RESEARCH

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Report No. UT-24.24

UTAH TRAVEL MODELS FREE-FLOW SPEED RESEARCH

Prepared For:

Utah Department of Transportation
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Final Report
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16. Abstract

Utah's six travel demand models (TDM) are essential tools for the state's transportation planning. Virtually every transportation plan and environmental study uses the TDMs to develop and evaluate transportation solutions, making the TDMs the most important transportation planning tool in the state. Currently, all of the TDMs employ a similar methodology to estimate link-level free-flow speeds which have been in use for more than 20 years. However, UDOT has never fully vetted this methodology and compared it to observed travel speeds in areas outside of the Wasatch Front metropolitan planning area. With accessible statewide speed data now available, UDOT can conduct this research with the goal of improving the accuracy of the TDMs.

The objective of this research is to determine the accuracy of the methodologies and data used to estimate free-flow speeds in the six Utah TDMs and recommend any improvements to those methodologies. The research team performed a comprehensive GIS-based comparison analysis of free-flow model speeds and observed free-flow speeds that were obtained from UDOT-owned datasets. These datasets were then joined to form a common dataset. The data was cleaned and then filtered based upon various data combinations including the TDM, roadway type, and area type. Researchers made several findings using the aggregate statistics created for these combinations.

Findings suggest a high variety in speed-difference results between the TDMs and real-world speeds in rural areas. Smaller models seem to perform better than larger, state-level models. Speed factors help to improve accuracy in the models. Some issues apparently exist in model functional types, which may warrant review. The research resulted in the development of a series of recommendations which may help enhance future TDM performance.

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UNIT CONVERSION FACTORS

SI* (MODERN METRIC) CONVERSION FACTORS				
APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. (Adapted from FHWA report template, Revised March 2003)

LIST OF ACRONYMS

AASHTO	American Association of State Highway and Transportation Officials
ANOVA	Analysis of Variance
ARC	Atlanta Regional Commission
CTC	County Transportation Commission
DOT	Department of Transportation
FHWA	Federal Highway Administration
FSTDM	Florida Statewide Travel Demand Model
FSUTMS	Florida Standard Urban Transportation Modeling Structure
GIS	Geospatial Information Systems
HCM	Highway Capacity Manual
HOV	High-Occupancy Vehicle
I	Interstate
ISTDM Indiana	Statewide Travel Demand Model
MAG	Mountainland Association of Governments
MPH	Miles Per Hour
MPO	Metropolitan Planning Organization
MWCOG	Metropolitan Washington Council of Governments
NCDOT	North Carolina DOT
NPMRDS	National Performance Management Research Data Set
SANDAG	San Diego Association of Governments
SCAG	Southern California Association of Governments
SegID	Segment Identification Number (from WFRC Master Segmentation Dataset)
SQL	Structured Query Language
TAC	Technical Advisory Committee
TOC	Traffic Operations Center
TRMSB	Triangle Regional Model Service Bureau
TRMT	Triangle Regional Model Team
UDOT	Utah Department of Transportation
USTM	Utah Statewide Travel Model
VMT	Vehicle Miles Traveled
WFRC	Wasatch Front Regional Council

EXECUTIVE SUMMARY

Utah's six travel demand models (TDM) are essential tools for the state's transportation planning. Virtually every transportation plan and environmental study uses the TDMs to develop and evaluate transportation solutions, making the TDMs the most important transportation planning tool in the state. Vehicle speeds are critical to the operation of TDMs. They heavily affect the distribution and assignment of trips which are fundamental components of the models. Having accurate model speeds is essential to producing accurate forecasts. Currently, all the models employ a similar methodology to estimate link-level free-flow speeds. This methodology was originally developed more than 20 years ago for the Wasatch Front Travel Demand Model. It is based on facility type (which includes assumptions regarding stops/mile) and area type (e.g., urban, rural, etc.) for arterials, collectors, and local roads. This methodology has largely focused on speeds on the Wasatch Front and not throughout the entire state. With accessible statewide speed data now available, UDOT can conduct research with the goal of improving the accuracy of the TDMs. This research included a comprehensive geospatial information system (GIS)-based comparison analysis of free-flow model speeds and observed free-flow speeds obtained from UDOT-owned datasets.

As part of this research a method and plan were developed to determine free-flow speeds that UDOT and the state's metropolitan planning organizations (MPOs) can subsequently implement into their TDMs. The plan includes minor modifications to the existing methodology, such as recommendations of the speed differences among area types. The work included evaluating directly asserting free-flow speeds via segment identifications (IDs) and the GIS speed database that will be developed as part of the research. The observed speed dataset includes peak period speeds so that the data could also be used for model calibration of congested speeds.

Observed speed data was obtained from the Iteris ClearGuide mobility platform via an agreement with UDOT to provide both live and historical speed data for the entire state. Iteris provided the research team with statewide speed data in five-minute bins for thousands of link segments for the month of October 2023. The ClearGuide link data was converted to a point file and spatially joined to a predefined travel-model master-segment GIS file, creating a common

field between it and the TDM free-flow speed data. This process included several instances of identifying join issues with the ClearGuide links and performing manual corrections to ensure the data was as correct as possible. This combined dataset was then joined with UDOT speed limit data which provided additional speed reference. The ClearGuide speeds dataset was likewise prepared and cleaned, primarily through the identification of speed outliers by using upper- and lower-bound thresholds. These outliers were then removed. After an analysis of the cleaned speed dataset, the hour with the fifth-highest speed of the day was selected to represent the free-flow speed. The ClearGuide speeds could then be associated with the ClearGuide links compared to the TDM free-flow speeds.

A speed-difference dataset was created which showed the difference between TDM and ClearGuide speeds organized by Segment Identification Number (SegID). The speed-difference dataset was then utilized to create several filtered combinations of data. Statistics were aggregated for these different filter combinations, providing an overview of data results. Aggregates suggest that average speed differences by model between TDM and ClearGuide speeds are generally close, though standard deviations indicate some improvements could be made to model speeds. Local roads experienced the most significant speed difference in statistics based on functional type; other functional types had closer speed differences. Scatterplots of model results show that TDM speeds are typically clustered around a certain speed value, while ClearGuide speeds are more dispersed and may see a wider range of speeds overall than the TDM data. Speed distributions for the smaller models were often similar in many respects.

1.0 INTRODUCTION

1.1 Problem Statement

Utah's six travel demand models (TDM) are essential tools for the state's transportation planning. Virtually every transportation plan and environmental study uses the TDMs to develop and evaluate transportation solutions, making the TDMs the most important transportation planning tool in the state. Vehicle speeds are critical to the operation of the TDMs. They heavily affect the distribution and assignment of trips which are fundamental components of the models. Having accurate model speeds is essential to producing accurate forecasts. Currently, all the models employ a similar methodology to estimate link-level free-flow speeds. This methodology was originally developed more than 20 years ago for the Wasatch Front TDM. It is based on facility type (which includes assumptions regarding stops/mile) and area type (e.g., urban, rural, etc.) for arterials, collectors, and local roads. However, UDOT has never fully vetted this methodology and compared it to observed travel speeds in areas outside the Wasatch Front. With accessible statewide speed data now available, UDOT can conduct this research with the goal of improving the accuracy of the TDMs. This research performed a comprehensive GIS-based comparison analysis of free-flow model speeds and observed free-flow speeds obtained from UDOT-owned datasets.

1.2 Objectives

The objective of this research was to determine the accuracy of the methodologies and data used to estimate free-flow speeds in the five Utah TDMs not affiliated with the Wasatch Front Regional Council (WFRC) and Mountainland Association of Governments (MAG) and recommend any improvements to those methodologies. Avenue Consultants (the research team) led this research by validating available data to observed and collected speeds; applying analysis using GIS and structured-query language (SQL)-based tools; and providing results. The work also included reviewing the state of Utah's current methods and best practices from other states.

1.3 Scope

The scope and work plan of this research study was divided into six principal tasks, as described below.

- Task 1– Project Management and Meetings: This task covered internal project management, including regular invoicing and progress reports, to ensure that the research was performed on schedule and within budget. This task also covered coordination with UDOT staff, the kickoff meeting, up to three technical advisory committee (TAC) meetings, and a final presentation meeting. The purpose of the kick-off meeting was to review the problem statement, discuss the study methodology, and to introduce members of the TAC to the research team. The purpose of the final meeting is to deliver the final presentation to a larger group as the final deliverable.

- Task 2 – Literature Review: The research team conducted a literature review of research on best practices for setting free-flow speeds as well as on how other Departments of Transportation (DOTs) and MPOs determine the vehicle free-flow speed in their models. As part of the literature review, the research team documented the current free-flow speed development methodology employed in the Utah models for use in the analysis, findings, and recommendations portions of the work. The findings were summarized and incorporated into the overall research report.

- Task 3 – Observed Speed Data Validation: The research team worked with the UDOT Traffic Management Division to gather vehicle speeds from ClearGuide. The validation was completed on varying roadway types to ensure that the ClearGuide data sufficiently represents the speeds on all types of roads found in the state’s TDMs. The work was conducted using GIS and SQL-based tools to apply, aggregate, and analyze the data. The research team provided a summary of the validation explaining the results and identifying any issues or concerns.

- Task 4 – Spatial Data Reconciliation: The state's TDMs and the ClearGuide speed data do not share segment definitions. Using GIS, the research team created a spatial relationship between the TDM highway networks and the observed speed data from ClearGuide This reconciliation allowed for further data analysis between TDM and ClearGuide free-flow speeds.

- Task 5 – Speed Data Analysis: The research team compared the observed speed data to the TDM free-flow speed data and conducted statistical analysis to identify and quantify how well the model data matches the observed data. The analysis included cross tabulations of multiple variables. The research team worked with the TAC to identify variables that would be analyzed for correlation with observed speeds. Variables considered included number of lanes, facility type, speed limit, area type, county, and traffic signal density. GIS was used to visualize many of the comparisons.

- Based on the findings of that analysis, the research team would recommend enhancements to improve the accuracy of the model's free-flow speed development methodology. The research team also considered the feasibility of asserting the free-flow speeds for existing roadways via the observed speed data (see section 6 for study recommendations).

- Task 6 – Documentation: The research team prepared this report document outlining the research process, including the literature review and recommendations crafted by the research team and TAC based on the findings of the analysis. This report includes a section on an implementation plan that documents details provided primarily by the Research Champion and TAC with input from the research team. The project team also prepared a final presentation for UDOT at the conclusion of the project.

1.4 Outline of Report

The outline of this report was created as follows:

- Section 2 provides a review of literature on the topic of setting free-flow speeds in TDMs, which is organized by a review of methods at other agencies and a review of scientific papers.
- Section 3 presents the processes and methods utilized for data collection.
- Section 4 presents an evaluation of collected data, with a review of findings from the data collection.
- Section 5 provides conclusions based upon the project findings.
- Section 6 outlines recommendations and the implementation plan.

2.0 RESEARCH METHODS

2.1 Overview

The research team completed a literature review on the topic of setting free-flow speeds in TDMs to identify details about existing TDMs. The findings from the literature review are presented in the two following sections: *Review of Methods at Other Agencies* and *Review of Scientific Papers*.

2.2 Review of Methods at Other Agencies

The team researched the methods used by a sample of agencies across the United States to determine their methodology for setting free-flow speeds for their TDMs. A survey of these nine agencies revealed the use of five separate methods: (1) lookup tables based on area type and functional type, (2) collection of real free-flow speeds on the roadway network, (3) custom formulas developed with statistical methods based on previously collected speed data, (4) variations on the posted speed limit, and (5) equations provided in the American Association of State Highway and Transportation Officials (AASHTO) Highway Capacity Manual (HCM). The following sections provide details on each of these five methods. The agencies from the survey included the following:

- Alameda County Transportation Commission (CTC)
- Atlanta Regional Commission (ARC)
- Florida Statewide Travel Demand Model (FSTDM)
- Indiana Statewide Travel Demand Model (ISTDM)
- Metropolitan Washington Council of Governments (MWCOG)
- North Carolina Department of Transportation (NCDOT)
- Ohio Department of Transportation (ODOT)
- Oregon Department of Transportation (ORDOT)

2.2.1 Southern California Association of Governments (SCAG) Lookup Tables

One of the more common methods used by other agencies is the use of lookup tables that are developed based on a segment's functional type (e.g., collector, arterial, etc.) and the area type (e.g., rural, suburban, etc.).

The Metropolitan Washington Council of Governments developed six area types that vary in population and employment density as shown in Figure 2.1. MWCOG then developed a lookup table of free-flow speeds for all combinations between its six area types and seven functional types as shown in Figure 2.2 (National Capital Region Transportation Planning Board, 2023).

Table 31 Area type codes, based on population and employment density

One-Mile "Floating" Population Density (Pop/Sq mi)	One- mile "Floating" Employment Density (Emp/Sq mi)						
	0-100	101-350	351-1,500	1,501-3,550	3,551-13,750	13,751-15,000	15,001+
0-750	6	6	5	3	3	3	2
751-1,500	6	5	5	3	3	3	2
1,501-3,500	6	5	5	3	3	2	2
3,501-6,000	6	4	4	3	2	2	1
6,001-10,000	4	4	4	2	2	2	1
10,000-15,000	4	4	4	2	2	2	1
15,001+	2	2	2	2	2	1	1

Figure 2.1 MWCOG Area Types

Table 93 Lookup table: Highway link speeds in free-flow conditions (mph)

		Area Type					
		1	2	3	4	5	6
0	Centroid Connectors	17	17	23	29	35	40
1	Freeways	63	63	69	69	75	75
2	Major Arterials	40	40	52	52	58	58
3	Minor Arterials	40	40	46	46	46	52
4	Collectors	35	35	35	40	40	40
5	Expressways	52	52	58	58	58	63
6	Ramps	23	23	35	35	40	58

Ref: "I:\ateam\docum\fy21\Verson24Development\travel_model_user_guide\ver2.4_highway_link_lookupTables_capacity_speed.xlsx"

Figure 2.2 MWCOG Network Free-Flow Speeds

The Alameda CTC has ten unique facility types, with some broken into subgroups, and six area types. Figure 2.3 and Figure 2.4 show the lookup free-flow speeds for each facility type/area type combination. Alameda CTC documents that it intentionally stayed away from completely “free flow” speeds and instead opted for speeds that “can be thought of as the ‘11:00 P.M.’ speed, when there are few conflicts with other vehicles, but signals are still operating normally at intersections” (Kittleson & Associates, 2019).

Table 4: Speeds and Capacities, Standard Road Types

Facility Type	Area Type	Typical Speed[1] (mph)	Capacity (pce[2] per lane per hour)
Freeway-Freeway (1)	Core/CBD (0,1)	40	1,850
	UBD/Urban (2,3)	45	1,950
	Suburban/Rural (4,5)	50	2,000
Freeway (2)	Core/CBD (0,1)	55	2,050
	UBD/Urban (2,3)	60	2,100
	Suburban/Rural (4,5)	65	2,150
Expressway/Highway (3)	Core/CBD (0,1)	40	1,450
	UBD/Urban (2,3)	45	1,600
	Suburban (4)	50	1,650
	Rural (5)	55	1,650
Collector (4)	Core (0)	10	600
	CBD (1)	15	650
	UBD (2)	20	700
	Urban (3)	20	650
	Suburban (4)	30	900
	Rural (5)	35	950
Freeway Ramp (5)	Core (0)	30	1,450
	CBD (1)	30	1,500
	UBD/Urban (2,3)	35	1,550
	Suburban/Rural (4,5)	40	1,550
Connector (6)	Core (0)	5	No limit
	CBD (1)	10	No limit
	UBD (2)	15	No limit
	Urban (3)	20	No limit
	Suburban (4)	25	No limit
	Rural (5)	30	No limit
Arterial (7)	Core (0)	20	900
	CBD (1)	25	950
	UBD/Urban (2,3)	30	1,000
	Suburban (4)	35	1,050
	Rural (5)	40	1,050

Notes:

[1]Within Alameda County, individual speeds may be coded for each road segment.

[2]pce = passenger car equivalents, calculated as Heavy Trucks * 2.0 + Medium Trucks *1.5 + All Other Vehicles

Figure 2.3 Alameda CTC Network Free-Flow Speeds for Standard Road Types

Table 5: Speeds and Capacities, Special Road Types

Facility Type	Area Type	Typical Speed[1] (mph)	Capacity (pce[2] per lane per hour)
Metered Ramp (8)	Core/CBD (0,1)	25	750[3]
	UBD/Urban (2,3)	30	900[3]
	Suburban/Rural (4,5)	35	1,000[3]
TOS[4] Freeway (9) (TOS=1)	Core/CBD (0,1)	55	2,100
	UBD/Urban (2,3)	60	2,150
	Suburban/Rural (4,5)	65	2,200
Managed Freeway (2)[5] (TOS=2)	Core/CBD (0,1)	55	2,150
	UBD/Urban (2,3)	60	2,200
	Suburban/Rural (4,5)	65	2,250
Golden Gate Bridge (9)	n/a	50	1,950
TOS[4] Freeway-Freeway (9)	Core/CBD/UBD/Urban (0-3)	45	2,000
	Suburban/Rural (4,5)	50	2,000
TOS[4] Expressway (10)	Core/CBD (0,1)	40	1,500
	UBD/Urban (2,3)	45	1,650
	Suburban/Rural (4,5)	55	1,700
SC[6] Arterial (10)	Core/CBD (0,1)	25	1,000
	UBD/Urban (2,3)	30	1,050
	Suburban/Rural (4,5)	40	1,100

Notes:

[1]Within Alameda County, individual speeds may be coded for each road segment.

[2]pce = passenger car equivalents, calculated as Heavy Trucks * 2.0 + Medium Trucks *1.5 + All Other Vehicles

[3]Within Alameda County, individual metered capacities may be coded for each ramp and peak period.

[4]TOS = Traffic Operations Systems (ramp metering, etc...)

[5]Managed freeways (adaptive ramp metering, corridor management, etc...) designated as FT= 8 and TOS=2 in MTC Model One.

[6]SC = Signal coordination

Figure 2.4 Alameda CTC Network Free-Flow Speeds for Standard Road Types

The ARC has 19 facility types and seven area types that are combined to form groups for free-flow-speed lookup values as shown in figure 2.5 (Atlanta Regional Commission, 2019a). The Commission documents that if observed speed data is available, then a segment's model free-flow speed should be set as the average between the value in the lookup table and the observed free-flow speed as will be described in the "Real Free-Flow Speeds" section (Atlanta Regional Commission, 2019b).

Table 6-8 Free-Flow Speeds

NAME	FACTYPE	ATYPE1	ATYPE2	ATYPE3	ATYPE4	ATYPE5	ATYPE6	ATYPE7
centroid connector	0	7	11	11	11	11	14	14
interstate/freeway	1	62	63	63	63	64	65	66
expressway	2	43	46	49	52	55	58	61
parkway	3	43	46	49	52	55	58	61
freeway HOV (concurrent)	4	64	65	65	65	66	67	68
freeway HOV (barrier sep)	5	64	65	65	65	66	67	68
freeway truck only	6	62	63	63	63	64	65	66
system to system ramp	7	50	50	50	55	55	55	55
exit ramp	8	50	50	50	50	50	50	50
entrance ramp	9	50	50	50	50	50	50	50
principal arterial	10	23	26	31	35	41	48	53
minor arterial	11	21	26	29	33	38	43	48
arterial HOV	12	21	26	29	33	38	43	48
arterial truck only	13	21	26	29	33	38	43	48
collector	14	17	23	24	26	30	35	45
Transit Only: Neighborhood Local	50	12	12	12	12	12	12	12
Transit Only: Locals and Collectors	51	20	20	20	20	20	20	20
Transit Only: PNR lot connector	52	20	20	20	20	20	20	20
Transit Only: Transfer between rail and bus	53	20	20	20	20	20	20	20

Note: ATYPE1-CBD; ATYPE2-Urban Commercial; ATYPE3-Urban Residential; ATYPE4-Suburban Commercial; ATYPE5-Suburban Residential; ATYPE6-Exurban; ATYPE7-Rural

Figure 2.5 Atlanta Regional Commission Network Free-Flow Speeds

The SCAG includes the posted speed limit alongside functional class and area type in its lookup table. As shown in Figure 2.6, the lookup free-flow speed for freeways, high-occupancy vehicle (HOV) lanes, and expressways is 5 MPH plus the posted speed limit. The remaining freeway-related functional classes do not include speed limits as these facilities often have no posted speed limit. Arterials and Collectors have a lookup free-flow speed for all combinations between the three variables (area type, functional class, and posted speed) as shown in Figure 2.7 (SCAG, 2016).

Table 4-1: Year 2012 Freeway/Expressway Free-Flow Speed

Functional Class	AT1	AT2	AT3	AT4	AT5	AT6	AT7
Freeway	PS+5	PS+5	PS+5	PS+5	PS+5	PS+5	PS+5
HOV	PS+5	PS+5	PS+5	PS+5	PS+5	PS+5	PS+5
Expressway (Limited Access)	PS+5	PS+5	PS+5	PS+5	PS+5	PS+5	PS+5
Fwy-Fwy Connector	45	45	50	50	55	55	55
On-Ramp (peak)	15	15	20	20	30	35	35
On-Ramp (off-peak)	25	25	30	30	35	35	35
Off-Ramp	25	25	30	30	35	35	35

Notes:
AT1: Core — *AT3: Urban Business District* — *AT5: Suburban* — *AT7: Mountain*
AT2: Central Business District — *AT4: Urban* — *AT6: Rural* — *PS = Posted Speed*

Figure 2.6 SCAG Network Free-Flow Speeds for Freeways

Table 4-2: Year 2012 Arterial Free-Flow Speed

Posted Speed	AT1	AT2	AT3	AT4	AT5	AT6	AT7
				-- Principal Arterial --			
20	21	22	22	24	25	27	27
25	23	24	25	27	28	31	31
30	25	26	27	29	31	34	34
35	27	28	29	32	35	38	38
40	28	30	32	34	37	41	41
45	30	32	34	37	40	45	45
50	33	35	37	41	45	51	51
55	34	38	39	44	49	56	56
				-- Minor Arterial --			
20	19	20	21	23	24	27	27
25	21	22	23	25	27	30	30
30	22	24	25	28	30	34	34
35	24	26	27	30	33	37	37
40	25	28	29	32	36	41	41
45	27	29	31	34	38	44	44
50	29	32	33	38	43	50	50
55	30	33	35	40	46	55	55
				-- Major Collector --			
20	17	18	19	21	23	26	26
25	18	20	21	23	26	30	30
30	19	21	22	25	28	33	33
35	20	22	24	27	31	36	36
40	21	24	25	28	33	39	39
45	22	25	26	30	35	43	43
50	23	27	28	33	39	48	48
55	24	28	30	35	42	52	52

Notes: *Add 4% for divided streets*
AT1: Core — *AT4: Urban* — *AT7: Mountain*
AT2: Central Business District — *AT5: Suburban*
AT3: Urban Business District — *AT6: Rural*

Figure 2.7 SCAG Network Free-Flow Speeds for Arterials

Although the free-flow speeds differ among them, the agencies that use lookup tables agree that the free-flow speed increases as segments move into rural areas and as the segment access is more controlled/limited. Within the documentation, no rationales for the lookup free-flow speeds are provided; the origin of the values can only be inferred.

2.2.2 Real Free-Flow Speeds

Using collected free-flow speeds is another method that some of the surveyed agencies use to set free-flow speeds.

As mentioned in the previous section, the Atlanta Regional Commission chooses to set free-flow speed equal to the average of the lookup value and observed free-flow speed if observed speeds are available. The particular observed speeds the Commission uses are the "early AM period speeds" from a federally provided dataset called the National Performance Management Research Data Set (NPMRDS), which uses probe vehicle data to obtain speeds ("NPMRDS Analytics") (Atlanta Regional Commission, 2019b).

ODOT states that its preferred method to collect free-flow speeds is also using the Probe Data Analytics Suite (part of NPMRDS) or StreetLight Insight, specifying that the "50th percentile speeds on the study corridor between 6:00 AM and 10:00 AM averages on Saturdays and Sundays between April and October (to ensure daylight hours) should be considered as free-flow speeds" (Ohio DOT, 2023).

ORDOT documents that its preferred method of setting free-flow speeds is to measure it, though the department has other options if collecting speed data is not possible or feasible (to be discussed in later sections). ORDOT defines the free-flow speed as "the average vehicle speed measured during low-volume periods (e.g., 500 passenger cars per hour, per lane [pc/h/lane] or less), with good weather and no work activity or incidents." The department also specifies that speeds from continuous-count sensors are preferred over those from continuous probe data, which is preferred over speeds from short-term speed studies (Oregon DOT, 2018).

2.2.3 Custom Formulas

Compared to the models in the previous section, the Indiana Statewide Travel Demand Model (ISTDM) collects free-flow speeds for only a selection of its roadways (a total of 64 locations). The ISTDM ran Analysis of Variance (ANOVA) tests on the data to look for statistically significant differences in free-flow speeds based on a few different roadway characteristics. Finding statistical significance, the ISTDM developed nonlinear regression models for a variety of facility types. As shown in Figure 2.8, the ISTDM has separate models (equations) for combinations of facility type, rural/urban type, and posted speed limit range. Each equation requires the input of only the posted speed limit (Bernardin, Lochmueller & Associates, Inc., 2006).

Table 2. Free-Flow Speed Estimation Formula

Area Type	Free-Flow Speed [1, 2]	Condition	Note
2-lane 2-way undivided highways			
Rural	$0.009751 \cdot PSPD^2 + 30.03397$	$25 \le PSPD \le 55$	No or Partial Access Control
	25	$PSPD < 25$	
Suburban	$117.640917 \cdot PSPD^{0.0015+0.001279 \cdot PSPD} - 98.065483$	$25 \le PSPD \le 55$	
	25	$PSPD < 25$	
Urban	$6.189 + 0.9437 \cdot PSPD$	$25 \le PSPD \le 55$	
	25	$PSPD < 25$	
2-lane 2-way divided highways			
Rural	$\left(0.000017 \cdot (PSPD - 72.323105)^2 + 0.019702\right)^{-1} + 19.835323$	$25 \le PSPD \le 55$	No Access Control
	25	$PSPD < 25$	
Suburban	$3.180682 \cdot PSPD^{0.857638} - 84.105587 \cdot e^{-41.803252/PSPD}$	$25 \le PSPD \le 55$	
	25	$PSPD < 25$	
Urban	$(0.119687 - 0.023365 \cdot \ln(PSPD))^{-1} + 0.373821 \cdot PSPD$	$25 \le PSPD \le 55$	
	25	$PSPD < 25$	
Multilane undivided highways			
Rural	$\left(0.000017 \cdot (PSPD - 72.323105)^2 + 0.019702\right)^{-1} + 19.835323$	$25 \le PSPD \le 65$	
	25	$PSPD < 25$	
Suburban	$3.180682 \cdot PSPD^{0.857638} - 84.105587 \cdot e^{-41.803252/PSPD}$	$25 \le PSPD \le 55$	
	25	$PSPD < 25$	
Urban	$(0.119687 - 0.023365 \cdot \ln(PSPD))^{-1} + 0.373821 \cdot PSPD$	$25 \le PSPD \le 55$	
	25	$PSPD < 25$	
Multilane divided highways			
Rural	$2.836165 \cdot PSPD - 0.071256 \cdot PSPD^2 + 0.000744 \cdot PSPD^3$	$25 \le PSPD \le 50$	No or Partial Access Control
	$16.0359 + 0.8223 \cdot PSPD$	$50 < PSPD \le 65$	
	25	$PSPD < 25$	
Suburban	$\left(0.000071 \cdot (PSPD - 64.166165)^2 + 0.035258\right)^{-1} + 9.061039 \cdot \ln(PSPD)$	$25 \le PSPD \le 55$	
	25	$PSPD < 25$	
Urban	$(0.081714 - 0.016217 \cdot \ln(PSPD))^{-1}$	$25 \le PSPD \le 55$	
	25	$PSPD < 25$	
Full access controlled multilane highways			
All	64.00	$PSPD = 55$	
	67.06	$PSPD = 60$	
	70.21	$PSPD = 65$	
	73.30	$PSPD = 70$	

Note: [1] Free-flow speeds in mph, [2] PSPD: Posted speeds in mph
Source: Bernardin, Lochmueller & Associates, Inc., 2004

Figure 2.8 ISTDM Network Free-Flow Speed Equations

2.2.4 Posted Speed Limit

Another of the more common methods used by surveyed agencies is using a variation of the speed limit to define free-flow speed.

For example, the FSTDM uses the posted speed limit as its free-flow speed in its statewide model (Florida DOT, 2018). The ORDOT uses the speed limit plus 5 MPH (or, in the case of a segment with a curve-advisory speed sign, the advisory speed limit plus 5 MPH) if its other preferred methods (directly collecting free-flow speed, and estimating using HCM equations) cannot be used (Oregon DOT, 2018). Similarly, and as briefly mentioned in an earlier section, the SCAG uses the posted speed plus 5 MPH for freeway mainline, HOV lane, and expressway free-flow speeds (SCAG, 2016).

2.2.5 HCM Equations

ORDOT uses HCM 7th Edition Equations 12-2 and 12-3 to estimate the free-flow speed based on roadway characteristics if directly collecting free-flow speed data is not possible. It was not stated explicitly if ORDOT uses default HCM values when necessary data is not available.

For the base free-flow speed in these equations, ORDOT states that it "is taken to be the design speed (if available) or can be estimated as the speed limit plus 5 MPH (for speed limits ≥50 MPH) or the speed limit plus 7 MPH (for speed limits <50 MPH). If the segment contains one or more horizontal curves with an advisory speed less than the speed limit, use the lowest advisory speed as the base [free-flow speed]" (Oregon DOT, 2018).

North Carolina DOT originally used variations on the speed limit to set free-flow speed, but then decided to research other methods, explaining that the motivation to change was that "area types and link attributes [were] not considered, and intersection delay [was] not explicitly considered for arterials, collectors, and local streets" (Triangle Regional Model Service Bureau [TRMSB] and Triangle Regional Model Team [TRMT], 2016). NCDOT surveyed six other models and found that three used lookup tables, one used custom equations, and two used HCM equations. NCDOT opted to base its free-flow speeds on HCM methods, electing to use default values for roadway attributes in the equations whenever it did not have corresponding data. For example, to set freeway free-flow speeds, NCDOT used the default values for lane width (12 feet) and lateral clearance (6 feet) but calculated the total ramp density throughout the model (TRMSB and TRMT, 2016).

2.3 Review of Scientific Papers

In searching the literature on the topic of setting free-flow speeds for TDMs, two research studies of note were found and are described in the following subsections.

2.3.1 FSUTMS Study

Florida DOT conducted a study in 2013 that, in part, researched the free-flow speeds for the Florida Standard Urban Transportation Modeling Structure (FSUTMS) and recommended a lookup table for free-flow speeds on uninterrupted facilities based on number of lanes, speed limit, urban/rural area type, and toll/non-toll type. Florida DOT researchers gathered speed data from permanent count stations around the state of Florida, filtered that data for free-flow speeds only (defined by 200 pc/h/lane or less and 5 passenger cars per mile per lane [pc/mi/lane] or less), and then took the 85th percentile of those free-flow speeds. The researchers applied a linear regression model to the data and then used that model to predict the free-flow speed for the combinations of number of lanes, speed limit, and urban/rural type for which they did not have permanent count stations. Their resultant recommended lookup table is displayed in Figure 2.9, where the numbers in red are the predicted values determined using the linear regression model (Moses et al., 2013). It is unknown if the proposed lookup table was ever implemented in a Florida model; the documentation which stated that the Florida Statewide Model defines free-flow speed as the speed limit was updated in 2018, while the research described here was published in 2013.

Table 1. Recommended Free Flow Speeds

Area type	Non-toll Uninterrupted Flow Facilities				Toll Facilities			
	2-Lanes	3-Lanes	4-Lanes	5-Lanes	2-Lanes	3-Lanes	4-Lanes	5-Lanes
Speed Limit = 55 MPH								
Urban	64	65	64	70	65	67	63	69
Residential	63	65	67	67	73	65	67	67
Rural	67	68	68	69	67	68	68	69
Speed Limit = 60 MPH								
Urban	66	66	67	67	69	66	67	67
Residential	68	68	69	69	68	68	69	69
Rural	69	70	70	71	69	70	70	71
Speed Limit = 65 MPH								
Urban	68	67	69	69	68	76	69	69
Residential	70	72	71	70	70	68	71	73
Rural	71	72	72	73	77	72	72	73
Speed Limit = 70 MPH								
Urban	70	70	71	71	70	70	71	71
Residential	73	74	72	73	79	78	77	73
Rural	74	74	74	75	74	78	74	75

Figure 2.9 FSUTMS Research Recommended Network Free-Flow Speeds

2.3.2 SANDAG Sensitivity Tests

While the literature described to this point primarily noted methods for setting free-flow speed, there has also been research on the sensitivity of free-flow speed. The San Diego Association of Governments (SANDAG) performed two sensitivity tests on its TDM's free-flow speed, although documentation on how SANDAG defines free-flow speed was not located. In the first test, SANDAG decreased the freeway free-flow speed by 5 MPH at all freeway locations. SANDAG found that in the model, overall, "VMT (Vehicle Miles Traveled) decreased by nearly 0.5%," there were "insignificant mode share changes," and the "average trip distance decreased slightly from 7.3 miles to 7.2 miles" (SANDAG, 2020). In the second test, SANDAG decreased all free-flow speeds by 5 MPH in all locations. The results of that model indicated that, overall, "VMT decreased by nearly 1.3%," there were "insignificant mode share changes," and the "average trip distance decreased slightly from 7.3 miles to 7.2 miles" (SANDAG, 2020). From these results, a DOT may conclude that changes in VMT and trip length will follow the direction of changes in free-flow speed, though practical significance also needs to be considered.

2.4 Summary

From research of the literature, five methods of setting free-flow speeds were found: lookup tables based on area type and functional type, collection of real free-flow speeds on the roadway network, custom formulas developed with statistical methods based on previously collected speed data, variations on the posted speed limit, and equations provided in the AASHTO HCM. Several agencies listed a hierarchy of preferred methods for determining free-flow speed, which often recommended directly collecting the data from count stations and/or taking advantage of federally provided data from probe vehicles instead of using pre-determined tables or variations on the speed limit. Despite the data intensity of HCM methods, a few agencies recommend using HCM equations and providing back-up methods if the required data is unavailable (ranging from using default HCM values to using a different method entirely). One agency performed a sensitivity test in its free-flow speeds, finding that decreases in the free-flow speed affected the network VMT by less than 1.5 percent. The minimal nature of that effect may be the reason that some agencies recommend using simpler means of estimating free-flow speed (such as lookup tables or variations on speed limit) when the data needed for more complicated methods (such as HCM equations or directly collecting the free-flow speed) are not available. Overall, it appears that agencies agree that the more accurate a method is, the more data-intensive it will be, and that data intensity comes at a cost that requires balance against the potential usefulness that the more accurate free-flow speeds could bring to the model's performance.

3.0 DATA COLLECTION

3.1 Overview

To conduct the analyses performed in this study, the research team collected several datasets which included information on free-flow speeds and roadway segments. These were sourced from organizations such as the WFRC and programs such as Iteris ClearGuide. These datasets were cleaned, prepared, and joined in various processes to create a comparison between recorded TDM free-flow speeds and observed free-flow speeds. Several tools were utilized for this process, enabling the research team to clean and prepare data for further analysis. During this process, challenges present in the data were identified and overcome, allowing for data to be reconciled successfully to the needs of the study.

3.2 Datasets and Tools

Five data sources and their subsequent datasets were primarily utilized in this study for free-flow speed comparison. The following datasets were utilized throughout the data analysis process.

- ClearGuide Speed Data
    - A large ClearGuide dataset for October 2023, which contains speed data in five-minute intervals, obtained from ClearGuide probe data along routes throughout Utah. The speed data was aggregated up to one-hour intervals.
    - Source: Iteris.
- ClearGuide Link Data
    - ClearGuide link data consisted of a shapefile which contains the location of ClearGuide link segments across Utah.
    - Source: Iteris.

- Utah TDM Data
    - Data from Utah TDMs in the form of a shapefile containing estimated free-flow speeds. The links include segment IDs to allow for aggregation to the Utah master segments.
    - Source: UDOT/Utah MPOs.
- Utah Master Segmentation Data
    - A shapefile which contains roadway segments throughout Utah with associated SegIDs.
    - Source: UDOT/WFRC.
- UDOT Speed Limit Data
    - A shapefile which contains posted speed limits along state-managed routes.
    - Source: UDOT Data Portal.

Among them, these datasets contained the information to allow for an effective comparison between the current TDM data speeds and observed free-flow speeds from ClearGuide. In this study, the TDM dataset speeds were compared to the ClearGuide speed data by joining ClearGuide link segments to a corresponding master segment ID (referred to in this report as a SegID) from the master segmentation data. UDOT speed limit data was also joined to a SegID to provide a benchmark of which posted speed limits would be expected. The TDM data and ClearGuide link data were then joined based on the SegID. Finally, the ClearGuide speed data was joined to the corresponding ClearGuide links, allowing the research team to measure the comparison between TDM and ClearGuide free-flow speeds.

3.2.1 Tools

At various points in the research, the team utilized several tools to collect, clean, prepare, and evaluate data for this study. The team utilized the tool deemed best to provide solutions to the various steps carried out in this study. These tools included the following:

- ArcGIS Pro: utilized to perform joins based on geospatial location, and to identify and troubleshoot some data errors.
- Big Query/Google Cloud Storage: utilized to work with the large ClearGuide dataset for this study. Google Cloud Storage was utilized to store large amounts of data, and Big Query using SQL was used to run data processing on the stored information.
- R Programming Language: utilized for occasional joins and related cleanup activities conducted on the ClearGuide speeds dataset.
- Microsoft Access: was utilized for certain data joins, to process the ClearGuide link and TDM datasets, and to calculate differences between free-flow speeds.
- Microsoft Excel: utilized for processing and handling dataset imports and exports from ArcGIS Pro. Excel was also utilized to perform calculations related to the ClearGuide speeds dataset, and to visualize data.

3.3 GIS Data Preparation and Processing

GIS data preparation and processing formed an integral part of this study. GIS data was utilized to assign SegIDs to each link of ClearGuide data, which could then be compared to TDM data by using the SegIDs. Speed-limit data was also joined to the other speed data in GIS. The following sections describe the procedures utilized to prepare GIS data in this study.

3.3.1 ClearGuide Link Data Processing in GIS

The ClearGuide link speed dataset and WFRC master segmentation dataset were obtained from their respective sources and imported to an ArcGIS Pro project. These datasets consisted of shapefiles with associated geospatial associations. To allow for the eventual comparison of ClearGuide free-flow speeds against TDM speeds, a common field was assigned to each to join the data accurately. TDM data contains a SegID field corresponding to the master segmentation data. If a SegID could be joined to the ClearGuide data, the ClearGuide speeds dataset could later be tied to the ClearGuide link data and corresponding SegID, creating a common field across the various datasets. ArcGIS Pro’s geoprocessing functions were utilized to perform a spatial join between the ClearGuide link data and the WFRC master segments, assigning a SegID to each ClearGuide link segment.

Before this could be performed, the research team recognized that potential join issues could occur, particularly where various ClearGuide segments converged with a single master segment, or where ClearGuide segments fell outside the join range performed in ArcGIS Pro. To help reduce join issues, the ‘Generate Points Along Lines’ function was performed on ClearGuide segments. This function generates a point feature in place of a line feature, while maintaining data from the original line feature. The resulting dataset contained all ClearGuide links in the form of points, which could be joined more accurately to the master segments while avoiding issues common to spatial joins. Figure 3.1 illustrates a sample of the results of this process.

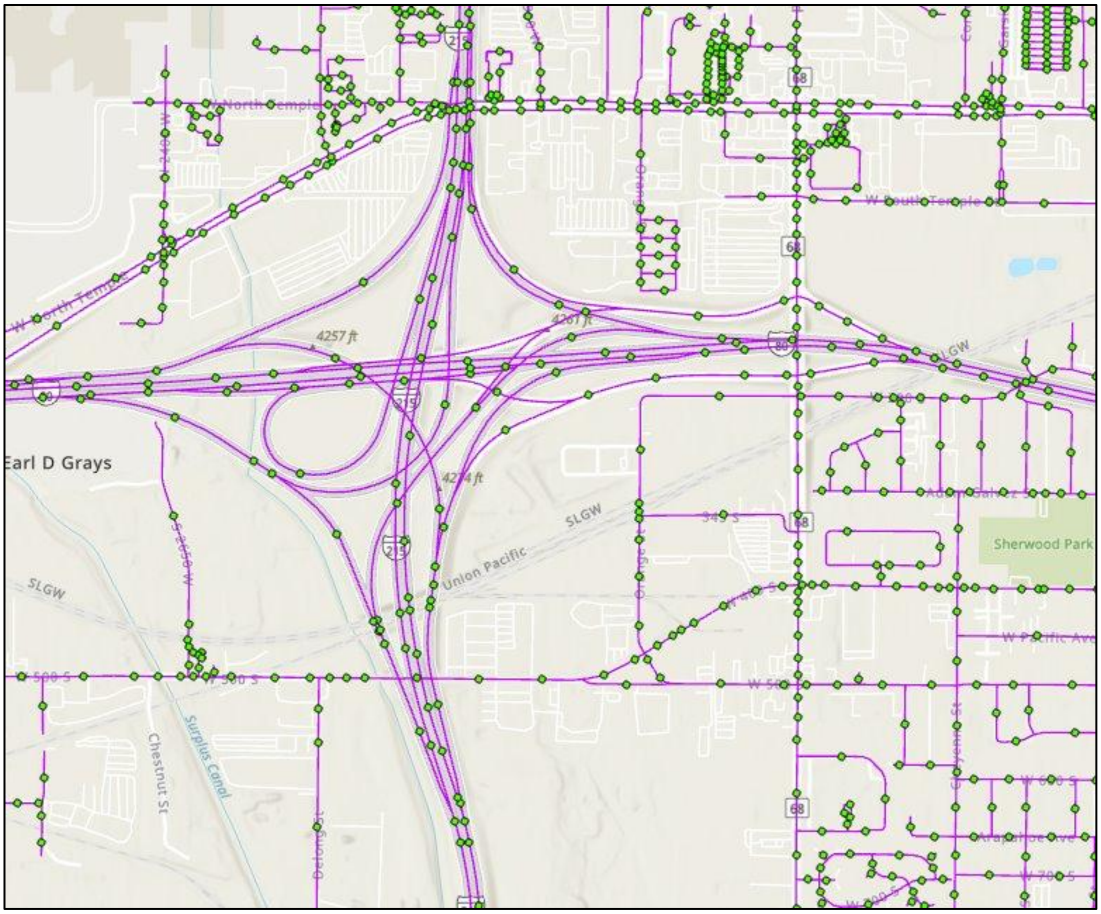

Figure 3.1 ClearGuide Points vs. Original Line Segments

After the ClearGuide link data was converted to points, the ClearGuide link data was joined to master segments using a special join. This assigned each segment of ClearGuide data with a SegID, creating a common field between ClearGuide and TDM data.

3.3.2 Manual Adjustment and Cleaning of ClearGuide GIS Data

The research team identified that some issues pertaining to the spatial join occurred after it was performed on the ClearGuide data in ArcGIS Pro. This was observed primarily by identifying where ClearGuide speeds were very low or high compared to the roadway type. The research team identified several samples where ClearGuide speeds appeared incorrect and manually examined them. The team identified that the primary issue occurred in locations where freeways or other large roadway functional classes (e.g., highways and expressways) were crossed by a roadway with a lower functional classification (e.g., an arterial road). In these instances, the spatial join occasionally assigned the cross-street speed to a freeway SegID, or vice-versa, resulting in mismatched speeds. Another instance included nearby frontage roads or side streets being incorrectly assigned freeway speeds. Also, several ClearGuide link points associated with freeway ramps were assigned freeway SegIDs.

To resolve these issues, the research team conducted a manual check of ClearGuide data points along freeway corridors and other large roadways in ArcGIS Pro. Most of the joins were correct; in areas where incorrect joins were found, the data was manually adjusted. This consisted of changing SegIDs in the ClearGuide link points to ensure they had the correct SegIDs associated with them. Although most of the mismatches occurred in locations where cross streets intersected freeways or other high-capacity roadways, in some cases the spatial join 'missed' or excluded certain ClearGuide points from the initial join. In these cases, the correct SegID was added to the missing points. Another issue the team identified was that in several locations on the Interstate 15 (I-15) corridor, the SegID to the north or south of the ClearGuide point had been assigned instead of the SegID that directly corresponded to it. Although these instances did not create a speed discrepancy, they were also manually adjusted. Figures 3.2 through 3.5 display examples of data adjustment.

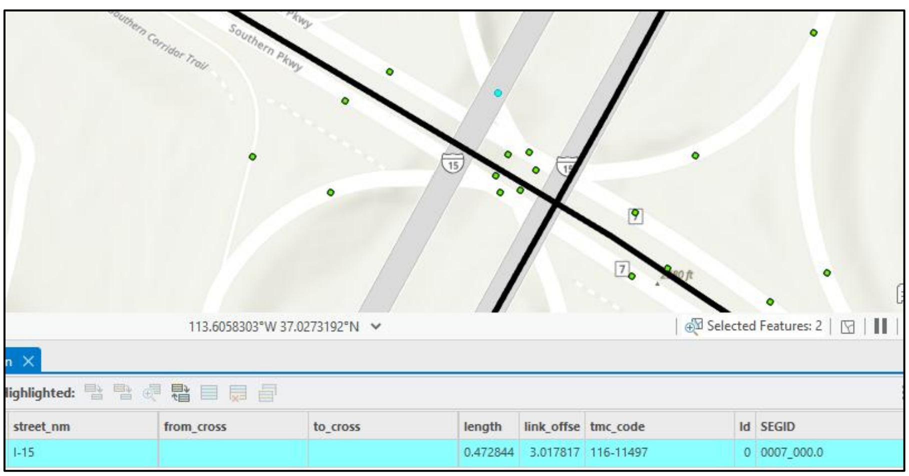

Figure 3.2 Sample of Erroneous ClearGuide Data

Figure 3.2 displays an I-15 ClearGuide link point in St. George that was erroneously joined with the SegID for Southern Parkway (SegID 0007_000.0) which crosses I-15 at this point. This was reconciled by confirming the I-15 SegID located closest to the point, and manually assigning that SegID to that point. In this instance, the correct SegID was 0015_002.1. The updated data record is seen in Figure 3.3.

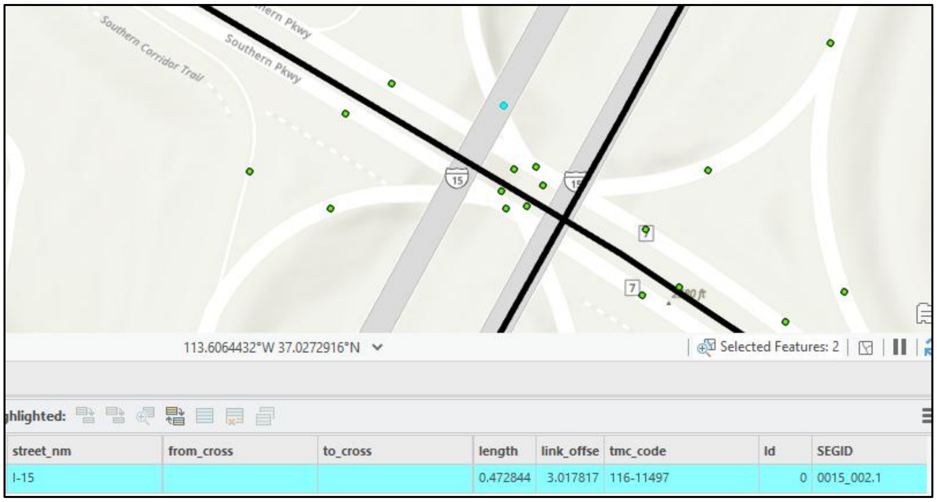

Figure 3.3 Adjusted ClearGuide Data

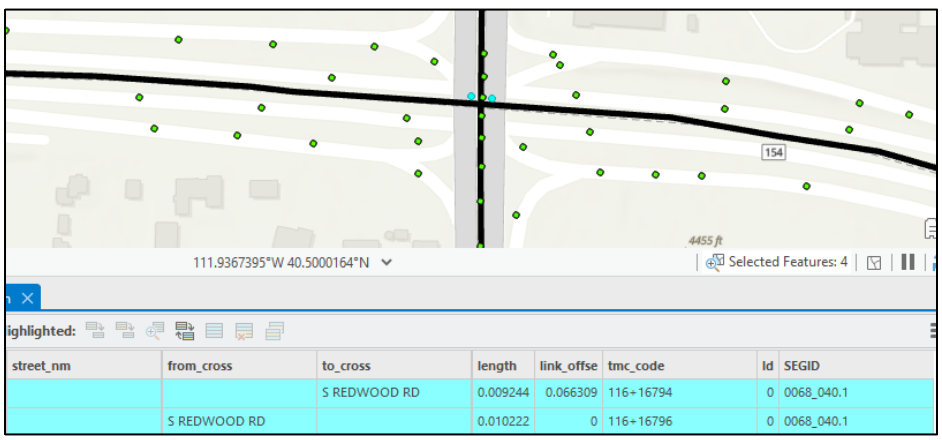

Figure 3.4 Erroneous Ramp ClearGuide Data

In another example of manual adjustment, Figure 3.4 displays highlighted data points on Bangerter Highway crossing Redwood Road in southern Salt Lake County. The highlighted link points are associated with ramps from Bangerter Highway in this instance but were joined to the Redwood Road SegID (0068_040.1). In the case of ramp link points erroneously being joined with other roadway SegIDs, the SegID was removed, and the field was left as a null value. This was done to ensure that ramps were not associated with higher speeds for roadways and removed from data analysis. See Figure 3.5 for the adjusted data.

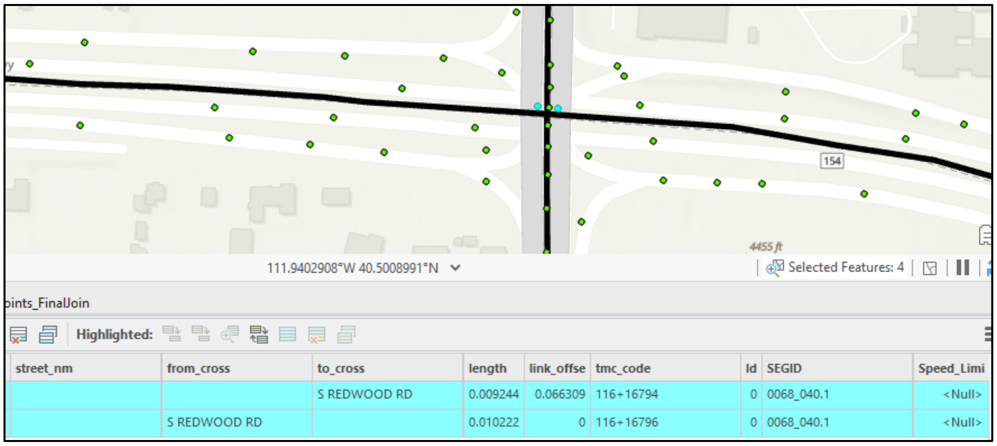

Figure 3.5 Adjusted Ramp ClearGuide Data

By performing manual adjustments, the research team was able to ensure that these incorrectly joined segments were joined to the correct SegID, allowing for proper data evaluation. After this manual adjustment process, the ClearGuide link data was prepared for further analysis.

3.3.3 Speed Limit Data Processing in GIS

The same process was used to join UDOT speed limit data to a master segment file and assign a SegID. Unlike the ClearGuide link data, the UDOT speed-limit layer was left as line data (potential join issues were not expected to occur with the same frequency as the ClearGuide data as there are fewer speed-limit segments than either ClearGuide data or master segments). The speed-limit data was joined to master segments using a spatial join. This resulted in the speed-limit data having an associated SegID and allowed for joining and comparison with the ClearGuide and TDM data.

3.4 TDM Data Preparation and Join with ClearGuide Data

The TDM dataset utilized in this study contained free-flow speed information along with other data types useful to analysis, as well as SegID which had been pre-assigned. This dataset was also manually checked and cleaned to ensure that evaluation processes would be successful. Ultimately, a dataset was created in this research which joined ClearGuide link data (along with the joined speed limits described in section 3.3.2) and TDM-speeds data. This process created a dataset containing aggregated TDM and ClearGuide speed information based on master segment

ID from which differences between the speeds could be calculated. It was determined that the process of joining the TDM link summary data file and ClearGuide link file containing ClearGuide data would be best performed in Microsoft Access due to potential issues with one-to-one join limitations in other programs.

3.4.1 TDM Data Reconciliation and Preparation

TDM speed data was not joined spatially to SegIDs as with the ClearGuide data because TDM segments already had SegIDs attached to them. However, during initial evaluation and testing of the datasets, some discrepancies were noted in the TDM data SegIDs. Several TDM segments appeared not to be associated correctly with master segments. Upon review, it was identified that an incorrect master segment had been generated for these segments. Seventy-two individual TDM segments were found to have incorrect SegIDs, which did not correspond to any existing SegIDs in the master segmentation file. Figure 3.6 displays an example of two of these TDM segments with an erroneous SegID on 7800 South in West Jordan, Utah. The SegID (seen in the highlighted fields) assigned to these segments was 2036_003.1. The SegID which should have been associated with these segments was 2036_003.2.

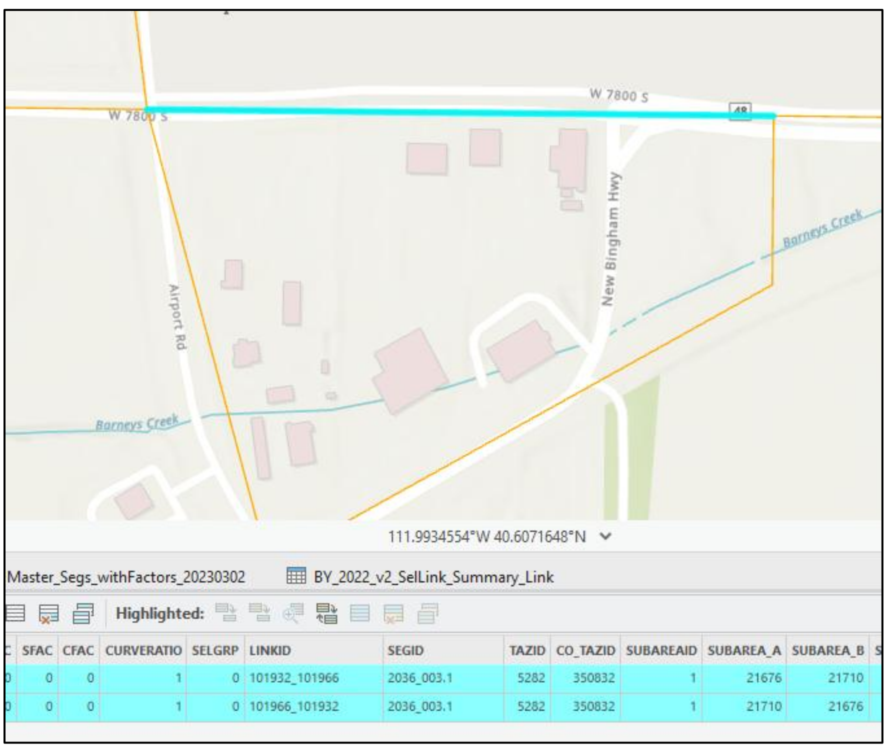

Figure 3.6 Sample of Erroneous TDM Segments

The TDM dataset contains 83,757 individual segments, so only a small number of TDM segments overall contained erroneous SegIDs. All 72 segments were corrected in the same manner as the erroneous ClearGuide points (by manually inputting the correct underlying master segment SegID) to match the TDM data with the correct SegIDs. This resolved this discrepancy in the TDM data and allowed for further evaluation and preparation. Figure 3.7 displays the edited TDM segments from Figure 3.6.

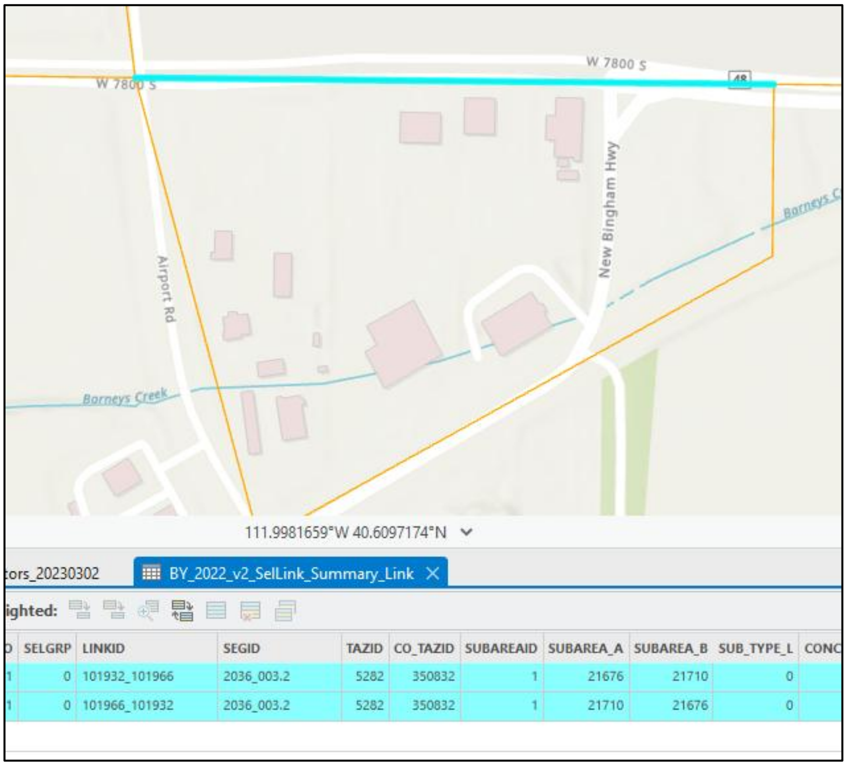

Figure 3.7 Sample of Edited TDM Segments

3.4.2 Data Queries and Dataset Development

For this process, the TDM link summary file and ClearGuide link data file were extracted from ArcGIS Pro software as raw data tables. These tables were then added to a Microsoft Access database for the join process. In this process, queries were designed which aggregated or grouped the variables within each dataset by SegID. In the ClearGuide link file, the link length, speed limit, and link ID were included for each SegID (where available). The query for the TDM dataset was more complex, and aggregated all available TDM data by master segment ID. The TDM variables included:

- Distance
- Street
- Lanes
- Speed Limit
- Roadway Classification (name and numerical value)
- One-Way Road Classification
- CFAC (Capacity Factor)
- SFAC (Speed Factor)
- Area Type (name and numerical value)
- Free-Flow Speed
- Daily Traffic Volume
- Link ID

The average was taken for each of these data variables, with exceptions for text variables (where the first was taken) and exceptions for the following:

- Distance – value was summed, divided by two, and rounded to account for directional distances.
- Free-Flow Speed – A weighted average was taken, which consisted of multiplying free-flow speed by associated distance and dividing by the sum of distance.
- Daily Volume – A weighted average using the same process as used for free-flow speed was taken.
- Link ID – Link IDs were counted to provide information on how many smaller ClearGuide links were present within the master segments.

After the TDM data was aggregated by SegID, another query was utilized which joined the TDM data and ClearGuide data SegID. All variables from the TDM data and speed-limit data from the ClearGuide link dataset were included. This join resulted in a final dataset organized by SegID, containing speed-limit information and aggregated TDM data for applicable master segments. The speed difference calculation using this dataset is described in section 4.3.

3.5 ClearGuide Speed Data Processing

The research team conducted data processing on the raw ClearGuide speeds dataset to identify outliers based on speeds and to conduct additional data cleaning. This data was compiled with the ClearGuide link data to assign SegIDs and allow for later analysis.

3.5.1 Processing Method

The research team considered how best to manipulate and analyze the free-flow speed data sourced from the ClearGuide speeds dataset. This dataset was very large and would require specialized tools to clean and manipulate. Initially, the research team experimented with a method using the analysis program PySpark; however, because of integration and processing speed, this was not successful. As a result, the team utilized Google's BigQuery instead. The dataset was uploaded to Google Cloud storage in several stages. Once the data was uploaded, BigQuery was utilized to access the dataset as an SQL table. The team then was able to create various SQL queries to discover the limitations and discrepancies in the data, clean and identify outliers, and generally manipulate the data.

3.5.2ClearGuide Data Manipulation

The ClearGuide speeds raw data spans the month of October 2023 and consists of 2,581,696,521 rows and 15 columns. However, only four fields were applicable to the analysis in this study: local_timestamp, source_id, length_mi, and avg_speed_MPH. Each row represents the average speed over five minutes for a single source_id and by direction.

The first step in cleaning the ClearGuide speeds dataset was to add SegIDs using the link_id field from the ClearGuide link file. The link_id field corresponds directly to source_id from the ClearGuide speed dataset. Then the ClearGuide speed data was filtered to include only rows that included a SegID, which reduced the total row count to 1,275,964,314 records (nearly a 50-percent reduction). The next step was breaking out the local_timestamp field into the following fields: Month, Day, Hour, and Day of Week.

3.5.3 Identification of Outliers and Cleaning

The next portion of the data analysis was removing any speed outliers that could potentially skew the final results. The research team explored several options for how to consider outliers; Figures 3.8 and 3.9 below provide a sample of several speed and percentage of speed differences from the avg_speed_mph field. These speed values are aggregated by source_id as well as hour of day.

Row	source_id	hour_of_day	AVGSPEED	Q1	Q3	UB_BW	LB_BW	UB_5p	LB_5p	UB_10p	LB_10p	UB_15p	LB_15p	UB_5mph	LB_5mph	UB_10mph	LB_10mph	UB_15mph	LB_15mph
1	858702207	14	69.2626...	67.00...	72.19...	79.99...	59.20...	72.72...	65.79...	76.18...	62.33...	79.65...	58.87...	74.262...	64.262...	79.2626...	59.2626...	84.262...	54.262...
2	1189491828	4	68.4668...	66.00...	72.19...	81.49...	56.70...	71.89...	65.04...	75.31...	61.62...	78.73...	58.19...	73.466...	63.466...	78.4668...	58.4668...	83.466...	53.466...
3	-1189398997	19	68.7929...	66.00...	72.19...	81.49...	56.70...	72.23...	65.35...	75.67...	61.91...	79.11...	58.47...	73.792...	63.792...	78.7929...	58.7929...	83.792...	53.792...
4	-1219342296	8	68.7484...	65.20...	72.19...	82.69...	54.70...	72.18...	65.31...	75.62...	61.87...	79.06...	58.43...	73.748...	63.748...	78.7484...	58.7484...	83.748...	53.748...
5	1183630601	20	68.0342...	65.00...	72.19...	82.99...	54.20...	71.43...	64.63...	74.83...	61.23...	78.23...	57.82...	73.034...	63.034...	78.0342...	58.0342...	83.034...	53.034...
6	122412137	12	68.3096...	65.00...	72.19...	82.99...	54.20...	71.72...	64.89...	75.14...	61.47...	78.55...	58.06...	73.309...	63.309...	78.3096...	58.3096...	83.309...	53.309...
7	-1192474727	16	68.7217...	65.00...	72.19...	82.99...	54.20...	72.15...	65.28...	75.59...	61.84...	79.02...	58.41...	73.721...	63.721...	78.7217...	58.7217...	83.721...	53.721...
8	-1183636919	8	69.1919...	65.00...	72.19...	82.99...	54.20...	72.65...	65.73...	76.11...	62.27...	79.57...	58.81...	74.191...	64.191...	79.1919...	59.1919...	84.191...	54.191...
9	1183630574	15	68.6207...	65.00...	72.19...	82.99...	54.20...	72.05...	65.18...	75.48...	61.75...	78.91...	58.32...	73.620...	63.620...	78.6207...	58.6207...	83.620...	53.620...
10	1238312773	17	70.9603...	68.99...	72.19...	77.00...	64.19...	74.50...	67.41...	78.05...	63.86...	81.60...	60.31...	75.960...	65.960...	80.9603...	60.9603...	85.960...	55.960...
11	-1195454198	0	67.8002...	64.00...	72.19...	84.49...	51.70...	71.19...	64.41...	74.58...	61.02...	77.97...	57.63...	72.800...	62.800...	77.8002...	57.8002...	82.800...	52.800...
12	-1189932904	10	69.9616...	67.25...	72.19...	79.61...	59.83...	73.45...	66.46...	76.95...	62.96...	80.45...	59.46...	74.961...	64.961...	79.9616...	59.9616...	84.961...	54.961...
13	1189720011	4	69.1819...	66.00...	72.19...	81.49...	56.70...	72.64...	65.72...	76.10...	62.26...	79.55...	58.80...	74.181...	64.181...	79.1819...	59.1819...	84.181...	54.181...
14	1188801013	17	69.4206...	66.74...	72.19...	80.37...	58.57...	72.89...	65.94...	76.36...	62.47...	79.83...	59.00...	74.420...	64.420...	79.4206...	59.4206...	84.420...	54.420...
15	778367464	17	68.8904...	66.20...	72.19...	81.19...	57.20...	72.33...	65.44...	75.77...	62.00...	79.22...	58.55...	73.890...	63.890...	78.8904...	58.8904...	83.890...	53.890...
16	-711611221	15	70.5543...	69.00...	72.19...	76.99...	64.20...	74.08...	67.02...	77.60...	63.49...	81.13...	59.97...	75.554...	65.554...	80.5543...	60.5543...	85.554...	55.554...
17	-1188138657	2	69.0851...	65.99...	72.19...	81.49...	56.70...	72.53...	65.63...	75.99...	62.17...	79.44...	58.72...	74.085...	64.085...	79.0851...	59.0851...	84.085...	54.085...
18	-950310143	17	69.0400...	65.20...	72.19...	82.69...	54.70...	72.49...	65.58...	75.94...	62.13...	79.39...	58.68...	74.040...	64.040...	79.0400...	59.0400...	84.040...	54.040...
19	1189605164	10	69.4997...	65.40...	73.40...	85.39...	53.40...	72.97...	66.02...	76.44...	62.54...	79.92...	59.07...	74.499...	64.499...	79.4997...	59.4997...	84.499...	54.499...
20	-771568412	9	66.2242...	58.99...	74.60...	98.00...	35.59...	69.53...	62.91...	72.84...	59.60...	76.15...	56.29...	71.224...	61.224...	76.2242...	56.2242...	81.224...	51.224...

Figure 3.8 Sample of Bounds of Percentages and Speed Boundaries

A "box-and-whisker-inspired" equation (from a box-and-whisker plot) was used to find outliers in the avg_speed_MPH field. The following formulas were applied to this column to determine any outliers.

$$\text{Lower Bound: } Q1-1.5(Q3-Q1)$$

$$\text{Upper Bound: } Q3+1.5(Q3-Q1)$$

- Where:
  - Q1 = 1st quartile or 25th percentile

- Q3 = 3rd quartile or 75th percentile

More than 66 million (66,060,477) outliers were found and removed to produce a clean dataset and allow for effective evaluation. This left a clean dataset with 1,209,903,837 rows.

Given the size of the ClearGuide speeds dataset, it was too large to analyze wholistically for common mistakes realistically. To overcome this, the research team often extracted a small sample to repeat the outlier process methodology and formulas in Microsoft Excel. This allowed the research team to ensure that the methodology was correct and would lead to the desired results.

3.6 Summary

Using tools such as ArcGIS Pro, Microsoft Excel and Access, and R programming language, the research team was able to collect, clean, and prepare data successfully for evaluation. ClearGuide link data was converted to a point file and joined to a SegID from the Utah master segmentation layer, creating a common field between it and the TDM free-flow speed data. This process included several instances of identifying join issues with the ClearGuide links and performing manual corrections to ensure the data was as accurate as possible. These datasets were then joined to form a common dataset, along with UDOT speed-limit data which provided additional speed reference. The ClearGuide speeds dataset was likewise prepared and cleaned, primarily through the identification of speed outliers by using upper- and lower-bound thresholds. These outliers were then removed. The ClearGuide speeds could then be associated with the ClearGuide links and compared to the TDM free-flow speeds. Section 4 describes the data evaluation process.

4.0 DATA EVALUATION

4.1 Overview

Utilizing the data collected and prepared as described in Section 3, the research team carried out a comprehensive data evaluation process. The team utilized ArcGIS Pro software to map the calculated difference between TDM and ClearGuide speeds grouped by segment ID, and then performed a speed-data evaluation by creating several filter combinations based upon fields from the speed-difference dataset. These filter combinations organized the data by functional classification type, area type, and TDM. These statistics allowed for an overview of speed-data differences and comparisons between TDM and ClearGuide data across various combinations of area and roadway types, as well as examining speed-data information for each of the six TDMs.

4.2 Free-Flow Speed Method Identification

Two methods were considered to determine the most accurate free-flow speed variable for the ClearGuide speed data, percentiles, and highest hour. BigQuery was used to separate the ClearGuide free-flow speed data into hour bins using the local_timestamp field:

```
SELECT  *,
EXTRACT(HOUR FROM DATETIME(local_timestamp)) AS hour_of_day,
FROM `TrafficCountAnalysis.FreeFlowSpeed`;
```

BigQuery was then used to analyze the following percentile values of the weighted_avg field (where weighted_avg is the average speed for each segment weighted by the segment's length) using ClearGuide free-flow speed data: 15th, 50th, 75th, 85th, 95th, and 98th percentiles. In the same query, the average of the weighted_avg variable was collected for each hour of the day 0-23, though only 0-3 are shown:

```
SELECT SEGID, Direction,
   ROUND(AVG(weighted_avg),1) AS Average,
   APPROX_QUANTILES(weighted_avg, 100)[OFFSET(15)] AS perc_15,
```

```
    APPROX_QUANTILES(weighted_avg, 100)[OFFSET(50)] AS perc_50,
    APPROX_QUANTILES(weighted_avg, 100)[OFFSET(75)] AS perc_75,
    APPROX_QUANTILES(weighted_avg, 100)[OFFSET(85)] AS perc_85,
    APPROX_QUANTILES(weighted_avg, 100)[OFFSET(95)] AS perc_95,
    APPROX_QUANTILES(weighted_avg, 100)[OFFSET(98)] AS perc_98
    ROUND(AVG(IF(hour_of_day = 0, weighted_avg, NULL)), 1) AS hour_0,
    ROUND(AVG(IF(hour_of_day = 1, weighted_avg, NULL)), 1) AS hour_1,
    ROUND(AVG(IF(hour_of_day = 2, weighted_avg, NULL)), 1) AS hour_2,
    ROUND(AVG(IF(hour_of_day = 3, weighted_avg, NULL)), 1) AS hour_3
FROM `TrafficCountAnalysis.vwFFhour`
GROUP BY SEGID, Direction;
```

To determine which hour speed was best for analysis, real-world speed observations were compared to the free-flow speed data value. It was found that the fifth-highest hour speeds were most accurate compared to manual observations; for this reason, the research team determined that the fifth-highest hour would best represent reality. The RANK() OVER function was used in BigQuery to extract the fifth-highest hour speed for each segment by direction. Using a WITH statement was required to make a temporary view of the ranked data. Each weighted average value – grouped by hour – was sorted in a descending order; each value was assigned a rank and only values with a rank of five were kept. This temporary view was then joined to the query above to include FreeFlowSpeed with the final results.

4.3 Speed Difference Calculation and Results

As described in Section 3, ClearGuide, TDM, and speed-limit data were joined based upon master-segmentation-file after-data following cleaning and reconciliation processes. This allowed for a comparison to be conducted between the TDM free-flow speeds and real-world speeds, represented by ClearGuide, organized by SegID. After completing this join, the difference was calculated between TDM and ClearGuide speeds to identify where speeds were similar and where they differed. Microsoft Excel was utilized to calculate the differences between the speeds, and the resulting dataset was mapped to highlight differences (see section 4.3.1).

4.3.1 Speed Difference Mapping

ArcGIS Pro was utilized to display the differences in speed between TDM and ClearGuide data segments. The speeds were organized by positive/negative direction though free flow speeds generally are the same directionally. Figure 4.1 below displays the results of the mapping where areas in red are those where the TDM speeds are slower than the ClearGuide data segments, while areas in blue are those where the TDM speeds are faster.

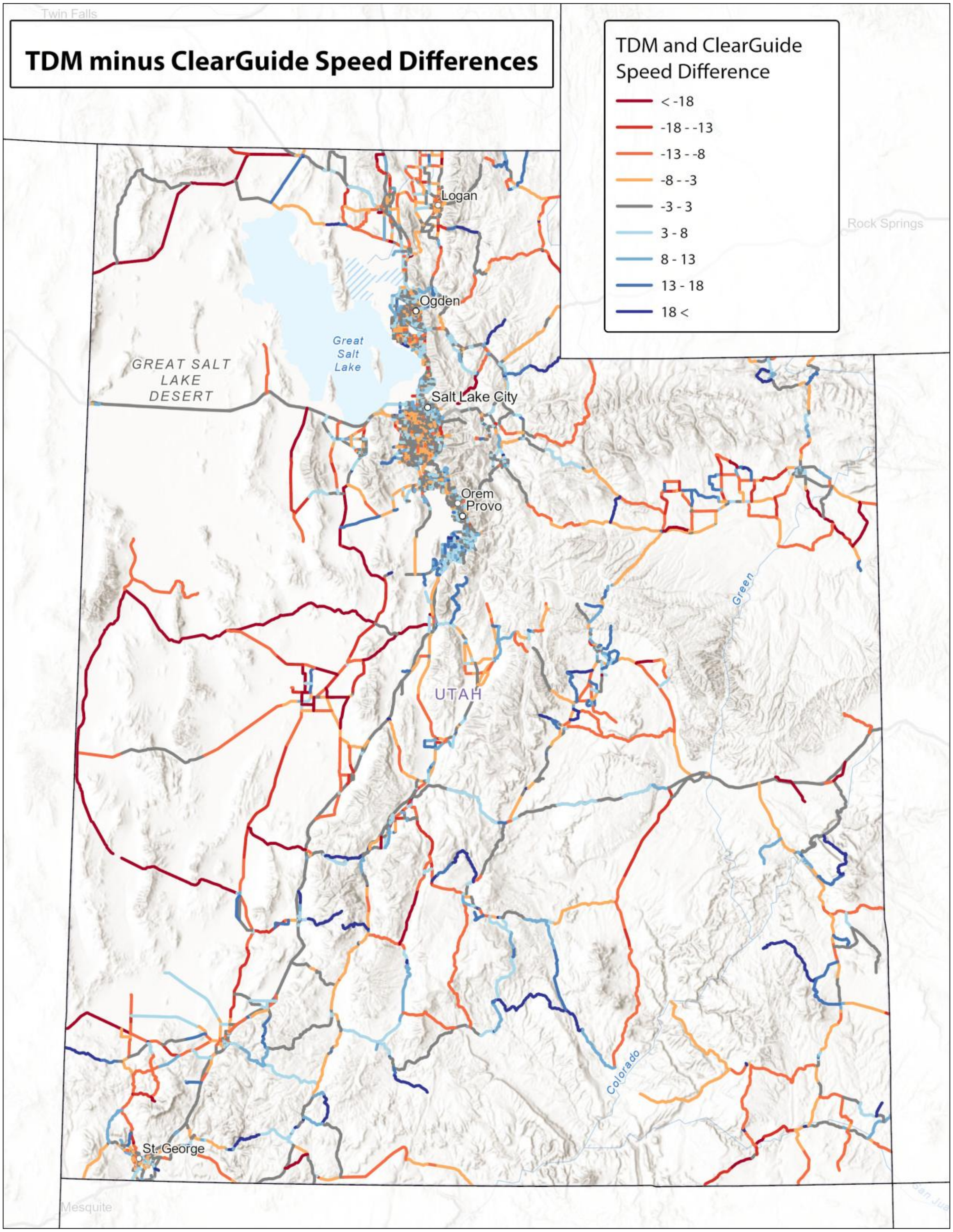

Figure 4.1 TDM - ClearGuide Speed Differences

These maps illustrate that many of the most notable examples of discrepancy between TDM and ClearGuide speed data seem to occur in more rural areas on larger roadways, while less discrepancy between the datasets is generally seen in urban areas.

The original master segment dataset utilized in this research contained 8,727 unique segments and associated SegIDs. However, as data was joined and processed, the resulting speed-difference dataset contained only 6,249 unique SegIDs from the original master segment dataset. Because of two primary factors, 2,478 SegIDs were left out of the speed difference dataset:

1. To provide speed calculation analysis, a SegID must have ClearGuide and TDM Speed data associated with it. A number of SegIDs were found not to have such data associated with them. As a result, these SegIDs did not have any speed calculation data associated with them after calculating differences. Figure 4.5 provides such an example: SegID 0006_141.0 near Eureka, Utah, did not have associated TDM data. Therefore, no speed-difference data was present.

2. During data processing, it was found that a number of SegIDs throughout Utah are associated with proposed or planned roadways which often do not yet exist. These SegIDs are typically associated with the tags 'MAG,' UDOT,' 'UTA,' or 'WFRC' in their number, and currently do not have associated ClearGuide speed data. Figure 4.2 displays SegIDs MAG_6091 and MAG_6155 in Utah County which are non-existent roadways at this time and did not have associated speed information.

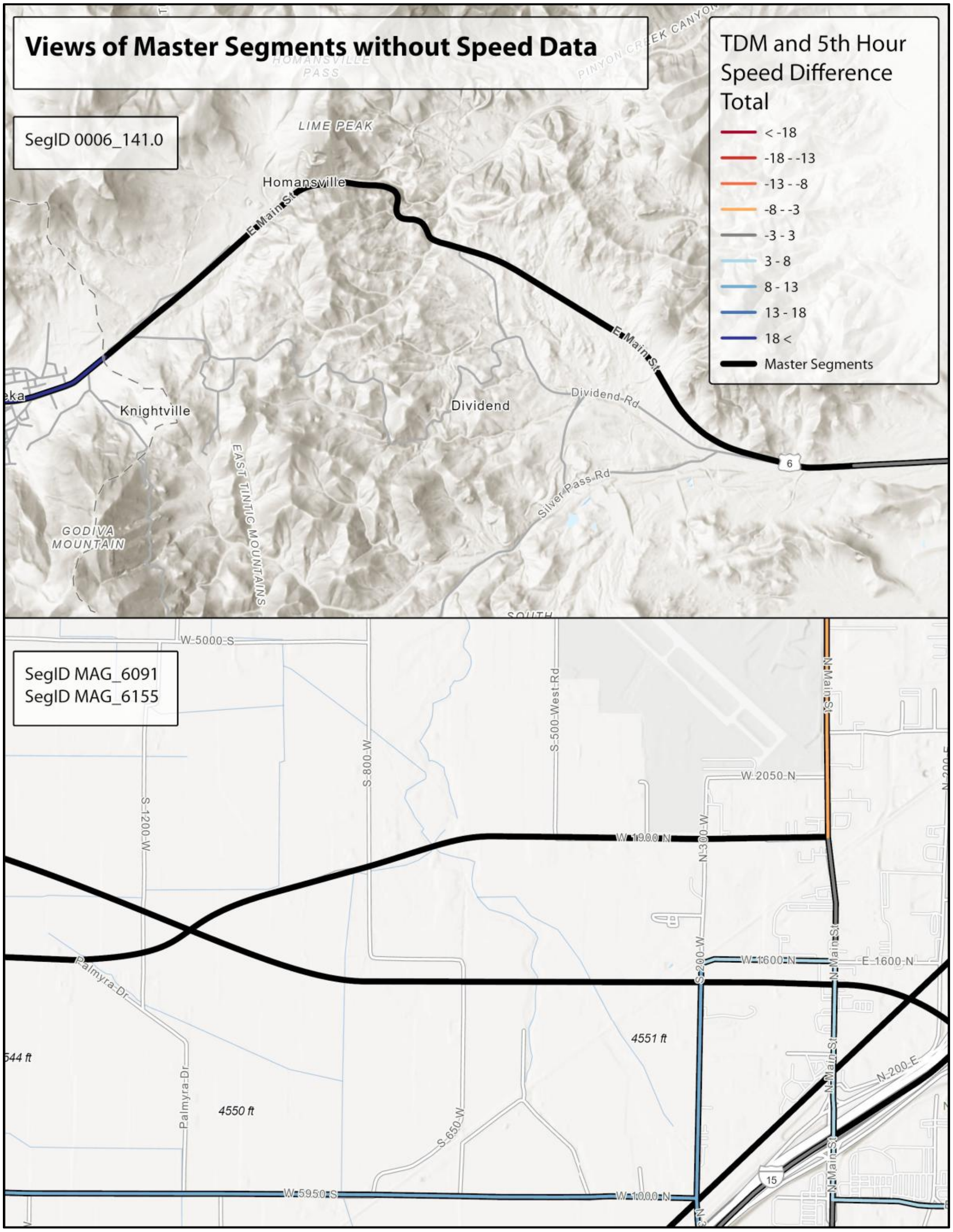

Figure 4.2 Sample of SegIDs With No Associated Speed Calculation Data

4.4 Speed Data Evaluation

As described in sections 3.2 through 3.5, the research team acquired, cleaned, and prepared ClearGuide and TDM data containing information on free-flow speeds on numerous routes throughout Utah. Using the master segment layer and the ClearGuide dataset the team joined ClearGuide segments to a master segment ID. ClearGuide free-flow speeds could then be associated with their corresponding SegID and joined with statewide TDM free-flow speed data (which also corresponded to a SegIDs).

4.4.1 Speed Data Aggregation

The bulk of the speed data evaluation was performed in Microsoft Excel, with additional tasks performed in R programming language. The analysis was performed using the dataset that the research team created from a combination of statewide TDM and the filtered ClearGuide speeds datasets (filtered to include SegID and to exclude any speed outliers.) Figure 4.7 provides a sample of this aggregated dataset. The fields used for data evaluation included the following:

- Difference in free-flow speeds (Field Name: Difference in Speeds) calculated in a previous step and signifies the difference between the ClearGuide free-flow speed field and the TDM free-flow speed field.

Functional Type Classification (Field Name: Functional Type)

- Functional Type of each roadway taken from the statewide TDM dataset.

- Area Type (Field Name: Area Type) Area Type of roadways taken from statewide TDM dataset.

TDM (Field Name Model Name):

- Field noting which TDM the TDM free-flow speed data (see below) was sourced from.

ClearGuide fifth-highest hour speed (Field Name: ClearGuide FF)

- Free-flow speeds sourced from the ClearGuide speeds dataset

TDM free-flow speed.(Field Name: TDM FF)

- Roadway speed data associated with a specific TDM taken from the statewide TDM dataset

During the joining and aggregation process, it was found that several segments contained links with different area types. The most common area type value was used during data evaluation. As area types range from one through five, this was calculated by rounding to the nearest whole number.

	A	B	C	D	E	F
1	Functional Type	Area Type	Model Name	Difference in speeds	ClearGuide FF	TDM FF
17	Principal Arterial	1	USTM	3.20	56.8	60
18	Principal Arterial	1	USTM	4.40	55.6	60
19	Principal Arterial	1	USTM	4.80	55.2	60
20	Principal Arterial	3	USTM	11.93	32.2	42.66666667
21	Principal Arterial	3	USTM	11.73	32.4	42.66666667
22	Principal Arterial	3	USTM	11.67	30.2	42
23	Principal Arterial	3	USTM	11.77	30.1	42
24	Minor Arterial	1	USTM	-7.96	58.5	48.2
25	Minor Arterial	1	USTM	-8.86	59.4	48.2
26	Minor Arterial	1	USTM	-13.50	66.5	53
27	Minor Arterial	1	USTM	-13.90	66.9	53

Figure 4.3 Sample of Aggregated Records

Using Microsoft Excel, seven summary statistics tables were created for the difference in speeds field, TDM free-flow speed data, and ClearGuide free-flow speed data (fifth-highest hour speed). These summary statistics included the following:

- Average
- Minimum
- Median
- Maximum
- 85th Percentile
- Standard Deviation
- 95-Percent Confidence Interval
- ClearGuide and TDM free-flow speed columns (for comparative purposes)

The research team created a table for each of the following filter combinations, displaying the above summary statistics for each:

- Functional Type: six functional types include the following:
    - Local
    - Collector
    - Minor Arterial
    - Principal Arterial
    - Expressway
    - Freeway
- Area Type: five area types include the following (area types are designated with a number in the TDM dataset, the associated number is included here as well).
    - 1/Rural
    - 2/Transition
    - 3/Suburban
    - 4/Urban
    - 5/CBD-Like
- Model: six TDMs from the TDM dataset include the following:
    - Utah Statewide Travel Model (USTM)
    - WFRC/ MAG
    - Cache
    - Dixie
    - Summit/Wasatch
    - Iron County
- Functional Type by Area Type

- Functional Type by Model
- Model by Area Type
- Functional Type by Area Type by Model

Formulas were developed to aggregate statistics for each combination, most of which required multiple criteria in each aggregate formula (see section 4.4.2 for more information on formulas used in data aggregation). Through this process, tables for each combination displayed comprehensive summary statistics. See Figure 4.4 for a sample of one such table (functional type by model). Complete tables are included in section 4.5.

	A	B	C	D	E	F	G	H	I	J	K
1	TDM Name	Area Type	Average	Min	Median	Max	85th Percentile	95% CI	Standard Deviation	Clearguide FF	TDM FF
2	Cache	1	-1.5	-15.0	-2.2	20.0	8.0	1.3	8.2	48.2	46.6
3	Cache	2	-3.8	-29.3	-2.4	9.7	2.8	1.2	7.1	40.6	36.6
4	Cache	3	-4.5	-20.4	-4.5	5.8	-0.6	0.6	4.1	34.5	29.9
5	Cache	4	-5.6	-19.6	-4.7	7.5	-1.0	1.0	5.3	31.0	25.4
6	Dixie	1	0.1	-20.3	-3.2	32.5	14.0	2.1	12.2	48.9	47.7
7	Dixie	2	0.1	-25.8	0.4	23.2	7.5	1.5	8.7	44.3	43.2
8	Dixie	3	-0.4	-11.9	-1.8	20.8	6.7	0.9	6.1	37.4	36.6
9	Dixie	4	-0.8	-15.9	-0.7	10.3	5.2	0.9	5.7	33.2	32.1
10	Iron County/Cedar	1	-0.5	-24.1	-1.5	23.9	9.8	1.6	10.8	49.3	48.4
11	Iron County/Cedar	2	0.5	-12.5	0.3	15.8	8.8	1.7	7.5	43.5	43.9
12	Iron County/Cedar	3	4.4	-6.7	3.5	22.5	9.5	1.6	5.6	35.6	39.8
13	Iron County/Cedar	4	2.6	-8.9	3.8	11.7	5.5	1.6	4.3	30.5	33.1
14	Summit/Wasatch	1	1.2	-16.1	0.0	19.1	11.1	1.2	8.4	52.6	53.8
15	Summit/Wasatch	2	0.7	-21.5	1.2	15.6	7.2	1.6	6.9	43.7	44.6
16	Summit/Wasatch	3	1.4	-10.5	1.8	9.1	6.1	1.2	4.8	34.4	35.9
17	Summit/Wasatch	4	-0.6	-12.4	-0.1	10.1	1.7	0.9	3.9	31.1	30.5
18	USTM	1	-2.0	-47.0	-3.5	34.2	11.3	0.5	11.5	51.9	49.0
19	USTM	2	2.0	-26.5	2.8	26.4	11.0	0.8	8.6	40.7	42.1
20	USTM	3	2.3	-22.9	3.1	18.0	9.1	0.7	6.5	33.0	35.3
21	USTM	4	1.7	-7.6	1.1	10.6	5.9	1.0	3.9	28.0	29.6
22	WFRC/MAG	1	6.5	-20.6	8.0	22.1	15.5	0.9	8.0	44.4	50.5
23	WFRC/MAG	2	2.4	-19.8	1.9	39.7	8.9	0.5	6.7	39.5	41.7
24	WFRC/MAG	3	0.5	-20.5	0.4	50.3	6.8	0.2	6.1	35.2	35.7
25	WFRC/MAG	4	-0.8	-24.8	-0.9	48.4	4.0	0.2	5.1	32.8	31.9
26	WFRC/MAG	5	-2.7	-9.9	-3.5	10.1	1.7	0.5	3.7	24.8	22.1

Figure 4.4 Sample of Functional Type by Model Table

4.4.2 Aggregation Formulas

The formulas described below were utilized to calculate and aggregate summary statistics for the various filter combinations. Several criteria were utilized in the formulas to ensure that the correct values were calculated.

- Average of Model Type =AVERAGEIFS('Difference Data'!$Y:$Y, 'Difference Data'!$AD:$AD,A3), where
    - Difference Data Y:Y = the 5th Highest Hour Speed,

- Difference Data AD:AD = Model, and
- A3 = Model value to filter by

- Minimum of Functional Type by Area Type =MINIFS('Difference Data'!$Y:$Y,'Difference Data'!$T:$T,C4, 'Difference Data'!O:O,B4), where
  - Difference Data Y:Y = the 5th Highest Hour Speed,
  - Difference Data T:T = Area Type,
  - C4 = Area Type value to filter by,
  - Difference Data O:O = Functional Type, and
  - B4 = Functional Type value to filter by filter by
- 85th Percentile of Area Type by Model Type =PERCENTILE(IF('Difference Data'!$T:$T=$C5,IF('Difference Data'!$AD:$AD=$B5,'Difference Data'!$Y:$Y)), 0.85), where
  - Difference Data Y:Y = the 5th Highest Hour Speed,
  - Difference Data T:T = Area Type,
  - C5 = Area Type value to filter by,
  - Difference Data AD:AD = Model Type, and
  - B5 = Model Type value to filter by
- 95% Confidence Interval of Functional Type by Area Type by Model Type =CONFIDENCE.T(0.05,$J2,COUNTIFS('Difference Data'!$T:$T,$B2,'Difference Data'!$O:$O,$C2, 'Difference Data'!$AD:$AD,'FT by Area by Model'!$A2)), where
  - J2 = Standard Deviation,
  - Difference Data T:T = Area Type,
  - B2 = Area Type value to filter by,
  - Difference Data O:O = Functional Type,
  - C2 = Functional Type value to filter by,
  - Difference Data AD:AD = Model Type, and
  - A2 = Model Type value to filter by

When filtering by the subareaID data column, the research team encountered one issue in Excel. To remedy this, a new field titled “TDM Name” was created in R and consisted of the Travel Demand Model name rather than an identification number. This functioned properly and allowed for the correct values to be identified. R was also used to create the structure for the filter combinations quickly, which was copied and pasted into Excel to apply the aggregate formulas.

4.5 Speed Data Evaluation Results

Using the formulas and processes described in section 4.4 enabled the research team to develop aggregate statistics for speed comparison between ClearGuide and existing TDM free-flow speeds, based upon different filter combinations. This section displays several tables and figures which show these results. Sections 4.5.1 and 4.5.2 display overview statistics, while sections 4.5.3 through 4.5.8 display specific results based upon TDM Name.

4.5.1 Overview Aggregation Statistics

The research team created filter combination aggregates from the overall dataset which displayed several general statistics, providing a basic comparison of ClearGuide vs. TDM speeds. Tables 4.1 through 4.3 show several of these aggregates, including aggregates by TDM Name, Functional Type, and Area Type. Statistics included the following:

- Average: The average difference in ClearGuide and TDM speeds on segments throughout the models
- Min: Highest recorded value of ClearGuide speed over TDM speed on a segment in the models
- Median: Middle value of speed differences on a segment in the models
- Max: Highest recorded value of TDM speed over ClearGuide speed on a segment in the models
- 85th Percentile: Value indicating the speed difference that 85% of segments were at or below in the models

- 95% CI: Confidence interval indicating the reliability of the estimated free-flow speed calculation results in this study; here the confidence intervals were all under one indicating that the results of these calculations can be expected to be accurate.

- Std Dev: Standard Deviation which measures the amount of variation in the models; here it indicates the variation that can be expected in mph between ClearGuide and TDM speeds.

- ClearGuide FF: Average recorded ClearGuide speeds on segments in the models

- TDM FF: Average recorded TDM speeds on segments in the models

- Count: Total number of segments in a model with associated data

- Length: Estimated length (in miles) of segments in a model with associated data

Table 4.1 Aggregate Statistics by TDM Name

TDM Name	Average	Min	Median	Max	85th Percentile	95% CI	Std. Dev.	ClearGuide FF	TDM FF	Count	Total Length
USTM	-0.6	-47	-0.4	34.2	10.8	0.4	10.7	48	47.4	3342	22921.5
WFRC/MAG	0.3	-24.8	0.1	51.4	6	0.1	6	34.5	34.8	7143	9074.4
Cache	-3.7	-29.3	-3.7	20	2.4	0.5	6.6	39	35.3	572	1187.9
Dixie	0.3	-22.5	-0.1	32.5	8.3	0.7	8.2	40.4	40.7	598	1518.2
Summit/Wasatch	0.9	-17	0.3	19.1	7.4	0.7	7	44.6	45.5	415	1392.9
Iron County	0.8	-24.1	1.4	23.9	9.5	1	9.2	44.2	45	336	1834.8

The aggregated statistics by TDM show several notable results. Statistics for TDM Name reveal that currently the Cache model has the highest average difference between ClearGuide and TDM free-flow speeds (-3.7 MPH). However, the Utah Statewide Travel Model (USTM) has the largest difference between minimum and maximum speed differences (81.2 MPH). The WFRC/MAG TDM also has a large difference between minimum and maximum speed (76.2 MPH). The standard deviation for each TDM ranges from six MPH to 10.7 MPH, which indicates that there is significant variation consistently throughout the models between the TDM and ClearGuide speeds. It should be noted that USTM has the largest count of individual segments and segment lengths given its statewide coverage of roadways, followed by the WFRC/MAG TDM, with the other TDMs all smaller in count and length. Though the Cache model had the highest difference, it also has a smaller 85th percentile than the other models, indicating that most speed differences are smaller, while they are larger in the other models.

Table 4.2 Functional Type Aggregate Statistics

Functional Type	Average	Min	Median	Max	85th Percentile	95% CI	Std. Dev.	ClearGuide FF	TDM FF	Count	Total Length
Local	-17.8	-47	-15.2	15	-1.8	2	14.1	34.4	16.5	189	3036.1
Collector	0.4	-33	0.3	22	8	0.2	7.6	33.6	34	5280	16348.3
Minor Arterial	0.1	-29	-0.1	26	7	0.2	7.2	37.9	38	3257	7634.4
Principal Arterial	-0.7	-20	-1.6	34	5.7	0.3	7.1	44.1	43.4	2867	6697.4
Expressway	-2	-21	-3.1	32	4.5	1	7.6	51.4	49.3	204	367.6
Freeway	4.1	-9.5	3	51	8.4	0.5	6.7	69.5	73.6	609	3845.9

Statistics by Functional Type reveal several notable findings. Local roads saw the most significant difference between ClearGuide and TDM free-flow speeds (-17.8 MPH), as well as the highest standard deviation (14.1 MPH). Both these values for local functional type were much more significant than for any other functional type. All functional types (except local roads) have a similar standard deviation ranging from 6.7 to 7.6 MPH. Functional Type statistics also saw more similar differences between minimum and maximum speeds than TDM Name, with differences ranging from 53 to 61.9 MPH. Local functional type saw the highest difference between minimum and maximum speeds.

Table 4.3 Area Type Aggregate Statistics

Area Type	Average	Min	Median	Max	85th Percentile	95% CI	Std. Dev.	ClearGuide FF	TDM FF	Count	Total Length
1/Rural	-0.6	-47	-0.2	34.2	11.8	0.4	11.2	50.9	50.4	3416	26694
2/Transition	1.6	-29.3	0.1	39.7	9.3	0.4	7.6	40.7	42.4	1594	3084.1
3/Suburban	0.6	-22.9	0.1	50.3	7	0.2	6.2	35.1	35.7	3418	4453.4
4/Urban	-0.8	-24.8	-0.3	51.4	4.1	0.2	5.2	32.6	31.9	3725	3608.2
5/CBD - Like	-2.7	-9.9	-0.2	10.1	1.7	0.5	3.7	24.8	22.1	253	90

Statistics for Area Type saw less average difference between ClearGuide and TDM free-flow speeds compared to TDM Name and Functional Type aggregates. The CBD-Like area type saw the highest average difference between ClearGuide and TDM free-flow speeds, though it has the lowest standard deviation, and has significantly less segment count and length values than the other area types. Rural area type has the most count and length values, as well as the highest standard deviation in MPH (11.2) and the highest 85th percentile value (11.8). Rural area type also sees the highest difference between minimum and maximum speeds.

4.5.2 Additional Overview Statistics

The research team utilized additional filter combinations to display results based upon Area Type, TDM Name, and other parameters. Table 4.4 displays results of Area Type by Functional Type statistics. Additional tables follow which display other statistics (Tables 4.5 and 4.6).

The results in Table 4.4 show that average speeds by Functional Type may differ significantly, depending on functional type. For Rural and Transition area type, Local roads see the highest average difference, with TDM speeds significantly less than ClearGuide speeds. Freeways typically see greater differences as well and have the greatest differences in Suburban and Urban area types. The average difference among other functional types is not as pronounced within the other area types.

Table 4.4 Area Type by Functional Type Aggregate Statistics

Area Type	Functional Type	Average	Min	Median	Max	85th Percentile	95% CI	Std. Dev.	ClearGuide FF	TDM FF	Count	Total Length
1/Rural	Local	-18	-47	-15.2	14.9	0.8	2.1	14.2	34.4	16.4	181	3,020
1/Rural	Collector	0.8	-33.4	0.7	22.1	15	0.6	11.5	43.5	44.3	1,501	11,448
1/Rural	Minor Arterial	0.3	-16.1	-1.1	25.8	12.6	0.8	10.5	52.6	52.9	686	4,883
1/Rural	Principal Arterial	-0.7	-11.8	-3.5	34.2	6.2	0.6	8.3	60.3	59.6	767	4,488
1/Rural	Expressway	-2.9	-4.4	-2.9	-1.3	-1.8	13.9	1.6	58.9	56	2	12
1/Rural	Freeway	1.4	-7	1	15.8	4.4	0.4	3.3	71.9	73.3	279	2,843
2/Transition	Local	-23.1	-26.5	-23.4	-19.1	-19.7	5.3	3.4	38.1	15	4	12
2/Transition	Collector	1.3	-16.7	0.9	17.6	7.1	0.4	5.8	33.7	35	647	1,315
2/Transition	Minor Arterial	1.5	-29.3	2	21.1	9.6	0.8	8.4	40.2	41.7	442	664
2/Transition	Principal Arterial	2.5	-19.8	3.1	26.4	11.8	0.9	8.7	45.6	48.1	371	623
2/Transition	Expressway	-3.9	-21.1	-3.8	13.6	3.1	2.2	7.1	53.3	49.4	43	85
2/Transition	Freeway	5	-4.2	4.7	39.7	8	1.4	6.7	69	74	87	385
3/Suburban	Local	-3.8	-5.7	-3.9	-1.7	-2	2.9	1.8	27.4	23.6	4	4
3/Suburban	Collector	0.9	-22.9	0.8	17.8	7.2	0.3	5.4	29.9	30.8	1,577	2,061
3/Suburban	Minor Arterial	0.1	-20.4	0.1	18	6.3	0.4	5.9	35.2	35.3	939	1,119
3/Suburban	Principal Arterial	-0.5	-19.7	-0.8	22.5	6	0.5	6.7	40	39.5	689	773
3/Suburban	Expressway	-0.8	-15.1	-2.1	31.9	6.4	1.5	7.5	50.6	49.9	105	185
3/Suburban	Freeway	7.9	-9.5	5.8	50.3	13.9	1.5	7.8	66	73.9	104	311
4/Urban	Local	n/a	0	n/a	0	n/a	n/a	n/a	n/a	n/a	0	0
4/Urban	Collector	-0.8	-24.8	-0.3	11.8	3.4	0.2	4.5	28.3	27.5	1,439	1,484

Area Type	Functional Type	Average	Min	Median	Max	85th Percentile	95% CI	Std. Dev.	ClearGuide FF	TDM FF	Count	Total Length
4/Urban	Minor Arterial	-0.4	-19.6	-0.5	14.3	4.5	0.3	4.7	31.2	30.7	1,103	937
4/Urban	Principal Arterial	-2	-19.6	-2	16.2	3.4	0.3	5.1	34.7	32.7	990	795
4/Urban	Expressway	-3	-16.7	-4.2	30.2	2	2.1	7.8	51	48	54	86
4/Urban	Freeway	6.2	-4.8	4.5	51.4	9.5	1.4	8.3	67.6	73.8	139	307
5/CBD - Like	Collector	-2.9	-7.5	-3.9	3.8	1.5	0.6	3.1	23	20.1	116	39
5/CBD - Like	Minor Arterial	-2.5	-9.9	-3.5	10.1	2.5	1	4.6	25.1	22.6	87	32
5/CBD - Like	Principal Arterial	-2.4	-9.3	-1.8	4.7	1	0.9	3.3	28.4	25.9	50	19
5/CBD - Like	Freeway	n/a	0	n/a	0	n/a	n/a	n/a	n/a	n/a	0	0

Table 4.5 displays the TDM name by Functional Type statistics. All models except the Summit/Wasatch and Iron County see the highest average difference on local roads, again typically with TDM local road speeds being significantly lower on average than local ClearGuide speeds (except the Cache model where the local TDM speeds are higher). USTM also sees significantly lower expressway TDM speeds than ClearGuide. The Summit/Wasatch and Iron County models by functional type had less difference in their speeds. Generally, the average difference on local roads across the models was the highest, with freeways and expressways having the next highest average differences.

Table 4.5 Model Type by Functional Type Aggregate Statistics

TDM Name	Functional Type	Average	Min	Median	Max	85th Percentile	95% CI	Std. Dev.	ClearGuide FF	TDM FF	Count	Total Length
USTM	Local	-19.6	-47	-18.9	3.9	-2.6	2.2	14	35.6	16	159	2,797
USTM	Collector	0	-33.4	-0.1	21.8	12.8	0.6	10.8	41.7	41.7	1,385	9,729
USTM	Minor Arterial	0.1	-20.7	-0.8	25.8	10.7	0.7	9.7	48.1	48.2	650	3,985
USTM	Principal Arterial	0.9	-17.1	-0.9	34.2	10.9	0.5	8.5	53.6	54.5	935	4,082
USTM	Expressway	-13.2	-16.8	-13.8	-9.4	-10.2	3.4	2.7	61.2	48	5	16
USTM	Freeway	1.8	-5.3	1.3	15.4	4.3	0.4	3.1	72.7	74.5	208	2,312
WFRC/MAG	Local	-16.6	-20.6	-16.6	-12.5	-13.7	36.4	4.1	31.6	15	2	12
WFRC/MAG	Collector	0.9	-24.8	0.8	22.1	6.6	0.2	5.4	29.4	30.3	3,175	4,063
WFRC/MAG	Minor Arterial	0.2	-18.3	0	19.7	5.6	0.3	5.8	33.7	33.9	1,981	2,147
WFRC/MAG	Principal Arterial	-1.8	-19.8	-1.8	26	3.5	0.3	5.5	38	36.2	1,521	1,741
WFRC/MAG	Expressway	-1.5	-16.7	-2.7	31.9	4.5	1.1	7.2	50.9	49.4	177	308
WFRC/MAG	Freeway	7	-9.5	5.1	51.4	11.4	0.9	8	67.4	74.5	287	805
Cache	Local	7.5	-5.7	13.2	14.9	14.8	9.8	9.3	22.6	30	6	15
Cache	Collector	-3.3	-16.7	-4.2	20	3	0.7	6.5	35.9	32.5	289	675
Cache	Minor Arterial	-4.4	-29.3	-2.9	7.8	1.1	1.1	6.6	39.7	35.3	146	223
Cache	Principal Arterial	-4.2	-19.6	-4.3	16.5	2	1.1	6.2	45.9	41.7	131	275
Dixie	Local	-14.5	-20.3	-11.3	-11	-11	1.9	3.9	29.5	15	18	154
Dixie	Collector	-0.4	-15.9	-2	19	9	1.2	7.4	33.4	33.1	139	374
Dixie	Minor Arterial	0	-22.5	0.2	21.1	6.8	0.8	7.1	39.6	39.6	286	542
Dixie	Principal Arterial	4.9	-11.2	4	32.5	11.5	2.1	9.8	40	44.8	88	189
Dixie	Expressway	-3.9	-21.1	-4.4	13.6	6.2	4.1	9.2	53	49.2	22	44

TDM Name	Functional Type	Average	Min	Median	Max	85th Percentile	95% CI	Std. Dev.	ClearGuide FF	TDM FF	Count	Total Length
Dixie	Freeway	3.2	-5.5	1.9	15.8	8.2	1.5	4.8	66.4	69.6	45	215
Summit/Wasatch	Local	n/a	0	n/a	0	n/a	n/a	n/a	n/a	n/a	0	0
Summit/Wasatch	Collector	3.2	-13.2	1.1	19.1	11.5	1.4	8.1	34.7	37.9	134	581
Summit/Wasatch	Minor Arterial	2.4	-17	2.3	16.7	9.3	1.4	7.1	41.5	43.9	102	251
Summit/Wasatch	Principal Arterial	-1.9	-12.4	-0.8	15.6	3	0.9	5.3	49.2	47.3	136	284
Summit/Wasatch	Freeway	-1.2	-7	-1.4	8.6	2.3	1.1	3.5	68.2	67	43	276
Iron County	Local	-1.5	-5.1	-1.5	2	2	5.6	3.5	27.7	26.1	4	58
Iron County	Collector	-1.2	-24.1	-1.5	21.1	7.7	1.5	9.6	41.5	40.3	158	926
Iron County	Minor Arterial	2.4	-14.9	3.8	23.9	13.4	2.1	10.1	42.8	45.2	92	487
Iron County	Principal Arterial	3.8	-7.2	3.2	22.5	11.4	1.9	7	41.5	45.3	56	127
Iron County	Freeway	0.7	-2.3	-0.2	4.9	2.9	0.8	2.1	74.3	75	26	238

Table 4.6 displays TDM Name by Area Type statistics. The statistics based on this filter combination were not as uniform as other combinations. No one area type necessarily stood out for having a more significant difference in average speeds than another, and no model necessarily had higher overall differences than another consistently. The most significant differences were seen for rural areas in the WFRC/MAG model (6.8 MPH) and for suburban and urban areas for the Cache model (-4.5 and -5.6 MPH).

Table 4.6 Model Type by Area Type Aggregate Statistics

TDM Name	Area Type	Average	Min	Median	Max	85th Percentile	95% CI	Std. Dev.	ClearGuide FF	TDM FF	Count	Total Length
USTM	1/Rural	-1.6	-47	-2.4	34.2	11.3	0.5	11.5	51.9	50.3	2,458	21,596
USTM	2/Transition	2.3	-26.5	3.1	26.4	11.3	0.8	8.4	40.6	43	482	967
USTM	3/Suburban	2.4	-22.9	3.1	18	9.1	0.7	6.4	33	35.4	340	322
USTM	4/Urban	1.7	-7.6	1.1	10.6	5.9	1	3.9	28	29.7	62	36
WFRC/MAG	1/Rural	6.8	-20.6	8	22.1	15.5	0.9	7.8	44.2	50.9	280	792
WFRC/MAG	2/Transition	2.5	-19.8	2.1	39.7	8.9	0.5	6.7	39.6	42.1	693	1,268
WFRC/MAG	3/Suburban	0.6	-19.7	0.4	50.3	6.9	0.2	6.1	35.3	35.9	2,623	3,631
WFRC/MAG	4/Urban	-0.7	-24.8	-0.8	51.4	4.1	0.2	5.1	32.8	32.1	3,294	3,293
WFRC/MAG	5/CBD - Like	-2.7	-9.9	-3.5	10.1	1.7	0.5	3.7	24.8	22.1	253	90
Cache	1/Rural	-1.5	-15	-2.2	20	8	1.3	8.2	48.2	46.7	163	782
Cache	2/Transition	-3.8	-29.3	-2.4	9.7	2.8	1.2	7.1	40.6	36.8	129	187
Cache	3/Suburban	-4.5	-20.4	-4.5	5.8	-0.6	0.6	4.1	34.5	29.9	161	144
Cache	4/Urban	-5.6	-19.6	-4.7	7.5	-1	1	5.3	31	25.4	119	75
Dixie	1/Rural	1	-20.3	-0.1	32.5	14.8	2.1	12	49.2	50.2	131	827
Dixie	2/Transition	0.8	-22.5	1.6	23.2	7.5	1.4	8.2	43.9	44.7	135	332
Dixie	3/Suburban	0	-11.9	-1.2	20.8	7.3	0.9	6.3	37.4	37.4	186	217
Dixie	4/Urban	-0.5	-15.9	-0.3	10.3	5.7	0.9	5.8	33.2	32.7	146	142
Summit/Wasatch	1/Rural	1.2	-16.1	0	19.1	11.1	1.2	8.4	52.6	53.8	206	1,132
Summit/Wasatch	2/Transition	1.1	-17	1.4	15.6	7.2	1.4	6.3	43.7	44.8	77	153
Summit/Wasatch	3/Suburban	1.4	-10.5	1.8	9.1	6.1	1.2	4.8	34.4	35.8	60	67
Summit/Wasatch	4/Urban	-0.6	-12.4	-0.1	10.1	1.7	0.9	3.9	31.1	30.5	72	41

TDM Name	Area Type	Average	Min	Median	Max	85th Percentile	95% CI	Std. Dev.	ClearGuide FF	TDM FF	Count	Total Length
Iron County	1/Rural	-0.4	-24.1	-1.1	23.9	9.8	1.6	10.8	49.3	48.9	178	1,564
Iron County	2/Transition	0.5	-12.5	0.3	15.8	8.8	1.7	7.5	43.5	44.1	78	178
Iron County	3/Suburban	4.4	-6.7	3.5	22.5	9.5	1.6	5.6	35.6	40	48	72
Iron County	4/Urban	2.6	-8.9	3.8	11.7	5.5	1.6	4.3	30.5	33.1	32	21

4.5.3 USTM Results

Results were filtered by model by area type by functional type to provide additional, more specific views of data based upon model. This filter combination was also utilized to create several scatterplots for each model to visualize speed distributions by functional type. Table 4.7 and Figures 4.9 – 4.15 display results for USTM. Local roads had the most significant average speed differences in most area types, with expressways also having more significance. USTM saw much closer average speeds on freeways compared to the overview statistics discussed previously. Urban area type saw closer average speeds overall than the other area types, though again more significant differences were observed for local and expressway roads typically, where such roads were present. One notable result on data for the USTM is that it saw higher standard deviation of average speeds in rural and transition area types, while the standard deviation values were less significant in suburban and urban areas. Highest standard deviation values included local and collector roads in rural areas (14.1 and 11.8 MPH respectively).

Table 4.7 USTM by Area Type and Functional Type

TDM Name	Area Type	Functional Type	Average	Min	Median	Max	85th Percentile	95% CI	Std. Dev.	ClearGuide FF	TDM FF	Count	Total Length
USTM	1/Rural	Local	-19.7	-47	-18.3	3.9	-2.8	2.3	14.1	35.6	15.8	153	2782
USTM	1/Rural	Collector	-0.2	-33.4	-0.6	21.8	15.1	0.7	11.8	44.7	44.5	1,061	9183
USTM	1/Rural	Minor Arterial	-1.2	-16.1	-2.7	25.8	11.3	1	10.3	54	52.8	444	3755
USTM	1/Rural	Principal Arterial	-0.9	-11.8	-4.3	34.2	6.6	0.7	8.4	60.8	59.9	612	3702
USTM	1/Rural	Expressway	n/a	0	n/a	0	n/a	n/a	n/a	n/a	n/a	0	0
USTM	1/Rural	Freeway	1.8	-5.3	1.3	15.4	4.4	0.4	3	72.6	74.4	188	2175
USTM	2/Transition	Local	-23.1	-26.5	-23.4	-19.1	-19.7	5.3	3.4	38.1	15	4	12
USTM	2/Transition	Collector	1	-16.7	0.4	17.5	8.4	0.9	6.4	34.7	35.8	188	427
USTM	2/Transition	Minor Arterial	2.2	-20.7	5	15.8	11.6	1.8	9	39.3	41.6	102	133
USTM	2/Transition	Principal Arterial	4.6	-17.1	5.4	26.4	13.1	1.4	9	44.5	49.1	169	254
USTM	2/Transition	Expressway	-16.8	-16.8	-16.8	-16.8	-16.8	n/a	0	64.8	48	1	7
USTM	2/Transition	Freeway	2	-1.6	0.8	12.8	3.2	1.9	3.8	73	75	18	134
USTM	3/Suburban	Local	-2	-2.3	-2	-1.7	-1.8	2.7	0.3	29.2	27.2	2	3
USTM	3/Suburban	Collector	-0.6	-22.9	1.9	5.5	3.5	1	5.3	29.3	28.7	112	105
USTM	3/Suburban	Minor Arterial	3.7	-12.8	4.8	18	9.3	1.2	5.9	31.6	35.4	94	90
USTM	3/Suburban	Principal Arterial	4.5	-14.6	4.6	17.5	11.7	1.1	6.2	35.9	40.5	126	112

TDM Name	Area Type	Functional Type	Average	Min	Median	Max	85th Percentile	95% CI	Std. Dev.	ClearGuide FF	TDM FF	Count	Total Length
USTM	3/Suburban	Expressway	-12.3	-15.1	-12.3	-9.4	-10	3.6	2.3	60.3	48	4	10
USTM	3/Suburban	Freeway	-0.8	-1.2	-0.8	-0.4	-0.5	3.6	0.4	75.8	75	2	3
USTM	4/Urban	Collector	0	-3.5	-0.3	6.2	2.1	1	2.5	25	25	24	15
USTM	4/Urban	Minor Arterial	3.2	-1	4.4	6.1	4.9	1.6	2.3	27.4	30.6	10	7
USTM	4/Urban	Principal Arterial	2.5	-7.6	2.9	10.6	7.1	1.8	4.7	30.8	33.3	28	15
USTM	4/Urban	Expressway	n/a	0	n/a	0	n/a	n/a	n/a	n/a	n/a	0	0

Figure 4.9 provides the results of USTM data after it was charted in scatterplot form. This scatterplot, and others in this section, display plotted data by TDM free-flow speed (x-axis) and ClearGuide free-flow speed (y-axis). Results from the USTM scatterplot show that TDM speeds tend to be grouped at similar values, while ClearGuide speeds are more dispersed. Local roads tend to show the lowest free-flow speeds while freeways show the highest, which is to be expected; however, there is some variation in the result for all functional types. Collector, minor arterial, and principal arterial roads all had a similar distribution in USTM. Expressway results were limited and grouped to a single TDM speed (just under 50 MPH), though they varied for ClearGuide speeds.

Figures A.1 through A.31 in Appendix A display results broken out by functional type and area type for more specific analysis for all the TDMs in this study.

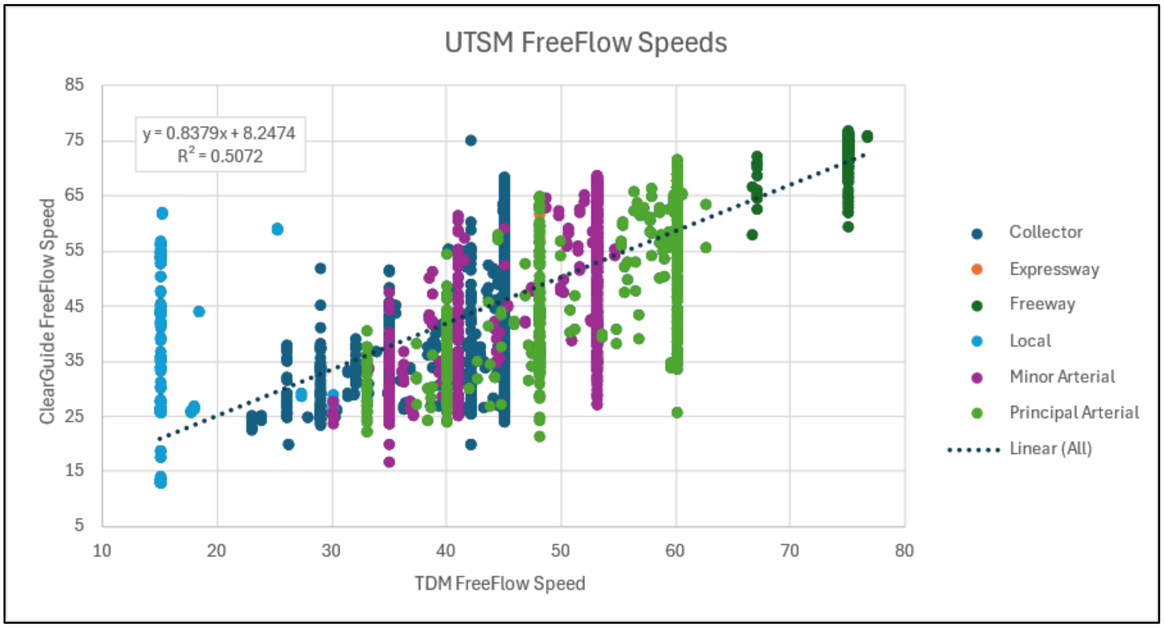

Figure 4.5 USTM Speeds by Functional Type Scatterplot

4.5.4 WFRC/MAG Model Results

Table 4.8 and Figure 4.10 display results for the WFRC/MAG model type. Notably, the WFRC/MAG model saw higher average differences on freeways than USTM, with freeways having the most or second-most significant difference for the area types within the WFRC/MAG model. Minor arterial roadways typically saw the lowest speed difference (except in rural areas). Generally arterial roadways saw the lowest speed differences overall, though in this model there were some area-to-area variations. Standard deviation values for the WFRC/MAG TDM varied, with no one functional type or area type returning higher or lower standard deviations generally. The highest standard deviation value could be seen on freeways in urban areas (8.4 MPH).

Table 4.8 WFRC/MAG Model by Area Type and Functional Type

TDM Name	Area Type	Functional Type	Average	Min	Median	Max	85th Percentile	95% CI	Std. Dev.	ClearGuide FF	TDM FF	Count	Total Length
WFRC/MAG	1/Rural	Local	-16.6	-20.6	-16.6	-12.5	-13.7	36.4	4.1	31.6	15	2	12
WFRC/MAG	1/Rural	Collector	9	-11.4	10	22.1	16	1.3	7.5	34	43.1	124	244
WFRC/MAG	1/Rural	Minor Arterial	8.8	-11.2	10.3	19.7	16	1.5	6.9	44.8	53.6	82	166
WFRC/MAG	1/Rural	Principal Arterial	0.4	-7.7	0	13.1	5.2	1.5	5.3	57.2	57.5	52	240
WFRC/MAG	1/Rural	Expressway	-2.9	-4.4	-2.9	-1.3	-1.8	13.9	1.6	58.9	56	2	12
WFRC/MAG	1/Rural	Freeway	3.8	-4.1	4.5	7.6	5.8	1.2	2.5	73.5	77.3	18	118
WFRC/MAG	2/Transition	Local	n/a	0	n/a	0	n/a	n/a	n/a	n/a	n/a	0	0
WFRC/MAG	2/Transition	Collector	2.6	-14.3	2.1	17.6	7.3	0.5	4.7	32.6	35.2	321	598
WFRC/MAG	2/Transition	Minor Arterial	3	-16.8	2.3	17.8	11.8	1.1	7.8	39.1	42.1	178	263
WFRC/MAG	2/Transition	Principal Arterial	0.4	-19.8	-0.3	26	7.5	1.4	7.8	45.8	46.2	128	232
WFRC/MAG	2/Transition	Expressway	-2.4	-7.5	-3.2	7.1	2.4	1.7	3.8	52	49.6	22	36
WFRC/MAG	2/Transition	Freeway	8.1	3.1	5.7	39.7	10.5	2.2	7.3	68.3	76.3	44	139
WFRC/MAG	3/Suburban	Local	n/a	0	n/a	0	n/a	n/a	n/a	n/a	n/a	0	0
WFRC/MAG	3/Suburban	Collector	1.6	-15.6	1.3	17.8	7.7	0.3	5.3	29.9	31.5	1,290	1781
WFRC/MAG	3/Suburban	Minor Arterial	-0.5	-18.3	-0.1	17.1	5	0.4	5.7	35.7	35.2	685	867
WFRC/MAG	3/Suburban	Principal Arterial	-2.1	-19.7	-1.9	19.9	3.1	0.5	5.9	40.6	38.6	459	551
WFRC/MAG	3/Suburban	Expressway	-0.5	-12.5	-1.8	31.9	5.8	1.5	7.3	50.4	50	99	174
WFRC/MAG	3/Suburban	Freeway	8.5	-9.5	6.5	50.3	14.4	1.7	8	65.6	74.1	90	259
WFRC/MAG	4/Urban	Local	n/a	0	n/a	0	n/a	n/a	n/a	n/a	n/a	0	0
WFRC/MAG	4/Urban	Collector	-0.7	-24.8	-0.2	11.8	3.5	0.2	4.5	28.4	27.7	1,324	1401
WFRC/MAG	4/Urban	Minor Arterial	-0.4	-18	-0.5	14.3	4.4	0.3	4.5	31.2	30.8	949	819
WFRC/MAG	4/Urban	Principal Arterial	-2.1	-18.3	-2.2	16.2	3	0.3	4.8	34.8	32.7	832	700
WFRC/MAG	4/Urban	Expressway	-3	-16.7	-4.2	30.2	2	2.1	7.8	51	48	54	86
WFRC/MAG	4/Urban	Freeway	6.2	-4.8	4.5	51.4	9.7	1.4	8.4	67.5	73.7	135	288
WFRC/MAG	5/CBD - Like	Collector	-2.9	-7.5	-3.9	3.8	1.5	0.6	3.1	23	20.1	116	40
WFRC/MAG	5/CBD - Like	Minor Arterial	-2.5	-9.9	-3.5	10.1	2.5	1	4.6	25.1	22.6	87	32
WFRC/MAG	5/CBD - Like	Principal Arterial	-2.4	-9.3	-1.8	4.7	1	0.9	3.3	28.4	25.9	50	19
WFRC/MAG	5/CBD - Like	Freeway	n/a	0	n/a	0	n/a	n/a	n/a	n/a	n/a	0	0

Similar to USTM, the scatterplots for the WFRC/MAG TDM show that TDM speeds tend to cluster around certain values while ClearGuide speeds are more varied. Freeway and expressway functional types have the highest speeds in this model, though there is a cluster of freeway segments with lower ClearGuide speeds between 20 and 40 MPH. Minor and principal arterial roads had very similar distributions, while collector roads typically had the lowest speeds overall for both ClearGuide and TDM.

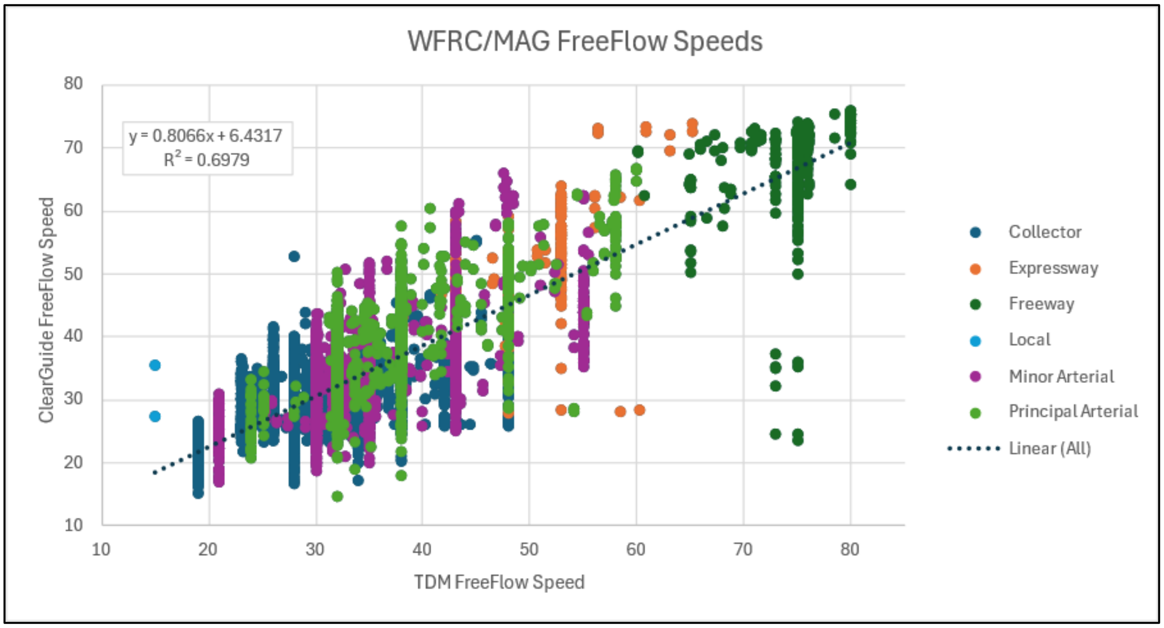

Figure 4.6 WFRC/MAG Model Speeds by Functional Type Scatterplot

<u>4.5.5 Cache Model Results</u>

Table 4.9 and Figure 4.11 display results for the Cache model. Outside of local roads in rural areas (14 MPH), the Cache model generally returned similar results in speed difference, with TDM speeds generally ranging from 1 to 6 MPH below ClearGuide speeds for the various functional types by area. Standard deviation values varied for this model; notably, principal arterials often saw standard deviations with more than 6 MPH difference, while collector roads in rural areas saw the highest standard deviation overall (8.7 MPH).

Table 4.9 Cache Model by Area Type and Functional Type

TDM Name	Area Type	Functional Type	Average	Min	Median	Max	85th Percentile	95% CI	Std. Dev.	ClearGuide FF	TDM FF	Count	Total Length
Cache	1/Rural	Local	14	12.5	14.3	14.9	14.8	1.5	0.9	21	35	4	14
Cache	1/Rural	Collector	-2.1	-15	-4.3	20	8.1	1.6	8.7	45.8	43.6	110	518
Cache	1/Rural	Minor Arterial	-2	-11	-0.8	5.6	3.1	2	4.8	54.3	52.4	26	92
Cache	1/Rural	Principal Arterial	-0.5	-11.3	-0.9	16.5	5.8	2.9	6.6	57.5	57	23	159
Cache	2/Transition	Collector	-1.9	-16	0.3	9.7	3.2	1.6	6	32.6	30.6	55	
Cache	2/Transition	Minor Arterial	-5.8	-29.3	-3.3	7.8	0.1	2.1	7.8	43.6	37.9	54	63
Cache	2/Transition	Principal Arterial	-3.7	-18.7	-2.5	7.3	2.3	3.1	6.6	54.4	50.7	20	85
Cache	3/Suburban	Local	-5.7	-5.7	-5.7	-5.6	-5.6	0.4	0	25.7	20	2	1
Cache	3/Suburban	Collector	-5.3	-16.7	-4.9	-0.2	-1.7	0.7	3.2	29.6	24.3	85	70
Cache	3/Suburban	Minor Arterial	-2.5	-20.4	-1.1	5.8	1.9	2.1	5.6	30.9	28.4	30	22
Cache	3/Suburban	Principal Arterial	-4.3	-12.4	-5.1	4.7	0.9	1.2	4.1	46.7	42.4	44	51
Cache	4/Urban	Collector	-4.6	-9.7	-4.7	1.3	-1.9	0.9	2.8	26.5	22	39	24
Cache	4/Urban	Minor Arterial	-5.8	-19.6	-4	2.5	-0.7	1.9	5.6	30.5	24.8	36	24
Cache	4/Urban	Principal Arterial	-6.4	-19.6	-5.4	7.5	0	2	6.5	35.3	28.9	44	27

Scatterplots for the Cache model had a fairly wide distribution. For example, collector roads in the Cache model were fairly evenly spread over TDM speeds of 15 to just under 50 MPH (though there was a cluster of TDM speeds at just under 50 MPH) and 20 to 60 MPH for ClearGuide speeds. Minor and principal arterial roads also had a fairly wide distribution, with many minor arterial roads having ClearGuide speeds over 40 MPH. The Cache model does not have any expressway or freeway data.

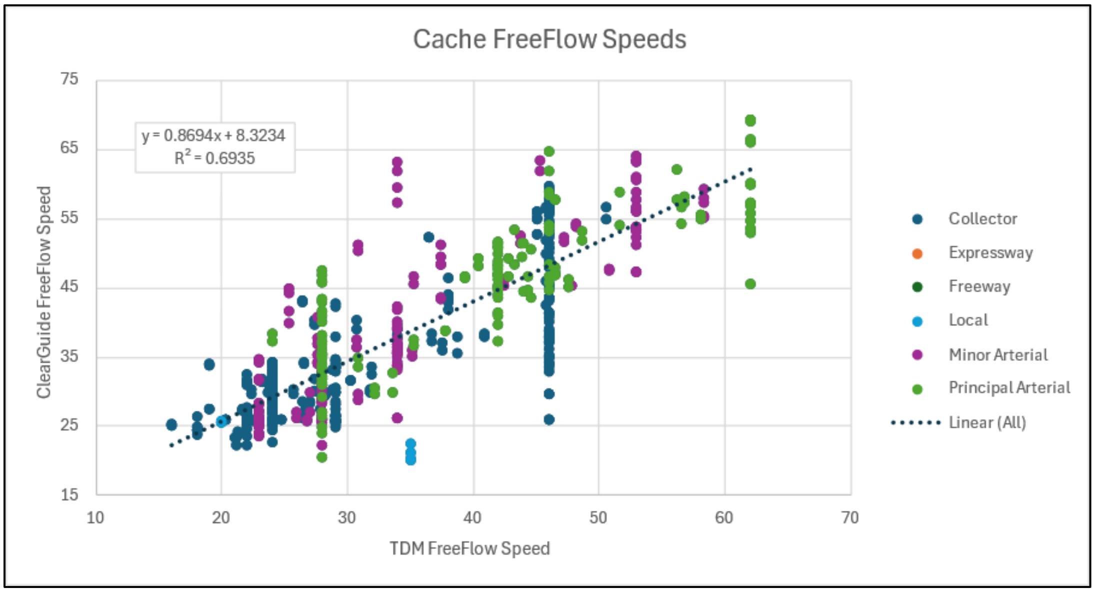

Figure 4.7 Cache Model Speeds by Functional Type Scatterplot

4.5.6 Dixie Model Results

Table 4.10 and Figure 4.12 display results for the Dixie model. The Dixie model shows a variety of results across various areas and functional types. The TDM average speed differences were generally higher than ClearGuide speeds across the various areas. Meanwhile, local roads in rural areas again saw a very significant difference in speed. Overall, this model returned more variation in results than the Cache model, and more similar to the results of the USTM and WFRC/MAG models. This model saw several instances of higher standard deviations of more than 5 MPH in rural and transition areas, with some additional instances in other area types. The highest standard deviations could be found on minor/principal arterials in rural areas (11.5 and 14.7 MPH, respectively).

Table 4.10 Dixie Model by Area Type and Functional Type

TDM Name	Area Type	Functional Type	Average	Min	Median	Max	85th Percentile	95% CI	Std. Dev.	ClearGuide FF	TDM FF	Count	Total Length
Dixie	1/Rural	Local	-14.5	-20.3	-11.3	-11	-11	1.9	3.9	29.5	15	18	154
Dixie	1/Rural	Collector	8.3	-6.7	10.1	19	15.3	3	7.1	36.5	44.8	24	192
Dixie	1/Rural	Minor Arterial	0.1	-13.7	-1.9	20.8	15.6	3.5	11.5	52.7	52.8	44	249
Dixie	1/Rural	Principal Arterial	8.4	-8.3	7.1	32.5	30.1	6.9	14.7	51.1	59.5	20	105
Dixie	1/Rural	Freeway	1	-5.5	0.5	15.8	2.7	1.6	3.8	68	69	25	128
Dixie	2/Transition	Local	n/a	0	n/a	0	n/a	n/a	n/a	n/a	n/a	0	0
Dixie	2/Transition	Collector	1.3	-9.2	-0.1	15.9	8.8	2.6	7.3	33.9	35.3	33	87
Dixie	2/Transition	Minor Arterial	0.3	-22.5	2	21.1	4.8	1.9	7.4	43	43.3	60	113
Dixie	2/Transition	Principal Arterial	8.7	0.4	7.5	23.2	15.2	4.5	7.1	42.4	51.2	12	38
Dixie	2/Transition	Expressway	-4.9	-21.1	-5.3	13.6	3.8	4.2	9	54.2	49.3	20	43
Dixie	2/Transition	Freeway	4.2	-1	2	15.5	8.9	3.5	4.9	63.3	67.5	10	52
Dixie	3/Suburban	Collector	-3.5	-11.6	-3.6	9.6	-0.1	1.2	4.3	33.9	30.3	54	68
Dixie	3/Suburban	Minor Arterial	-0.2	-11.9	-1	10.5	7.3	1.2	5.7	37.7	37.5	94	106
Dixie	3/Suburban	Principal Arterial	5.1	-8.5	4.6	20.8	11	2.4	6.5	37.3	42.4	30	26
Dixie	3/Suburban	Expressway	7	6.5	7	7.4	7.3	4	0.4	41.1	48	2	1
Dixie	3/Suburban	Freeway	8.7	3.7	8.9	14.3	12.4	3.9	3.8	63.9	72.6	6	17
Dixie	4/Urban	Local	n/a	0	n/a	0	n/a	n/a	n/a	n/a	n/a	0	0
Dixie	4/Urban	Collector	-3.7	-15.9	-1.5	3.8	1.2	2.2	5.6	29.5	25.8	28	28
Dixie	4/Urban	Minor Arterial	0	-12.9	0.6	9.1	5.9	1.1	5.1	32.8	32.9	88	75
Dixie	4/Urban	Principal Arterial	0.1	-11.2	2.6	10.3	7.1	2.7	6.8	33.3	33.3	26	20
Dixie	4/Urban	Expressway	n/a	0	n/a	0	n/a	n/a	n/a	n/a	n/a	0	0
Dixie	4/Urban	Freeway	5.8	2.5	6.1	8.6	7.8	3.6	2.2	68.5	74.3	4	18

The Dixie model also had a fairly wide distribution. One notable speed result in this model is that the TDM speeds for local roads were notably lower than associated ClearGuide speeds (about 15 MPH vs. more than 25 MPH, respectively). Minor arterial roads in the Dixie model had slightly more concentrated speeds than principal arterials, and principal arterials in many instances had higher speeds for both TDM and ClearGuide than expressways. Freeways had the highest speeds overall.

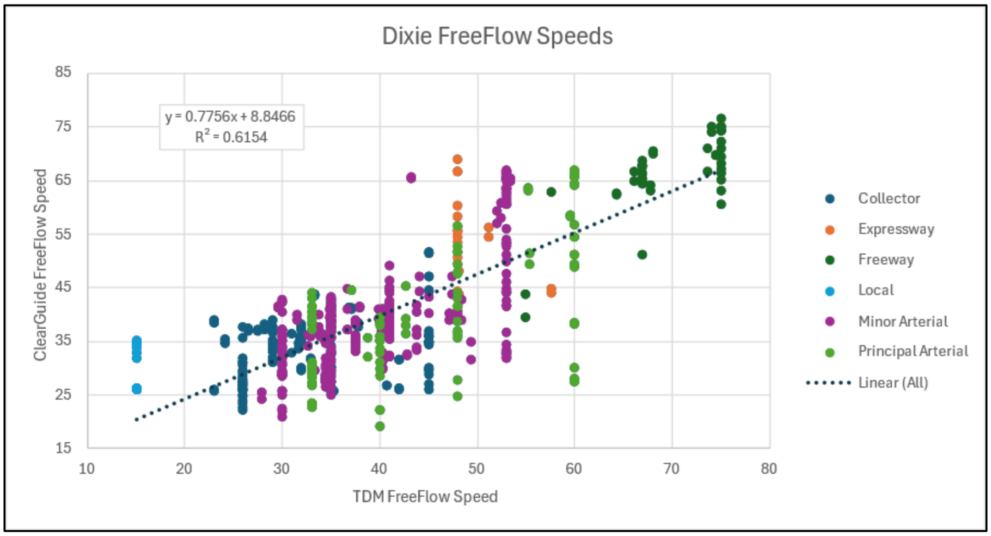

Figure 4.8 Dixie Model Speeds by Functional Type Scatterplot

4.5.7 Summit/Wasatch Model Results

The Summit/Wasatch model shows a variety of results across the different area and functional types, with no apparent trends or consistency. Most notable is that the Summit/Wasatch model returned average difference speeds between ClearGuide and TDM of less than 5 MPH, without some of the more significant speed differences seen in other models (e.g., the local road functional type returning significant speed differences in many cases in other models). Most standard deviation values for this model fell under a 5 MPH difference, except collector and minor arterial roads in rural areas (10.1 and 8.6 MPH, respectively) and minor/principal arterial roads in transition areas (7.2 and 7.3 MPH, respectively).

Table 4.11 Summit/Wasatch Model by Area Type and Functional Type

TDM Name	Area Type	Functional Type	Average	Min	Median	Max	85th Percentile	95% CI	Std. Dev.	ClearGuide FF	TDM FF	Count	Total Length
Summit/Wasatch	1/Rural	Collector	4.9	-13.2	5.4	19.1	18.1	2.3	10.1	39.8	44.7	76	504
Summit/Wasatch	1/Rural	Minor Arterial	1.3	-16.1	0.1	16.7	11.6	2.6	8.6	51.1	52.4	44	187
Summit/Wasatch	1/Rural	Principal Arterial	-2.3	-10.3	-1	7	2.1	1.3	4.7	62.2	59.9	54	213
Summit/Wasatch	1/Rural	Freeway	-1.6	-7	-2.3	8.6	1.2	1.3	3.6	68.6	67.1	32	228

TDM Name	Area Type	Functional Type	Average	Min	Median	Max	85th Percentile	95% CI	Std. Dev.	ClearGuide FF	TDM FF	Count	Total Length
Summit/Wasatch	2/Transition	Local	n/a	0	n/a	0	n/a	n/a	n/a	n/a	n/a	0	0
Summit/Wasatch	2/Transition	Collector	0.9	-6.2	0.6	7.3	4.8	1.7	3.5	31.4	32.3	18	39
Summit/Wasatch	2/Transition	Minor Arterial	2.7	-17	2.7	12	9.7	2.9	7.2	39.8	42.5	26	42
Summit/Wasatch	2/Transition	Principal Arterial	-0.1	-11.2	1.4	15.6	5.6	3.1	7.3	48.6	48.5	24	33
Summit/Wasatch	2/Transition	Freeway	0.4	-4.2	0.7	4	3.5	2.2	2.9	66.4	66.8	9	39
Summit/Wasatch	3/Suburban	Collector	0.9	-5.3	0.8	5.4	4.7	1.6	3.4	28.3	29.2	20	23
Summit/Wasatch	3/Suburban	Minor Arterial	4.7	-2.3	5.5	9.1	7.9	1.3	3.1	30.8	35.5	24	19
Summit/Wasatch	3/Suburban	Principal Arterial	-2.9	-10.5	-3.9	4.6	4.1	3	5.2	44.2	41.3	14	16
Summit/Wasatch	3/Suburban	Freeway	-1.9	-1.9	-1.9	-1.8	-1.8	0.4	0.1	68.9	67	2	9
Summit/Wasatch	4/Urban	Collector	1.4	-0.1	0.3	6.2	6	1.1	2.3	24.7	26.1	20	15
Summit/Wasatch	4/Urban	Minor Arterial	1.2	-0.7	0.8	4.1	3.6	1.4	1.7	25.7	26.9	8	4
Summit/Wasatch	4/Urban	Principal Arterial	-1.9	-12.4	-1.1	10.1	0.6	1.3	4.2	35.1	33.2	44	22

The distribution of speeds for different functional types in the Summit/Wasatch model varied from one another. There is a wide range of speeds for both TDM and ClearGuide on minor and principal arterials. Collector roads see a cluster of TDM speeds at about 47 MPH, while ClearGuide speeds are more widely distributed between 20 and 40 MPH. Freeway speeds have a fairly concentrated cluster for both TDM and ClearGuide and make up the highest speeds overall.

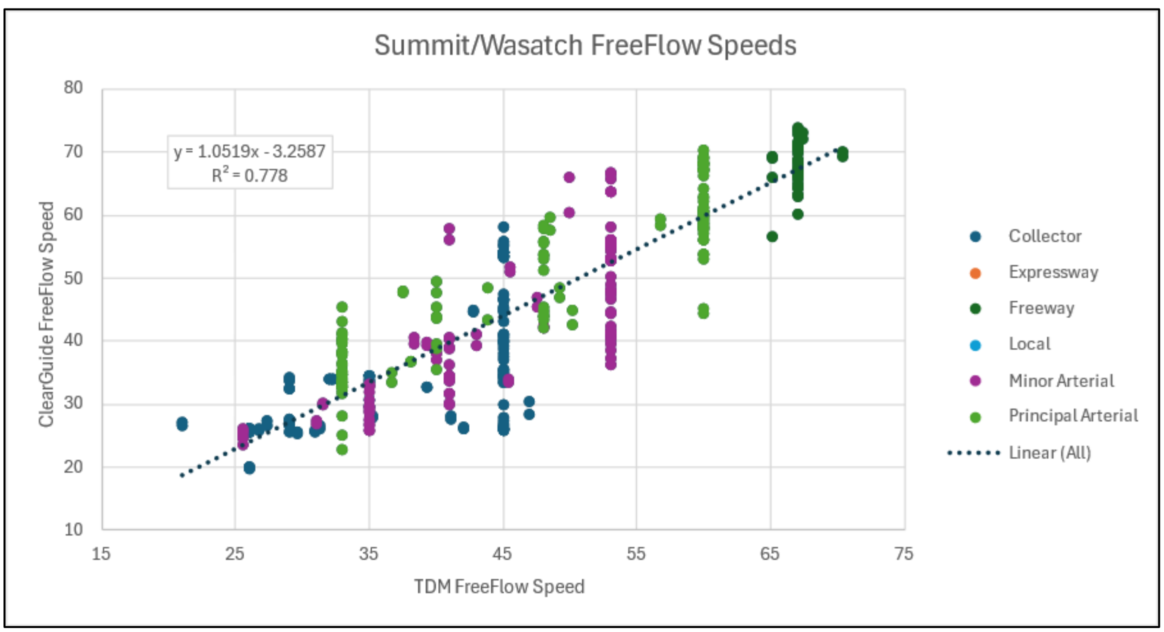

Figure 4.9 Summit/Wasatch Model Speeds by Functional Type Scatterplot

4.5.8 Iron County Model Results

The Iron County Model also shows a variety of results across area and functional types. Similarly to the Summit/Wasatch model there is little apparent consistency in the results from one area/functional type to another. The most significant speed difference between ClearGuide and TDM is seen in the principal arterial functional class in the suburban area type (7.6 MPH). Most other average speeds are under 5 MPH in significance. Standard deviation for the Iron County model is largely around or under 5 MPH in significance, with a few notable high standard deviation values for collector and minor arterial roads in rural areas (11.1 and 12.9 MPH, respectively) and principal arterials in transition areas (8.4 MPH).

Table 4.12 Iron County Model by Area Type and Functional Type

TDM Name	Area Type	Functional Type	Average	Min	Median	Max	85th Percentile	95% CI	Std. Dev.	ClearGuide FF	TDM FF	Count	Total Length
Iron County	1/Rural	Local	-1.5	-5.1	-1.5	2	2	5.6	3.5	27.7	26.1	4	58
Iron County	1/Rural	Collector	-0.5	-24.1	-0.3	21.1	9.5	2.1	11.1	44	43.5	106	808
Iron County	1/Rural	Minor Arterial	-0.3	-14.9	-6.3	23.9	16.7	3.8	12.9	53.2	52.9	46	435
Iron County	1/Rural	Principal Arterial	-2	-5.8	-2.4	1.8	1	2.7	2.6	61.9	59.9	6	69
Iron County	1/Rural	Freeway	0.2	-2.3	-0.5	4.8	2	1	1.9	74.8	75	16	194
Iron County	2/Transition	Collector	-4.7	-12.5	-4.3	3.7	1	1.8	5.1	41.7	37.1	32	101
Iron County	2/Transition	Minor Arterial	5.7	-2.4	5.4	14.7	12.3	2.3	5.2	36.7	42.4	22	29
Iron County	2/Transition	Principal Arterial	3.7	-7.2	3.1	15.8	13.5	4.2	8.4	44.5	48.2	18	28
Iron County	2/Transition	Freeway	-0.1	-0.9	-0.4	1.3	0.5	0.8	0.7	75.1	75	6	20
Iron County	3/Suburban	Local	n/a	0	n/a	0	n/a	n/a	n/a	n/a	n/a	0	0
Iron County	3/Suburban	Collector	1.2	-6.7	1.7	7.4	4.3	2	3.7	28.6	29.8	16	15
Iron County	3/Suburban	Minor Arterial	4.7	-3.6	7.2	10.1	9.5	3.3	5.2	31	35.7	12	16
Iron County	3/Suburban	Principal Arterial	7.6	1.5	4.8	22.5	11.3	3.3	6.2	37.3	44.8	16	18
Iron County	3/Suburban	Freeway	3.8	2.7	3.7	4.9	4.8	1.7	1.1	71.3	75	4	23
Iron County	4/Urban	Collector	-2	-8.9	-1.2	3.4	2.4	7.5	4.7	28	26	4	2
Iron County	4/Urban	Minor Arterial	4.5	-0.6	4.2	8.7	5.8	1.4	2.1	25.9	30.4	12	8
Iron County	4/Urban	Principal Arterial	2.4	-6.5	2.8	11.7	6	2.4	4.5	34.6	37	16	11

The Iron County Model speed distributions are often similar to Summit/Wasatch distribution results discussed previously. Freeways constitute the highest speeds and are fairly concentrated. The other functional type roads have more dispersed speed distributions. Collector roads see a cluster of TDM speeds at about 47 MPH, while ClearGuide speeds are more widely distributed between 20 and 40 MPH. Arterial roads have a varied distribution overall.

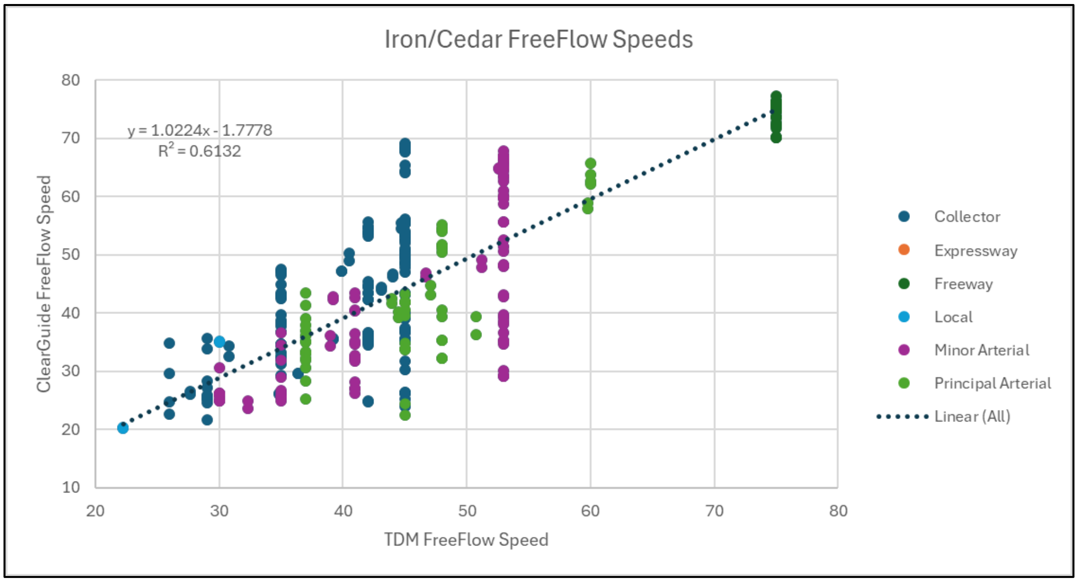

Figure 4.10 Iron County Model Speeds by Functional Type Scatterplot

4.5.9 Notable Findings from Model Charts

From these charts, the research team was able to identify several key findings as a result of this analysis. Several of the charts are highlighted with a brief description of the associated findings. These scatterplot charts are organized by model and functional type. Coloration is organized by area type, allowing for analysis of these factors by model. Complete scatterplots for each model are included in Appendix B.

Figures 4.15 and 4.16 display the chart for collector roads in the USTM and WFRC/MAG models. As seen in the charts, many models and functional types show rural areas with very widespread results in ClearGuide speeds, which are not reflected in the TDM free-flow speeds. This highlights a possible discrepancy between TDM speeds and real-world speeds in rural areas, where the TDM model does not reflect the wide range of speeds found in these areas. Note that these models are included here to visualize these differences; charts for all models can be found in the Appendix.

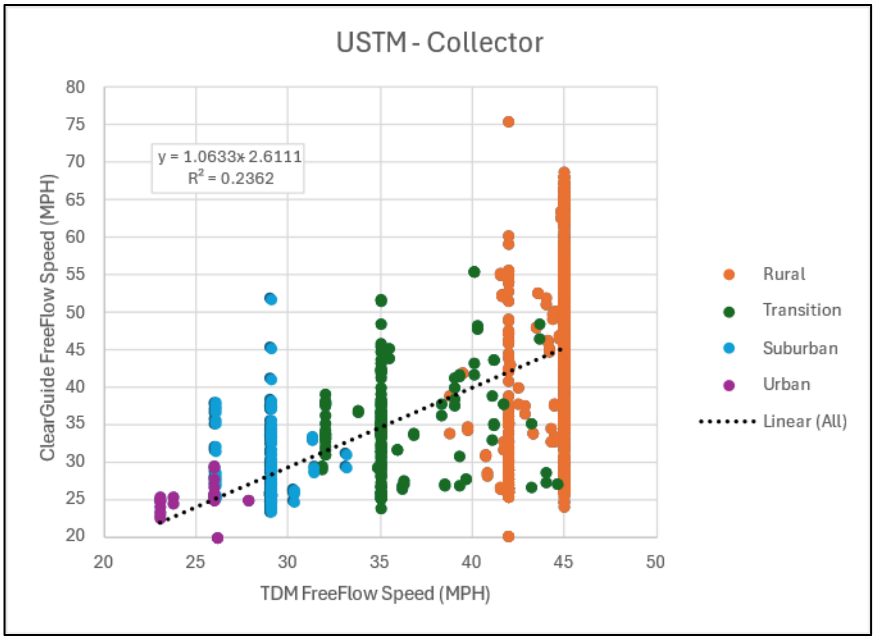

Figure 4.11 USTM – Collector Roads with Area Type

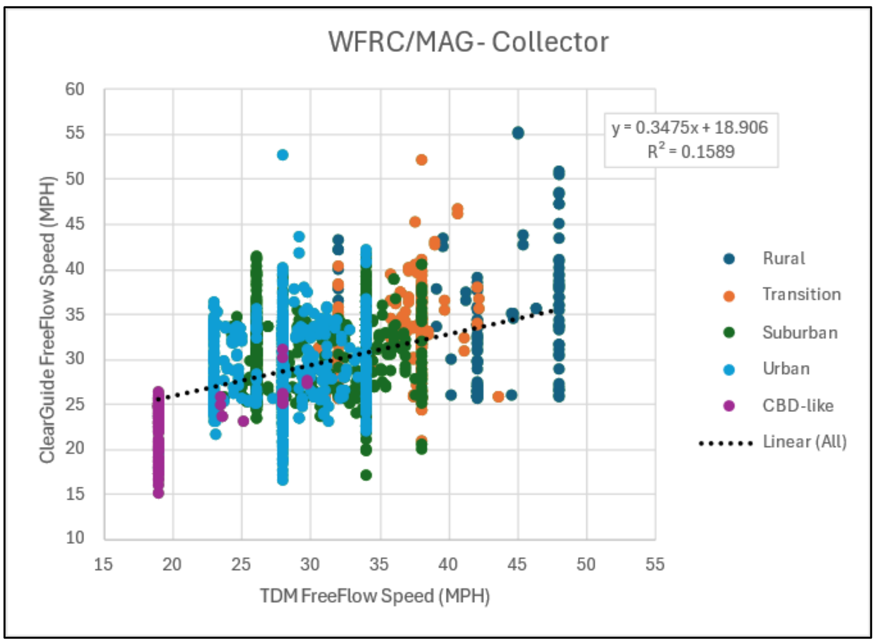

Figure 4.12 WFRC/MAG Model – Collector Roads with Area Type

Figure 4.17 displays results for principal arterial roads in the Cache model. This chart shows how, in comparison to other models in the study, the Cache model contains some of the best and most consistent results. The range of speeds between ClearGuide and the TDM are much closer and do not show as wide a discrepancy as seen in Figures 4.15 and 4.16. Many results for the Cache model are similar in showing a more consistent relationship between the TDM and ClearGuide speeds

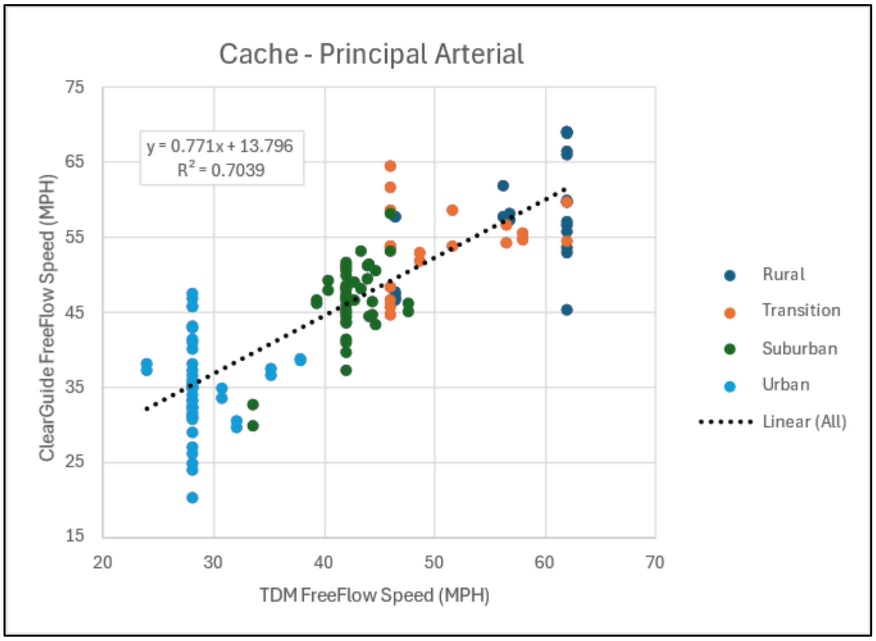

Figure 4.13 Cache Model – Principal Arterial Roads with Area Type

Figure 4.18 displays results for principal arterial roads in the Summit/Wasatch model. This model and functional type combination provided one of the highest R-Squared values in the study. A higher R-Squared value indicates better performance on the part of the model in predicting speeds (see Section 4.6.1 for more information on R-Squared values). Such results are more consistent across the smaller models (such as Cache and Summit/Wasatch) as opposed to the larger models, indicating that the smaller models are seeing better performance regarding free-flow speeds.

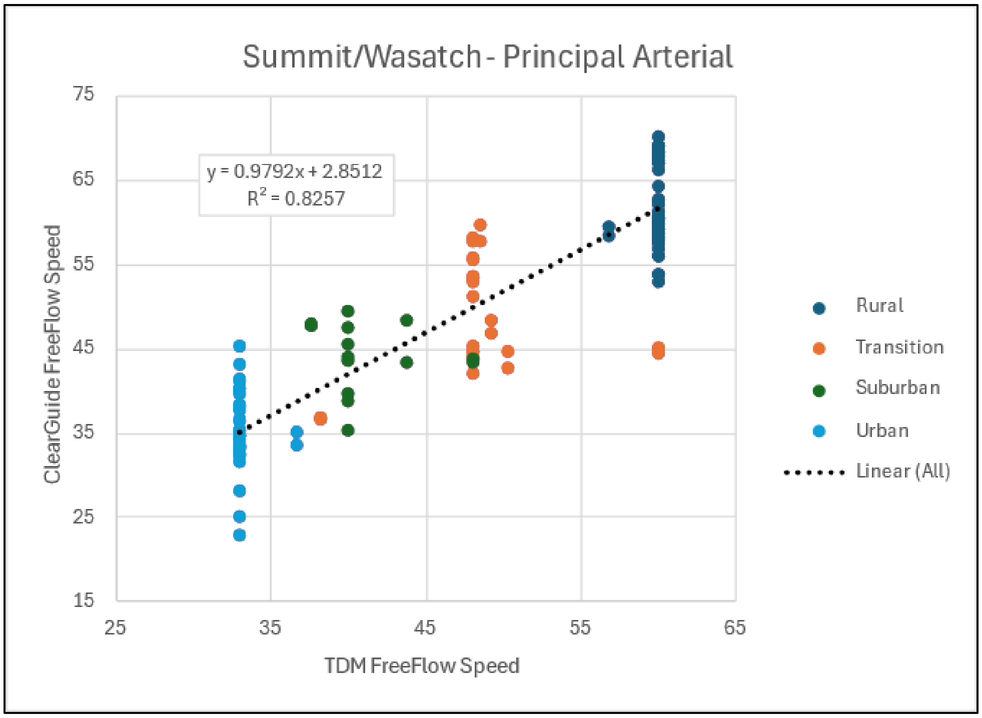

Figure 4.14 Principal Arterial Model – Principal Arterial Roads with Area Type

4.6 Model SegID Statistics, R-Squared Values, and Speed Factors

The models explored in this study vary in size from one another. The USTM and WFRC/MAG models are the largest and contain information on a state and regional level. The Cache, Dixie, Iron County, and Summit/Wasatch models are smaller and cover speeds within a county-sized area. Table 4.13 provides statistics for the number of SegIDs per model. As seen in the table, the WFRC/MAG model has the most SegIDs within it (though the USTM covers the widest area around Utah overall). The Iron County model has the least amount of SegIDs associated with it.

Table 4.13 SegID Statistics Per Model

Model	Functional Type	Number of SegIDs
USTM	Local	159
USTM	Collector	1385
USTM	Minor Arterial	650
USTM	Principal Arterial	935
USTM	Expressway	5
USTM	Freeway	208

Model	Functional Type	Number of SegIDs
USTM Total		***3342***
WFRC/MAG	Local	2
WFRC/MAG	Collector	3181
WFRC/MAG	Minor Arterial	1983
WFRC/MAG	Principal Arterial	1521
WFRC/MAG	Expressway	177
WFRC/MAG	Freeway	287
WFRC/MAG *Total*		***7151***
Cache	Local	6
Cache	Collector	289
Cache	Minor Arterial	146
Cache	Principal Arterial	131
Cache	Expressway	0
Cache	Freeway	0
Cache Total		***572***
Dixie	Local	18
Dixie	Collector	139
Dixie	Minor Arterial	286
Dixie	Principal Arterial	88
Dixie	Expressway	22
Dixie	Freeway	45
Dixie Total		***598***
Iron County	Local	4
Iron County	Collector	158
Iron County	Minor Arterial	92
Iron County	Principal Arterial	56
Iron County	Expressway	0
Iron County	Freeway	26
Iron County Total		***336***
Summit/Wasatch	Local	0
Summit/Wasatch	Collector	134
Summit/Wasatch	Minor Arterial	102
Summit/Wasatch	Principal Arterial	136
Summit/Wasatch	Expressway	0
Summit/Wasatch	Freeway	43
Summit/Wasatch Total		***415***

4.6.1 R-Squared Calculations

The research team calculated the R-Squared values for each model based on functional type. This would show how well the models performed overall on different roadway types. Table 4.14 displays results of the R-Squared values calculations for each model.

Table 4.14 TDM R-Squared Calculations

Model	Local	Collector	Minor Arterial	Principal Arterial	Expressway	Freeway
USTM	0.00	0.24	0.47	0.62	n/a	0.20
WFRC/MAG	n/a	0.16	0.37	0.52	0.35	0.14
Cache	0.89	0.65	0.69	0.70	n/a	n/a
Dixie	n/a	0.08	0.48	0.39	0.10	0.53
Iron County	0.12	0.28	0.57	0.54	n/a	n/a
Summit/Wasatch	n/a	0.39	0.64	0.83	n/a	0.06

As seen in the table, the smaller models (Cache, Dixie, Iron County, and Summit/Wasatch) for the most part have higher R-Squared values across the different functional types than the larger models (USTM and WFRC/MAG). This would indicate that the smaller models have better predictive ability and performance at this time than the larger models. However, results are not necessarily constant, particularly when looking at R-Squared values based on functional type. Generally arterial roads have the highest R-Squared values for each model type, while collector and local roads are lower (except for the Cache model, which had a higher value for local and collector roads). Expressway roads were found only in the WFRC/MAG and Dixie models and had lower R-Squared values, while freeway roads had lower values as well (except for the Dixie model).

4.6.2 Speed Factors

A number of link segments within the different TDMs in this study had an associated speed factor. A speed factor is a value associated with an individual segment which is a multiple of the recorded speed. Speed factors help the model predict real-world speeds more accurately, therefore theoretically enhancing model performance. The research team found that stated lookup speeds on segments without a speed factor within the models are less accurate compared to when a speed factor is present in the data (this was especially true for urban area types). The Cache model had the largest number of speed factors associated with its data, contributing to that model's higher performance compared to the others, as discussed previously in this section.

4.7 Summary

Utilizing the data prepared in Section 3, the research team was able to carry out a comprehensive data collection process. A speed difference dataset was created which showed the difference between TDM and ClearGuide speeds organized by SegID. ArcGIS Pro software was utilized to create a map displaying this information across Utah, highlighting where speeds between datasets are closer, and where they may differ. The speed difference dataset was then utilized to create several filtered combinations based on speed, functional classification (roadway type) area type, and model type. Statistics were aggregated for these different filter combinations, providing an overview of data results. Aggregates by model type suggest that average speed differences by model between TDM and ClearGuide speeds are generally close, but the standard deviation for each model suggests that some improvements could be made to the models. Local roads saw the most significant speed difference in statistics based on functional type; other functional types had closer speed differences. Area type results were more consistent overall with less notable differences present. A deeper dive into statistics based on model type revealed that there is a fair amount of variation in model results, but oftentimes rural and transition areas see more discrepancy in speed difference, and often on local roads. Scatterplots of model results show that TDM speeds are typically clustered around a certain speed value, while ClearGuide speeds are more dispersed and may see a wider range of speeds overall than the TDM data. Speed distributions for the smaller models were often similar in many respects.

5.0 CONCLUSIONS

5.1 Summary

The results of data collection and data evaluation performed in this study allowed the research team to determine key findings from the comparison between TDM and ClearGuide free-flow speeds along roadway segments in Utah.

5.2 Findings

Principal findings in this study are associated with comparisons between TDM and ClearGuide speeds. This comparison allows for the examination of speeds within the current models and their accuracy when compared to real-world speed conditions. Also, important findings from this study include information on data quality and consistency within the models. Some discrepancies and issues were found within model data, which impact on model performance. Overall findings are summarized in the following sections.

5.2.1 Key Speed-Related Findings

Speed findings showed that there is great variety in the TDM speeds from models as opposed to ClearGuide speeds. TDM speeds tend to cluster exactly at certain speeds when viewed as a scatterplot, as opposed to ClearGuide speeds, which are more dispersed. The Cache model had a greater average speed difference than the other models, but all models had a standard deviation of more than 5 MPH, indicating that greater accuracy can be achieved in the model speeds. Rural areas saw the greatest standard deviation in speeds (though CBD-like areas saw the highest average speed difference). Local roads saw the most difference in speeds, followed by freeways; freeways also saw the highest standard deviation in speed.

When examining results by model, and while not true in every case, a greater variety in speeds between TDM and ClearGuide could be seen in rural (and to a degree transition) areas than suburban and urban areas. This could be due to the less dense traffic patterns on rural roads. Driver behavior may also have an impact. Related to rural areas, local roads also often saw the highest or nearly the highest average speed differences and standard deviations, (though this was not always the case). Overall, results often varied between the models generally.

A key takeaway from the analysis in this study is that the smaller models (Cache, Dixie, Iron County, and Summit/Wasatch) appear to be performing somewhat more efficiently in comparison to the two larger models (USTM and WFRC/MAG). Of all the models, the Cache model appears to be the most accurate at this time, despite having the highest average speed difference. The Cache model had a smaller spread of speed values overall, and the lowest 85th percentile speed value (in the Cache model this signifies that most vehicle speeds in that model have a speed difference under 2.4 mph, see Table 4.1). This research revealed that the Cache model also has the most speed factors within its data, which likely contributes to its higher performance compared to the other models.

Despite the small models performing somewhat better than the larger models, all models could see greater accuracy in their results, and all have some issues of speed accuracy when compared to ClearGuide speeds. In helping improve accuracy, the findings suggest that speed factors generally lead to more accurate results when applied to the model data. Speed factors can be suggested as a method of improving model accuracy and performance moving forward.

5.2.2 Importance of Data Quality

Research and analysis in this study revealed that there are functional type discrepancies between the TDMs and master segmentation data on many roadways. This appears especially apparent for local roads. The discrepancy between ClearGuide speeds and TDM speeds for local roads—which appeared in several of the tabular model results and scatterplots in Section 4—indicates that a number of local roads in the TDM may have been misclassified and should be classified as a different functional type. There are likely discrepancies within other TDM roadway classifications, though to a lesser extent than the 'local' TDM roadway classification. While some issues are expected given the amount of TDM segments and data which exist, misclassification of functional types will have the effect of skewing speed results in the models and lessen the accuracy of their data.

5.3 Limitations and Challenges

During this study, the research team met and overcame several issues related to data joins and relates. These issues were discussed primarily in Sections 3.3.2 and 3.4.1. These issues largely consisted of spatially joined data being erroneously joined with the incorrect ClearGuide and TDM segments, which were later adjusted. It was also found that several TDM segments had an erroneous SegID associated with them, leading to a mismatch between ClearGuide and TDM data segments. These were also altered to the correct SegID. The additional challenges experienced by the research team are discussed below.

5.3.1 Mismatched Functional Types and Segment IDs

The TDM dataset utilized by the research team in this study contained functional types associated with a corresponding SegID. A large number of TDM segments (8,236) were found not to have the correct functional type to match the SegID functional type. This creates a discrepancy whereby the TDM attributes the speeds for these segments to the incorrect functional type. Figure 5.1 displays the location of the SegID segments (those noted in red) that did not correspond with the SegIDs in the statewide TDM data. Most of these segments are found in rural areas. The research team does not anticipate that this discrepancy would create significant issues with the analysis described in this document, as these ‘mismatched’ functional types were found in a minority of TDM segments. However, this indicates that within the TDM dataset, numerous segments are assigned incorrect functional types.

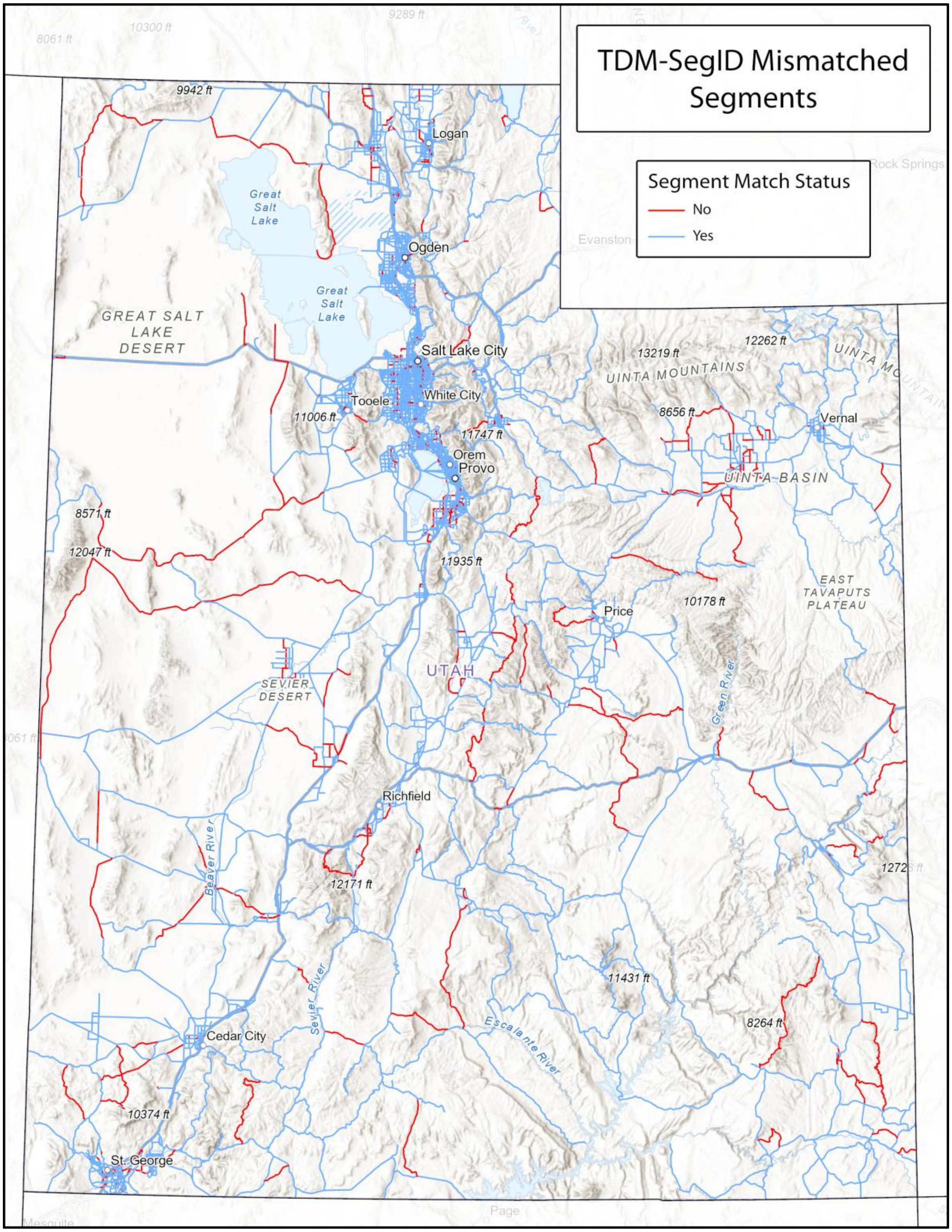

Figure 5.1 Mismatched TDM Segments

5.3.2 Resolution of TDM Functional Types

Similar to the issue described in section 5.3.1, the research team identified an issue in the final phases of analysis—during development of the speed-difference dataset—whereby a number of local roads in the TDM had high speed limits in ClearGuide that are more appropriate for freeway or expressway functional classifications. Through dataset cleaning, the research team removed most of these issues; however, several segments in the TDM are still labeled as 'local' roads when, in fact, they might be higher-speed roadway types. It is possible that other roads in the TDM dataset are also mislabeled, though these impacts were not seen to a notable degree in the study results. It is recommended that the reasons for this mislabeling of roadways in the TDM be explored to ensure that all roadways are correctly labeled moving forward.

6.0 RECOMMENDATIONS AND IMPLEMENTATION

As part of the Utah Travel Models Free-Flow Speed Research project, the research team made several recommendations to the UDOT TAC based on results of the project study. Part of these recommendations also include suggestions for a study implementation plan, which would utilize findings from the research to help enhance the Travel Demand Models (TDMs) in use at UDOT and associated speed data. This section highlights the recommendations and suggested implementation plan for the project.

Recommendations

Based on the research and analysis performed in this study, and input from the TAC and the UDOT Project Champion, the following recommendations have been identified:

- Consider asserting model free-flow speeds based on ClearGuide data for links with available data.
- Update functional types in the models:
  - Local functional types had the highest difference in speeds in many cases across the TDMs and would benefit from a focused review.
  - Consider reviewing and potentially updating any segment showing extreme differences in speeds.
- Consider creating additional groups within the "Rural" area type.
  - Rural area types saw significant variation in speeds. Creating different groups within the rural area type will help account for the greater variation and improve results.
- If ClearGuide data is not used to assert model free-flow speeds (see first bullet in this list) review more links to provide additional Speed Factors:
  - Links with Speed Factors in the TDMs tend to be more accurate compared to the ClearGuide data.

6.1 Implementation Plan

The implementation plan for this project was developed in conjunction with the UDOT project team. The research team met with the UDOT TAC and representatives from MPOs to discuss the initial findings from this study. After results were shared with the TAC, the group discussed how UDOT and the MPOs could best implement the findings from this research in the future. The following uses of data in this study serve as examples of implementation opportunities, along with the recommendations from section 6.1. Other potential data uses may be identified and implemented as part of this implementation plan moving forward.

- Free-flow speed data can be pulled into associated SegIDs (from the master network dataset) for further data validation uses. This provides opportunities for general data validation efforts for free-flow speeds.

- Data from this study may be implemented in developing future functional types for roadways. Free-flow speed information can help determine what functional type classification is most appropriate for roadways and contribute to enhancing model free-flow speed accuracy.

- The smaller TDMs (e.g., Cache or Iron County) may be utilized for speed data comparisons. Such tests may include application of model data in place of a flat speed drop for comparison purposes.

- In the future, it is possible to examine individual segments by comparing model speeds to ClearGuide speeds on those SegIDs. This process allows for specific review of desired roadway types or particular areas. This could be done as needed, and it is also possible to do this with other speeds available from UDOT resources.

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APPENDIX A: Model Speed Distributions

This appendix contains additional scatterplots which were created for each of the six TDMs analyzed in this study. These scatterplots provide a more detailed view of TDM speed results to accompany the tables and scatterplots in Section 4.5. Each model contains scatterplots displaying speed distributions by functional class, with additional coloration for area type included in each scatterplot.

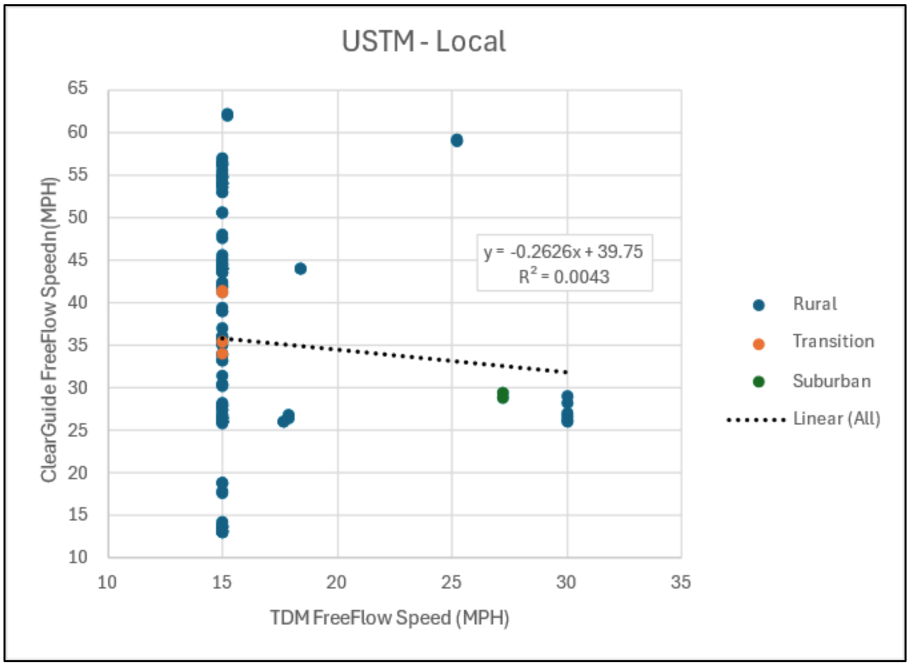

Figure A.1 USTM Scatterplot – Local Functional Type

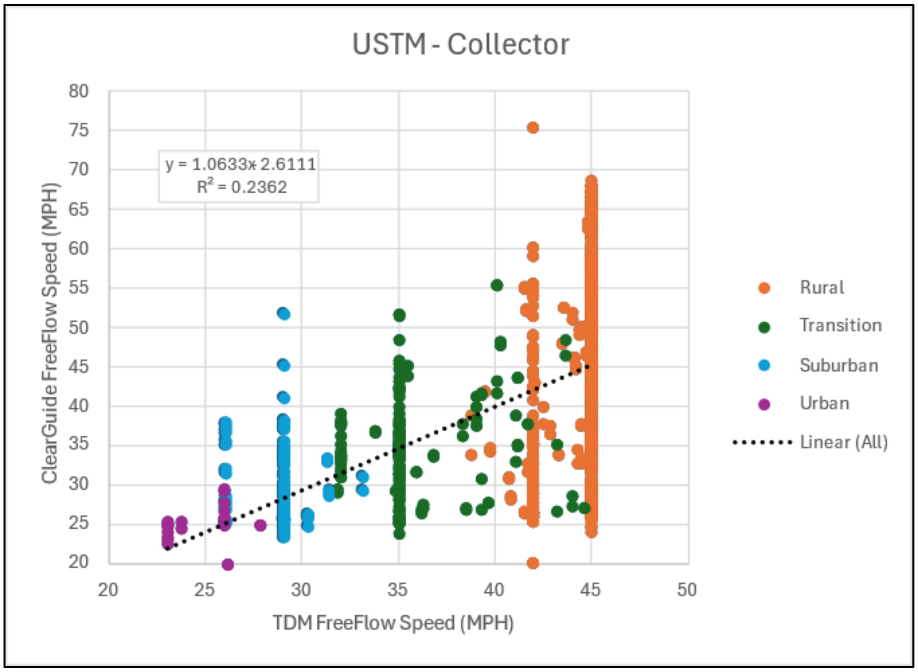

Figure A.2 USTM Scatterplot – Collector Functional Type

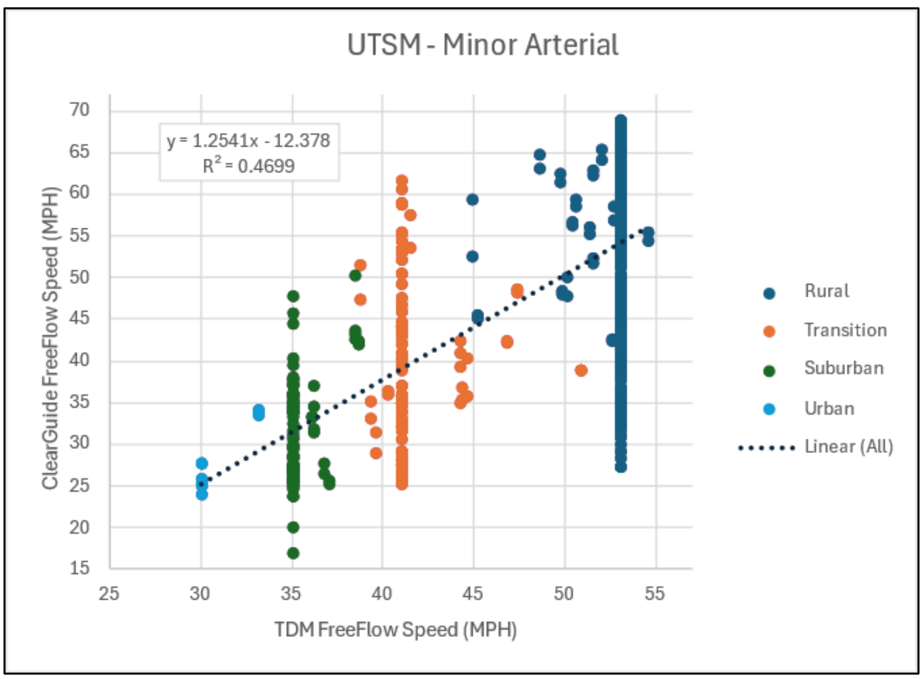

Figure A.3 USTM Scatterplot – Minor Arterial Functional Type

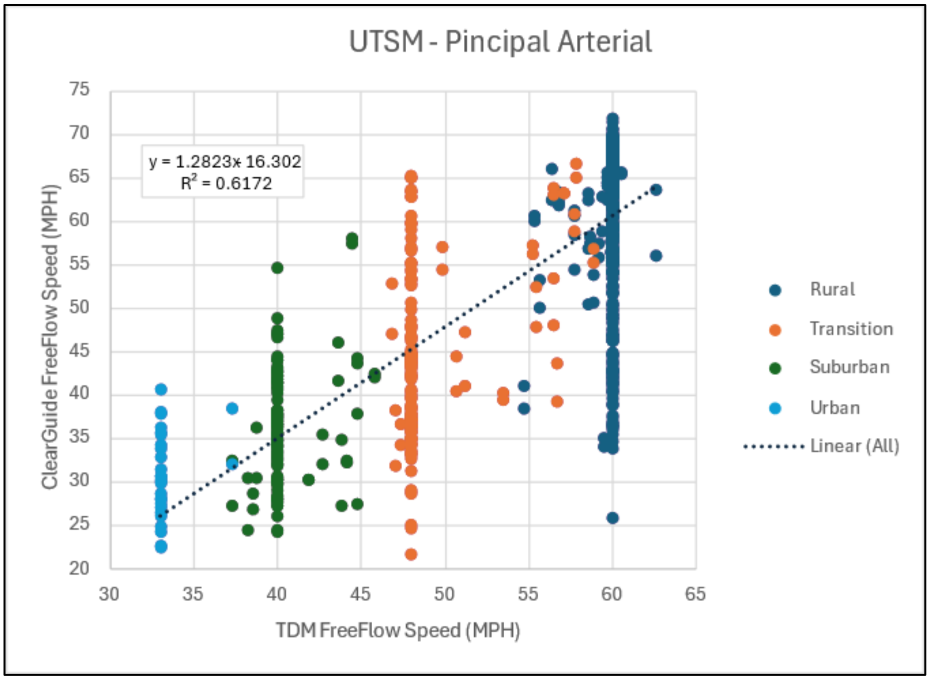

Figure A.4 USTM Scatterplot – Principal Arterial Functional Type

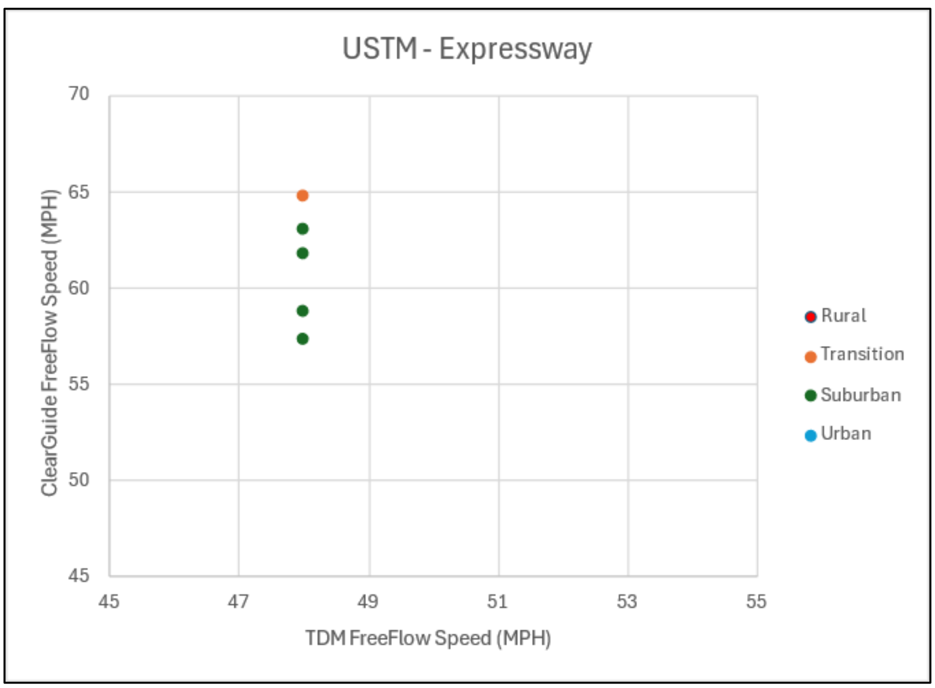

Figure A.5 USTM Scatterplot – Expressway Functional Type

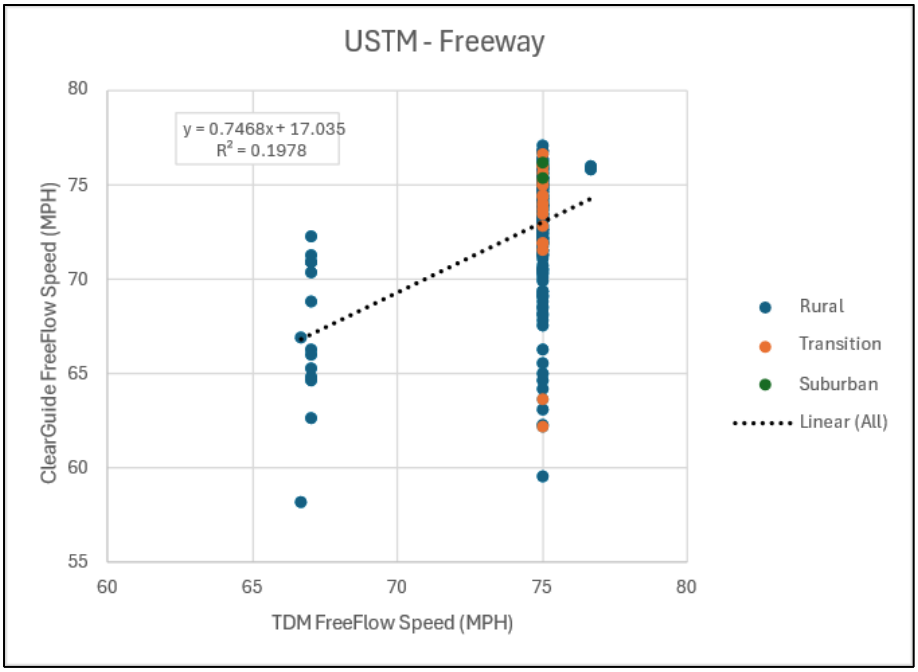

Figure A.6 USTM Scatterplot – Freeway Functional Type

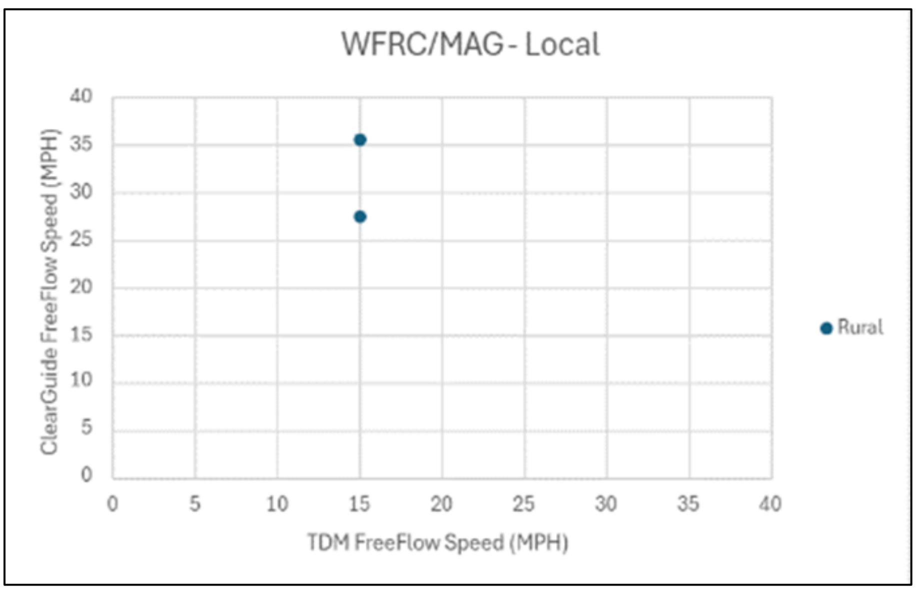

Figure A.7 WFRC/MAG Scatterplot – Local Functional Type

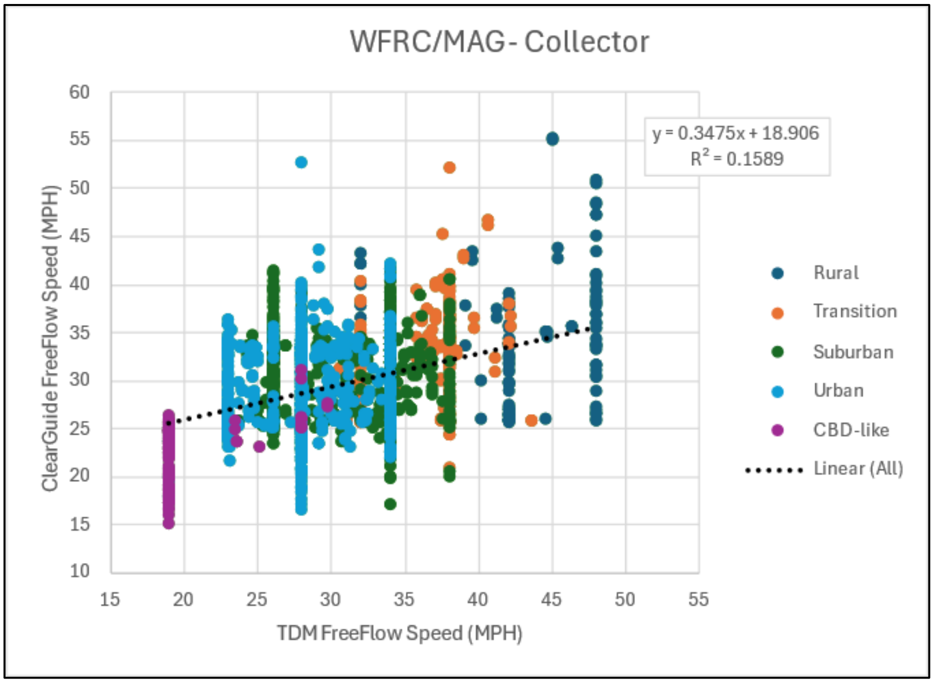

Figure A.8 WFRC/MAG Scatterplot – Collector Functional Type

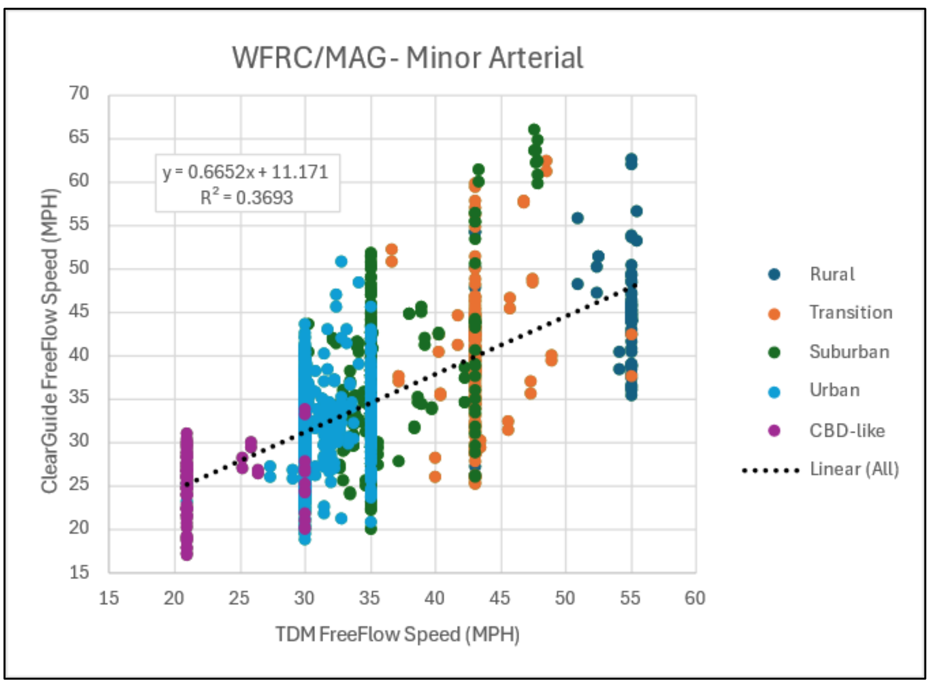

Figure A.9 WFRC/MAG Scatterplot – Minor Arterial Functional Type

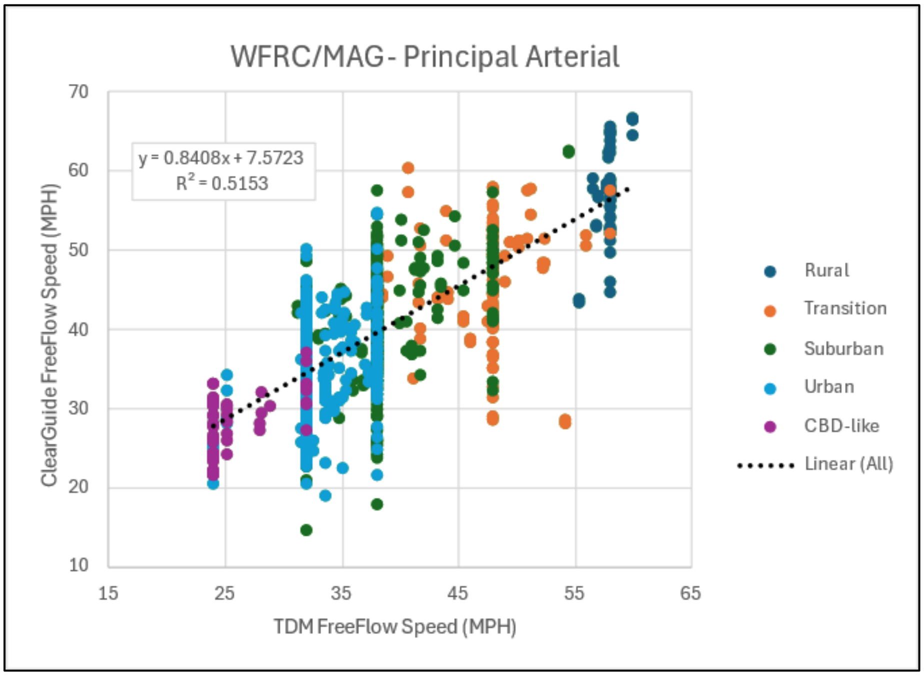

Figure A.10 WFRC/MAG Scatterplot – Principal Arterial Functional Type

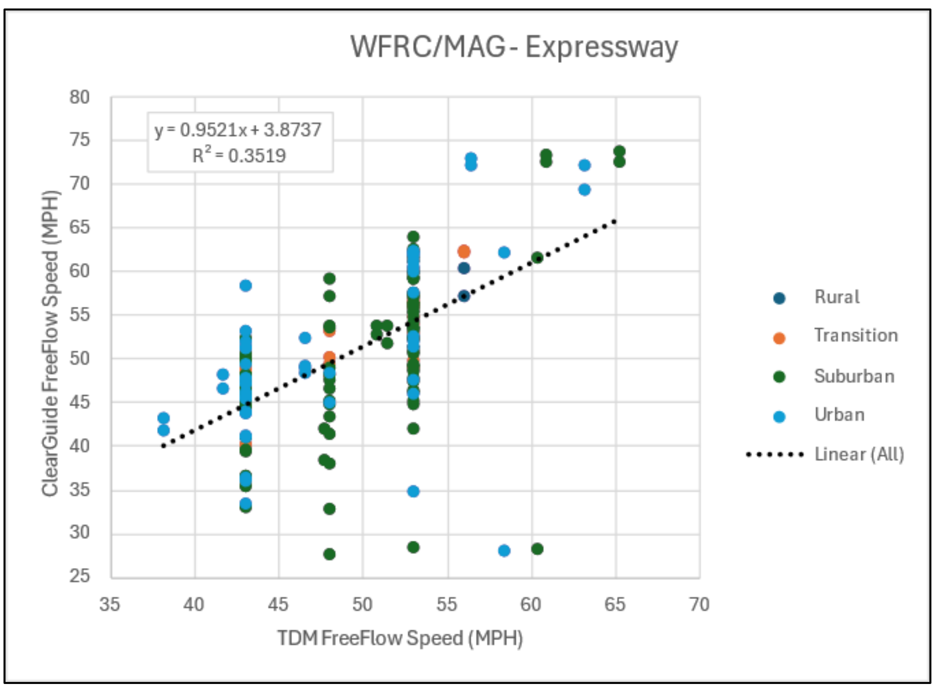

Figure A.11 WFRC/MAG Scatterplot – Expressway Functional Type

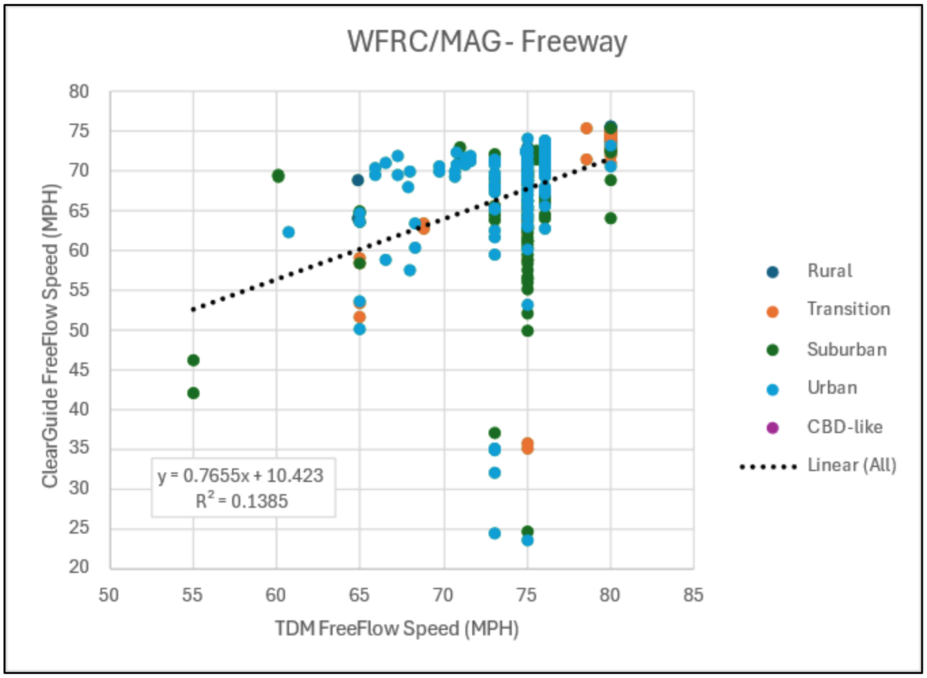

Figure A.12 WFRC/MAG Scatterplot – Freeway Functional Type

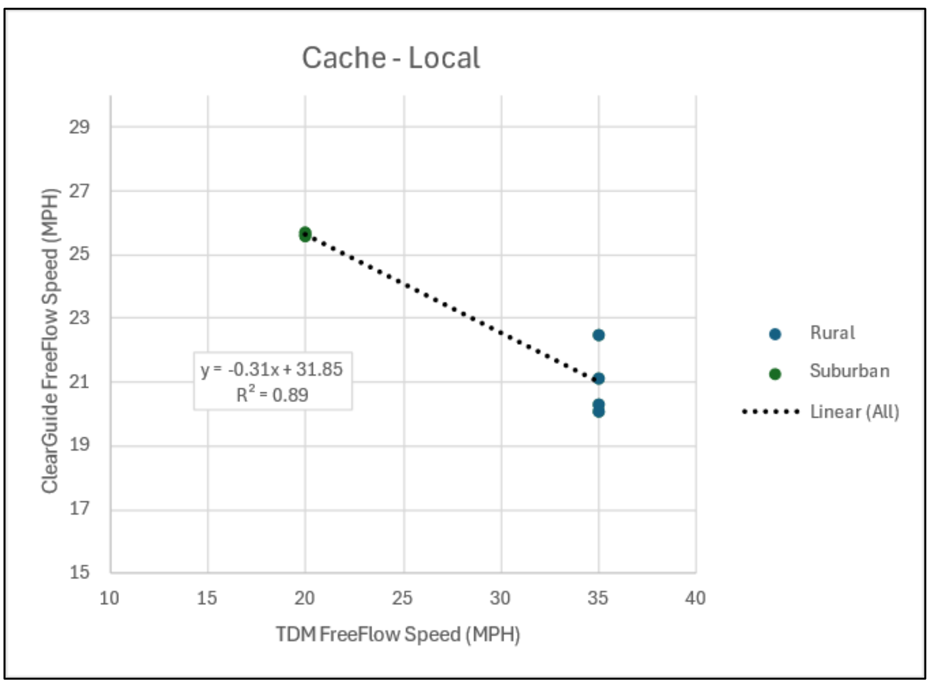

Figure A.13 Cache Scatterplot – Local Functional Type

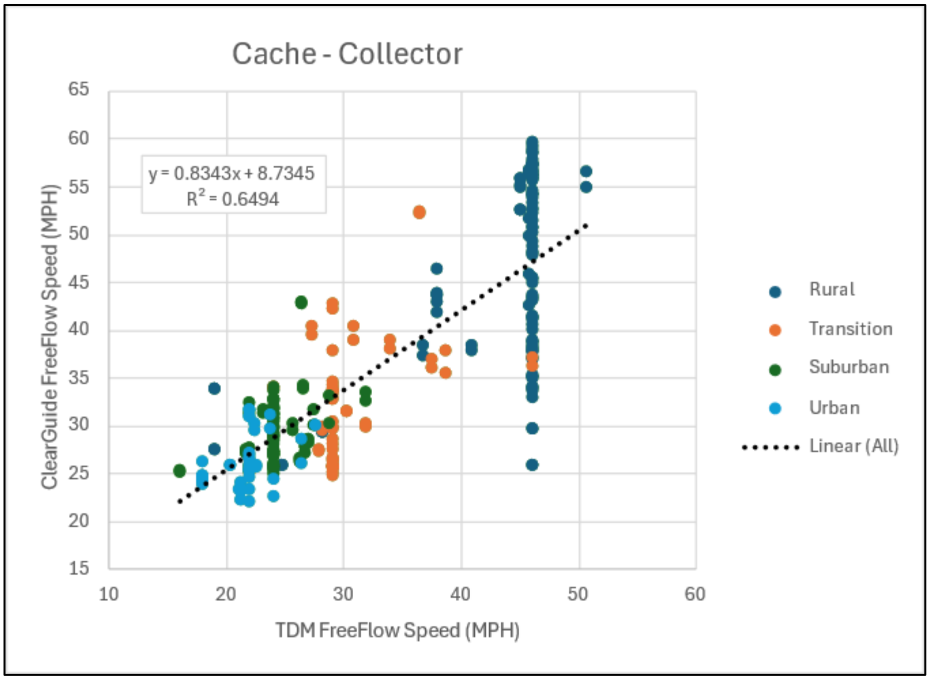

Figure A.14 Cache Scatterplot – Collector Functional Type

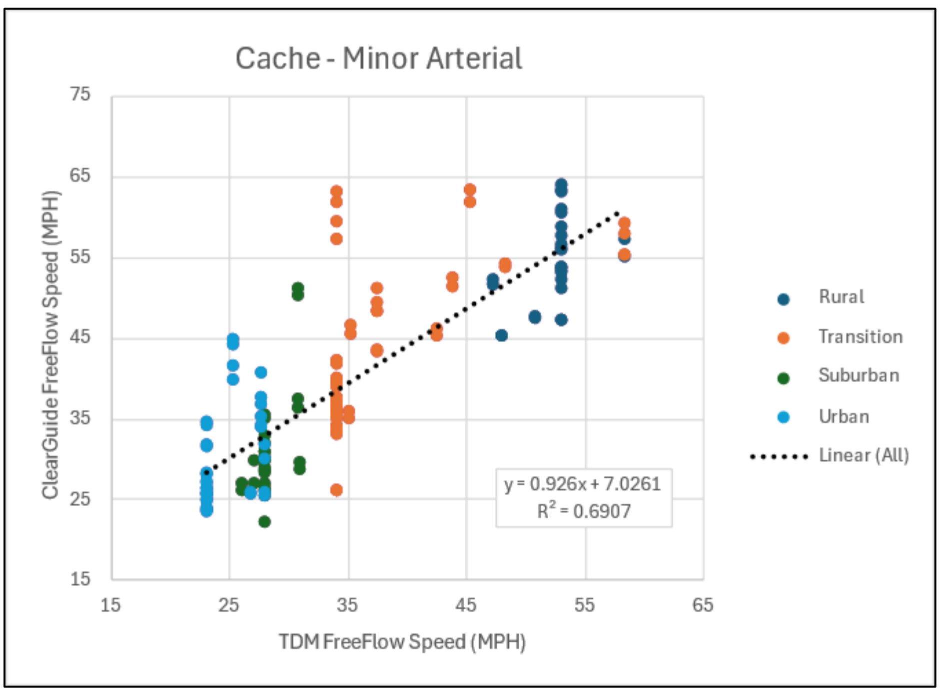

Figure A.15 Cache Scatterplot – Minor Arterial Functional Type

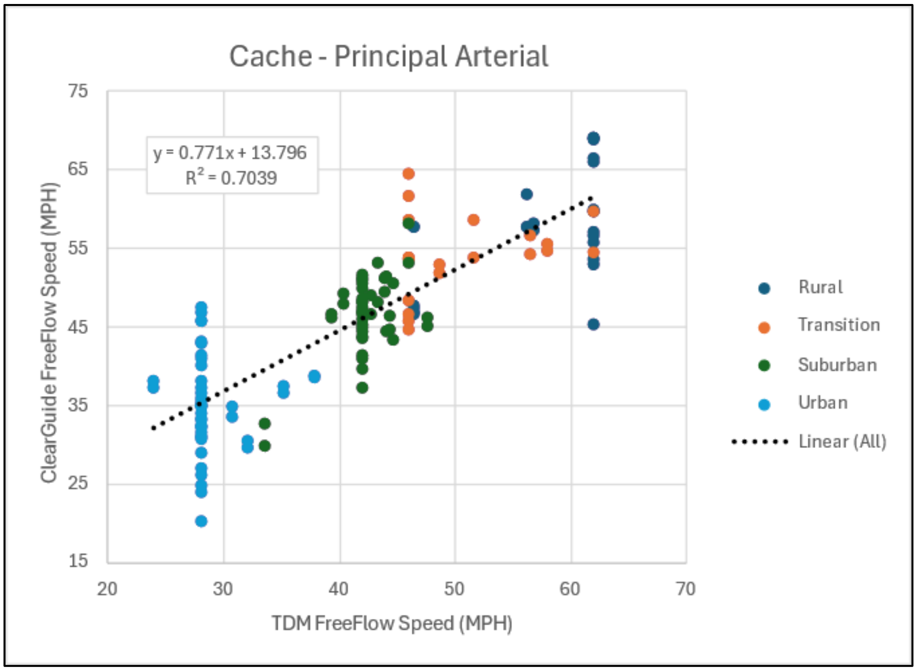

Figure A.16 Cache Scatterplot – Principal Arterial Functional Type

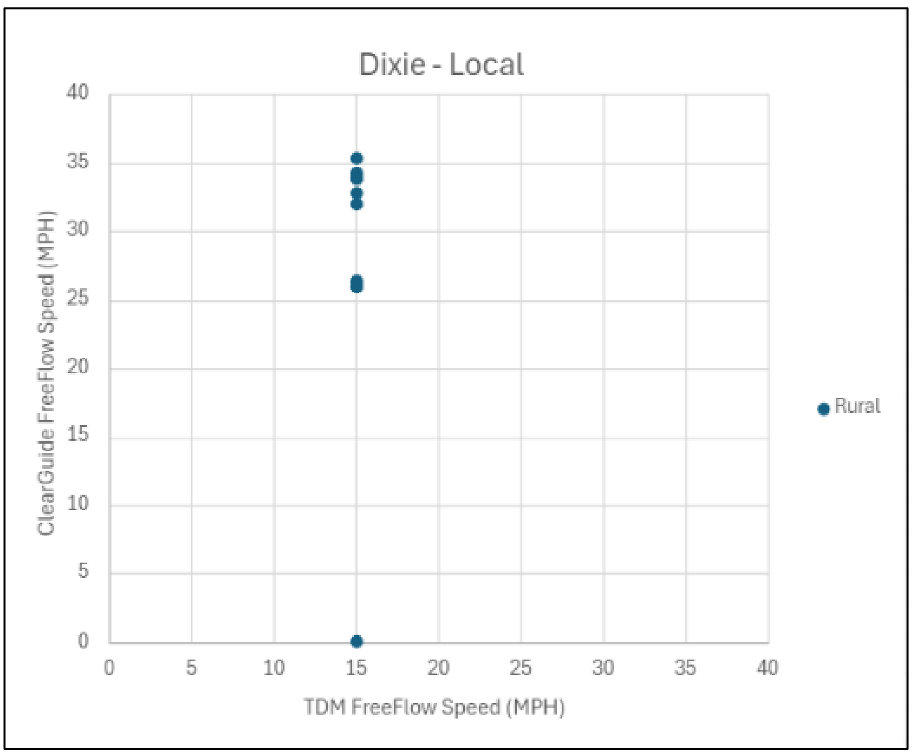

Figure A.17 Dixie Scatterplot – Local Functional Type

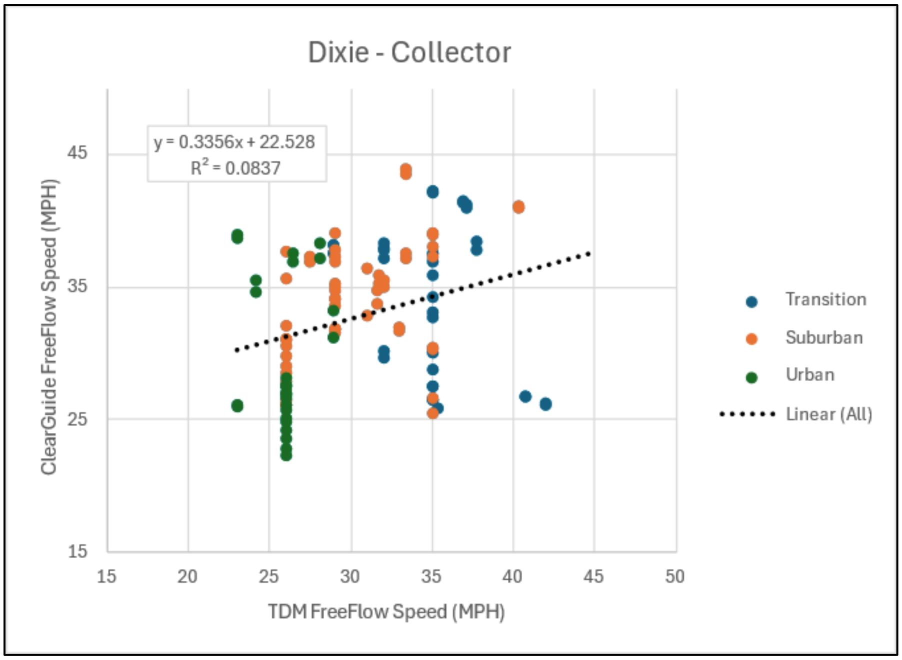

Figure A.18 Dixie Scatterplot – Collector Functional Type

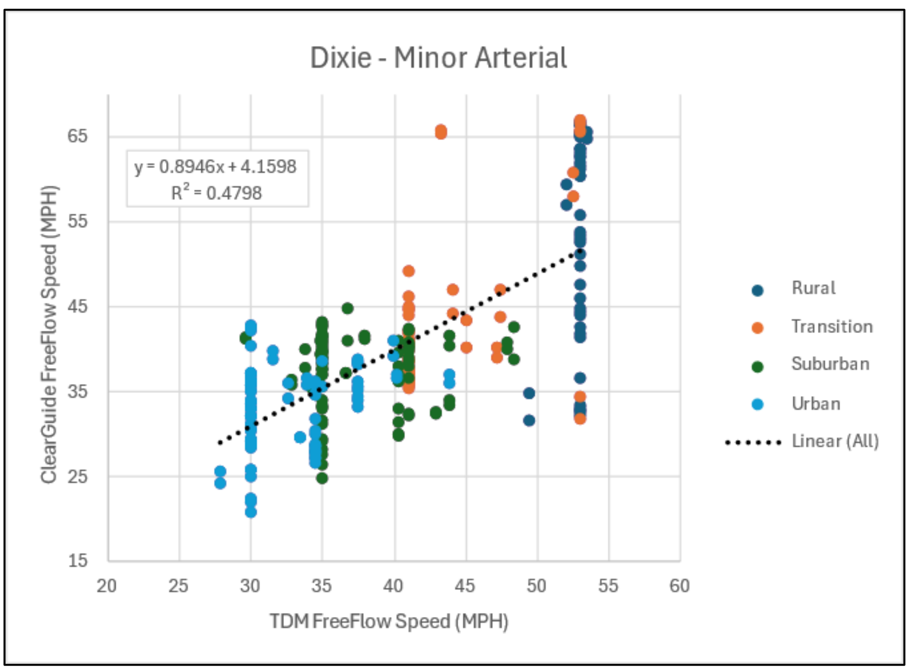

Figure A.19 Dixie Scatterplot – Minor Arterial Functional Type

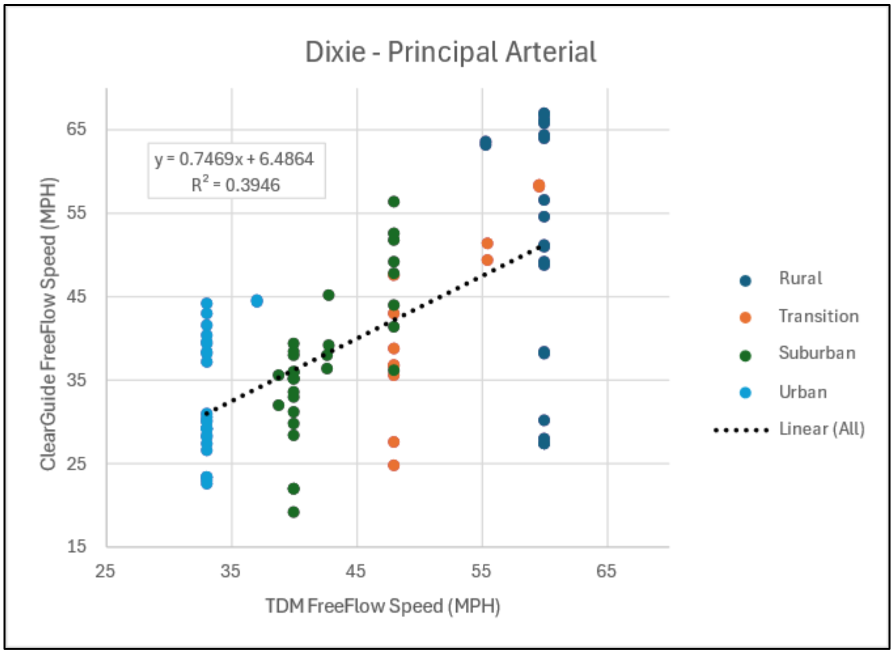

Figure A.20 Dixie Scatterplot – Principal Arterial Functional Type

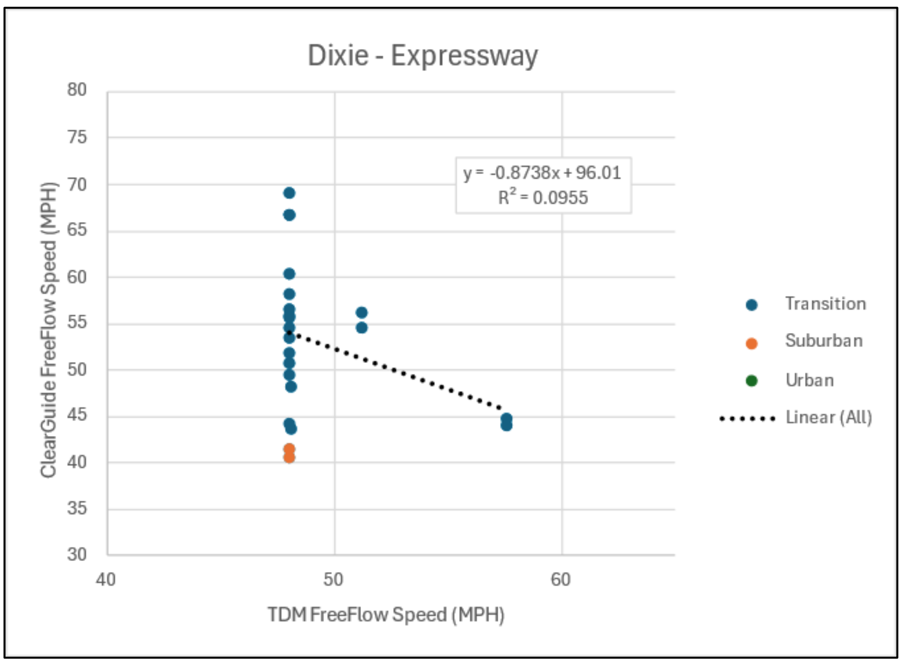

Figure A.21 Dixie Scatterplot – Expressway Functional Type

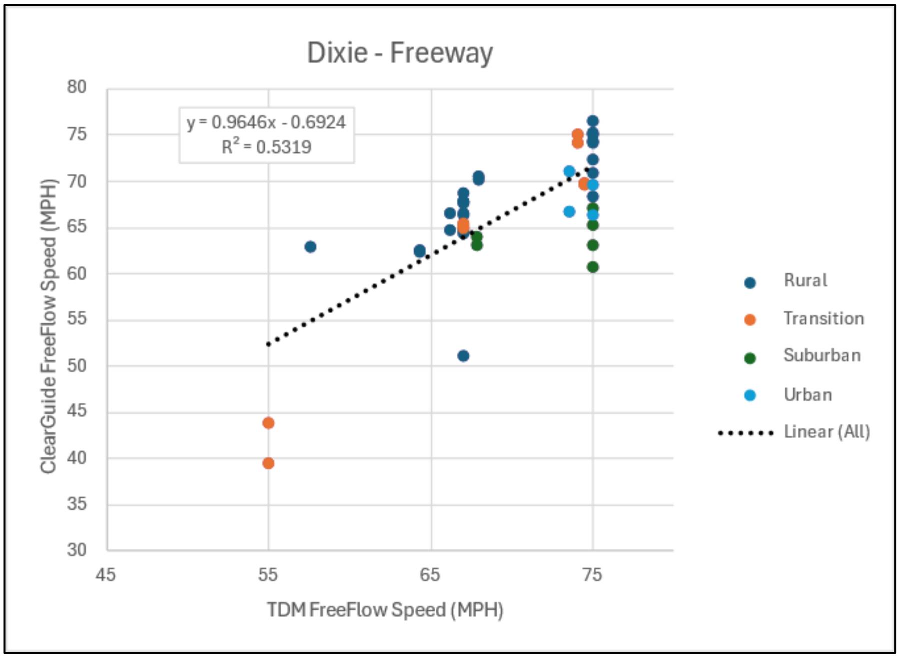

Figure A.22 Dixie Scatterplot – Freeway Functional Type

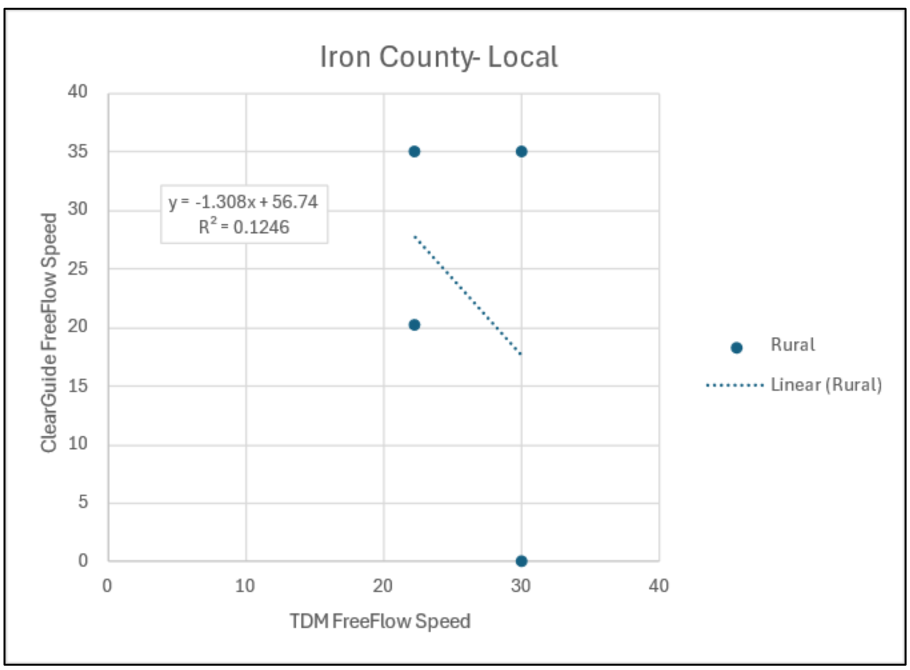

Figure A.23 Iron County Scatterplot – Local Functional Type

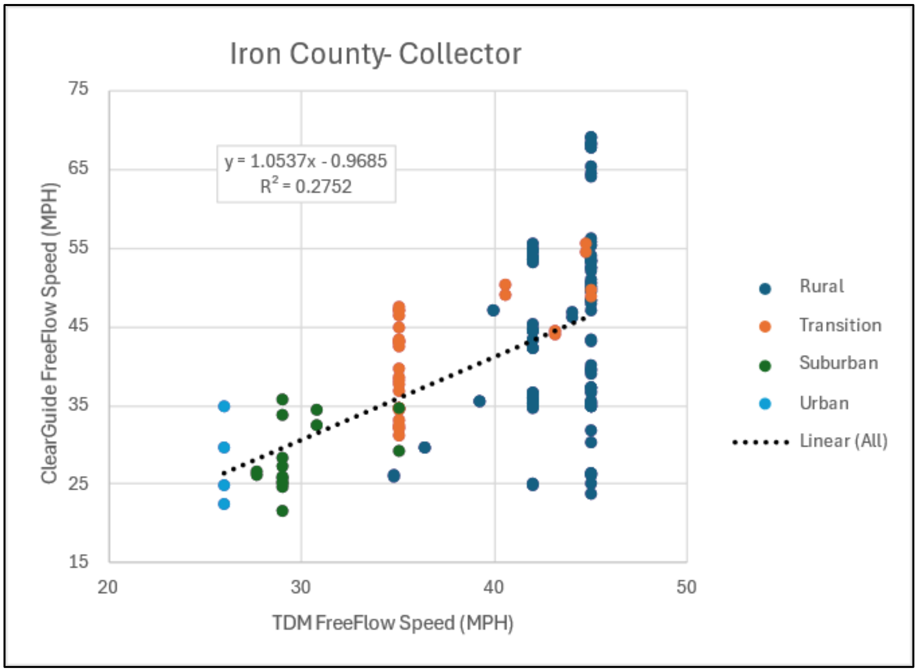

Figure A.24 Iron County Scatterplot – Collector Functional Type

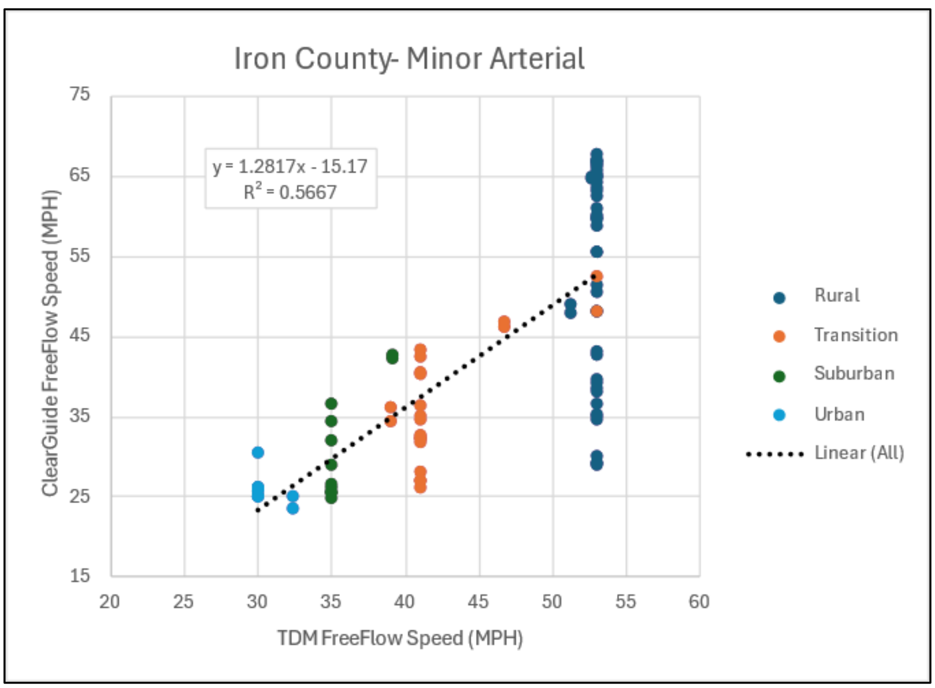

Figure A.25 Iron County Scatterplot – Minor Arterial Functional Type

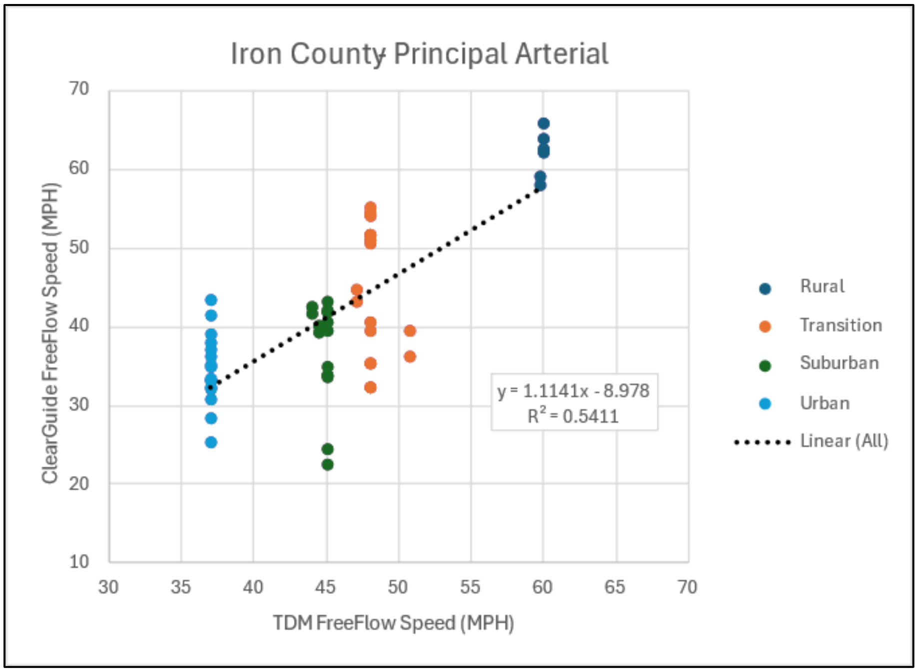

Figure A.26 Iron County Scatterplot – Principal Arterial Functional Type

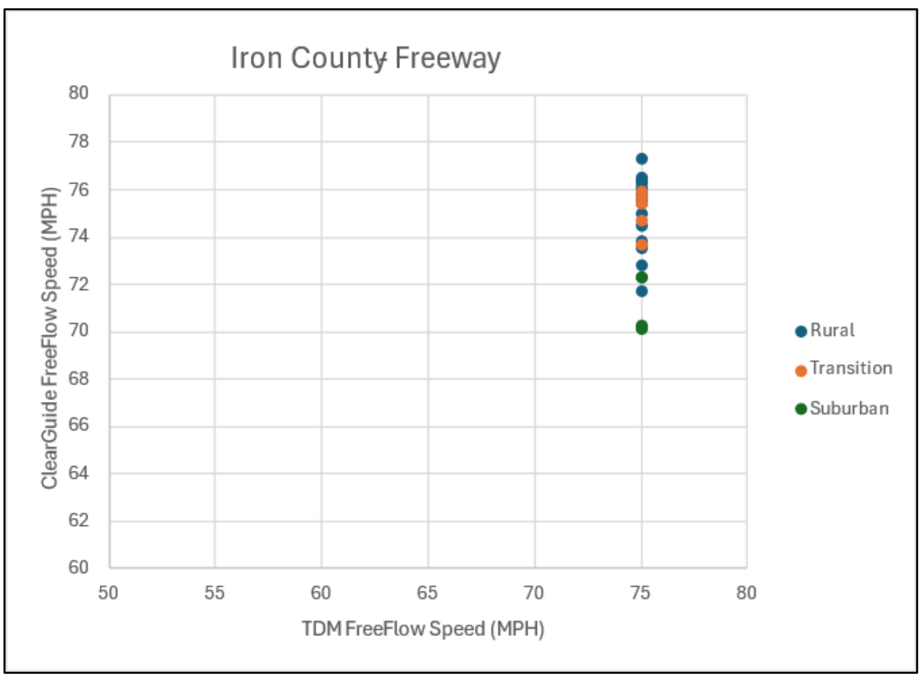

Figure A.27 Iron County Scatterplot – Freeway Functional Type

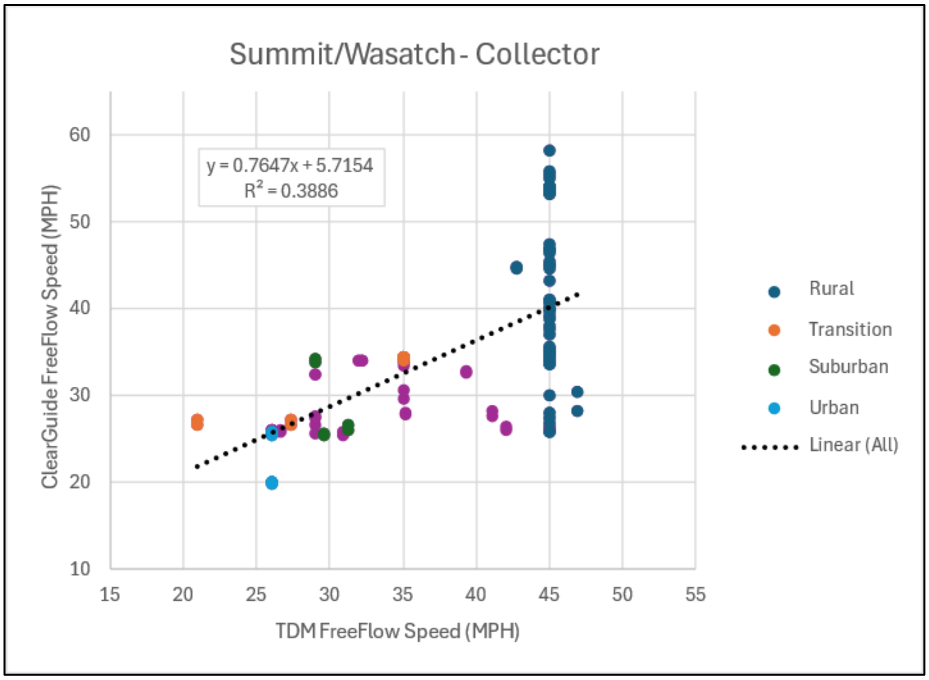

Figure A.28 Summit/Wasatch Scatterplot – Collector Functional Type

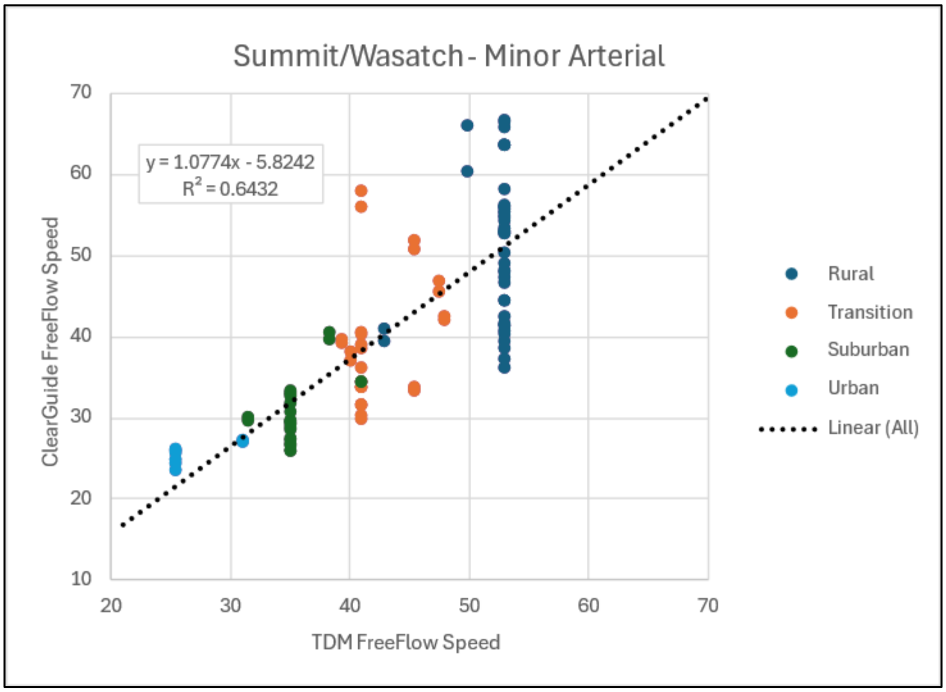

Figure A.29 Summit/Wasatch Scatterplot – Minor Arterial Functional Type

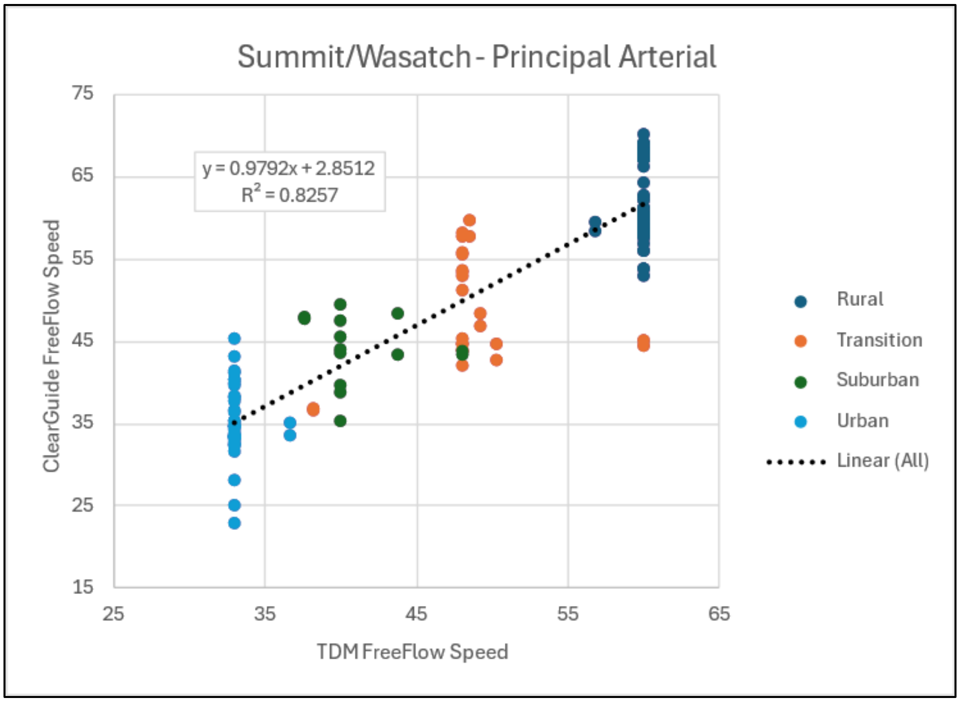

Figure A.30 Summit/Wasatch Scatterplot – Principal Arterial Functional Type

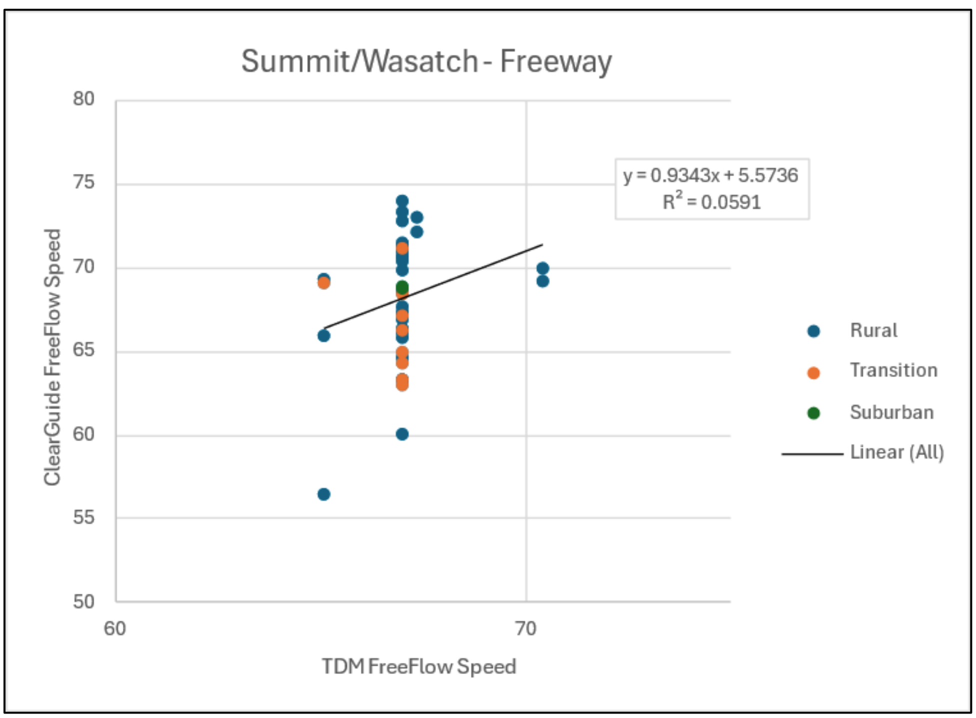

Figure A.31 Summit/Wasatch Scatterplot – Freeway Functional Type

APPENDIX B: Data Dictionary

Table B.1 contains a data dictionary which defines the various fields associated with the final speed-difference dataset created in this study. This dataset was utilized for data evaluation and for creation of the speed-difference maps in Section 4 of this document.

Table B.1 Speed Difference Data Dictionary

Field Name	Data Type	Description
SEGID	Text	Master Segmentation ID
Dir	Long	Roadway Direction (Positive or Negative)
5th Highest	Double	Calculated Free-Flow Speed from ClearGuide Speed Data
SumOflength	Double	Calculated Length of segments associated with the SegID
TDM_FF_SPF	Double	Free-Flow Speed from TDM Data
TDM_AT	Double	Numerical value signifying Area Type associated with each TDM segment
AreaType Rounded	Long	Numerical value signifying area type associated with each TDM segment (rounded to account for segments overlaying different area types)
TDM_ATname	Text	Area type name associated with each TDM segment
TDM_FTCLASS_NUM	Long	Numerical value signifying Functional Type (e.g., Roadway Type) with each TDM segment
TDM_FTCLASS_New	Text	Functional Type (e.g., Roadway Type) name associated with each TDM segment
Model	Long	Numerical value associated with each TDM
Model Name	Text	Name associated with each TDM
WFF_5th_Diff	Double	Calculated difference between ClearGuide (5th Highest) and TDM (TDM_FF_SPF) Free-Flow Speeds

Table B.2 TDM Raw Data Dictionary

Field Name	Data Type	Description
SEGID	Text	Master Segmentation ID
Dir	Long	Roadway Direction (Positive or Negative)
5th Highest	Double	Calculated Free-Flow Speed from ClearGuide Speed Data
SumOflength	Double	Calculated Length of segments associated with the SegID
TDM_FF_SPF	Double	Free-Flow Speed from TDM Data
TDM_AT	Double	Numerical value signifying Area Type associated with each TDM segment
AreaType Rounded	Long	Numerical value signifying area type associated with each TDM segment (rounded to account for segments overlaying different area types)
TDM_ATname	Text	Area type name associated with each TDM segment
TDM_FTCLASS_NUM	Long	Numerical value signifying Functional Type (e.g., Roadway Type) with each TDM segment
TDM_FTCLASS_New	Text	Functional Type (e.g., Roadway Type) name associated with each TDM segment
Model	Long	Numerical value associated with each TDM
Model Name	Text	Name associated with each TDM
WFF_5th_Diff	Double	Calculated difference between ClearGuide (5th Highest) and TDM (TDM_FF_SPF) Free-Flow Speeds

Table B.3 ClearGuide Speeds Data Dictionary

Field Name	Data Type	Description
SEGID	Text	Master Segmentation ID
Dir	Long	Roadway Direction (Positive or Negative)
5th Highest	Double	Calculated Free-Flow Speed from ClearGuide Speed Data
SumOflength	Double	Calculated Length of segments associated with the SegID
TDM_FF_SPF	Double	Free-Flow Speed from TDM Data
TDM_AT	Double	Numerical value signifying Area Type associated with each TDM segment
AreaType Rounded	Long	Numerical value signifying area type associated with each TDM segment (rounded to account for segments overlaying different area types)
TDM_ATname	Text	Area type name associated with each TDM segment
TDM_FTCLASS_NUM	Long	Numerical value signifying Functional Type (e.g., Roadway Type) with each TDM segment
TDM_FTCLASS_New	Text	Functional Type (e.g., Roadway Type) name associated with each TDM segment
Model	Long	Numerical value associated with each TDM
Model Name	Text	Name associated with each TDM
WFF_5th_Diff	Double	Calculated difference between ClearGuide (5th Highest) and TDM (TDM_FF_SPF) Free-Flow Speeds

Table B.4 ClearGuide Links Data Dictionary

Field Name	Data Type	Description
SEGID	Text	Master Segmentation ID
Dir	Long	Roadway Direction (Positive or Negative)
5th Highest	Double	Calculated Free-Flow Speed from ClearGuide Speed Data
SumOflength	Double	Calculated Length of segments associated with the SegID
TDM_FF_SPF	Double	Free-Flow Speed from TDM Data
TDM_AT	Double	Numerical value signifying Area Type associated with each TDM segment
AreaType Rounded	Long	Numerical value signifying area type associated with each TDM segment (rounded to account for segments overlaying different area types)
TDM_ATname	Text	Area type name associated with each TDM segment
TDM_FTCLASS_NUM	Long	Numerical value signifying Functional Type (e.g., Roadway Type) with each TDM segment
TDM_FTCLASS_New	Text	Functional Type (e.g., Roadway Type) name associated with each TDM segment
Model	Long	Numerical value associated with each TDM
Model Name	Text	Name associated with each TDM
WFF_5th_Diff	Double	Calculated difference between ClearGuide (5th Highest) and TDM (TDM_FF_SPF) Free-Flow Speeds