as a suffix. For example, if you see the highway sign I-29 on a map, 29 is the highway suffix; "I" is a prefix of the high name, which is from a code of RTE_SIN. It might appear in HWY_DIR and HWY_SUFF00 as well with direction information. The value of a highway is also equivalent to an attribute of HWY. Thus, to avoid redundancy, HWY is canceled in the attribute table.

ROADNAME. This column represents a road name. A missing value is updated by combining RTE_ID, STR_TYP, and SUF_DIR.

TRANSATT. This is a flag for acknowledging a unique identification from the SF and county lines.

- 1 if both UNIQIDT and UNIQIDS exist.
- 0 if UNIQIDS does not exist.

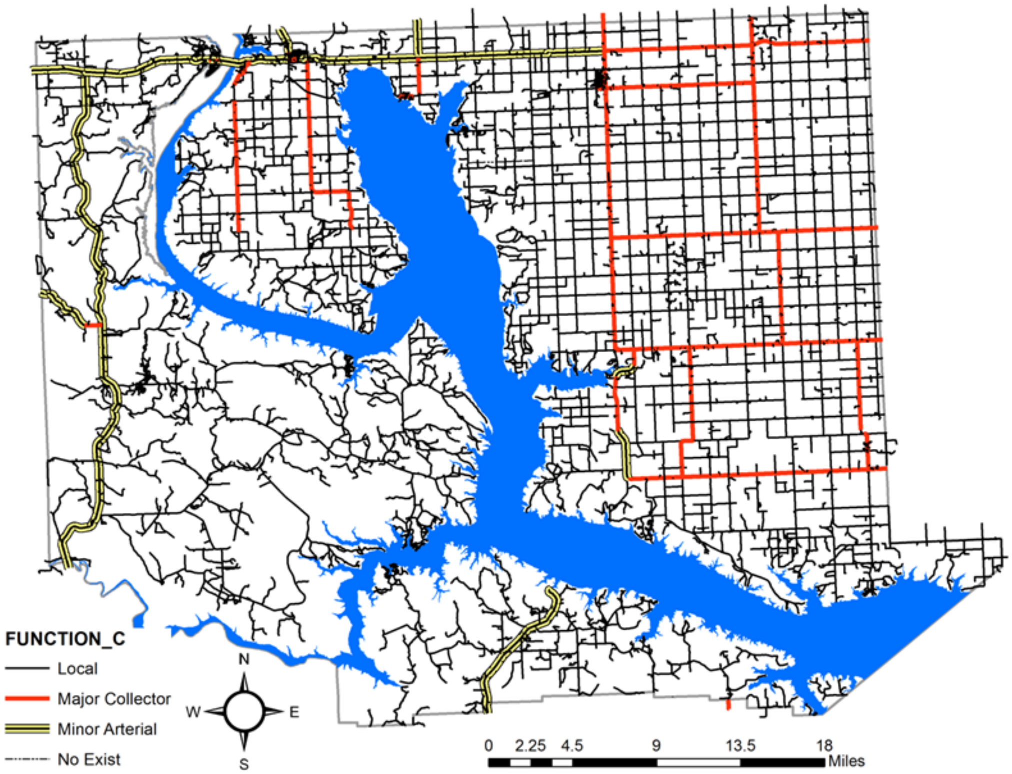


Figure 3.17 Functional class (FUNC_C)

LANE_DIR. This attribute should be updated by the MHA nation transportation agency.

- One way: Roadways with one-way directional travel were identified in this file. All interstate highways in North Dakota were marked as one way because each direction was divided by median (i.e., central reservation). However, no interstate highways are found in the Fort Berthold Reservation.
- Both: It is assumed all local roads are bidirectional except in a few cases.

ROUTE_ID. This column represents route identification of a segment. This originally comes from the state and federal lines. A similar column of RTE_ID is found from the county lines. RTE_ID may be combined with ROUTE_ID because ROUTE_ID and RTE_ID are exclusive; however, RTE_ID and ROUTE_ID have heterogeneous data types of character and number, respectively, resulting in failure of a direct combination.

CMC_ROUTE. This is a unique route identification for county major roads. The value of the column is copied to ROUTE_ID using the function of LEFT(CMC_ROUTE, 4), which takes the first four characters from the left, because some of CMC_ROUTE contains redundant characters such as "2821SPUR."

RTE_ID. This is a route identification of county lines, which include local, rural, and urban roads.

RTE_SIN. This indicates a route sign as follows (see Figure 3.18):

- S: State highway
- P: Private roads
- M: Municipal
- I: Indian service, this code does not match to BIA_RD_NUM, so the users should not be confused with them. Some of the county roads contain BIA road numbers and names.
- F: County federal
- C: County
- U: Undefined

ROUTE_ID. A route identification differs from highway number. This route identification (ROUTE_ID) is of help for linear referencing systems (LRS) by combining F_MILE (i.e., from mile point) and T_MILE (i.e., to mile point). The local and BIA roads do not include this route identification, so a transportation agency should update this column in compliance with a national standard of an LRS system.

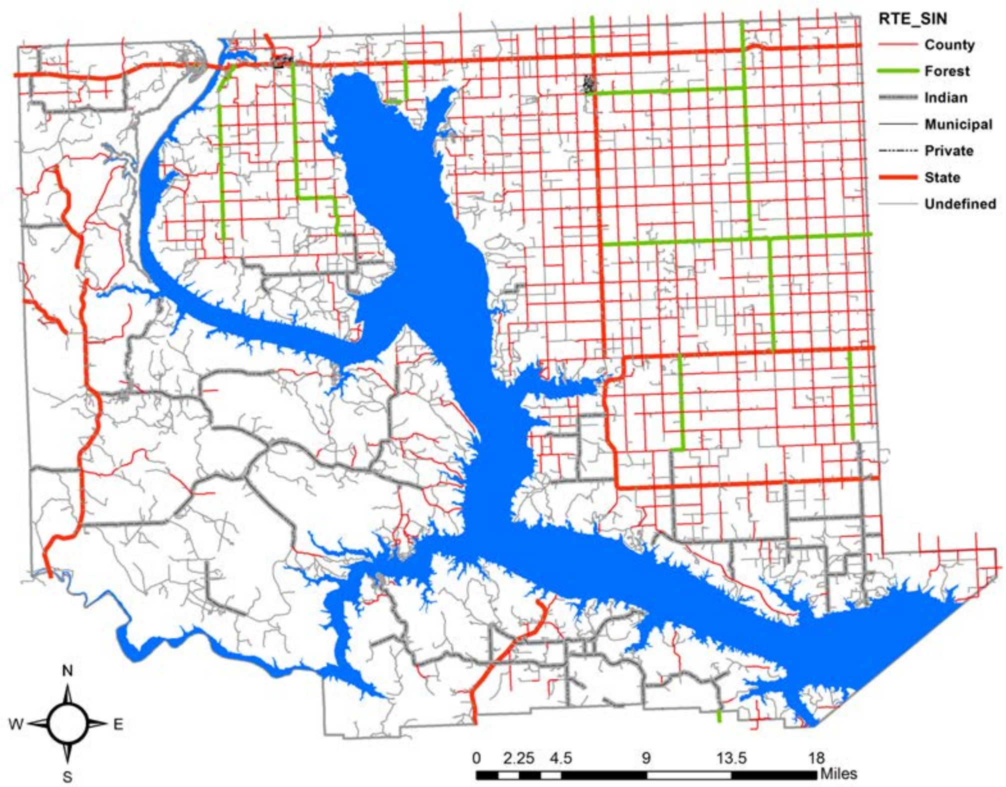


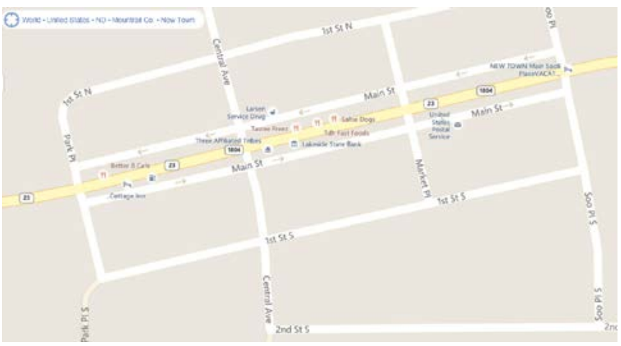
Figure 3.18 Route sign (RTE_SIN)

FS_RD_Name. The field is to better track Forest Service roads.

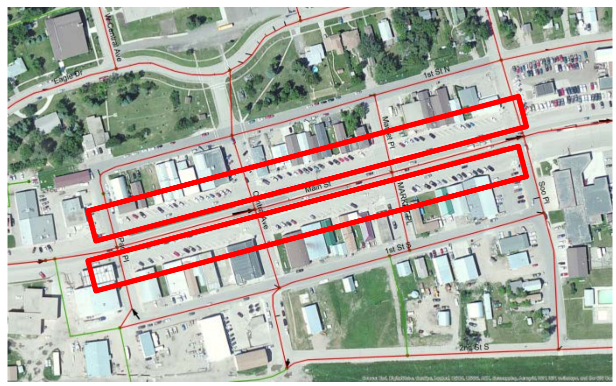
ONEWAY. This column indicates one way or both directions. LANE_DIR from the county lines provide this kind of information. LANE_DIR is a character type data. To have integer type data for one-way information, a new column, ONEWAY, was created. In the region, only two Main Streets along State Highway 23 and 804 represent one-way roads located in New Town, ND, as shown in Figure 3.19 (Microsoft Corporation, 2015). In the GIS shapefiles of local lines and Tiger lines, the one-way Main St. in New Town is not visually recognizable to see if it is a one-way street. Thus, this study just ignores them for now. However, in the near future, the transportation agency should create new segments for the roads to utilize them for realistic transportation planning and operations. The integer values used for the column are as follows:

- 1: One-way
- 2: Two-way

This is a very useful attribute and provides critical information for the purpose of routing. Furthermore, travel demand modeling (TDM) for transportation planning utilizes this attribute frequently. In the area, only two routes indicate one-way traffic (Figure 3.19a). The routes are not shown in TIGER links, however (Figure 3.19b).



a) Bing map



b) Missing segments for Main St. (red boxes)

Figure 3.19 One-way direction in New Town based on Bing® map

SURFACE_TY. This attribute provides information on a surface type of the roads. The surface type is crucial information in order for life-cycle cost analysis to estimate deterioration and required treatment. The roads from the member, "Proposed," should be ignored when a user generates routes, but the other members should be included with appropriate travel speed. The surface type is from SF and county lines, so many of the TIGER links are simply shown as Unknown. The study recommends tribal transportation engineers survey surface type and keep records.

ESPEED. This is an estimated speed for routing purpose in units of mile per hour (MPH). The estimate of the speed follows the county road needs study and the state highway needs study conducted by the Upper Great Plains Transportation Institute (UGPTI). Some should be adjusted to reflect driving behavior and condition in the region.

Table 3.6 Functional class and surface type

Functional Class (FUNCTION_C)	Surface Type (SURFACE_TY)	MPH
Collector	Gravel	45
Collector	Paved	50
Collector Front Rd	Gravel	35
Collector Front Rd	Paved	45
Local	City Existing	25
Local	Graded & Drained	35
Local	Gravel	50
Local	Paved	55
Local	Trail	15
Local	Unimproved	10
Local	-	10
Major Collector	Graded & Drained	35
Major Collector	Gravel	55
Major Collector	Paved	60
Major Collector	Trail	20
Minor Arterial	Gravel	55
Minor Arterial	Paved	65
Minor Arterial	City Existing	35
Minor Arterial	-	35
Minor Arterial	Graded & Drained	45
Principal Arterial	Paved	65
Collector	Trail	20
Collector	City	25
	Unimproved	10
Ramp-U.S. highway		50
Ramp-others		45

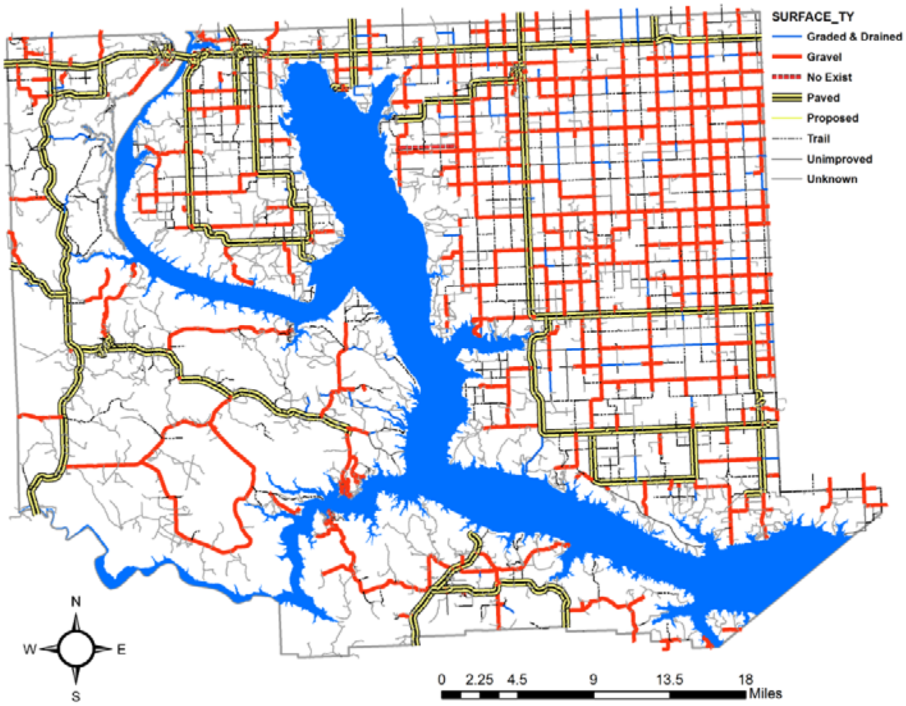


Figure 3.20 Surface type (SURFACE_TY)

PSPEED. This represents posted speed limit over the links in units of MPH. The posted speed may not be released to the public because of liability issues. Nevertheless, the attribute is very useful to estimate a value for ESPEED and to find the quickest routes from origin points to destination points. This should be set up by the local transportation agency.

BRIDGE. A point shapefile of the National Bridge Inventory is available from FHWA (U.S. Department of Transportation, 2015). A 14-digit structure number (see ITEM No. 8) was used to join the inventory data to the roads network (Figure 3.21).

THROUGH_RO. This attribute represents dead-end point (end terminal of a road). If any start or end points of an input road is not connected to any other lines, the point along the line is a dangle point. The dangle node can be considered as dead end. In total, the network includes 2,399 dangle nodes (Figure 3.22).

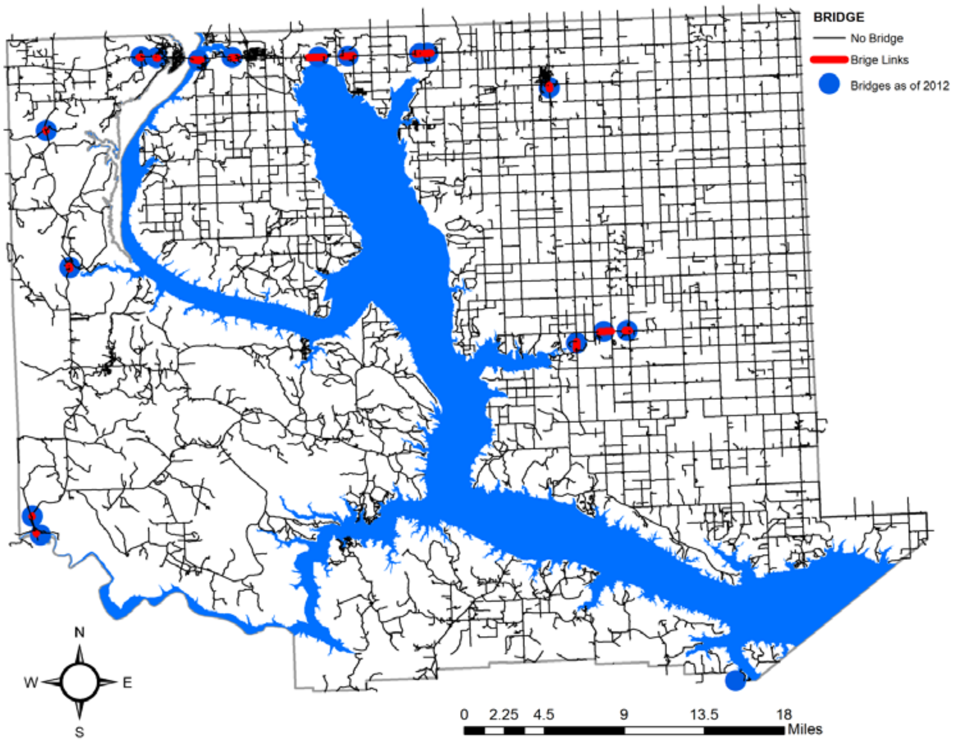


Figure 3.21 Bridges as of 2012 (National Bridge Inventory)

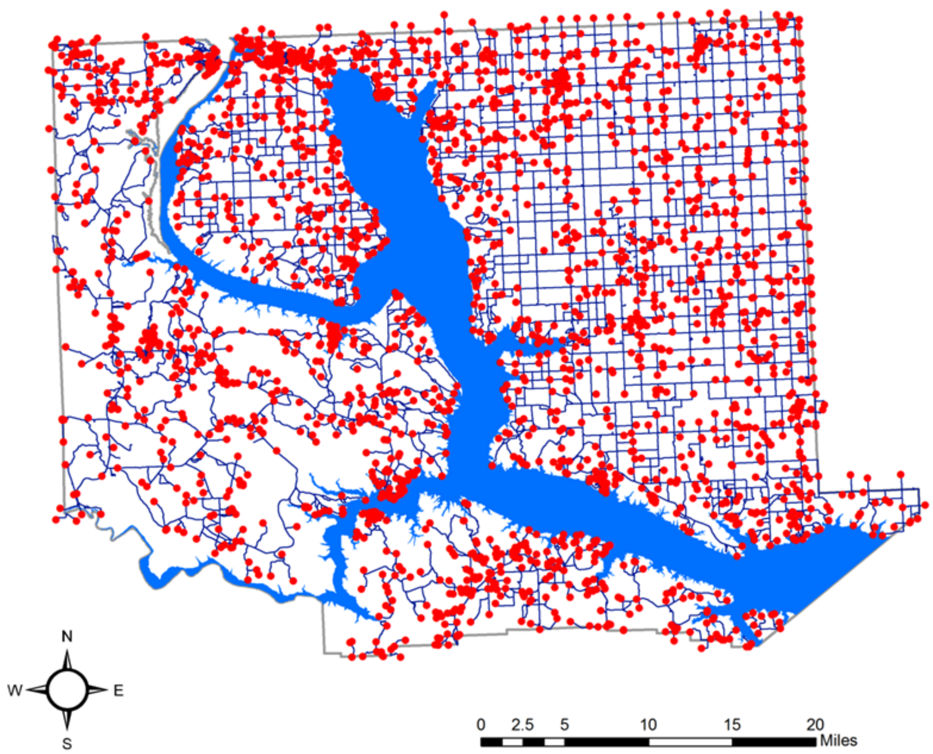


Figure 3.22 Dangle nodes

Of 2,000 dangle nodes (Figure 3.22), if a segment is connected to two dangle nodes, the segment is considered as an orphan link. The rule found five dangle nodes from the network. However, if an orphan link crosses a border boundary, it is assumed that the link should be connected to another link located in another county (Figure 3.23), thereby being a through road. In general, orphan links are not removed from the network. However, they should be excluded when the network is used for routing (Figure 3.24).

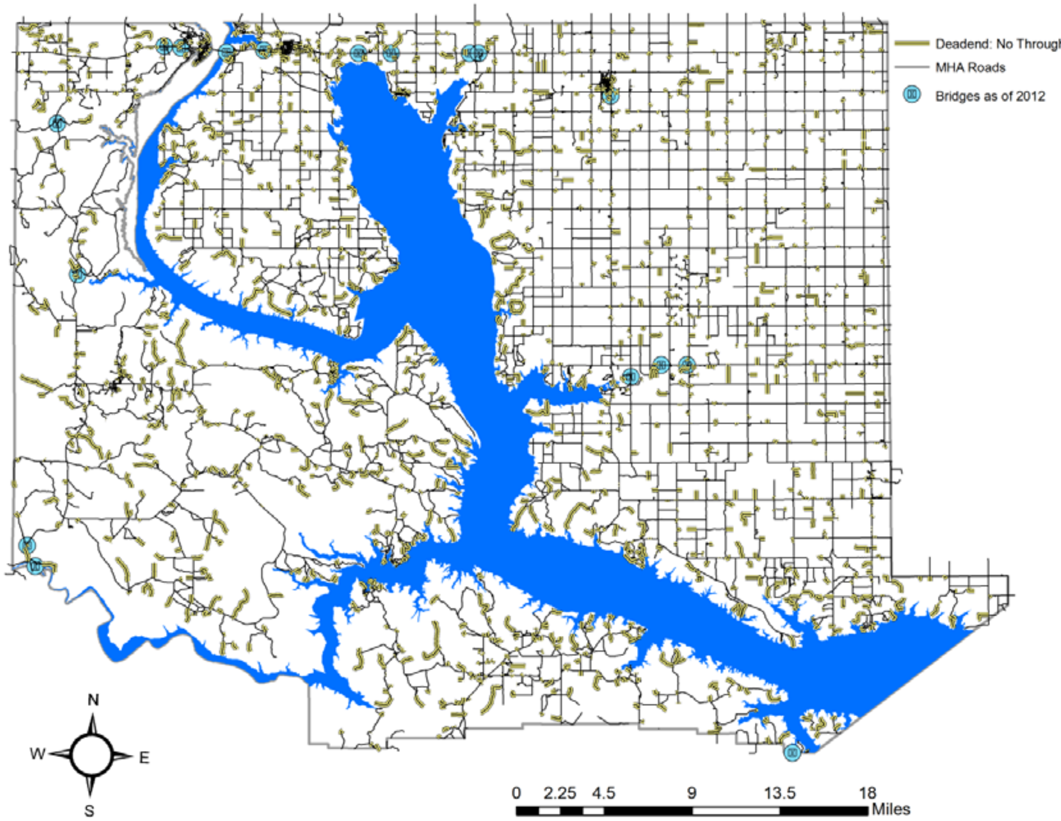


Figure 3.23 No through-traffic links

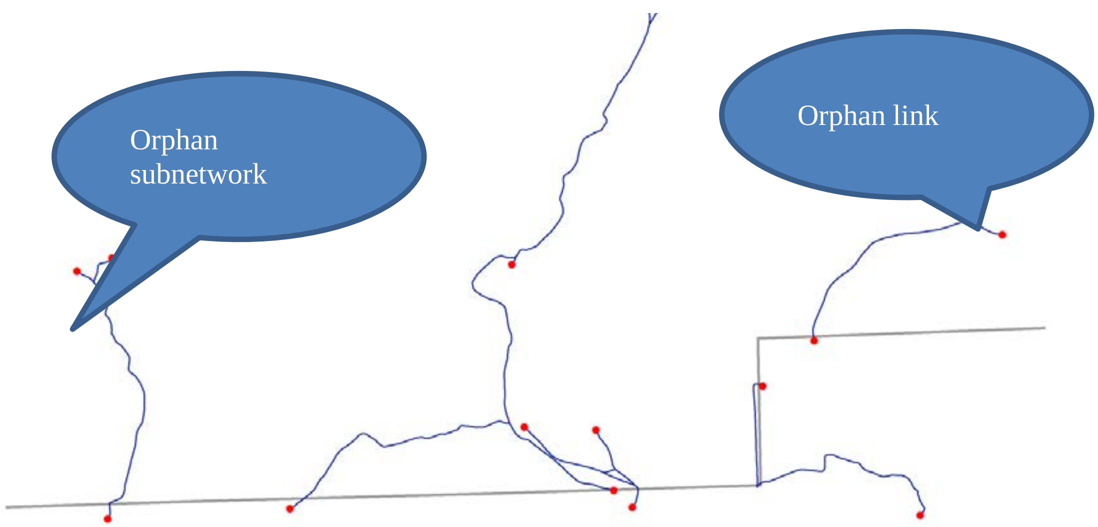


Figure 3.24 Orphan links and subnetworks

3.4 Data Review/Quality Assurance & Quality Control

To produce high-quality road network datasets, standardized processes and consensus across multiple departments for sharing the datasets are necessary. With clear requirements and definitions, standardized steps will help the process be useful and proceed quickly. Thus, the cleaned data can be shared within a community and with other public entities. In general, the verification of data quality varies depending on project specification and purpose. However, this paper focuses on the public in general for sharing the transportation network data set.

The quality assurance and quality control (QA/QC) are procedures to evaluate spatial accuracy, completeness of the roads, and logical consistency of the attributes, temporal quality, and usability (ArcGIS reference). While QA focuses on prevention of future errors, QC focuses on the steps to reveal data defects (ArcGIS). A defect is a nonconformity that causes an item to fail to meet specification requirements. A shapefile such as road network with one or more defects is categorized as a defective product (DeVor, et al., 2007).

The cost of poor data quality can be extreme, resulting in inaccurate ambulance analysis, loss of personal credibility, loss of an organization's positive reputation, and loss of emergency response, which is closely related to the ability to save lives (ArcGIS also refer to F-M ambulance).

The QC review process consists of three distinct phases: review, correction, and verification (ESRI). During the **review** process, the quality manager configures the checks considering organizational standards on the datasets and the requirement for the datasets. Then the problems and errors will be fixed using available tools and methods or deemed as an exception. While **fixing** the problems, the history of fixing should be kept in a separate table or documented for quality control and auditing processes in the future. It also helps the organization to track corrections and modifications for future reference. Access to historical records will increase utilization and improve maintenance. Changes made during the **correction** phase should be ensured by a **verification** phase. Verification also will need documentation, including the verification status, date, and technician (ESRI). This process is similar to the quality management procedure for developing management information systems (MIS). Therefore, the document can be used for auditing.

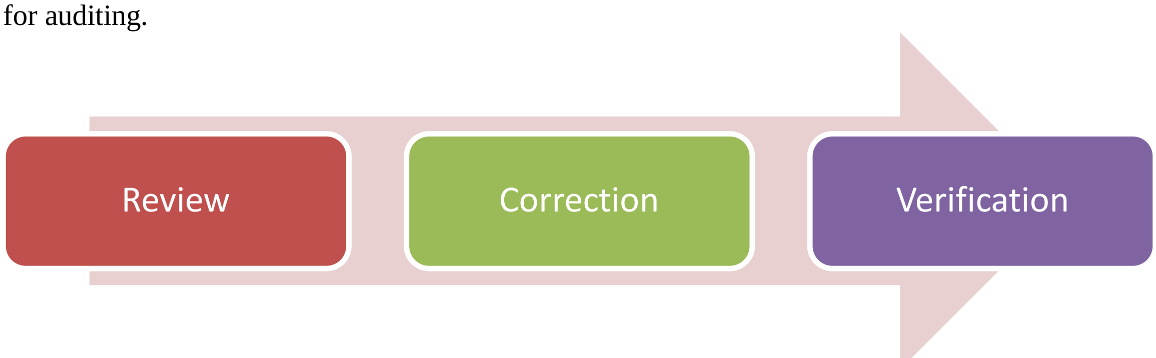


Figure 3.25 Quality control review process

For **reviewing** data, this study will provide data specifications (i.e., rules) to guide quality management (Table 3.7). This paper is focused on transportation projects such as routing, locating siting facilities, and analyzing service coverage over road networks. Therefore, the review process outlines criteria used in project plans and quality assurance plans. This task will be completed on business rules to manage the works. The business rules integrate attributes of features and topological relationships between features to validate the databases.

Table 3.7 Business rules for data reviewing

Category	Rules
Attribute	MTFCC should not be null.
	ROUTE_ID should not be null.
	HWY_SUFF00 should equal to HWY_SUFFIX & DIRECTION.
	FUNCTION_C should not be null.
	TRANSATT should not be null.
	ONEWAY should not be null.
	Speed cannot exceed 80 mph.
	Speed should be faster than 0 mph.
	Link length should not be 0.0 mile.
	If BRIDGE=1, BRIDGEITEM8 should have a string code.
Topology	Segments should not be dangle.
	A road crossing over multiple jurisdictions should be split at the border of the tribal area boundary.
	Local roads crossing each other should have a shared node (intersection)
	First. Roads crossing should be split at the intersection.
	Second. Roads should be connected to any terminal nodes of roads.
	Segments over a river should have a bridge code.
	Roads crossing over a state highway system and local roads should be connected, not overpassing.

The data checks will use the business rules to validate the road network data. The business rules will be checked with data reviewer checks. Then we set the configuration with data reviewer checks (Table 3.7) and then ran the data checks.

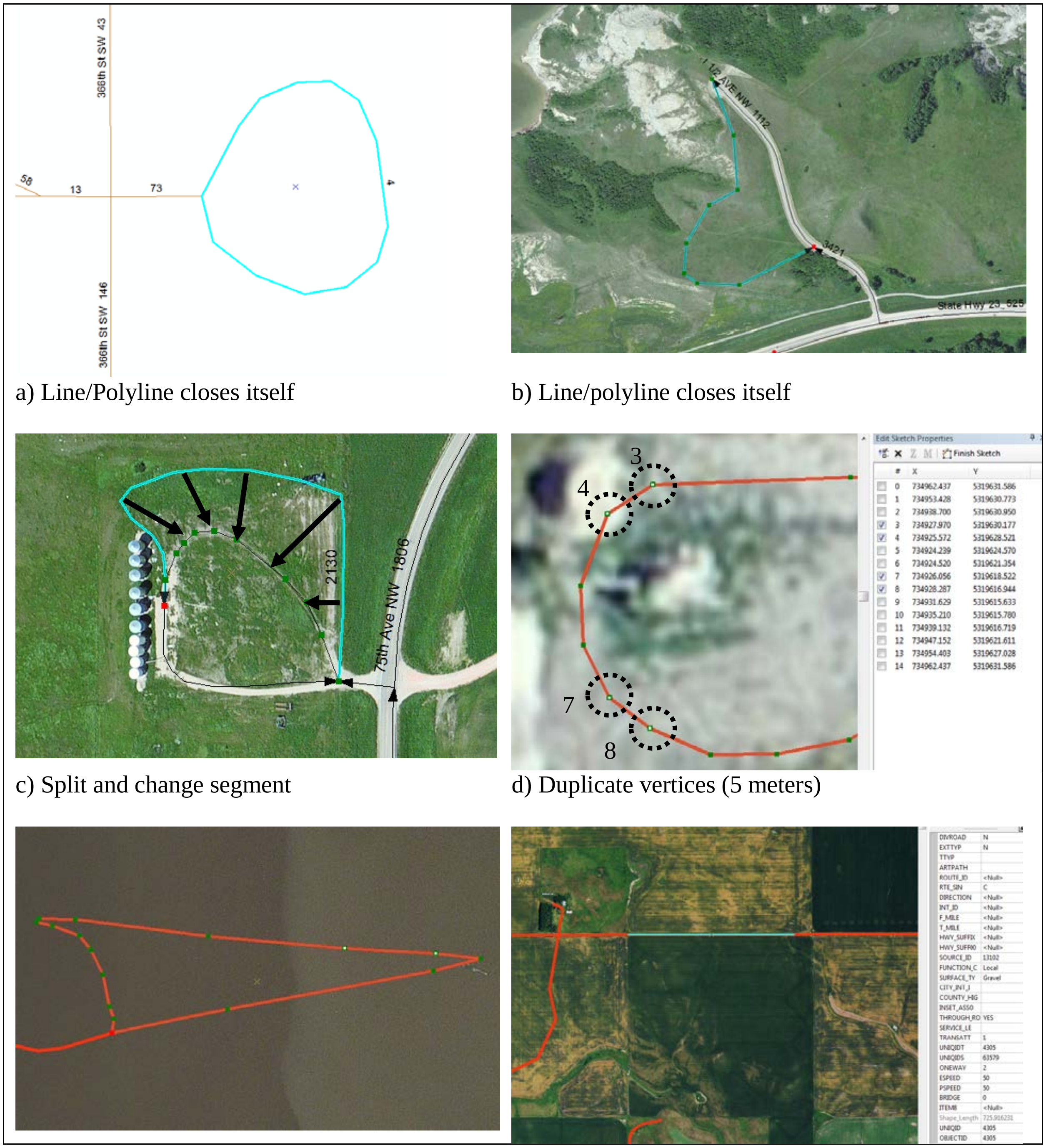
Table 3.8 summarizes the data check. This study checks six categories: default, duplicate geometry, feature-on-feature, polyline, table, and spatial parameter evaluation. Three types of default checks were applied. One of the checks find null, empty, and zero length links throughout the full database with severity of 1. Severity 1 has high priority among all the checks. Multiple line checks the links, which have more than one part throughout the full database with severity of 1. The item of polyline or path closes on self-searches-polyline that either touch or cross themselves through the dull database with severity of 1. Duplicate vertex checks vertices for features within 10 meters with a severity of 4. Intersection on geometry returns geometries for features in Feature Class 1 that intersect with the intersection of features from Features Class 2. Cutbacks checks the links with the angle between segments in a polyline is beneath 25 degrees. The reviewer also evaluates polyline length. The length of a segment should be more than one meter. SQL query was used to check attributes of the table. Using SQL query, the study validated if the PSPEED and ESPEED are larger than 0 and smaller than 80 miles per hour. UNIQDT should be also unique in the table. Sixteen bridges are found in the region. Some of them cross river and lake, so intersection of the water polygon and roads should be no more than two. The study also limits the number of vertices along a segment by 200. The items related to table check has low severity of 5.

Table 3.8 Selected data checks from data reviewer checks

Checks	Item	What	How	Severity
Default Checks	Invalid Geometry	Null, empty, zero length links	Full database	1
	Multipart Line	More than one part	Full database	1
	Polyline or Path Closes on Self	Polyline that either touch or cross themselves	Full database	1
Duplicate Geometry Checks	Duplicate Vertex	Returns vertices for features within a user-specified tolerance for selected polyline or polygon feature classes	Tolerance with 10 meters	4
Feature on Feature Checks	Intersection on Geometry	Returns geometries for features in Feature Class 1 that intersect with the intersections of features from Feature Class 2 and 3		3
Polyline Checks	Cutbacks	The angle between in a polyline is beneath a user defined minimum	Angle < 25^{o} through full database	3
	Evaluate Polyline length	The length of a segment is within specified parameter	Length < 1 meter through full database	3
Table Checks	Execute SQL	SQL Query	PSPEED<=0 and PSPEED>80	5
	Unique ID	Uniqueness within each field	UNIQDT through a shapefile	5
Spatial Parameter Evaluation Checks	Evaluate Intersection Count	Intersect either polygon features in River feature	Intersection>2	5
	Evaluate Vertex Count	Number of vertices within	Great than 200	5

Note: Severity 1 – high and 5 – low

After running the data check, the process found 202 features to fix. Some of the outputs are shown in Figure 3.26. The polylines from Figure 3.26a and 3.26b were closed by themselves. Figure 3.26a kept the original feature as it is, while Figure Figure 3.26b was split at the end of the dead end because half of the closed loop belonged to a local unpaved road and the other half belonged to a trail. Figure 3.26c shows an example of splitting and changing segments based on the base map. The loop was reconfigured to align to the image of the road by adjusting the existing vertices. Figure 3.26d shows the duplicate vertices using the 5-meter threshold. Vertices 3 and 4 are considered as the same points, and vertices 7 and 8 are also considered as the same location. Figure 3.26e indicates that the segment is a cutback, which turn back toward themselves (i.e., less than 25 degrees). So the segment that turns back toward the origin node should be removed or change its original shape. In this study, it remains as it is. However, in the near future, that should be fixed by a transportation engineer or GIS coordinator.



a) Line/Polyline closes itself

b) Line/polyline closes itself

c) Split and change segment

d) Duplicate vertices (5 meters)

e) Polyline cutback

f) Polyline length

Figure 3.26 Checks

4. RESULTS

A batch job found 674 errors using the data check rules. A single line was found violating the cutback check. In total, 473 duplicate vertex checks were reported, but they may be ignored for this study because the small-scale road network consumes such a small amount of computational time. Three violations were reported for the intersection count check. A single violation was reported for vertex count check. Twenty-four polylines were less than 1 meter. Interestingly, 172 closed polylines or paths were reported from the data check.

SQL queries reports no violation since the attributes were updated after conflation. More queries can be developed to check with more delicate rules.

Table 4.1 Automated Check Report by Group

Batch Job Group	Check Type	Check Title	Total Results
Default	Invalid Geometry Check	Invalid Geometry Check (Bridge data)	0
		Invalid Geometry Check (River data)	0
MHA Roads	Cutback Check	Polyline Cutback	1
	Duplicate Vertex Check	Duplicate Geometry - Vertex	473
	Evaluate Intersection Count Check	Spatial Parameter – Intersection Count	3
	Evaluate Vertex Count Check	Spatial Parameter – Vertex Count	1
	Evaluate Polyline Length Check	Polyline Length	24
	Execute SQL Check	Table SQL – PSPEED	0
		Table SQL – ESPEED	0
		Table SQL – Bridge	0
	Invalid Geometry Check	Default Multipart Check	0
	Polyline or Path Closes on Self Check	Default Closed Polyline	172
Total			674

Note: Reviewer Workspace Location at \MHA-DataReviewer.gdb and session identification of Session 1.

Note that the updated road network has several attributes to be updated frequently such as surface type and speed. The use of linear referencing systems (LRS) by the state agency is helpful in maintaining consistency throughout the database system. Statewide public roads are required to be reported in line with LRS for purposes of funding and asset management.

5. CONCLUSIONS

This study proposed a method to integrate multiple public road networks to support a tribal transportation agency. The workflows and techniques proposed are transferrable to other tribal transportation agencies. Depending on current data being used for transportation planning and operations, the workflow and processes are subject to change from agency to agency, but the study will provide general guidance for the agency. Once the road network is completed, it can be utilized in various ways such as ambulance coverage analysis (Lee, 2014), tourism management, and logistics analysis.

With the integrated road networks, the tribal transportation agency can develop bike lane management, ambulance service coverage analysis, truck-only lane management, road sign asset management, road maintenance management, and so on. The authors recommend that the agency develop LRSs on the proposed road network to adopt efficient asset management and version control. The LRS should comply with state or federal guidelines for improved communication. To develop an application in an appropriate manner, the road network should include additional attributes based on needs of the MHA nation.

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