Report No. UT-22.05

FORECASTING TRAVEL-TIME RELIABILITY

Prepared For:

Utah Department of Transportation
Research & Innovation Division

Final Report
February 2022

RESEARCH
UDOT Keeping Utah Moving
Utah Department of Transportation - Research Division
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ACKNOWLEDGMENTS

The authors acknowledge the Utah Department of Transportation (UDOT) for funding this research, and the following individuals from UDOT on the Technical Advisory Committee for helping to guide the research:

- Stephanie Tomlin
- Kevin Nichol, PE, MPA
- Grant Farnsworth, PE

TECHNICAL REPORT ABSTRACT

1. Report No. UT- 22.05	2. Government Accession No. N/A	3. Recipient's Catalog No. N/A
4. Title and Subtitle Forecasting Travel-Time Reliability		5. Report Date February 2022 6. Performing Organization Code
7. Author(s) Ben Swanson, Justin Culp		8. Performing Organization Report No.
9. Performing Organization Name and Address RSG 55 Railroad Row White River Junction, Vermont 05001		10. Work Unit No. 5H086 44H 11. Contract or Grant No. 21-8592
12. Sponsoring Agency Name and Address Utah Department of Transportation 4501 South 2700 West P.O. Box 148410 Salt Lake City, UT 84114-8410		13. Type of Report & Period Covered Final Dec 2020 to Feb 2022 14. Sponsoring Agency Code PIC UT20.502

15. Supplementary Notes

Prepared in cooperation with the Utah Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration

16. Abstract

This analysis examined passively collected probe-vehicle travel-time data and traditional traffic counts to identify relationships between travel-time reliability and volume-to-capacity (V/C) ratios. Travel time and traffic volume data came from Utah Department of Transportation (UDOT) data portals, and roadway capacities came from the Wasatch Front Travel Demand Model.

RSG used the buffer-time index (BTI) metric to represent travel-time reliability in this analysis. Historical BTI values were calculated from observed travel-time data for study roadways. Observed traffic volumes and model roadway capacities were used to calculate V/C ratios for these same roadways.

Relationships between V/C and BTI were established through regression analysis separately for freeway, ramp, and arterial roadways, after identifying and filtering out nonrecurring congestion events results using historical weather and crash data. BTI versus V/C lookup tables were established from these regressions and used to assign BTI values to model roadway links based on model V/C ratios.

17. Key Words Reliability, Travel Time, Buffer Time Index, BTI		18. Distribution Statement Not restricted. Available through: UDOT Research Division 4501 South 2700 West P.O. Box 148410 Salt Lake City, UT 84114-8410 www.udot.utah.gov/go/research		23. Registrant's Seal N/A
19. Security Classification (of this report) Unclassified	20. Security Classification (of this page) Unclassified	21. No. of Pages 46	22. Price N/A	

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LIST OF ACRONYMS

BTI	Buffer Time Index
FHWA	Federal Highway Administration
FT	Functional Type
HOV	High-Occupancy Vehicle
PeMS	Performance Measurement System
SANDAG	San Diego Association of Governments
UDOT	Utah Department of Transportation
V/C	Volume to Capacity
WFCCS	Wasatch Front Central Corridor Study

EXECUTIVE SUMMARY

RSG researched using passively collected travel-time data to inform a model for forecasting travel-time reliability on Utah roadways. The results of this analysis were applied to freeways, ramps, and arterials within the Wasatch Front Travel Demand Model Version 8.3.2 ("the model"). This report documents the data collection, analysis, and model application.

This analysis examined passively collected probe-vehicle travel-time data and traditional traffic counts to identify relationships between travel-time reliability and volume-to-capacity (V/C) ratios. Travel time and traffic volume data came from Utah Department of Transportation (UDOT) data portals, and roadway capacities came from the Wasatch Front Travel Demand Model. RSG used the buffer-time index (BTI) metric to represent travel-time reliability in this analysis. Historical BTI values were calculated from observed travel-time data for study roadways. Observed traffic volumes and model roadway capacities were used to calculate V/C ratios for these same roadways.

Relationships between V/C and BTI were established through regression analysis separately for freeway, ramp, and arterial roadways. BTI versus V/C lookup tables were then established from these regressions and used to assign BTI values to model roadway links based on model V/C ratios. With the updated BTI lookup table and revised assignment and skimming scripts, the RSG-modified model now calculates period buffer times (minutes) on model roadway links and zone-to-zone buffer times (minutes) in period network skims. It then saves these in the scenario run outputs.

Previous work conducted in the Wasatch Front Central Corridor Study (WFCCS) developed BTI versus V/C lookup values to project travel-time reliability for freeway links based on continuous count station speed data. Updated freeway BTI versus V/C relationships established in this current study using probe-vehicle travel-time data confirm the previous WFCCS analysis, with the updated freeway BTI lookup values tracking closely with previous findings. This study further expands the travel model capabilities to project BTI for ramp and arterial roadways in addition to freeway links. Drive times and buffer times projected from the updated model were observed for notable origin-destination pairs and were found to match expectations, with relatively longer travel times and buffer times on congested commuter flows, when compared to the corresponding reverse-commute flows.

1.0 INTRODUCTION

1.1 Problem Statement

Improvements in the quality and availability of travel-time data have allowed agencies to begin quantifying and modeling travel-time reliability. As the Utah Department of Transportation (UDOT) updates its project prioritization process, it may look to include a travel-time reliability component, requiring a means by which to appropriately prioritize projects based on their contribution to improving reliability. UDOT currently measures travel-time reliability using the “buffer time index” (BTI) for segments of I-15 within the Wasatch Front urban area. UDOT is interested in forecasting the BTI for other highways under its jurisdiction.

1.2 Objectives

This project develops a method for forecasting travel-time reliability using historically derived buffer time indices and associated volume-to-capacity (V/C) ratios and applies this method within the Wasatch Front Travel Demand Model for a range of functional classes.

1.3 Scope

This research project was implemented in five tasks.

For Task 1, the research team, in collaboration with the technical advisory committee, selected a set of roadway segments with one-to-one correspondence with highways represented in the Wasatch Front Travel Demand Model. These selections covered a range of functional classes, capacities, and speeds.

In Task 2, the research team collected historical travel-time data from UDOT’s ClearGuide data portal (HERE) for the selected highway segments from Task 1. Using the historical HERE data, the research team calculated the BTI for the selected highway segments. Travel-time data was assembled for one full year (2019) and was segmented by hour of day. The travel-time data was filtered for weather and crash events to remove sources of nonrecurring congestion and thereby estimate a BTI based on recurring congestion (as opposed to nonrecurring congestion).

For Task 3, the research team estimated V/C ratio, by time slice, for each highway segment. Volumes were obtained from UDOT continuous traffic count data and capacities were obtained from the Wasatch Front Travel Demand Model.

In Task 4, the research team developed a lookup table that associates the BTI to the V/C ratio of the facility.

In Task 5, the research team developed model scripts to enable reporting of the BTI as a model output for interim and final forecast years with the Wasatch Front Travel Demand Model.

1.4 Outline of Report

This report is structured with the sections outlined below and two additional appendices, which provide a correspondence key between the travel time and traffic count datasets used in the project analysis and the study site model links (Appendix A) and attached data files (Appendix B).

- Chapter 1.0: Introduction
- Chapter 2.0: Research Methods
- Chapter 3.0: Data Collection
- Chapter 4.0: Analysis
- Chapter 5.0: Model Implementation
- Chapter 6.0: Conclusions

2.0 RESEARCH METHODS

2.1 Overview

Improvements in the quality and availability of travel-time data have allowed agencies to begin quantifying and modeling travel-time reliability. This section provides background information on projecting travel-time reliability and outlines the methodology used in this project.

2.2 Buffer Time Index

According to the Federal Highway Administration (FHWA), travel-time reliability is defined as “the consistency or dependability in travel times, as measured from day-to-day and/or across different times of the day.”[1]

BTI is one of four FHWA-recommended measures of travel-time reliability. Buffer time is calculated as the difference between the 95th percentile and average travel times, and BTI normalizes buffer time by dividing this difference by the average travel time.

Equation 2-1 BTI

$$BTI = \frac{(95th\ percentile\ Travel\ Time - Average\ Travel\ Time)}{Average\ Travel\ Time} * 100$$

Conceptually, buffer time is the additional time needed for a driver to ensure they arrive at their destination on time 95% of the time. Allowing for buffer time, a daily commuter will likely be on time all but one day of a typical work month (21 of 22 workdays).

2.3 Previous Travel-Time Reliability Forecasting Applications

This section outlines previous work conducted in forecasting travel-time reliability and the potential implications for this project.

[1] US Department of Transportation, Federal Highway Administration. 2017. “Travel-Time Reliability: Making It There on Time, All The Time.” Available at: https://ops.fhwa.dot.gov/publications/tt_reliability/ttr_report.htm.

2.3.1 Previous Reliability Forecasting from Congestion

As part of the Wasatch Front Central Corridor Study (WFCCS),[2] the Wasatch Front Regional Planning Commission led an effort to estimate link-based BTI values using speed data obtained from UDOT's Performance Measurement System (PeMS) dataset for 21 freeway stations. BTIs were calculated for observed data and then correlated to V/C ratio, for association with base and future/scenario run examination in the Wasatch Front Travel Demand Model. BTIs were calculated and correlated to V/C for weekday hour increments.

The WFCCS correlated BTI to V/C ratio using average weekday hourly volumes calculated for each station from PeMS volume data for the full year of 2014 and general-purpose freeway lane capacities (65 mph with auxiliary lanes) from the travel model. The Wasatch Front study found that BTI values remained relatively stable for low V/C conditions up until a break point beyond which they increase with increased V/C. As part of the study, a BTI versus V/C model was created that considered three distinct phases: Phase 1 with constant values for V/Cs from 0.0 to 0.6, Phase 2 transitioning between V/Cs 0.6 to 0.8, and Phase 3 fit to a linear regression for V/Cs greater than 0.8. Figure 2-1 from the WFCCS report illustrates these three phases graphically.

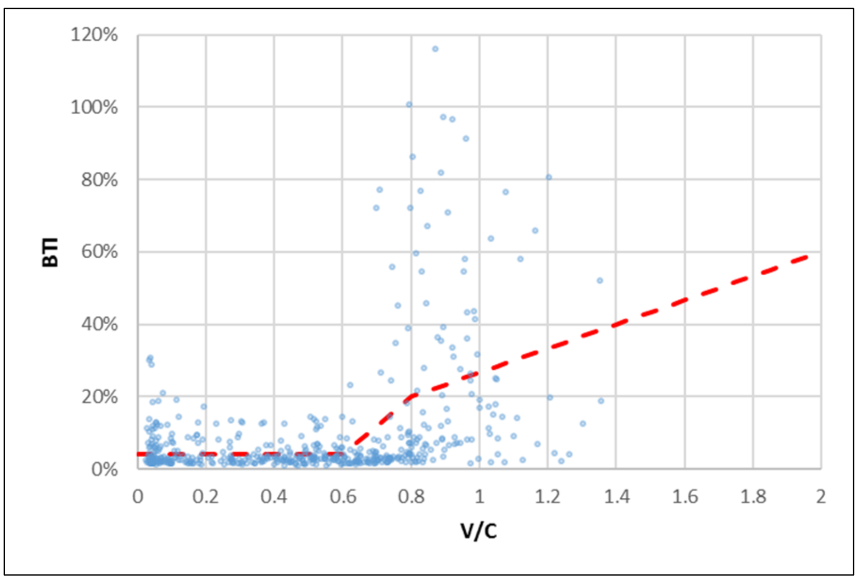

Figure 2-1 BTI vs. V/C Data with BTI Model Overlaid (WFCCS Figure 68)

[2] Wasatch Front Central Corridor Study, April 2017.

A similar study was conducted for a 3.5-mile section of I-5 through Seattle, Washington using GPS probe-vehicle data and induction loop traffic count data for the entire year of 2012.[3] Travel time and volume data were aggregated into average hourly bins for analysis. Like the WFCCS study, researchers also identified three distinct phases of travel-time reliability (coefficient of variation) versus demand (density) relationship, in this case through a k-means clustering algorithm prior to regression analysis.

2.3.2 Complex Reliability Forecasting Methods

More complex models relating travel-time reliability to congestion through additional factors beyond V/C have also been developed.

As noted in the Pricing and Reliability Model Improvement report conducted for the San Diego Association of Governments (SANDAG), RSG analyzed INRIX probe-vehicle data for the SANDAG region.[4] This analysis found reasonable relationships between travel-time reliability and network characteristics, including V/C (represented as level of service), but also including the number of roadway lanes, intersection controls, distances to interchanges, and time of day.

As part of this project, the SANDAG model was enhanced to include travel-time reliability (as standard deviation of travel time) at the origin-destination level by calculating and skimming a link reliability metric. Travel-time reliability was incorporated into assignment for SANDAG. To estimate this model, the SANDAG project team used INRIX travel-time data for the month of October in 2012. All regression variables were obtained from SANDAG model runs, including the V/C and level of service, which were obtained from network assignment and network capacity.

The SANDAG methodology was also applied by RSG for the Portland Oregon Metro region. However, the Portland application implemented the model estimated in SANDAG without re-estimating with local data. This was sufficient for the project implementation as a

[3] A methodology for forecasting freeway travel-time reliability using GPS data, Zun Wang, Anne Goodchild, Edward McCormack (Dept of Civil and Environmental Engineering, University of Washington), World Conference on Transport Research, 2016

[4] Pricing and Travel-Time Reliability Enhancements in the SNDAG Activity-Based Travel Model: Final Report, RSG, 6/30/2016

postprocessor; however, without local estimation, it was not deemed sufficient for skimming and incorporation in direct model processes, and thus travel-time reliability was not applied to the Portland Metro assignment.[5]

2.3.3 Importance of Demand and Capacity

While multiple factors can be considered for projecting travel-time reliability, the SHRP2 L03 report, "Analytical Procedures for Determining the Impacts of Reliability Mitigation Strategies," emphasizes the degree of impact found to be associated with V/C on link-based travel-time reliability. The report states: "[T]he importance of demand and capacity to predicting reliability measures cannot be overstated." [6] In comparing the relative impact on travel-time reliability from demand/capacity, incident lane hours lost, and rainfall, the SHRP2 L03 report states: "The Type III sums of squares all show that the marginal contribution of the d/c ratio is higher than the other factors."[7] For the SHRP2 L03 study, demand was calculated as the 99th percentile volume on a link rather than average volume. This was chosen specifically to replicate the traditional design hour volume used in traffic operations analysis, which is typically the 30th-highest hour of traffic on a given roadway.

2.3.4 Additional Considerations

A 2014 paper from the Mid-Atlantic Universities Transportation Center[8] compared link-based travel-time reliability measures calculated using Bluetooth versus INRIX probe data and found that reliability metrics calculated with the INRIX data underrepresented degradations in travel-time reliability when data could not distinguish between dedicated high-occupancy vehicle (HOV) lanes and general-purpose lanes. Many similar locations with adjacent HOV and general-purpose lanes exist within the Wasatch Front study area. While the model and PeMS data

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[5] Benefits Methodology for the BCA component of the MCE tool, RSG, January 25, 2017.
[6] National Academies of Sciences, Engineering, and Medicine 2012. Analytical Procedures for Determining the Impacts of Reliability Mitigation Strategies. Washington, DC: The National Academies Press, p. 145. https://doi.org/10.17226/22806.
[7] Ibid.
[8] Impact of Data Source on Travel-Time Reliability Assessment, Mid-Atlantic Universities Transportation Center, Haghani, Zhang, Hamedi, August 2014 (UMD-2013-01.pdf (psu.edu))

distinguish between HOV lanes and general-purpose lanes, the HERE probe data does not, and this issue will need to be considered in a study link selection or in data processing.

2.3.5 Conclusions Drawn from Previous Work

While several metrics of travel-time reliability are recommended by FHWA, BTI is used for this project given its simplicity and real-world applicability to a standard commute.

Methods of quantifying and modeling travel-time reliability require comprehensive speed data collected either through continuous count stations or probe vehicles. While the previous Wasatch Front application in the WFCCS relied on PeMS continuous count station data, this method limits the available study segments to those with continuous speed measurements. Probe-vehicle data is an effective source of informing travel-time reliability. It is used effectively in many regions and provides travel-time data availability on a larger set of roadway segments. For the current forecasting effort, UDOT's HERE probe-vehicle data is used to calculate historical buffer time indices.

This current forecasting project relates travel-time reliability with V/C. This is a direct extension of the previous implementation in the WFCCS. While other efforts to model travel-time reliability have investigated additional network attributes as predictor variables, these require additional complex datasets and have not resulted in substantially better projections. In all observed cases, reliability has been strongly correlated with traffic demand and capacity.

2.3.6 Research Methodology

The following steps were taken to generate BTI projections in the Wasatch Front Travel Demand Model based on model-projected V/C.

2.3.6.1 Data Collection

For this study, hourly travel time, traffic volume, crash, and weather data were assembled for a full study year (2019) for a selection of roadway segments spanning multiple functional classes.

2.3.6.2 Data Filtering

Crash and weather data are used to filter out events associated with nonrecurring congestion. This allows for estimation of BTI based on recurring congestion, which more directly relates to standard travel model outputs. Hourly records associated with crash and inclement weather events were removed from the dataset prior to calculating historical BTI and demand values.

2.3.6.3 Data Analysis

Because expectations of travel time vary with time of day—a driver anticipates higher levels of congestion during peak periods—BTI was calculated separately for each hour of the day, resulting in 24 BTI samples per study site. Average hourly traffic volumes were calculated for each hour of the day and for each study site.

Historical congestion, represented by V/C, was calculated for each study site for each hour of the day using average hourly volumes and roadway capacities from the travel model. Historical hourly BTI and V/C values for all sites of similar overall study site types—freeways, ramps, and arterials—were then combined and linear regression analyses were performed for each of these three roadway types.

2.3.6.4 Model Application

Regression analysis results were used to develop BTI versus V/C lookup tables for freeway, ramp, and arterial roadways. The travel model code was updated to use these lookup tables to associate BTI values with model roadway links after model assignment, based on the model’s projected period V/C ratios. Buffer times were then calculated for model links by multiplying period travel times by their associated BTI values and model code was updated to then skim the calculated buffer time values and save in period-specific buffer-time skim matrices.

3.0 DATA COLLECTION

3.1 Overview

RSG assembled hourly travel time, traffic volume, crash, and weather data for a full study year (2019) for a selection of roadway segments spanning multiple functional classes. Data were collected for 130 freeway links, 94 ramp links, and 54 arterial links in one-hour bins for all of 2019. Study segment locations are shown in Figure 3-1.

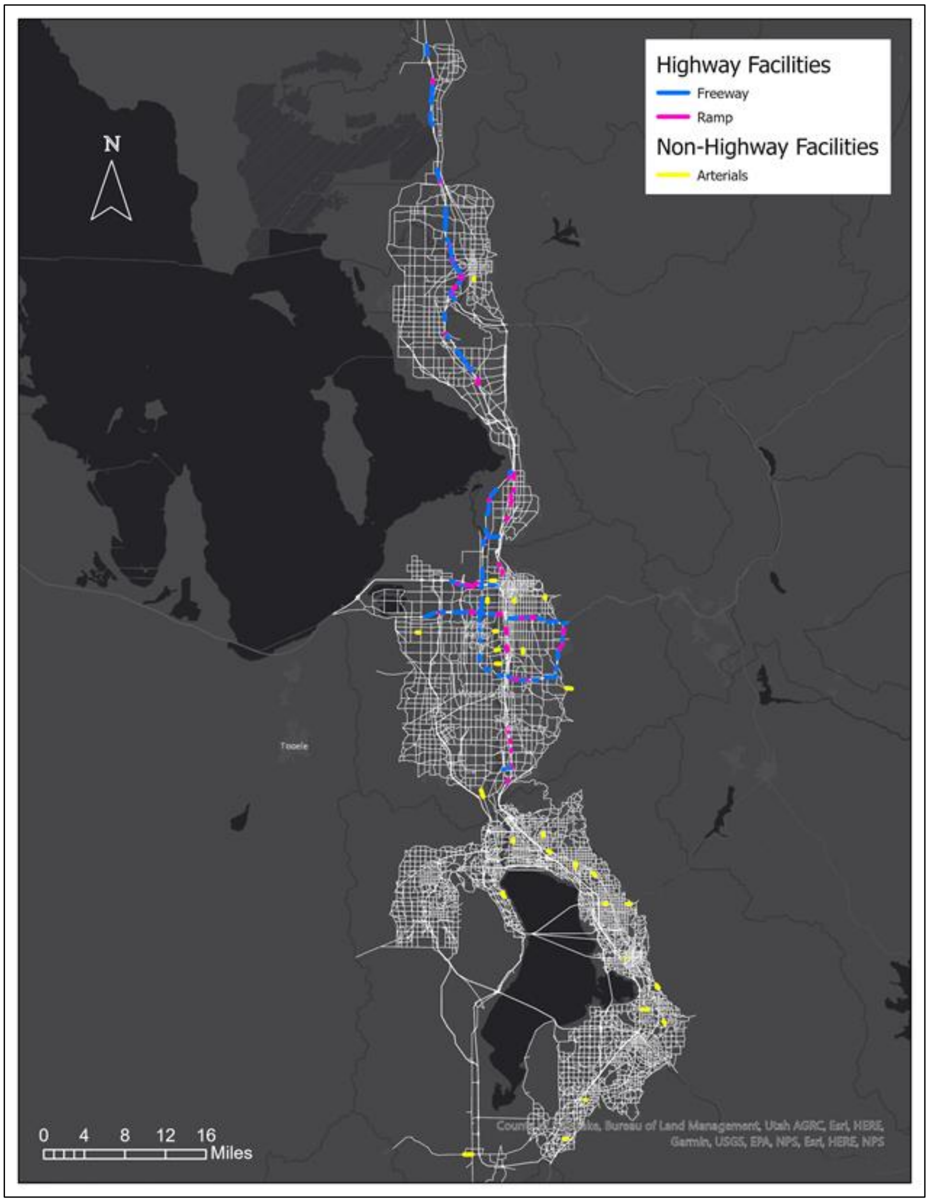

Figure 3-1 Study Area Links

Table 3-1 presents a count of study links by model functional type (FT) and larger study aggregation category (freeway, ramps, arterials).

Table 3-1 Study Links, by FT

Type	FT	Description	Count
Arterial	2	Principal Arterial	40
Arterial	3	Minor Arterial	10
Arterial	4	Major Collector	4
Freeway	32	Freeway: posted 55-60 mph	12
Freeway	33	Freeway: posted 65 mph, no aux lane	58
Freeway	34	Freeway: posted 65 mph, aux lane	46
Freeway	35	Freeway: posted 75 mph, no aux lane	14
Ramp	31	Freeway: C-D road, flyover ramp	9
Ramp	41	Freeway: On-ramp	43
Ramp	42	Freeway: Off-ramp	42

Study datasets are described in detail below. Raw data collected for this project are provided in attached zip files, as referenced in Appendix B.

3.2 Travel-Time Data

RSG collected travel-time data for 2019 from the UDOT ClearGuide data portal.[9] This data comprises roadway travel times informed by HERE™ probe-vehicle data. For this analysis, travel-time data were obtained through API queries, extracting average travel times by hour for all weekdays, excluding holidays, from January 1 through December 31, 2019.

Travel-time data were extracted for "routes" created within the ClearGuide system along roadway sections with continuous traffic count coverage and representation within the model. Study routes created in ClearGuide were given NAME attributes similar to their corresponding roadway link ID in the model and were consistently assigned tag attributes of "wfm."

[9] Iteris ClearGuide travel-time data. Available at: https://udot.iteris-clearguide.com Iteris ClearGuide (iteris-clearguide.com)

3.3 Traffic Count Data

RSG obtained traffic count data for all freeway and ramp study sites from UDOT through PeMS[10] API data queries. Data were extracted for weekdays, excluding holidays, from January 1 through December 31, 2019, in hourly bins.

Traffic count data for arterial study sites were not available on PeMS and were obtained from UDOT in Excel (.xlsx) format with hourly data by lane for all stations from January 1 through December 31, 2019. Data by lane were aggregated to total link volumes for this analysis.

3.4 Roadway Capacities

Roadway capacities were obtained from the model (v831_SE19_Net19) by multiplying the capacity per lane (CAP1HR1LN) by the number of lanes (LANES) for each study link.

3.5 Crash Data

All crash data on study roadways in 2019 were extracted from UDOT's Numetric crash data portal.[11] Crash data were associated with study sites and affected time periods based on spatial and temporal tagging described below.

3.6 Weather Data

Historical precipitation and temperature data generated by Automated Surface Observing System[12] weather stations were extracted from the Iowa Environmental Mesonet,[13] maintained by Iowa State University. All available weather observations from January 1 through December 31, 2019, were collected for the following Utah weather stations:

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[10] UDOT Performance Measurement System (PeMS). Available at: https://udot.iteris-pems.com

[11] UDOT AASHTOware Safety – Crash Data Query. Available at: https://udot.aashtowaresafety.com/signin?returnUrl=%2Fcrash-query

[12] National Oceanic and Atmospheric Administration, Department of Defense, Federal Aviation Administration, and United States Navy. "Automated Surface Observing System." Available at: https://www.weather.gov/media/asos/aum-toc.pdf.

[13] Iowa State University. 2022. "ASOS-AWOS-METAR Data Download." Available at: https://mesonet.agron.iastate.edu/request/download.phtml?network=UT_ASOS.

- BMC: Brigham City.
- HIF: Hill Airforce Base.
- LGU: Logan-Cache Airport.
- OGD: Ogden Hinckley Airport.
- PVU: Provo Airport.
- SLC: Salt Lake City International Airport.
- TVY: Tooele Airport.
- U42: South Valley Regional Airport.

The dataset includes all raw observations from each airport listed above, with observation timestamps rather than hourly aggregated data. For this analysis, average temperature in degrees Fahrenheit ("tmpf") and average one-hour precipitation totals in inches ("p01i") were calculated for each station and used in subsequent analysis.

3.7 Joining Datasets

RSG joined hourly records from the travel time and traffic count datasets using a correspondence key. This key associated UDOT count stations and ClearGuide routes for all study sites. Roadway capacities were joined to these hourly records with a similar key association with the appropriate model link. Appendix A presents the correspondence key used to connect these three primary datasets.

To associate crash data with study records, each study site was first joined to a UDOT linear referenced roadway layer. This was done to obtain the appropriate route and milepoint for each study site. Study site identifiers were joined to the full crash dataset where crashes were on study routes and within five miles upstream or downstream of study segments, resulting in a crash dataset with a record for each crash/study site combination. The site-tagged crash dataset was then joined to the larger study dataset (hourly travel time and count records) using the tagged site identifier and the hour of the crash. Records in the study dataset from two hours prior to a tagged crash hour through five hours following a tagged crash hour were flagged as being part of a crash event. This was done to account for reasonable geographic and temporal extents of crash influence.

To join weather data to the study dataset, a spatial join was first conducted between the study sites and weather stations to associate each study site with the closest available weather station. Average hourly precipitation and temperature records from the weather dataset were then joined to the full study dataset using the weather station identifiers and study hour. Figure 3-2 presents a map of available weather stations along with the study sites.

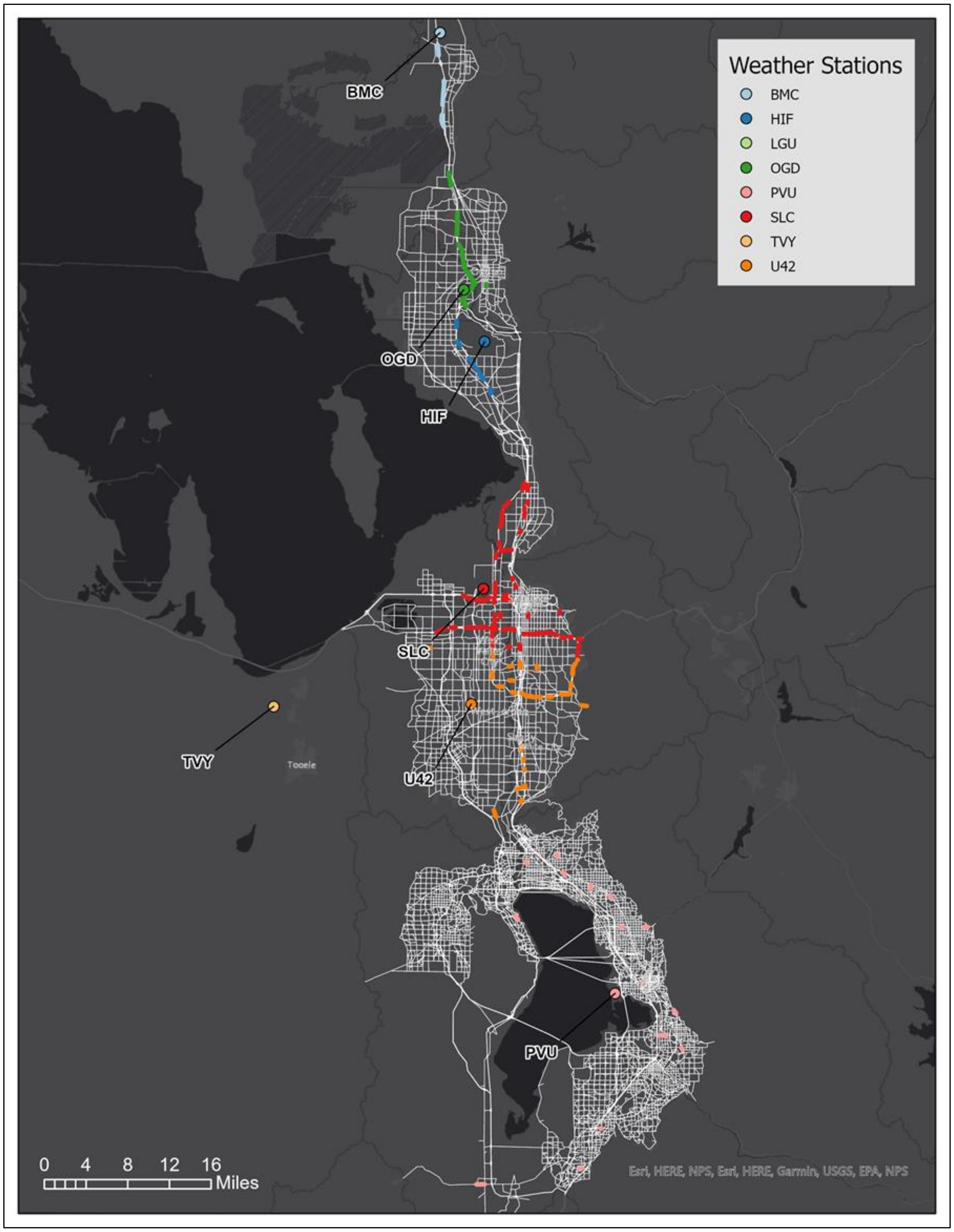

Figure 3-2 Study Site Weather Station Associations

4.0 ANALYSIS

4.1 Overview

RSG conducted data analysis by calculating BTI and average volumes by hour of day, plotting the relationship between BTI and V/C for all stations in each roadway type, and iteratively applying and refining data filters to remove events of nonrecurrent congestion (e.g., crashes, snowstorms) for the analysis.

4.2 BTI Calculations

After combining all datasets, the final study dataset consisted of records for each study site for each hour of the year. The attributes included average travel time, count volume, roadway capacity, crash flags, average temperature, and average one-hour precipitation totals.

Because expectations of travel time vary with time of day—a driver anticipates higher levels of congestion during peak periods—BTI was calculated separately for each hour of the day, resulting in 24 BTI samples per study site. The final dataset used as input to subsequent regression analysis included BTI and average volume by hour of the day for each study location, calculated by grouping the full dataset by study site and hour of day and calculating BTI as presented in Equation 2-1. V/C ratios for each record were calculated from the average hourly volumes and the study roadway capacities.

4.3 Data Filters

BTI versus V/C relationships were considered with varying degrees of data filters applied; this was done in an attempt to remove instances of nonrecurring congestion from the final analysis. Prior to aggregating to hour-of-day records, individual data records associated with crash and snow/ice events were flagged and dropped. Ultimately, records for sites within five miles upstream or downstream of crash events, and the hours extending from two hours prior to a crash through five hours after a crash, were flagged and dropped from the initial filtered dataset. Records with observed precipitation while average temperatures were less than 35 degrees Fahrenheit were also flagged and dropped from this initial filtered dataset.

RSG identified an additional source of nonrecurring congestion that was highly prevalent among apparent outliers. This became apparent after plotting BTI versus V/C relationships for the full dataset and with crash and weather events removed. Specifically, many data points with apparently poor travel-time reliability and low V/C were found to be at locations with active work zones during the study period. While no additional dataset was readily available to aid in identification of these events, an attempt was made to identify and remove records collected during construction events by examining the month-to-month variability in travel times at each site.

Figure 4-1 presents a plot of all travel times and flows observed at a study site on I-80 by the Salt Lake City airport. This site experiences considerable variability in travel time (unreliability) from approximately March through August 2019. Investigation into this site (and other similar sites) revealed work-zone activity during the same time periods of significant variability in travel time. Figure 4-2 shows a summary of "work-zone-related" crashes on this stretch of roadway during 2019. Crashes were flagged as work zone-related during these same months. Further review of aerial imagery from 2019 confirmed the presence of construction during this period.

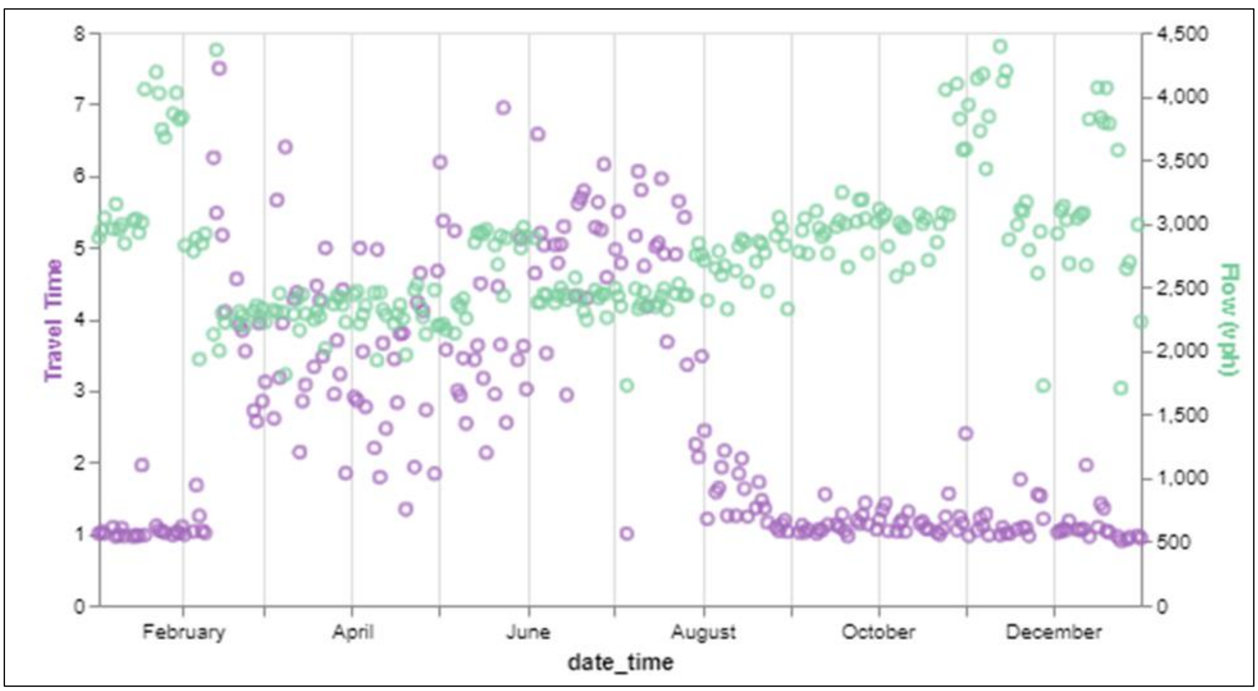

Figure 4-1 Travel-Time Variability on I-80 by SLC Airport

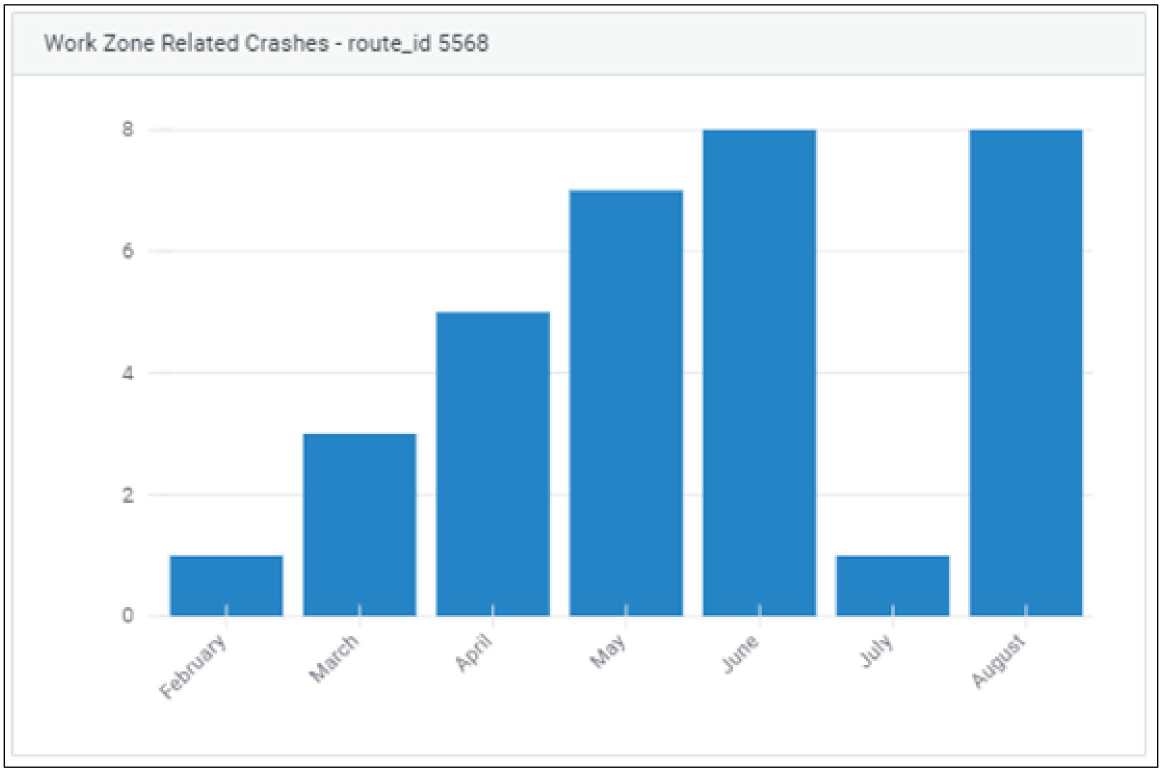

Figure 4-2 Work-Zone-Related Crashes on I-80 by SLC Airport, by Month

After detailed review of outlier sites, a filtering metric was established to flag potential outliers. This metric flagged any records during months where the average hourly travel time was more than 25% higher than the minimum monthly average travel time for a site.

Figure 4-3 through Figure 4-5 present plots of BTI versus V/C for freeway, ramp, and arterial roadways. Each plot shows, from left to right, the full dataset, the dataset filtered for crashes and weather events, and then further filtered for monthly variation (work zones). Bar charts displaying the average BTI per 0.2 V/C step bin are similarly presented for each level of filtering below the scatter plots.

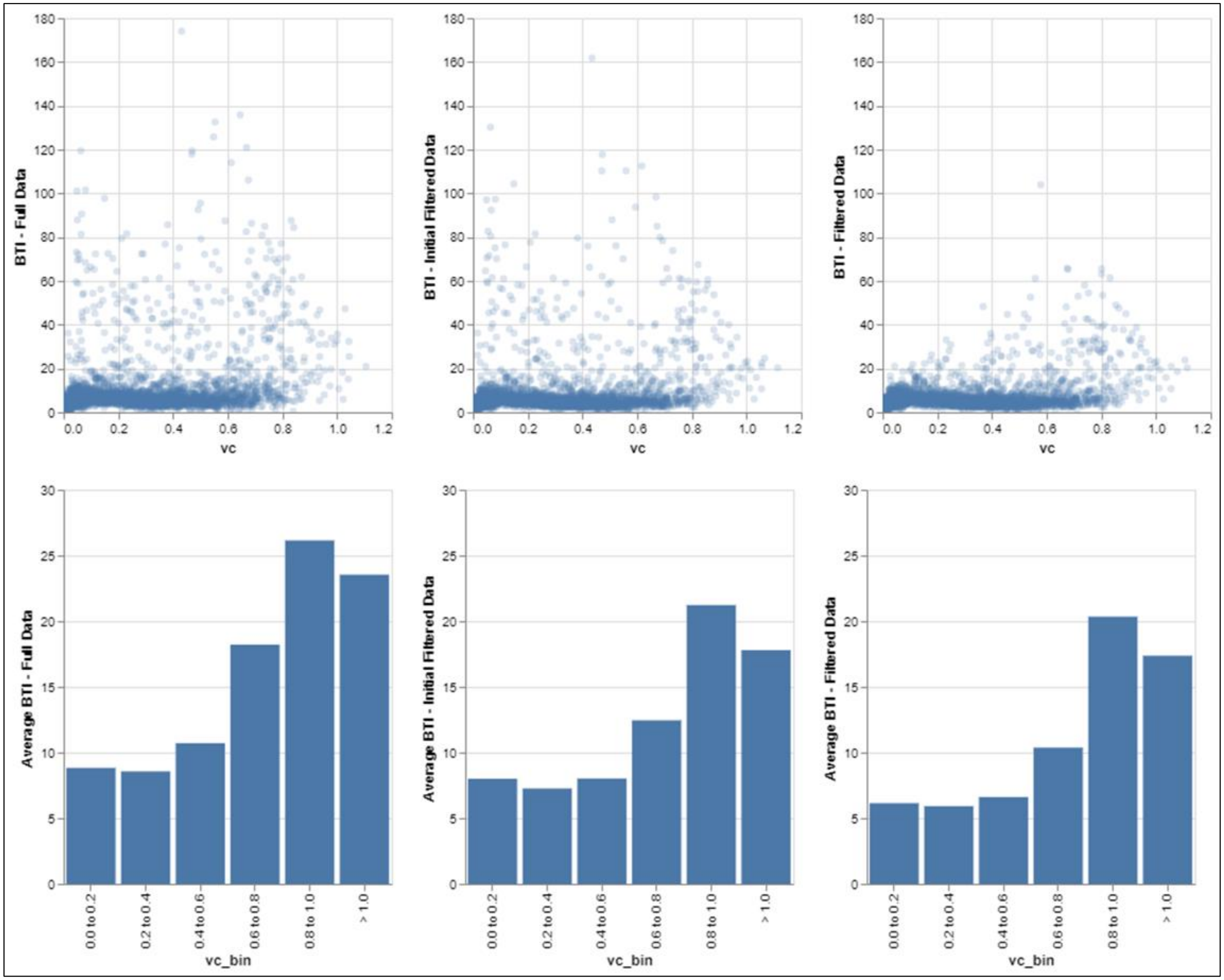

Figure 4-3 Freeway BTI vs. V/C, by Filter Level

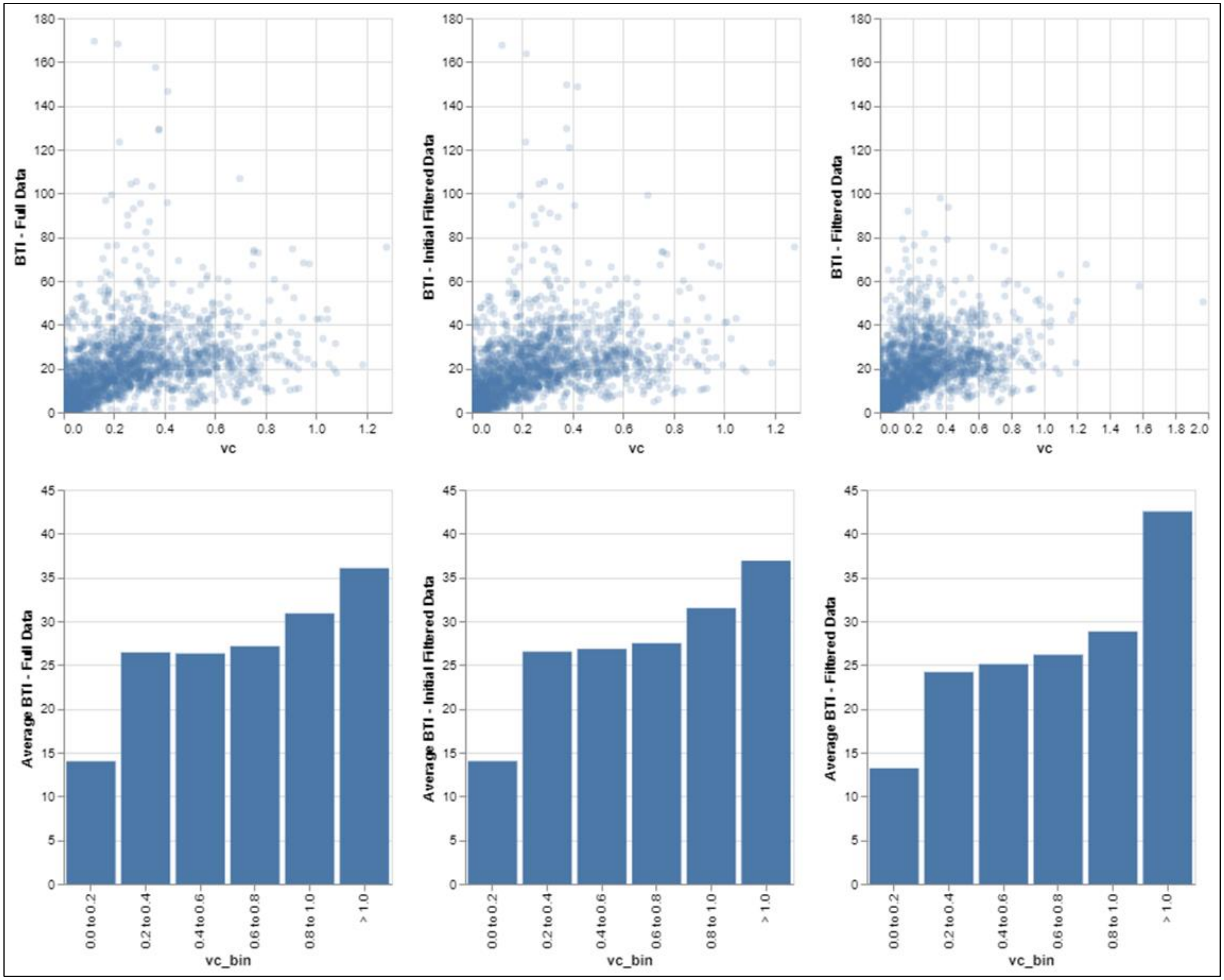

Figure 4-4 Ramp BTI vs. V/C, by Filter Level

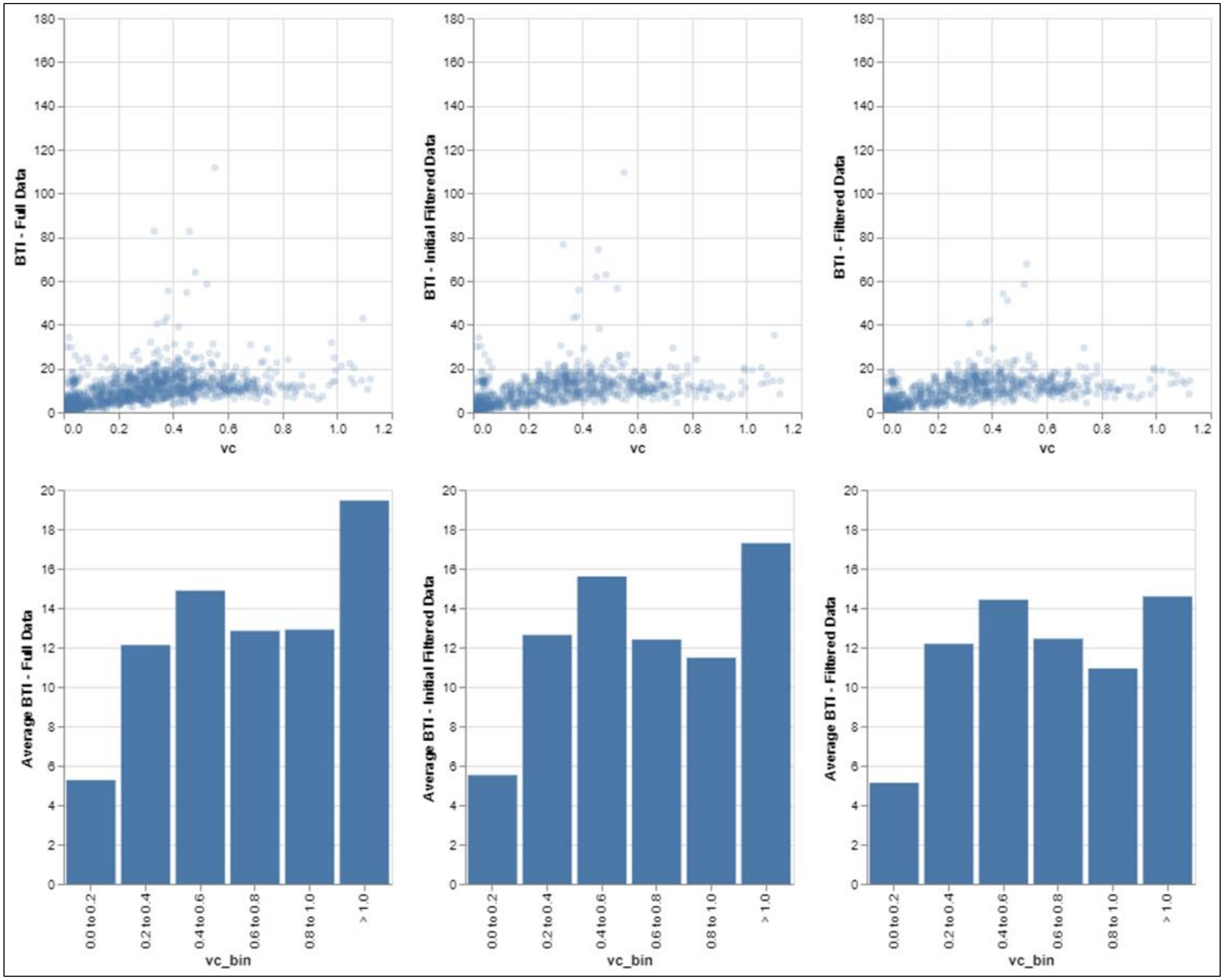

Figure 4-5 Arterial BTI vs. V/C. by Filter Level

4.4 Regression Analysis

Regression analyses were conducted on the dataset after dropping records with the most selective filters to remove instances of nonrecurring congestion. The ramp and arterial datasets exhibited relatively continuous linear relationships between V/C and BTI, and for these two roadway types, simple linear regressions were applied. The freeway dataset, however, included two distinct sections: a nearly flat section with low BTI levels for conditions with V/C less than 0.6, and a linearly increasing BTI section for conditions with V/C above 0.6. For the freeway roadway type, separate linear regressions were applied to these two distinct V/C ranges.

Figure 4-6, Figure 4-7 , and Figure 4-8 present the regression models for the freeway, ramp, and arterial datasets, respectively.

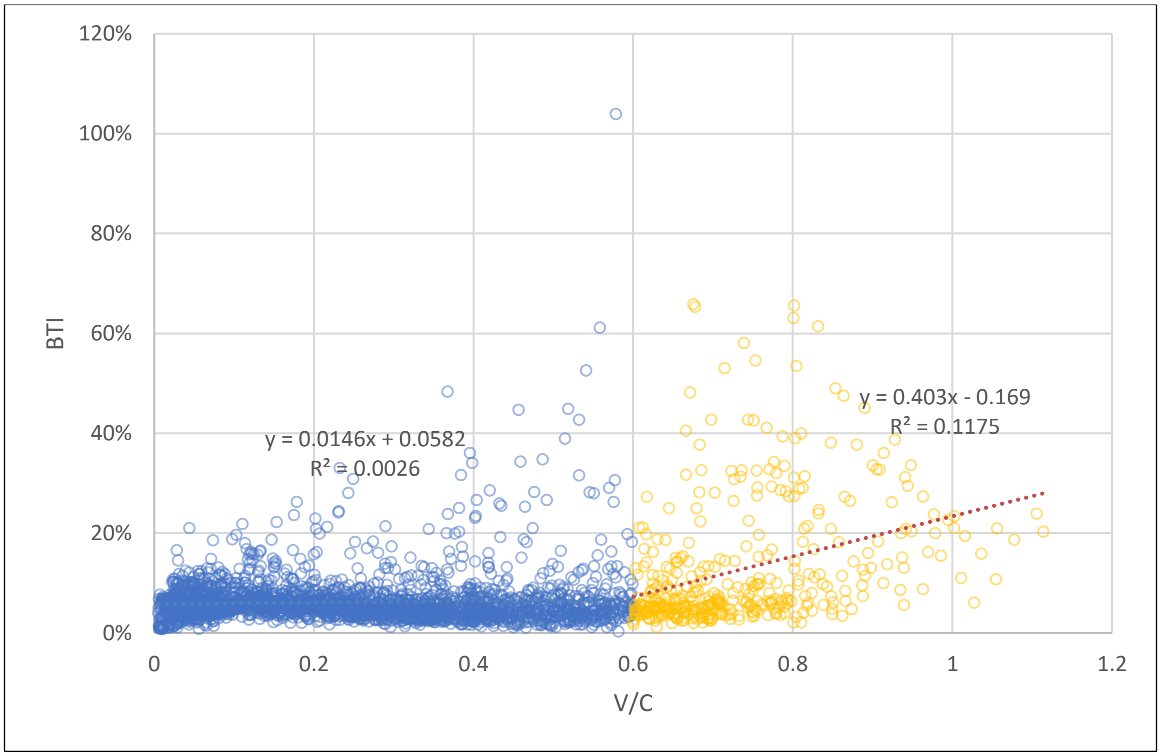

Figure 4-6 Freeway BTI Model

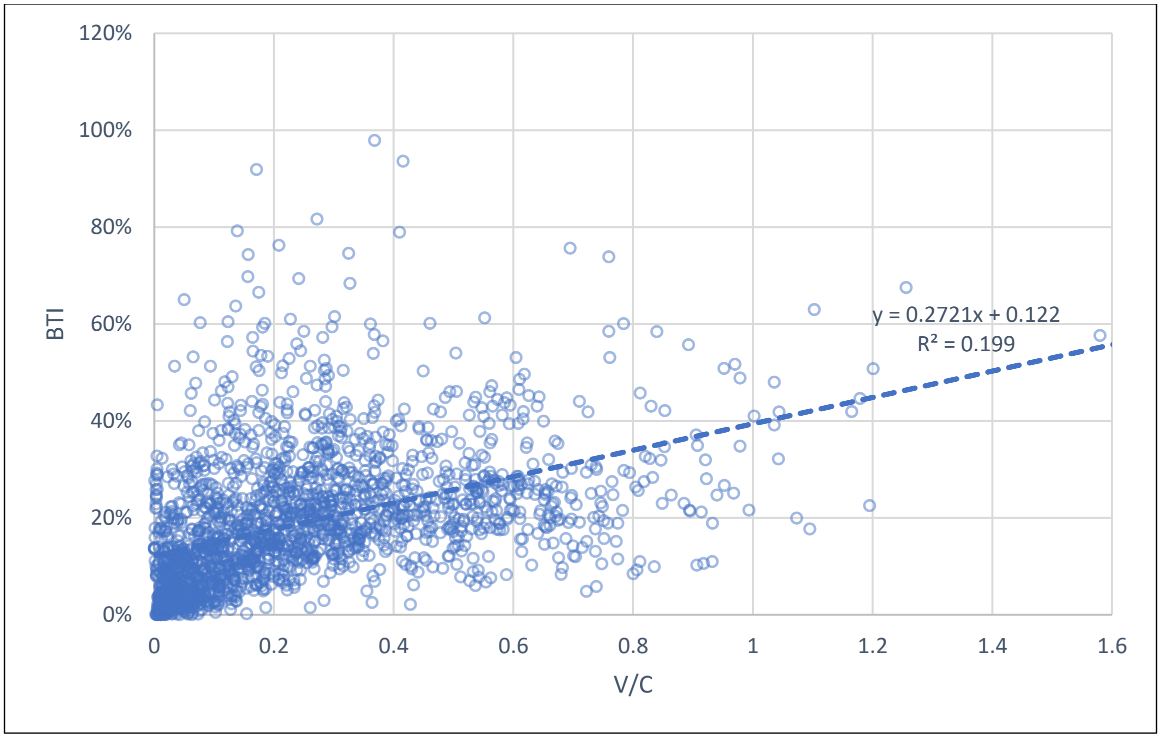

Figure 4-7 Ramp BTI Model

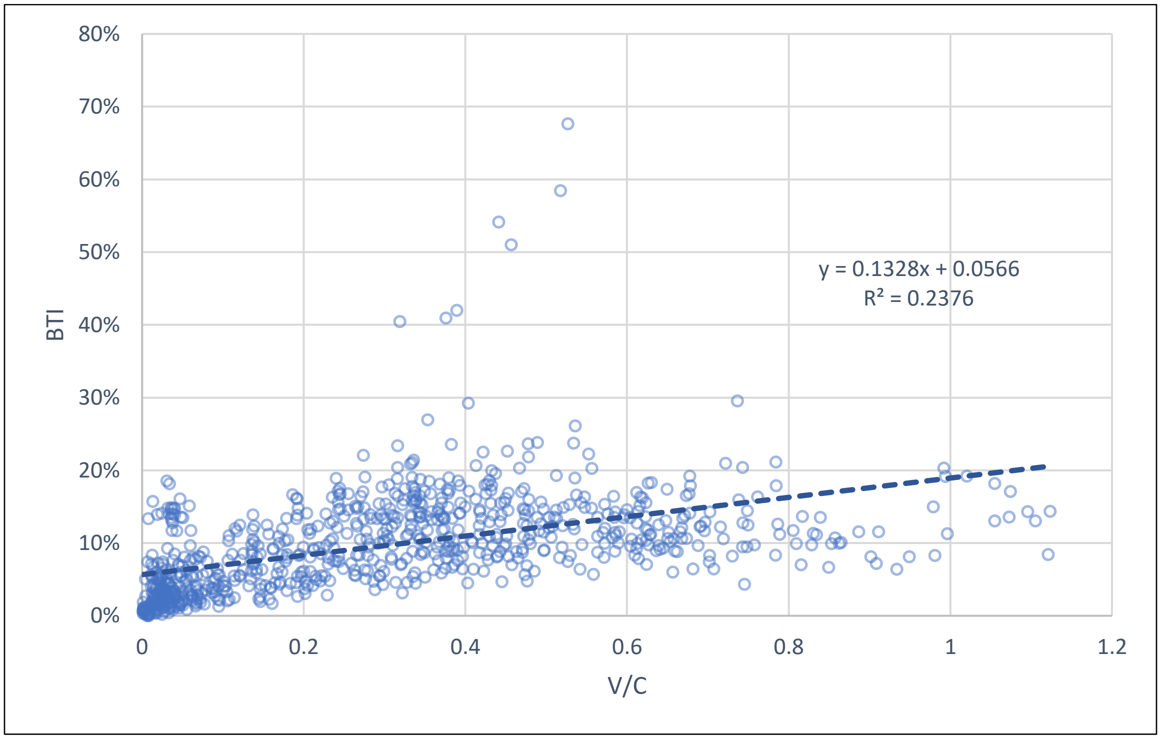

Figure 4-8 Arterial BTI Model

5.0 MODEL IMPLEMENTATION

5.1 Overview

RSG used regression analysis results to project travel-time reliability within the Wasatch Front Travel Demand Model by extending a methodology previously derived in the WFCCS.[14] This previous methodology used a BTI versus V/C lookup table for freeway links to associate BTI percentages with V/C ratios on freeway links for each model period. It then calculated "{period}_BTI_TME" attributes for each period by multiplying the assigned travel time for each period by the BTI percentage associated with the period V/C ratio.

For this analysis, the BTI versus V/C lookup table ("BTI_Lookup.csv") model input was extended to include values for ramp and arterial links and to use freeway lookups derived from the updated regression analysis. Model scripts were updated to include buffer time projections for these additional roadway types.

5.2 Model Updates

Figure 5-1 presents a plot of the BTI versus V/C lookup values from this analysis, alongside the original freeway BTI versus V/C lookup values derived from freeway PeMS speed data in the WFCCS. The current BTI versus V/C relationship derived for freeway links is like the relationship previously derived in the WFCCS, with low variability with low congestion and increasing variability for higher congestion (V/C conditions above 0.6).

Arterial roadways demonstrate higher variability than freeways at low congestion levels but less variability than freeways at higher congestion levels. Of the three roadway types studied, ramps demonstrate the highest overall variability at all levels of congestion.

[14] Wasatch Front Central Corridor Study, April 2017.

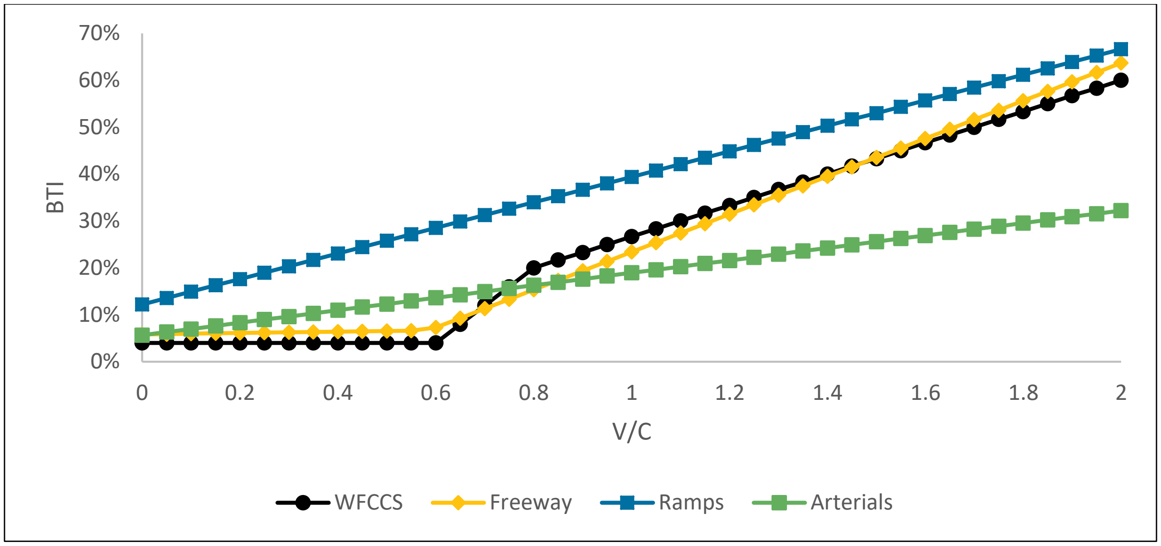

Figure 5-1 BTI Lookup Values

Along with the updated BTI versus V/C lookup table (Table 5-1), RSG updated model scripts to allow for buffer times to be calculated on ramp and arterial links as well as freeway links (*04_SummarizeLoadedNetworks.s*) and to then calculate zone-to-zone buffer time skims from these link attributes (*07_PerformFinalNetSkim.s*). With these updates, BTI is calculated for the following model roadway functional types.

Table 5-1 BTI Roadway Functional Types

Category	FT	Description
Freeway	22	Managed Motorways: posted 55-60 mph
Freeway	23	Managed Motorways: posted 65 mph, no aux lane
Freeway	24	Managed Motorways: posted 65 mph, aux lane
Freeway	25	Managed Motorways: posted 75 mph, no aux lane
Freeway	26	Managed Motorways: posted 75 mph, aux lane
Freeway	27	placeholder
Freeway	32	Freeway: posted 55-60 mph
Freeway	33	Freeway: posted 65 mph, no aux lane
Freeway	34	Freeway: posted 65 mph, aux lane
Freeway	35	Freeway: posted 75 mph, no aux lane

Category	FT	Description
Freeway	36	Freeway: posted 75 mph, aux lane
Freeway	37	Freeway: High-occupancy vehicle lane
Freeway	38	Freeway: Managed lane
Freeway	39	Freeway: Managed lane access
Freeway	40	Freeway: Tollway
Ramp	20	Managed Motorways: Freeway-to-Freeway loop ramp
Ramp	21	Managed Motorways: C-D road, flyover ramp
Ramp	28	Managed Motorways: On-ramp
Ramp	29	Managed Motorways: Off-ramp
Ramp	30	Freeway: Freeway-to-Freeway loop ramp
Ramp	31	Freeway: C-D road, flyover ramp
Ramp	41	Freeway: On-ramp
Ramp	42	Freeway: Off-ramp
Arterial	2	Principal Arterial
Arterial	3	Minor Arterial
Arterial	4	Major Collector

Table 5-2 BTI vs. V/C Lookup Table

V/C	FREEWAY	RAMPS	ARTERIALS
0	0.06	0.12	0.06
0.05	0.06	0.14	0.06
0.1	0.06	0.15	0.07
0.15	0.06	0.16	0.08
0.2	0.06	0.18	0.08
0.25	0.06	0.19	0.09
0.3	0.06	0.20	0.10

V/C	FREEWAY	RAMPS	ARTERIALS
0.35	0.06	0.22	0.10
0.4	0.06	0.23	0.11
0.45	0.06	0.24	0.12
0.5	0.07	0.26	0.12
0.55	0.07	0.27	0.13
0.6	0.07	0.29	0.14
0.65	0.09	0.30	0.14
0.7	0.11	0.31	0.15
0.75	0.13	0.33	0.16
0.8	0.15	0.34	0.16
0.85	0.17	0.35	0.17
0.9	0.19	0.37	0.18
0.95	0.21	0.38	0.18
1	0.23	0.39	0.19
1.05	0.25	0.41	0.20
1.1	0.27	0.42	0.20
1.15	0.29	0.43	0.21
1.2	0.31	0.45	0.22
1.25	0.33	0.46	0.22
1.3	0.35	0.48	0.23
1.35	0.38	0.49	0.24
1.4	0.40	0.50	0.24
1.45	0.42	0.52	0.25
1.5	0.44	0.53	0.26
1.55	0.46	0.54	0.26
1.6	0.48	0.56	0.27
1.65	0.50	0.57	0.28
1.7	0.52	0.58	0.28
1.75	0.54	0.60	0.29
1.8	0.56	0.61	0.30

V/C	FREEWAY	RAMPS	ARTERIALS
1.85	0.58	0.63	0.30
1.9	0.60	0.64	0.31
1.95	0.62	0.65	0.32
2	0.64	0.67	0.32

5.3Model BTI Outputs

With the updated BTI lookup table and revised assignment and skimming scripts, the RSG-modified model now calculates period buffer times (minutes) on model roadway links and zone-to-zone buffer times (minutes) in period network skims and saves these in the scenario run's */5_AssignHwy* output folder.

Link attributes are written to the network .net (*5_AssignHwy\2a_Networks*) and shapefile (*5_AssignHwy\2b_Shapefiles*) output files. Skim matrices are written to period-specific .mtx files (*5_AssignHwy\5_FinalNetSkims*).

6.0 CONCLUSIONS

6.1 Summary

The reliability, or unreliability, of a travel network affects the quality of life for those traveling on it. While travel models have been designed with significant attention to vehicle delay and projecting congestion on the roadway network, travel-time reliability has historically not been a focus of model forecasts.

This analysis examined passively collected probe-vehicle travel-time data and traditional traffic counts to identify relationships between travel-time reliability and volume-to-capacity (V/C) ratios. Relationships between V/C and BTI were established through regression analysis separately for freeway, ramp, and arterial roadways. BTI versus V/C lookup tables were then established from these regressions and used to assign BTI values to model roadway links based on model V/C ratios. With the updated BTI lookup table and revised assignment and skimming scripts, the RSG-modified model now calculates period buffer times (minutes) on model roadway links and zone-to-zone buffer times (minutes) in period network skims. It then saves these in the scenario run outputs.

6.2 Findings

Previous work in the Wasatch Front Travel Demand Model (WFCCS) developed BTI versus V/C lookup values that project travel-time reliability for freeway links based on continuous count station speed data. Updated freeway BTI versus V/C relationships established in this current study using probe-vehicle travel-time data confirm the previous WFCCS analysis, with the updated freeway BTI lookup values tracking closely with previous findings. This study further expands the travel model capabilities to project BTI for ramp and arterial roadways in addition to freeway links.

Figure 6-1 and Figure 6-2 present travel times and calculated buffer times between notable origin/destination pairs during the AM and PM periods. The plots show general-purpose in-vehicle travel times (GP_IVT) from the model assignment, along with calculated buffer times (GB_BTI_Time). While the assigned period in-vehicle travel times include the cumulative travel time on all links connecting the origin-destination pairs, buffer times are calculated and summed for only the freeway, ramp, and arterial links where buffer time calculations are applied, as presented in Table 5-1.

The observed magnitudes of drive times and buffer times match expectations, with relatively larger travel times and buffer times on dominant commuter flows, when compared to the corresponding reverse-commute flows. For example, during the AM peak period, both travel times and buffer times are longer inbound to Salt Lake City than outbound. Conversely, during the PM peak period, travel times and buffer times are longer outbound from Salt Lake City than inbound to Salt Lake City.

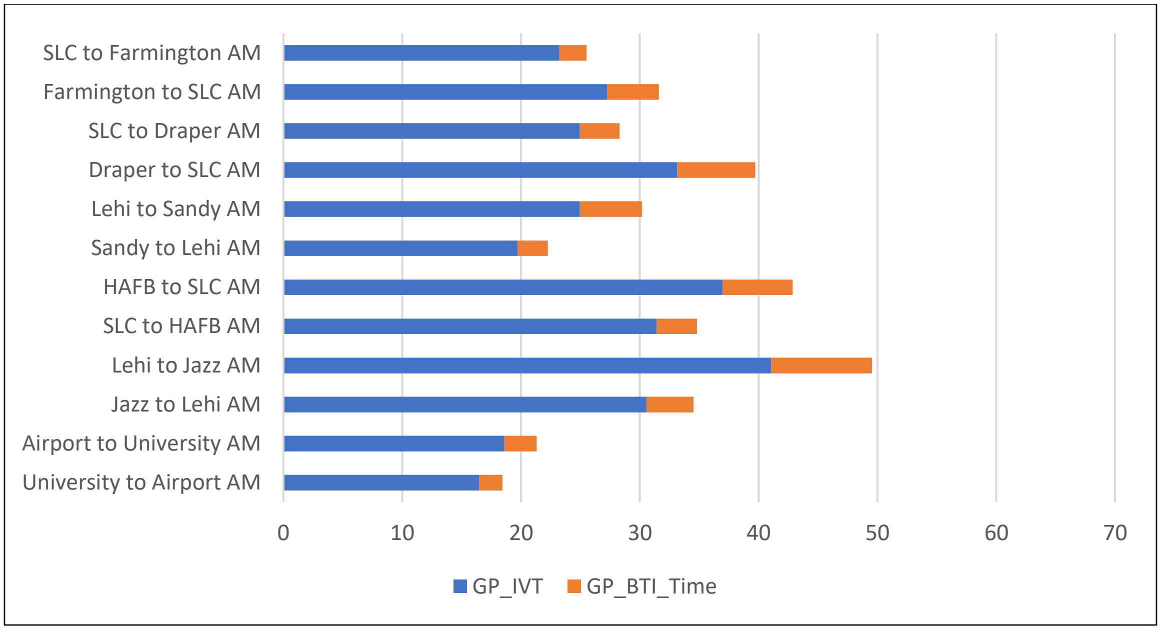

Figure 6-1 AM Period Travel-Time Skims with Buffer Times

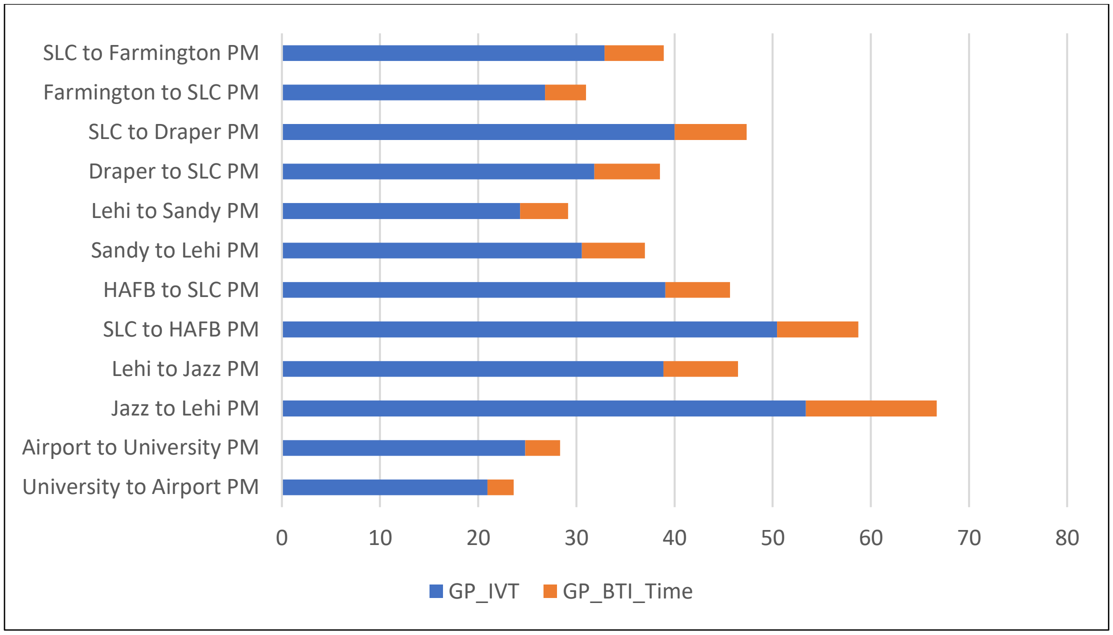

Figure 6-2 PM Period Travel-Time Skims with Buffer Times

6.3 Limitations and Challenges

While data indicates that decreased reliability is associated with increased V/C, many external factors influence traffic flows, and V/C alone cannot fully predict BTI. During the course of this research, a major source of unreliability was found to be associated with roadway construction events. The analysis conducted for this project attempted to filter out likely construction and maintenance events, but a comprehensive dataset identifying the location and dates of construction and maintenance could more precisely identify and remove these non-recurring events from future analysis.

An additional limitation of this analysis was its reliance on continuous traffic count stations to provide volumes used in calculating V/C. While travel-time data is currently available for nearly all UDOT roadways, continuous volume count data is available on a far smaller subset of these roadways. Additional sources of volume data or alternative methods for estimating V/C could be pursued in the future to expand analysis to a broader set of roadways.

APPENDIX A: STUDY SITE CORRESPONDENCE KEY

TYPE	MODEL LINK	COUNT STATION	CLEARGUIDE ROUTE
Freeway	10181_10280	52	5586
Freeway	10186_10190	285	5569
Freeway	10208_10187	289	5561
Freeway	10214_10212	3600	5573
Freeway	10215_10189	200	5568
Freeway	10219_10221	224	5643
Freeway	10220_10714	259	5644
Freeway	10221_10677	226	5645
Freeway	10223_10225	228	5650
Freeway	10224_10222	256	5651
Freeway	10225_10675	230	5652
Freeway	10231_10663	234	5661
Freeway	10242_10504	102	5535
Freeway	10243_10500	97	5536
Freeway	10248_10250	115	5556
Freeway	10250_10589	117	5557
Freeway	10251_10249	82	5555
Freeway	10254_10587	120	5571
Freeway	10261_10268	134	5580
Freeway	10263_10308	67	5575
Freeway	10267_10604	46	5589
Freeway	10269_10260	65	5579
Freeway	10272_10597	141	5583
Freeway	10277_10180	145	5585
Freeway	10279_10281	151	5587
Freeway	10281_10283	152	5588
Freeway	10286_10518	38	5591
Freeway	10291_10612	160	5592
Freeway	10295_10616	164	5687
Freeway	10298_10615	31	5686
Freeway	10307_10262	132	5576
Freeway	10308_10306	71	5574
Freeway	10309_10626	176	5680
Freeway	10317_10319	190	5670
Freeway	10318_10369	188	5671
Freeway	10355_21484	830	5517
Freeway	10360_10362	890	5526
Freeway	10364_10363	808	5527
Freeway	10370_10375	91	5531
Freeway	10498_10499	100	5537
Freeway	10505_10243	95	5534

TYPE	MODEL LINK	COUNT STATION	CLEARGUIDE ROUTE
Freeway	10507_10374	106	5530
Freeway	10583_10251	80	5558
Freeway	10586_10253	76	5572
Freeway	10593_10270	135	5581
Freeway	10595_10274	57	5584
Freeway	10611_10292	35	5593
Freeway	10618_10619	26	5683
Freeway	10620_10617	170	5684
Freeway	10622_10624	175	5681
Freeway	10623_10621	22	5682
Freeway	10625_10310	20	5679
Freeway	10630_10631	179	5677
Freeway	10632_10629	16	5678
Freeway	10636_10638	181	5675
Freeway	10637_10635	14	5676
Freeway	10655_10656	237	5665
Freeway	10657_10658	245	5664
Freeway	10660_6220	235	5663
Freeway	10664_10232	246	5662
Freeway	10670_10672	249	5658
Freeway	10673_10671	232	5657
Freeway	10674_10224	254	5653
Freeway	10676_10220	258	5646
Freeway	10682_10200	196	5562
Freeway	10688_10691	297	5594
Freeway	10720_10219	222	5642
Freeway	10761_9224	932	5464
Freeway	10762_9241	952	5465
Freeway	11251_21409	333	5609
Freeway	11515_7525	884	5518
Freeway	11526_7592	898	5528
Freeway	13015_13253	3103918	5441
Freeway	13030_13043	3103930	5449
Freeway	13038_13041	3103958	5446
Freeway	13044_13149	3103924	5445
Freeway	13045_13035	3103952	5450
Freeway	13070_13138	3103944	5452
Freeway	13143_13069	3103938	5451
Freeway	13145_13255	3103928	5447
Freeway	13254_13017	3103964	5442
Freeway	13257_13146	3103954	5448
Freeway	21485_10353	868	5516
Freeway	4234_4245	310	5603

TYPE	MODEL LINK	COUNT STATION	CLEARGUIDE ROUTE
Freeway	4243_4242	314	5577
Freeway	4244_4233	344	5604
Freeway	4247_4249	316	5578
Freeway	4258_11252	321	5608
Freeway	4310_4261	352	5596
Freeway	4334_4211	302	5595
Freeway	4793_8655	5253	5423
Freeway	5991_9253	976	5501
Freeway	6212_10654	243	5666
Freeway	7524_11519	814	5519
Freeway	7549_4228	348	5601
Freeway	7550_4234	308	5602
Freeway	7568_4227	306	5599
Freeway	7572_5940	350	5600
Freeway	7593_11527	800	5529
Freeway	7720_7719	5250	5426
Freeway	7721_7722	5251	5425
Freeway	8644_4163	5252	5424
Freeway	9011_9012	917	5490
Freeway	9013_9009	965	5489
Freeway	9016_9382	918	5487
Freeway	9209_9208	983	5504
Freeway	9211_5993	975	5502
Freeway	9218_9219	920	5484
Freeway	9220_9221	922	5478
Freeway	9222_9223	928	5472
Freeway	9223_10761	930	5466
Freeway	9227_9228	938	5456
Freeway	9236_9237	944	5455
Freeway	9240_10762	950	5463
Freeway	9243_9244	960	5477
Freeway	9245_9246	962	5483
Freeway	9247_9015	964	5486
Freeway	9255_9256	982	5503
Freeway	9258_9257	986	5505
Freeway	9270_9393	482	5496
Freeway	9277_10285	157	5590
Freeway	9365_9206	987	5510
Freeway	9388_9273	449	5495
Freeway	9389_9409	970	5497
Freeway	9402_9480	926	5474
Freeway	9404_9407	934	5458
Freeway	9406_9405	948	5457

TYPE	MODEL LINK	COUNT STATION	CLEARGUIDE ROUTE
Freeway	9416_9390	969	5498
Freeway	9446_9259	768	5509
Freeway	9481_9403	956	5473
Ramp	10013_5193	2461	5545
Ramp	10014_5196	2467	5523
Ramp	10030_4407	2322	5612
Ramp	10040_10149	1324	5610
Ramp	10047_3674	2503	5549
Ramp	10049_3809	2507	5550
Ramp	10118_4413	2528	5697
Ramp	10122_4726	2536	5694
Ramp	10125_4727	2409	5692
Ramp	10160_6238	2587	5703
Ramp	10227_4513	2231	5654
Ramp	10230_5590	2251	5655
Ramp	10231_4947	2234	5659
Ramp	10296_4993	2033	5688
Ramp	10314_4769	2011	5673
Ramp	10320_4561	2004	5667
Ramp	10333_7008	2282	5566
Ramp	10348_9185	2377	5701
Ramp	10356_5192	2826	5520
Ramp	10358_4299	2886	5525
Ramp	10551_4414	2416	5696
Ramp	10570_6237	2577	5702
Ramp	10677_4464	2228	5647
Ramp	10761_6997	2932	5461
Ramp	13042_13044	13103922	5443
Ramp	13047_13053	23103960	5444
Ramp	13069_13073	23103940	5453
Ramp	13079_13070	13103942	5454
Ramp	3411_10027	1761	5541
Ramp	3414_10022	1762	5540
Ramp	3433_10193	1203	5567
Ramp	3457_10033	1488	5539
Ramp	3520_10184	1287	5570
Ramp	3556_10048	1439	5552
Ramp	3599_3592	1443	5548
Ramp	3728_4211	1302	5598
Ramp	3928_5505	2466	5544
Ramp	4157_10167	1571	5700
Ramp	4223_4244	1344	5607
Ramp	4235_4225	1312	5606

TYPE	MODEL LINK	COUNT STATION	CLEARGUIDE ROUTE
Ramp	4245_4235	2310	5605
Ramp	4262_3728	2300	5597
Ramp	4263_10079	1332	5611
Ramp	4413_10120	1530	5698
Ramp	4455_3493	2093	5532
Ramp	4457_10244	1103	5533
Ramp	4464_10225	1228	5648
Ramp	4465_10676	1256	5649
Ramp	4561_10334	1004	5669
Ramp	4562_10319	1190	5668
Ramp	4727_10123	1411	5693
Ramp	4769_10332	1013	5674
Ramp	4847_4829	2183	5672
Ramp	4993_10294	1034	5689
Ramp	5028_10226	1252	5656
Ramp	5044_10295	1162	5690
Ramp	5193_10015	1751	5546
Ramp	5195_3669	2204	5565
Ramp	5196_10012	1463	5524
Ramp	5317_10161	1364	5704
Ramp	5500_10019	1459	5542
Ramp	5505_3934	1460	5543
Ramp	5512_5044	2162	5691
Ramp	5514_5080	1031	5685
Ramp	5644_10232	1246	5660
Ramp	5993_6500	2975	5500
Ramp	6339_9436	1738	5512
Ramp	6360_9204	2740	5514
Ramp	6387_9206	1987	5508
Ramp	6499_5991	1976	5499
Ramp	6622_9273	1449	5492
Ramp	6624_9271	1465	5494
Ramp	6634_6795	2920	5481
Ramp	6722_9243	1958	5475
Ramp	6732_9242	1954	5468
Ramp	6734_9223	1928	5471
Ramp	6795_6633	1920	5482
Ramp	6996_10762	1950	5460
Ramp	6997_9225	1932	5462
Ramp	7318_10156	1369	5437
Ramp	7479_10166	1382	5699
Ramp	9205_6387	2769	5507
Ramp	9221_8588	2924	5476

TYPE	**MODEL LINK**	**COUNT STATION**	**CLEARGUIDE ROUTE**
Ramp	9222_6734	2928	5470
Ramp	9239_6996	2950	5459
Ramp	9241_6732	2954	5467
Ramp	9248_9386	1966	5488
Ramp	9257_6385	2988	5506
Ramp	9260_6339	1739	5511
Ramp	9270_6624	2482	5493
Ramp	9272_6622	2451	5491
Ramp	9437_6360	2737	5513
Ramp	9468_6787	2962	5479
Ramp	9470_9283	1962	5480
Arterial	10709_4038	408_NEG	6040
Arterial	10973_4400	354_NEG	6048
Arterial	11561_5402	631_NEG	6050
Arterial	21813_24141	643_NEG	6065
Arterial	22103_23939	662_POS	6062
Arterial	22212_24006	658_NEG	6071
Arterial	22388_22389	645_NEG	6073
Arterial	22389_22388	645_POS	6072
Arterial	22417_22418	647_NEG	6075
Arterial	22418_22417	647_POS	6074
Arterial	22567_22619	661_NEG	6082
Arterial	22581_22583	642_POS	6081
Arterial	22583_22581	642_NEG	6080
Arterial	22619_22567	661_POS	6083
Arterial	23033_23038	649_NEG	6085
Arterial	23038_23033	649_POS	6084
Arterial	23179_26496	660_POS	6086
Arterial	23197_23199	646_POS	6090
Arterial	23199_23197	646_NEG	6089
Arterial	23222_23289	664_NEG	6092
Arterial	23289_23222	664_POS	6091
Arterial	23505_24216	654_POS	6094
Arterial	23526_25523	321_NEG	6097
Arterial	23556_26434	650_POS	6096
Arterial	23939_22103	662_NEG	6063
Arterial	24006_22212	658_POS	6070
Arterial	24141_21813	643_POS	6064
Arterial	24216_23505	654_NEG	6093
Arterial	24452_25988	663_NEG	6079
Arterial	25523_23526	321_POS	6098
Arterial	25988_24452	663_POS	6078
Arterial	26434_23556	650_NEG	6095

TYPE	MODEL LINK	COUNT STATION	CLEARGUIDE ROUTE
Arterial	26496_23179	660_NEG	6087
Arterial	3629_8554	409_POS	6038
Arterial	4022_4136	332_NEG	6044
Arterial	4038_10709	408_POS	6039
Arterial	4082_4083	325_POS	6041
Arterial	4083_4082	325_NEG	6042
Arterial	4136_4022	332_POS	6043
Arterial	4400_10973	354_POS	6049
Arterial	4591_4738	406_POS	6052
Arterial	4604_5717	407_POS	6058
Arterial	4738_4591	406_NEG	6053
Arterial	4807_4840	335_POS	6055
Arterial	4840_4807	335_NEG	6054
Arterial	5095_5096	322_POS	6057
Arterial	5096_5095	322_NEG	6056
Arterial	5402_11561	631_POS	6051
Arterial	5717_4604	407_NEG	6059
Arterial	6757_9578	329_POS	6036
Arterial	6904_7238	355_POS	6046
Arterial	7238_6904	355_NEG	6045
Arterial	8554_3629	409_NEG	6037
Arterial	9578_6757	329_NEG	6550

APPENDIX B: DATA FILES

While too large to include in the report document, data files used in this analysis are provided along with this report in zipped format with the following folder structure and contents:

- **1_Travel_Time**: hourly travel-time data files (.csv) for study sites.
- **2_Traffic_Count**: hourly traffic count data for study sites.
- **3_Network**: the model network used to identify study sites and capacities.
- **4_Crash**: 2019 crash data used to identify nonrecurring congestion events.
- **5_Weather**: 2019 weather data used to identify nonrecurring congestion events.