DEPARTMENT OF TRANSPORTATION

Assessment of Travel-Time Reliability and Operational Resilience of Metro Freeway Corridors

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Final Report 2024-27

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16. Abstract (Limit: 250 words)

This study estimated and analyzed the travel-time reliability (TTR) and traffic-flow measures of effectiveness (MOE) for 74 directional corridors in the metro freeway network in Twin Cities, Minnesota, from January 2018 to December 2023, for both morning and afternoon peak periods. The network-wide trends for both TTR and MOE indicate that the traffic flows in the Twin Cities freeway network have not reached the pre-pandemic level as of December 2023. The TTR and MOE estimation results were applied to identify a set of the most vulnerable routes in the current network. Further, the preliminary resilience model, developed in the previous phase, was enhanced and applied to determine the operational resilience of 74 directional corridors in the network and a set of the low-resilient routes were identified. The effects of the route-wide geometric configuration on TTR, MOE and operational resilience on individual corridors were also analyzed. The results from this research could provide the basis for geometric and operational improvements of the metro freeway corridors.

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Assessment of Travel-Time Reliability and Operational Resilience of Metro Freeway Corridors

Final Report

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EXECUTIVE SUMMARY

A key element in developing and maintaining a reliable and resilient freeway network is the ability to monitor and assess the travel-time reliability (TTR) and resilience at individual corridor levels under various operating conditions. The previous phases of this research developed and enhanced the Travel-Time Reliability Estimation System (TeTRES), which had been applied to estimate the TTR and traffic-flow measures of the 48 directional corridors in the metro freeway network from January 2016 to September 2020. In the current study, the metro-freeway network was reconfigured to have a total of 74 directional corridors, whose TTR and traffic-flow measures were continuously estimated until December 2023. The results from the individual-route analysis were used to determine the network-wide trends for the TTR and traffic-flow measures before and after April 2020, when the COVID-19 traffic-restriction started. The trends analysis showed that, after the sudden reduction in traffic flows in April 2020, the traffic flows in the metro freeway network have been slowly but continuously increasing; however, as of December 2023, they had not reached the pre-pandemic level. As a result, the network-wide TTR measures after April 2020 showed continuously better reliability conditions than those of the pre-pandemic period in both morning and afternoon networks. Furthermore, the yearly level of route vulnerability, i.e., the overall reliability condition of each route combining the buffer and planning indices, was also determined, and the most vulnerable routes were identified for each year from 2018 until 2023. In addition, the effects of the route-wide geometric configuration, quantified with the geometric-friction index (G), on the TTR and traffic-flow measures of each route were also analyzed by examining the G-TTR/traffic-flow measure relationships, which exhibited the expected patterns, i.e., the routes with low geometric friction handled higher traffic flows with less fluctuations in travel times than those with high friction.

This study also enhanced the preliminary resilience model, developed in the previous phase, by adopting the route-wide space-mean speed as the measure of the system performance. The resulting enhanced model showed significantly better performance than those from the preliminary model in terms of the consistency in the daily estimates of the corridor-wide operational resilience (CORI) for the sample routes. Furthermore, the CORI-geometric friction index (G) relationships for the sample routes show clear patterns with strong correlations for both dry and rainy periods. The enhanced model was applied to estimate the CORI of 74 directional corridors and a group of the directional routes exhibiting consistently low-level of resilience were identified for both morning and afternoon-peak periods. The CORI-G relationships of the metro corridors indicated that the routes with efficient geometric structure in terms of handling through traffic showed strong resilience compared with those routes with high levels of geometric friction. Finally, the analysis of the relationships between CORI and the TTR/traffic-flow measures at directional corridors indicated that the routes with strong resilience also showed better productivity and reliability, e.g., higher VMT/mile with less variability in travel times, than those routes with low levels of resilience.

The results from this research could provide the basis for geometric and operational improvements of the metro freeway corridors. Future research needs include the continuous assessment of the TTR/traffic-flow measures for the metro freeway network, the enhancement of the geometry-friction model by incorporating the connectivity and accessibility of a given route to adjacent corridors, and the study on the potential effects of heavy-vehicle flows on the corridor-wide operational resilience in the metro freeway network.

Chapter 1: Introduction

1.1 Background and Research Objectives

A key element in developing and maintaining a reliable and resilient freeway network is the capability to monitor and assess the travel-time reliability and resilience at individual corridor levels under various operating conditions. The previous phases of this research developed and enhanced the Travel-Time Reliability Estimation System (TeTRES), which has been applied to estimate and analyze the trends of the travel-time reliability and traffic-flow measures of the 48 directional corridors in the metro freeway network under different operating conditions from January 2016 to September 2020 [1, 2]. Furthermore, a preliminary model was developed to estimate the corridor-wide operational-resilience index (CORI), designed to quantify the inherent capability of a given corridor system in resisting and recovering from congestion. The prototype CORI model was tested with the sample data collected from 6 directional corridors in the metro area under dry weather conditions.

This study continuously assesses the reliability trends of the metro freeway network with TeTRES. Specifically, the travel-time reliability (TTR) measures of the individual freeway corridors are estimated until December 2023 and their historical trends under various operating conditions are analyzed. Furthermore, the prototype resilience model, developed from the previous phase, is enhanced to reflect different weather conditions with an expanded data set, and applied to determine the operational resilience of the individual corridors in the metro network. The specific objectives of this study include:

- Collection and processing of historical traffic and non-traffic data, required for travel-time reliability estimation, from multiple sources until December 2023, and population of the TeTRES database with the updated dataset.
- Estimation of monthly and yearly TTR measures for the individual corridors in the metro freeway network under various operating conditions from January 2018 to December 2023.
- Enhancement of the preliminary resilience model and estimation of the operational resilience of the individual corridors in the metro freeway network.
- Assessment of the effects of operational resilience on traffic-flow performance at individual corridors.

1.2 Report Organization

Chapter 2 describes the process to collect the historical traffic and non-traffic data and to populate the TeTRES database, where the travel times of a new set of directional freeway corridors are calculated, stored and linked to various operating conditions until December 2023. In Chapter 3, the updated TeTRES database is applied to estimate the travel-time reliability and traffic-flow measures for the individual freeway corridors in the metro network. Chapter 4 enhances the preliminary model to quantify the operational resilience of individual directional corridors. Using the enhanced resilience model, the operational resilience of individual directional corridors are estimated and assessed in Chapter 5. The effects of the operational resilience on the traffic-flow performance at individual corridors are also analyzed in Chapter 5. Finally, Chapter 6 summarizes conclusions, the benefits of the current study, potential implementation steps and future study needs.

Chapter 2: DATA COLLECTION AND POPULATION OF TeTRES DATABASE FOR FREEWAY CORRIDORS

2.1 Introduction

This chapter summarizes the types of data collected and processed in this study to continuously estimate and assess the travel-time reliability and traffic-flow measures for the freeway corridors in the metro network. The following list shows the types and time periods of the data collected and processed in the previous phase of this study [2]:

- Special- event data, including for both sport and non-sport events, from the venues located in the Twin Cities' metro area (1/2012-3/2020)
- Construction project location and time-period data on the metro freeways (4/2012 – 9/2020)
- Winter road-surface condition data for the metro freeways (10/2012 – 4/2019)
- Incident data from CAD, Computer-Aided-Dispatch system, Department of Public Safety, and IRIS, Intelligent Roadway Information System, MnDOT (1/2010 – 9/30/2020)
- Weather data from NOAA, *National Oceanic and Atmospheric Administration (NOAA:* 1/2010 – 9/30/2020)
- Traffic-detector data from the metro freeways (stored separately in a local hard disk): (1/2010 – 9/2020).

In the current study, the same types of data in the above list were collected for the period from the end of the previous phase until December 2023. It can be noted that the traffic-detector data, necessary for calculating route-travel times, are separately stored in a local hard disk in a structured format, while all other types of non-traffic data are processed separately and stored in the TeTRES database (T-database) following the schema and table formats developed in the previous study [1]. Further, the weather data from NOAA has been automatically downloaded and stored in the T-database by the weather-data processing module in TeTRES, while all other types of non-traffic data are manually processed to a set of the Excel-formatted files, which are then batch-processed to populate the T-database using a set of the scripts specifically developed for each data type. In particular, the data for the non-sport events, e.g., concerts, were collected manually from the publicly available websites of each concert.

The rest of this chapter describes the main features of each type of data collected and processed in this study. The updated T-database populated with all the new data collected in this study is applied to estimate the travel-time reliability and traffic-flow measures of the metro freeway corridors in the next chapter.

2.2 Collection and Processing of Special Event Data

First, the data for the Twin Cities' metro-area special events, whose attendance can affect the traffic conditions on the nearby freeways, are collected manually using the publicly available data sources for the period of March 2020 until December 2023. Specifically, the data for both sport and non-sport events, such as music concerts, were collected from the relevant websites for each event. The collected data for each event includes event name, date/start/end times, attendance, and coordinates of an event location. The following list shows the names of the special event locations, and the sources of the sport-event data collected for each location:

- U.S. Bank Stadium:

  Main Events: National Football League Games

  Data Sources: https://www.pro-football-reference.com/boxscores/

  https://www.espn.com/nfl/team/schedule/_/name/min/

- Target Center:

  Main Events: National Basketball Association Games

  Data Sources: https://www.basketball-reference.com/teams/MIN/

- Target Field:

  Main Events: Major League Baseball Games

  Data Sources: https://www.baseball-reference.com/teams/MIN/

  https://www.espn.com/mlb/team/schedule/_/name/min/

- Huntington Bank Stadium:

  Main Events: College Football Games

  Data Sources: https://www.espn.com/nfl/team/schedule/_/name/min/

  https://gophersports.com/sports/football/schedule/2022?path=football

- Xcel Energy Center:

  Event: National Hockey League Games

  Data Sources: https://www.hockey-reference.com/leagues/

  https://www.nhl.com/gamecenter/

  https://www.espn.com/nhl/team/schedule/_/name/min/season/2019

  Event: Minnesota State Highschool League Hockey Games

Data Source: https://www.mshsl.org/tournaments/state-tournament-archives/state-tournament-archive-boys-hockey-2022

For the non-sport event data, e.g., music concerts, due to the lack of relevant data from the agencies managing those venues, the data for each event needed to be searched and collected manually from publicly available websites. For example, the following websites were identified by searching the internet and used to collect the attendance data for two concert events at Target Center, i.e., 'Mercury Tour' and 'Metallica-Worldwired Tour':

https://en.wikipedia.org/wiki/Mercury_World_Tour

https://touringdata.wordpress.com/2019/07/18/metallica-worldwired-tour/

Figure 2.2.1 shows a portion of the Special-Event data collected and organized in an Excel format for the 2020-2022 events at the Huntington Bank Stadium in this task. A portion of the non-sport event data from the Target Center is also shown in Figure 2.2.2.

The special-event data collected and organized in an Excel format are then uploaded to the T-database using the script specifically designed to populate the T-database with the special-event data. Figures 2.2.3 and 2.2.4 show the screenshot of the script and a portion of the T-database populated with the special-event data collected in this study. The resulting T-database contains the sport-event data in the Twin Cities' metro area for the period of 1/2012 – 12/2023, while the non-sport event data ranges from 2016 to 2023.

DATE	START	END	TITLE	TYPE	ATTEND	LAT	LON
2020-10-24	18:30:00	22:11:00	MN Gophers vs Michigan	Football	589	44.9765288	-93.2267402
2020-11-13	18:05:00	21:20:00	MN Gophers vs Iowa	Football	771	44.9765288	-93.2267402
2020-11-20	18:32:00	21:56:00	MN Gophers vs Purdue	Football	593	44.9765288	-93.2267402
2021-09-02	19:05:00	22:35:00	MN Gophers vs Ohio State	Football	50805	44.9765288	-93.2267402
2021-09-11	11:05:00	14:28:00	MN Gophers vs Miami (Ohio)	Football	43372	44.9765288	-93.2267402
2021-09-25	11:07:00	14:24:00	MN Gophers vs Bowling Green	Football	46236	44.9765288	-93.2267402
2021-10-16	11:01:00	14:28:00	MN Gophers vs Nebraska	Football	45436	44.9765288	-93.2267402
2021-10-23	14:35:00	17:47:00	MN Gophers vs Maryland	Football	41011	44.9765288	-93.2267402
2021-11-06	11:01:00	14:13:00	MN Gophers vs Illinois	Football	46382	44.9765288	-93.2267402
2021-11-27	15:10:00	18:41:00	MN Gophers vs Wisconsin	Football	49736	44.9765288	-93.2267402
2022-09-01	20:05:00	23:08:00	MN Gophers vs New Mexico State	Football	44012	44.9765288	-93.2267402
2022-09-10	11:01:00	14:25:00	MN Gophers vs Western illinois	Football	43859	44.9765288	-93.2267402
2022-09-17	14:35:00	17:55:00	MN Gophers vs Colorado	Football	42101	44.9765288	-93.2267402
2022-10-01	11:01:00	14:22:00	MN Gophers vs Purdue	Football	48288	44.9765288	-93.2267402

Figure 2.2.1 A Sample Organized Data Set for the Special Events at Huntington Bank Stadium

DATE	START	END	TITLE	TYPE	ATTEND	LAT	LON
2022-12-05	21:15:00	22:35:00	Five Finger Death Punch at Target Center	Concert	13110	44.98	-93.28
2022-12-05	19:30:00	20:40:00	Brantley Gilbert at Target Center	Concert	13110	44.98	-93.28
2022-12-05	18:30:00	19:00:00	Cory Marks at Target Center	Concert	13110	44.98	-93.28
2022-11-13	19:30:00	23:20:00	Dave Matthews Band	Concert	9821	44.98	-93.28
2022-11-11	20:00:00	22:45:00	Rod Wave Beautiful Mind Tour	Concert	13110	44.98	-93.28
2022-10-25	19:30:00	22:40:00	Denim & Rhinestones Tour	Concert	13110	44.98	-93.28
2022-10-07	20:00:00	23:00:00	Bill Burr	Concert	13110	44.98	-93.28
2022-09-22	20:00:00	22:30:00	Ben Platt	Concert	13110	44.98	-93.28
2022-08-26	19:00:00	23:00:00	Kevin Hart	Concert	13110	44.98	-93.28
2022-07-30	20:00:00	23:05:00	Roger Waters - This is not a Drill	Concert	10913	44.98	-93.28
2022-06-24	20:00:00	23:00:00	keith sweat	Concert	13110	44.98	-93.28
2022-06-13	19:00:00	21:00:00	Chris Tomlin and Hillsong United at Target Center	Concert	13110	44.98	-93.28
2022-05-07	17:45:00	23:05:00	Twin city Takeover	Concert	13110	44.98	-93.28
2022-05-06	19:15:00	22:30:00	Justin Bieber, Jaden and Eddie Benjamin	Concert	13192	44.98	-93.28
2022-04-25	19:00:00	22:35:00	MercyMe and Rend Collective	Concert	13110	44.98	-93.28
2022-04-09	18:30:00	23:00:00	Slipknot at Target Center	Concert	13110	44.98	-93.28
2022-03-26	18:30:00	23:00:00	Korn, Chevelle and Code Orange	Concert	13110	44.98	-93.28
2022-03-20	15:00:00	18:00:00	Harlem Globetrotters	Event	13110	44.98	-93.28
2022-03-15	19:30:00	23:00:00	Happier Than Ever The World Tour	Concert	14924	44.98	-93.28
2022-03-13	19:30:00	23:00:00	Tool ,The Acid Helps	Concert	13110	44.98	-93.28
2022-03-12	19:00:00	23:00:00	Hits Deep Tour	Concert	13110	44.98	-93.28
2022-03-08	19:30:00	23:00:00	Dua Lipa Tour	Concert	11987	44.98	-93.28
2022-02-27	19:00:00	23:00:00	Mercury Tour	Concert	12587	44.98	-93.28
2022-02-26	19:00:00	23:00:00	Chris Tomlin Hillsong United at Target Center	Concert	13110	44.98	-93.28
2022-02-20	19:00:00	23:00:00	Call Me If You Get Lost Tour	Concert	9691	44.98	-93.28
2022-02-05	19:00:00	23:00:00	Volbeat, Ghost andTwin Temple	Concert	13110	44.98	-93.28

Figure 2.2.2 A Sample Organized Dataset for the Non-Sport Events at Target Center

populate_special_event_data - Notepad

File Edit Format View Help

```
import sys
sys.path.append("Server/src")
from tetres_data_populator.special_event_data.special_event_excel_reader import SpecialEventExcelReader
from tetres_data_populator.special_event_data.special_event_api_writer import SpecialEventAPIWriter

base_url = "http://localhost:5000"
special_event_add_route = "/tetres/adm/sevent/add"
special_event_list_route = "/tetres/adm/sevent/list"
only_file_name = input("Enter filename: ")
special_event_filename = "Server/src/tetres_data_populator/excel_data/special_event_data/{}".format(only_file_name)

# special_event_data = {
#     "name": "Cricket Match",
#     "description": "Biggest Cricket match in history",
#     "start_time": "2018-04-01 00:00:00",
#     "end_time": "2020-04-30 00:00:00",
#     "lat": 44.98422783516651,
#     "lon": -93.25538635253906,
#     "attendance": 5000,
#     "__module__": "pyticas_tetres.ttypes",
#     "__class__": "SpecialEventInfo"
# }


if __name__ == "__main__":
    special_event_excel_reader = SpecialEventExcelReader(filename=special_event_filename)
    special_event_api_writer = SpecialEventAPIWriter(base_url=base_url, add_url=special_event_add_route,
                                                     list_url=special_event_list_route)
    special_event_api_writer.post_special_event_data(special_event_excel_reader)
```

Figure 2.2.3 A Screenshot of the Script for Populating T-database with the Special-Event Data

public.specialevent/tetres/postgres@demo

100 rows

Query | Query History | Scratch Pad

```sql
SELECT * FROM public.specialevent
ORDER BY id DESC LIMIT 100
```

Data output | Messages | Notifications

	id [PK] integer	name character varying (100)	description text	years character varying (255)	start_time timestamp without time zone	end_time timestamp without time zone	lat double precision	lon double precision	attendance integer	reg_date timestamp without time zone
1	5640	Minnesota Wild vs St. ...	Hockey	2022	2022-05-10 21:30:00	2022-05-10 23:59:00	44.9448353	-93.103291	19197	2022-10-10 11:41:17.073083
2	5639	Minnesota Wild vs St. ...	Hockey	2022	2022-05-04 21:30:00	2022-05-04 23:59:00	44.9448353	-93.103291	19376	2022-10-10 11:41:15.010725
3	5638	Minnesota Wild vs St. ...	Hockey	2022	2022-05-02 21:30:00	2022-05-02 23:59:00	44.9448353	-93.103291	19053	2022-10-10 11:41:12.963961
4	5637	Minnesota Wild vs Col...	Hockey	2022	2022-04-29 20:00:00	2022-04-29 22:30:00	44.9448353	-93.103291	19261	2022-10-10 11:41:10.917259
5	5636	Minnesota Wild vs Cal...	Hockey	2022	2022-04-28 20:00:00	2022-04-28 22:25:00	44.9448353	-93.103291	18490	2022-10-10 11:41:08.854902
6	5635	Minnesota Wild vs Ariz...	Hockey	2022	2022-04-26 20:00:00	2022-04-26 22:30:00	44.9448353	-93.103291	18383	2022-10-10 11:41:06.792544
7	5634	Minneosta Wild vs Sea...	Hockey	2022	2022-04-22 20:00:00	2022-04-22 22:30:00	44.9448353	-93.103291	19047	2022-10-10 11:41:04.745811
8	5633	Minnesota Wild vs Van...	Hockey	2022	2022-04-21 20:00:00	2022-04-21 22:30:00	44.9448353	-93.103291	17894	2022-10-10 11:41:02.683454
9	5632	Minnesota Wild vs San...	Hockey	2022	2022-04-17 18:00:00	2022-04-17 20:30:00	44.9448353	-93.103291	19029	2022-10-10 11:41:00.621097
10	5631	Minnesota Wild vs Ed...	Hockey	2022	2022-04-12 20:00:00	2022-04-12 22:30:00	44.9448353	-93.103291	19035	2022-10-10 11:40:58.558739
11	5630	Minnesota Wild vs Los ...	Hockey	2022	2022-04-10 17:00:00	2022-04-10 19:30:00	44.9448353	-93.103291	19104	2022-10-10 11:40:56.44951
12	5629	Minnesota Wild vs Pitt...	Hockey	2022	2022-03-31 20:00:00	2022-03-31 22:40:00	44.9448353	-93.103291	18978	2022-10-10 11:40:54.387152
13	5628	Minneosta Wild vs Phil...	Hockey	2022	2022-03-29 20:00:00	2022-03-29 22:25:00	44.9448353	-93.103291	17874	2022-10-10 11:40:52.324795
14	5627	Minnesota Wild vs Col...	Hockey	2022	2022-03-27 18:00:00	2022-03-27 20:40:00	44.9448353	-93.103291	19140	2022-10-10 11:40:50.278062
15	5626	Minnesota Wild vs Col...	Hockey	2022	2022-03-26 20:00:00	2022-03-26 22:40:00	44.9448353	-93.103291	19089	2022-10-10 11:40:48.231329
16	5625	Minnesota Wild vs Van...	Hockey	2022	2022-03-24 20:00:00	2022-03-24 22:40:00	44.9448353	-93.103291	17333	2022-10-10 11:40:45.76275
17	5624	Minnesota Wild vs Veg...	Hockey	2022	2022-03-21 20:00:00	2022-03-21 22:20:00	44.9448353	-93.103291	17498	2022-10-10 11:40:43.73164
18	5623	Minnesota Wild vs Chi...	Hockey	2022	2022-03-19 14:00:00	2022-03-19 16:30:00	44.9448353	-93.103291	19226	2022-10-10 11:40:41.684907
19	5622	Minnesota Wild vs Bos...	Hockey	2022	2022-03-16 19:30:00	2022-03-16 22:10:00	44.9448353	-93.103291	17956	2022-10-10 11:40:39.622549
20	5621	Minnesota Wild vs Nas...	Hockey	2022	2022-03-13 19:00:00	2022-03-13 21:30:00	44.9448353	-93.103291	19009	2022-10-10 11:40:37.560192
21	5620	Minneosta Wild vs Ne...	Hockey	2022	2022-03-08 20:00:00	2022-03-08 22:20:00	44.9448353	-93.103291	18356	2022-10-10 11:40:35.497834
22	5619	Minnesota Wild vs Dall...	Hockey	2022	2022-03-06 16:00:00	2022-03-06 18:40:00	44.9448353	-93.103291	18791	2022-10-10 11:40:33.435478
23	5618	Minnesota Wild vs Cal...	Hockey	2022	2022-03-01 20:00:00	2022-03-01 22:30:00	44.9448353	-93.103291	16998	2022-10-10 11:40:31.373121
24	5617	Minnesota Wild vs Flor...	Hockey	2022	2022-02-18 20:00:00	2022-02-18 22:30:00	44.9448353	-93.103291	18300	2022-10-10 11:40:29.310763
25	5616	Minnesota Wild vs Detr...	Hockey	2022	2022-02-14 20:00:00	2022-02-14 22:40:00	44.9448353	-93.103291	18098	2022-10-10 11:40:27.248405
26	5615	Minnesota Wild vs Car...	Hockey	2022	2022-02-12 20:00:00	2022-02-12 22:30:00	44.9448353	-93.103291	18802	2022-10-10 11:40:25.076681

Figure 2.2.4 A Screenshot of the T-database Showing a Portion of Populated Special-Event Data

2.3 Collection and Processing of Work-Zone Data

Figures 2.3.1 and 2.3.2 show the construction-project maps and a sample portion of the detailed information for each project, provided by the Metro District, MnDOT, for the 2020-2023 period in the metro freeway network. In this study, the raw work-zone data up to December 2023 are manually processed and organized into an Excel-formatted file, which is then used by the work-zone data script written for populating the T-database. Figure 2.3.3 shows a sample screenshot of the Excel-formatted, work-zone data file processed in this study. The entire set of the Excel-formatted work-zone data file processed in this task is attached in Appendix. The snippets of the script used for populating the T-database are included in Figure 2.3.4. Finally, Figure 2.3.5 shows a portion of the T-database containing the work-zone data processed in this task. The updated T-database stores all the work-zone data in the metro freeways from 4/2012 to 12/2023.

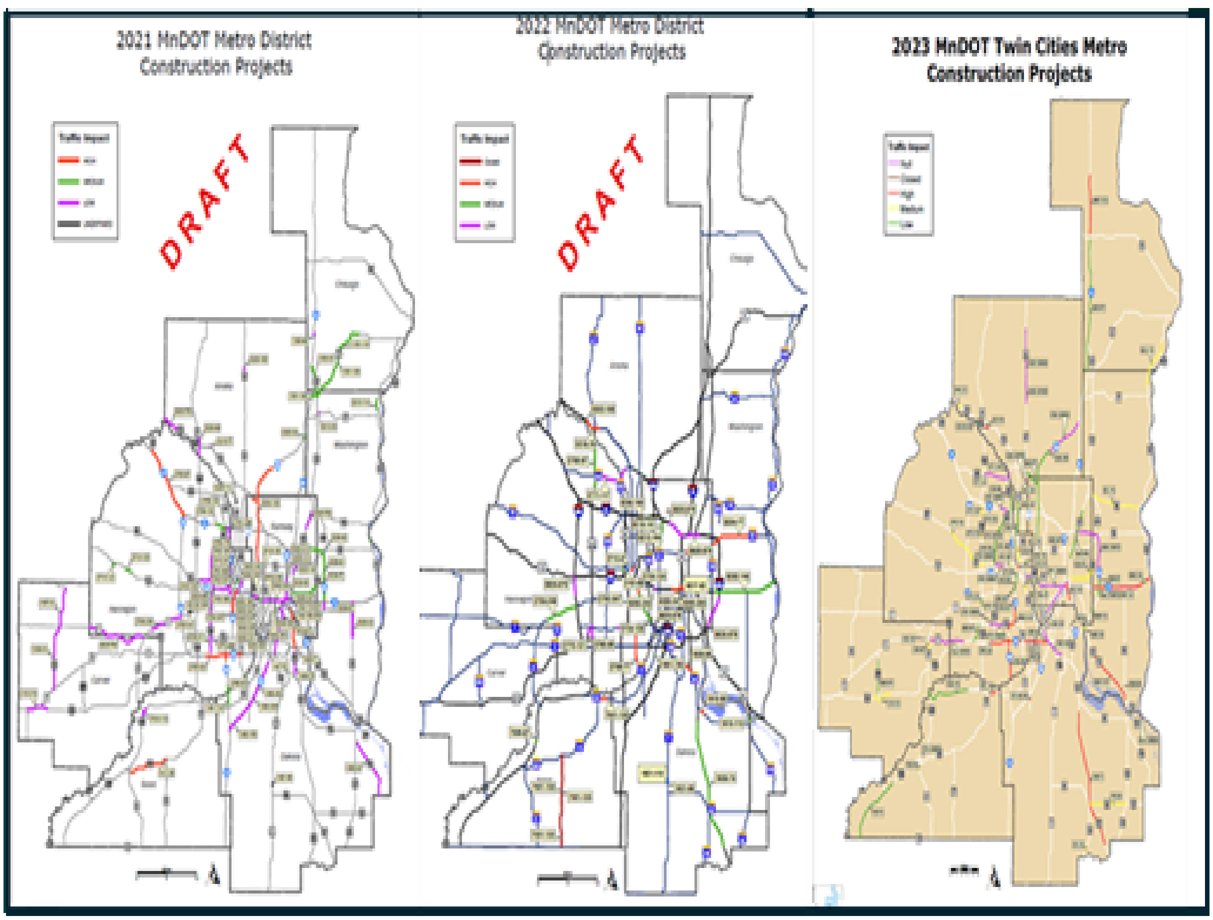

Figure 2.3.1 Construction-Project Maps in the Metro Freeway Network (Source: Metro District, MnDOT)

OBJECTID	SP_NBR	CONSTRUCTION_RESIDENT_ENGINEER	PROJROADS	PROJECT_ID	PROJECT_VERSION	PUBLIC_PROJECT_DESCRIPTION	TECHNICAL_PROJECT_DESC	PROGRAM_CODE	PRIM
51	0202-108	Penn, Dan	US10	1033451	10	Reconstruct interchange at Main St, c	**PRS**TED**US 10 169 FROM ANOK/	AM-Agreements Municipal	TRAFFIC CON
100	0215-76	Penn, Dan	US10	1032428	10	Replace 4 bridges and rehabilitate 2 t	**CHAP 3**US10, FROM 0.25 MI EAST	MC-Major Construction	BRPC - BRID(
309	1901-192	Asche, Greg	MN13	1069183	5	Repair/replace drainage infrastructur	MN13, AT CSAH 26 (LONE OAK RD) IN	DR-Drainage	DRAINAGE, TI
320	1906-74	Asche, Greg	US52	1078443	7	Add crossovers and temporary shoulc	US52, FROM CR86 HAMPTON TO CSAI	RS-Resurfacing	PAVEMENT RI
331	1909-99	Asche, Greg	MN55	1038362	12	Resurface, drainage, ADA, rehab bric	MN55 & MN62, FROM E END BRIDGE (	RC-Reconstruction	, BRRH - BRID
336	1910-56	Asche, Greg	MN55	1070023	4	Repair drainage Hwy 55 at Doyle Patl	**ELLE**MN55, AT DOYLE PATH IN RC	DR-Drainage	DRAINAGE, TI
347	1913-110	Asche, Greg	US61	1095803	2	TH 61 Hastings Bridge #19004 Weari	TH 61 HASTINGS BR #19004 WEARINC	BI-Bridge Improvement and Repair	
367	1921-110	Asche, Greg		1070263	3	Construct trail along west side of Hwy	ALONG WEST SIDE MN3 FROM WILLC	LP-Local Partnership Program	BRRH - BRID(
371	1921-90	Asche, Greg	MN3	1069243	4	Repair drainage, trail (east side), recc	MN3 FROM 0.1 MI N OF BRIDGE 19094	DR-Drainage	DRAINAGE, TI
429	2706-239	Benjamin, Elizabeth	MN7	1032243	12	Bituminous mill and overlay, micro sur	MN 7, FROM 0.07 MI W OF CHRISTMA:	RS-Resurfacing	PAVEMENT RI
436	2710-47	Barrett, Steven	MN65	1030651	10	Rehabilitate bridge on Hwy 65 at 3rd /	**AC**CHAP 3**CMGC** MN 65, AT BR	BI-Bridge Improvement and Repair	BRRH - BRID(
465	2724-124	Nelson, Tim	MN55	1032164	9	Redeck of bridges, pavement repair, r	MN55, FROM E OF 13TH AVE TO N OF	BI-Bridge Improvement and Repair	BRRH - BRID(
466	2724-126	Nelson, Tim	MN55	1032240	6	Resurface, repair sidewalk, pedestria	MN55 FROM 0.04 MI N OF 32ND ST TO	RS-Resurfacing	PAVEMENT RI
509	2750-97	Penn, Dan	US169	1048143	4	Install approximately 5.6 miles of cabl	US 169 FROM 85TH ST IN BROOKLYN I	SH-Safety Improvements	APPURTENAN
511	2751-58	Nelson, Tim	MN55	1071383	5	Remove remainder of bridge tunnel, (	**ELLE**MN55, BASSETT CREEK TUNI	BR-Bridge Replacement	BRPC - BRID(
519	2758-77	Asche, Greg	MN77	1024759	8	Resurface, extend right turn lane on H	MN 77, FROM N END OF MN RIVER BR	RS-Resurfacing	PAVEMENT RI
527	2763-59	Benjamin, Elizabeth	US212	1032429	7	Replace lighting on US Hwy 212 at Sl	**CHAP 3**US 212 AT SHADY OAK RO.	SC-Safety Improvements	APPURTENAN
531	2770-05	Nelson, Tim		1069883	5	Rehab bridge piers on bridges 27816	US952A OVER MULTIPLE ROADWAYS	BI-Bridge Improvement and Repair	BRRH - BRID(
536	2771-117	Penn, Dan	MN610	1079403	8	Construct traffic management system	MN610, FROM US169 IN BROOKLYN P/	TM-Traffic Management	INTELLIGENT
546	2772-121	Benjamin, Elizabeth	US169	1024765	7	Construct noise wall on NB Hwy 169 f	**CHAP 3**US 169, NB US169 FROM V.	NO-Noise Walls	APPURTENAN
613	2782-327	Barrett, Steven	I35W	1024940	8	Construct MnPASS lane; reconstruct	I35W, FROM 43RD ST TO 11TH AVE, W	MC-Major Construction	PAVEMENT RI
616	2782-347	Barrett, Steven	I35W	1026980	15	Construct stormwater holding cavern :	**AC**CMGC**PODI** I35W NB, AT 42I	DR-Drainage	DRAINAGE
637	2783-176	Barrett, Steven	I35W	1025025	6	Landscape on I35W under 5th St ped	I35W, UNDER PED BRIDGE #27987 AT	RB-Rest Area/Beautification	APPURTENAN
688	6212-194	Embacher, Eric	MN36	1077604	5	Replace signal on Hwy 36 at Hamline	MN36, AT HAMLINE AVE N IN ROSEVIL	SC-Safety Improvements	TRAFFIC CON
701	6216-141	Embacher, Eric	MN51	1049240	8	Install approximately 2.7 miles of cabl	MN 51 FROM CR C IN ROSEVILLE TO I	SH-Safety Improvements	APPURTENAN
710	6217-52	Asche, Greg		1069263	5	Repair 2 bridges on Hwy 3 at George	MN 3, AT GEORGE ST AND AT THE UN	BI-Bridge Improvement and Repair	BRRH - BRID(
779	6282-242	Embacher, Eric	I94	1068803	4	Landscape I94 east bound from Prior	I94 EB, FROM PRIOR AVE TO FAIRVIE	RB-Rest Area/Beautification	APPURTENAN
797	6283-247	Embacher, Eric	I35E, I94	1032009	10	Repair road and bridges on I-94 from	**ELLE**I94, FROM 0.2 MI W OF WES	RC-Reconstruction	BRRH - BRID(
799	6283-255	Embacher, Eric	I35E, I94	1068883	10	Resurface frontage roads and ramps,	I94, FROM WESTERN TO US 52 AND C	RS-Resurfacing	PAVEMENT RI
[illegible]	[illegible]	Nelson, Tim	I694	[illegible]	11	Replace signal on I-694 at Silver Lak	I694 AND SILVER LAKE RD N AND S R	SC-Safety Improvements	TRAFFIC CON

Figure 2.3.2 A Sample Screenshot of the Detailed Information for the Metro Construction Projects

(Source: Metro District, MnDOT)

Rote ID #	Memo	Start	End	Start Station	End Station
SP# 0215-76	No Lane Config Available	03/07/2022	11/01/2023	S940	S943
SP# 1906-74	No Lane Config Available	05/01/2022	11/01/2022	S5211	S5201
SP# 1909-99	No Lane Config Available	04/01/2022	10/31/2022	S5215	S1166
SP# 1913-110	No Lane Config Available	06/01/2022	10/01/2022	S1594	S2015
SP# 2750-97	No Lane Config Available	09/12/2022	10/15/2022	S1802	S2043
SP# 2758-77	No Lane Config Available	06/01/2023	11/30/2023	S522	S531
SP# 2763-59	No Lane Config Available	04/12/2022	08/12/2022	S361	S359
SP# 2771-117	No Lane Config Available	05/01/2022	07/15/2022	S2045	S1006
SP# 2772-121	No Lane Config Available	05/16/2022	11/04/2022	S427	S430
SP# 2782-347	No Lane Config Available	12/01/2019	08/01/2023	S77	S57
SP# 2783-176	No Lane Config Available	09/15/2020	07/01/2023	S583	S582
SP# 6212-194	No Lane Config Available	09/01/2022	11/01/2022	S591	S593
SP# 6217-52	No Lane Config Available	05/15/2022	08/15/2022	S791	S1069
SP# 6282-242	No Lane Config Available	04/01/2022	07/01/2022	S1809	S1808
SP# 6283-247	No Lane Config Available	07/01/2021	11/01/2022	S644	S642
SP# 6283-255	No Lane Config Available	04/18/2022	07/30/2022	S789	S97
SP# 6285-160	No Lane Config Available	04/01/2022	06/30/2022	S172	S151
SP# 8204-77	No Lane Config Available	04/25/2022	09/16/2022	S1829	S1852
SP# 8282-145	No Lane Config Available	08/01/2022	11/01/2022	S1064	S1359
SP# 8825-879	No Lane Config Available	05/01/2021	06/30/2022	S1457	S1423
SP# 0215-76	No Lane Config Available	03/07/2022	06/15/2024	S940	S942
SP# 157-108-035	No Lane Config Available	08/01/2021	06/30/2023	S922	S921
SP# 1906-71	No Lane Config Available	05/01/2023	11/01/2024	S5201	S5211
SP# 1928-90	No Lane Config Available	09/01/2023	11/01/2023	S1171	S1173
SP# 2735-202	No Lane Config Available	04/01/2023	05/31/2023	S393	S1614
SP# 2748-68	No Lane Config Available	07/01/2023	11/01/2023	S238	S2049
SP# 2772-115	No Lane Config Available	04/01/2023	11/01/2023	S767	S762

Figure 2.3.3 An Example Screenshot of the Excel-formatted Work-Zone Data File

populate_work_zone_data - Notepad

File Edit Format View Help

```
import sys

sys.path.append("Server/src")
import global_settings
from pyticas import ticas
from pyticas.infra import Infra
from pyticas_tetres import api_urls_admin

from tetres_data_populator.work_zone_data.work_zone_api_reader import WorkZoneAPIReader
from tetres_data_populator.work_zone_data.work_zone_api_writer import WorkZoneAPIWriter
from tetres_data_populator.work_zone_data.work_zone_excel_reader import WorkZoneExcelReader

if __name__ == "__main__":
    ticas.initialize(global_settings.DATA_PATH)
    infra = Infra.get_infra()

    base_url = "http://localhost:5000"
    only_file_name = input("Enter the name of the snow event excel file: ")
    work_zone_filename = "Server/src/tetres_data_populator/excel_data/work_zone_data/{}".format(only_file_name)
    work_zone_excel_reader = WorkZoneExcelReader(filename=work_zone_filename)

    # adding work zone group data
    work_zone_api_writer = WorkZoneAPIWriter(infra=infra)
    work_zone_api_writer.post_data(excel_reader=work_zone_excel_reader,
                                   post_url=base_url + api_urls_admin.WZ_GROUP_INSERT,
                                   list_url=base_url + api_urls_admin.WZ_GROUP_LIST,
                                   data_type="work_zone_group",
                                   api_reader_class=WorkZoneAPIReader)

    work_zone_api_writer.post_data(excel_reader=work_zone_excel_reader,
                                   post_url=base_url + api_urls_admin.WZ_INSERT,
                                   list_url=base_url + api_urls_admin.WZ_LIST_ALL,
                                   data_type="work_zone",
                                   api_reader_class=WorkZoneAPIReader)

    work_zone_api_writer.populate_work_zone_years(api_reader=WorkZoneAPIReader())
```

Figure 2.3.4 The Snippets of the Script for Processing Work-Zone Data

wz_group_id integer	memo text	start_time timestamp without time zone	end_time timestamp without time zone	route1 text	route2 text	reg_date timestamp without time zone	workzone_length double precision
326	No Lan...	2021-07-01 00:00:00	2023-04-23 23:55:00	{"__class_...	{"__class_...	2022-11-27 17:53:36.159268	2.01862171622635
325	No Lan...	2022-07-01 00:00:00	2023-07-30 23:55:00	{"__class_...	{"__class_...	2022-11-27 17:53:34.102632	2.7869492813839
324	No Lan...	2021-08-15 00:00:00	2023-11-01 23:55:00	{"__class_...	{"__class_...	2022-11-27 17:53:32.030979	1.34906695257318
323	No Lan...	2023-07-01 00:00:00	2024-06-30 23:55:00	{"__class_...	{"__class_...	2022-11-27 17:53:29.974882	5.85123258556678
322	No Lan...	2023-05-15 00:00:00	2023-09-30 23:55:00	{"__class_...	{"__class_...	2022-11-27 17:53:27.85414	1.67575790818557
321	No Lan...	2023-07-01 00:00:00	2023-11-15 23:55:00	{"__class_...	{"__class_...	2022-11-27 17:53:25.59036	0.949495823818629
320	No Lan...	2023-08-15 00:00:00	2023-11-01 23:55:00	{"__class_...	{"__class_...	2022-11-27 17:53:23.409651	0.887851714596173
319	No Lan...	2023-04-01 00:00:00	2024-11-01 23:55:00	{"__class_...	{"__class_...	2022-11-27 17:53:21.301621	9.04663658694889
318	No Lan...	2023-07-01 00:00:00	2024-06-30 23:55:00	{"__class_...	{"__class_...	2022-11-27 17:53:19.192197	4.02188548798134
317	No Lan...	2023-08-15 00:00:00	2024-06-15 23:55:00	{"__class_...	{"__class_...	2022-11-27 17:53:17.109924	10.367899915307
316	No Lan...	2023-07-01 00:00:00	2024-06-30 23:55:00	{"__class_...	{"__class_...	2022-11-27 17:53:14.974924	4.75948225806303
315	No Lan...	2023-09-01 00:00:00	2023-11-01 23:55:00	{"__class_...	{"__class_...	2022-11-27 17:53:12.888866	0.763582436748481
314	No Lan...	2022-04-15 00:00:00	2023-11-01 23:55:00	{"__class_...	{"__class_...	2022-11-27 17:53:10.830009	1.40698564906313
313	No Lan...	2023-04-15 00:00:00	2023-07-15 23:55:00	{"__class_...	{"__class_...	2022-11-27 17:53:08.76575	0.840511163152236
312	No Lan...	2023-04-01 00:00:00	2024-11-01 23:55:00	{"__class_...	{"__class_...	2022-11-27 17:53:06.692411	3.11454715143925
311	No Lan...	2023-11-15 00:00:00	2026-11-15 23:55:00	{"__class_...	{"__class_...	2022-11-27 17:53:04.624239	5.6730279726431

Figure 2.3.5 A Screenshot of the T-database Showing a Portion of the Work-Zone Data

2.4 Collection and Processing of Winter Road-Condition Data

Figure 2.4.1 shows a portion of the metro-area snow-event data, for the period of April 2019 – April 2022, provided by the MnDOT Metro District, which has also provided with the location of each snow-plow route in terms of cross–street information.

First, for each snow-plow route, the detector-station IDs at both starting/ending points were determined by examining the cross-street information and the detector-station map in TICAS, Traffic Information-Condition Analysis System [3]. Figure 2.4.2 includes a portion of the metro-freeway snow-plow route data file with the detector-station IDs at start/end locations. Next, the specific snow-event data, provided by the MnDOT Metro District, for each of the snow-plow routes on the metro freeways were converted into the Excel-formatted, snow-event data file, whose pre-defined data structure includes date/time, route ID and bare-lane lost/regain times for each event. Figure 2.4.3 includes a portion of the Excel-formatted, 2018-2019 snow-event data file for the metro-freeway snow-plow routes processed in this study. The Excel-formatted data file was then used by the snow-event data script, shown in Figure 2.4.4, to populate the T-database. Figure 2.4.5 shows a screenshot of the T-database populated with the snow-event data processed in this study. The updated T-database contains the winter road-condition data for the snow-plow routes on the metro-freeways from 10/2012 until 12/2023.

istrict Na	aintenance Area N	ruck Station Na	Project	Project Maintenance Route	ervice Level Na	ent Begin Date T	ent End Date T	ent Duration H
Metro District	Maintenance Area Metro	Mendota	TP9M4941	MN RIVER - 34TH AVE	SUPER COMMUTER	11/13/21 4:00 PM	11/13/21 6:00 PM	2
Metro District	Maintenance Area Metro	Mendota	TP9M4942	TH494 000+00.000 001+00.622	SUPER COMMUTER	11/13/21 4:00 PM	11/13/21 6:00 PM	2
Metro District	Maintenance Area Metro	Shakopee	TP5P0251	JCT OF US169-S JCT MN20	RURAL COMMUTER	11/13/21 2:30 PM	11/13/21 10:30 PM	8
Metro District	Maintenance Area Metro	Chaska Truck Station	TP5M0071	JCT MN 25-JCT MN41 IN SHOREWOOD	URBAN COMMUTER	11/13/21 2:00 PM	11/13/21 11:00 PM	9
Metro District	Maintenance Area Metro	Chaska Truck Station	TP5M0071	JCT MN 25-JCT MN41 IN SHOREWOOD	URBAN COMMUTER	11/13/21 2:00 PM	11/13/21 11:00 PM	9
Metro District	Maintenance Area Metro	Chaska Truck Station	TP5M0411	JCT US 169-JCT MN22	URBAN COMMUTER	11/13/21 2:00 PM	11/13/21 11:00 PM	9
Metro District	Maintenance Area Metro	Chaska Truck Station	TP5M0411	JCT US 169-JCT MN23	URBAN COMMUTER	11/13/21 2:00 PM	11/13/21 11:00 PM	9
Metro District	Maintenance Area Metro	Chaska Truck Station	TP5M1691	JCT MN 41-PIONEER TRAIL	SUPER COMMUTER	11/13/21 2:00 PM	11/13/21 11:00 PM	9
Metro District	Maintenance Area Metro	Chaska Truck Station	TP5M1691	JCT MN 41-PIONEER TRAIL	SUPER COMMUTER	11/13/21 2:00 PM	11/13/21 11:00 PM	9
Metro District	Maintenance Area Metro	Chaska Truck Station	TP5M2121	W JCT MN 5/25-LYMAN BLVD OVERPASS	URBAN COMMUTER	11/13/21 2:00 PM	11/13/21 11:00 PM	9
Metro District	Maintenance Area Metro	Chaska Truck Station	TP5M2121	W JCT MN 5/25-LYMAN BLVD OVERPASS	URBAN COMMUTER	11/13/21 2:00 PM	11/13/21 11:00 PM	9
Metro District	Maintenance Area Metro	Mendota	TP9M0031	DAKOTA CTY RD 42-JCT MN125	URBAN COMMUTER	11/13/21 3:00 PM	11/13/21 11:00 PM	8
Metro District	Maintenance Area Metro	Mendota	TP9M0131	JCT MN77-ANNAPOLIS ST	URBAN COMMUTER	11/13/21 4:00 PM	11/13/21 11:00 PM	7
Metro District	Maintenance Area Metro	Mendota	TP9M1491	JCT MN3-S JCT MN55	URBAN COMMUTER	11/13/21 3:00 PM	11/13/21 11:00 PM	8
Metro District	Maintenance Area Metro	Mendota	TP9M1491	JCT MN3-S JCT MN55	URBAN COMMUTER	11/13/21 3:00 PM	11/13/21 11:00 PM	8
Metro District	Maintenance Area Metro	Plymouth	TP5C0551	MOHAWK DR-I94	SUPER COMMUTER		11/13/21 11:00 PM	0
Metro District	Maintenance Area Metro	Plymouth	TP5C3941	JCT I494-JCT MN110	SUPER COMMUTER		11/13/21 11:00 PM	0
Metro District	Maintenance Area Metro	Plymouth	TP5C4941	JCT MN 7-BASS LAKE ROAD	SUPER COMMUTER		11/13/21 11:00 PM	0
Metro District	Maintenance Area Metro	Shakopee	TP5P0131	E JCT MN19-JCT MN101 IN SAVAGE	URBAN COMMUTER	11/13/21 4:10 PM	11/13/21 11:00 PM	6.83
Metro District	Maintenance Area Metro	Shakopee	TP5P1691	MN282/2ND ST-JCT MN 41/CSAH93	SUPER COMMUTER	11/13/21 3:30 PM	11/13/21 11:00 PM	7.5
Metro District	Maintenance Area Metro	Shakopee	TP5P2821	JCT US169 IN JORDAN-JCT MN28	RURAL COMMUTER	11/13/21 3:30 PM	11/13/21 11:15 PM	7.75

Figure 2.4.1 A Portion of the Snow-Event Data for the Metro Freeways (Source: Metro District, MnDOT)

Route	From	To	MP Begin	MP End		*Start Statio*	End Statio	Subarea
TP5A0101	WB exit ramp to US 169 NB/MN 101 SB	Creek, 1/2 way between Main St and	214.553	228.156	**US10 EB**	***S1214***	**S951**	ANOKA
TP9D0101	Junction I35W NB/US910A	US10 becomes CO with I694	238.393	240+01.183	**US10 EB**	***S2039***	**S1825**	ARDEN HILLS
TP9D35W1	South end of Bridge 27897 over Industrial	N jct I-35, N jct I-35E	21.507	41.743	**I35W NB**	***S573***	**S1561**	ARDEN HILLS
TP9D6941	BR# 9389 under 5th Ave NW (Old Hwy 8)	W end BR # 9209/9210 over Island	40.426	43.45	**I694 EB**	***S177***	**S1079**	ARDEN HILLS
TP5H0941	Junction MNTH - 252	Hennepin/Ramsey County Line	224.977	236.319	**I94 EB**	***S240***	**S775**	CAMDEN
TP5H35W1	Chicago Avenue in Minneapolis	South end of Bridge 27897 over	17.129	21.507	**35W NB**	***S565***	**S573**	CAMDEN
TP5H3941	Junction T.H. 100 in Golden Valley	Washington Avenue North in	5.925	9.735	**I394 EB**	***S281***	**S291**	CAMDEN
TP5J0621	West Junction USTH 212/Bri#27080	Junction of MN 55	105.867	115.982	**62 EB**	***S311***	**S1135**	CEDAR
TP5J0771	West 138th Street in Apple Valley	BR# 27021 under MN 62 WB	0.898	11.403	**77 NB**	***S920***	**S531**	CEDAR
TP5J35W1	Junction I-494 in Bloomington	Chicago Avenue in Minneapolis	8.741	17.129	**35W NB**	***S45***	**S565**	CEDAR
TP5J4941	East end of Bridge 27765 over 34th Avenue	West Junction MNTH 5 in Eden Prairie	1.608	11.921	**494 EB**	***S474***	**S494**	CEDAR
TP5N0621	Junction I-494 in Eden Prairie	W. junction US212/EB under US169 NB	103.592	105.867	**62 EB**	***S301***	**S311**	EDEN PRAIRIE
TP5N1692	Pioneer Trail CSAH 1	Junction T.H. 55 in Plymouth	118.682	130.940	**169 NB**	***S1143***	**S442**	EDEN PRAIRIE
TP5N2121	Lyman Blvd overpass	East junction MN 62	152.809	162.482	**TH 212 EB**	***S1379***	**S312**	EDEN PRAIRIE
TP5N4941	West Junction US 212 in Eden Prairie	Junction T.H. 7 westbound - Bridge	11.921	16.259	**494 NB**	***S484***	**S512**	EDEN PRAIRIE
TP9B0351	North Junction I-35E and I-35W	Washington-Chisago County Line	127.420	132.939	**I35 NB**	***S1591***	**S1511**	FOREST LAKE
TP9B35E1	North end of bridge 9568 northbound over	North Junction I-35 and I-35W	115.742	127.420	**35E NB**	***S1485***	**S1503**	FOREST LAKE
TP5E0941	BR #27707 under Boone Ave	Junction MNTH - 252	219.520	224.977	**94 EB**	***S223***	**S240**	GOLDEN
TP5E1001	Junction I494/Bridge #27V38	Junction I-694 in Brooklyn Center	0.000	16.158	**TH 100 NB**	***S375***	**S1614**	GOLDEN
TP5E6941	Junction I-94 in Brooklyn Center	BR # 9389 under 5th Ave NW (Old Hwy	34.197	40.426	**694 EB**	***S2059***	**S179**	GOLDEN
TP9P35E1	South Junction I-35 / I-35W	Bridge#19816 under Cliff Road	88.267	93.744	**35 E NB**	***S870***	**S879**	LAKEVILLE
TP9P35W1	South Junction I-35 / I-35E, end Bridge #	Junction I-494 in Bloomington/Bridge	0.000	8.741	**35W NB**	***S911***	**S43**	LAKEVILLE
TP9P35SI	SB exit ramp to MN 19	South Jct I-35E / I-35W	69.774	88.267	**I35 NB**	***S1585***	**S1096**	LAKEVILLE
TP5B0941	Wright/Hennepin County line, NW end of	BR #27707 under Boone Ave	205.367	219.520	**I94 EB**	***S1734***	**S223**	MAPLE GROVE
TP5B1011	Junction Hennepin Co. Rd. 81 in Rogers Jct.	Wright / Sherburne County Line (North	39.640	46.350	**TH 101 NB**	***S1430***	**S1435**	MAPLE GROVE
TP5B1691	Junction T.H. 55 in Plymouth	SB exit ramp to WB MN610	130.940	141.627	**US 169 NB**	***S442***	**S1799**	MAPLE GROVE

Figure 2.4.2 A portion of the Metro-Freeway Snow-Plow Route Location Data with Station IDs

(Source: Metro District, MnDOT. Start/End Point Detector-Station IDs added in this task)

Event Start	Event End	Affected Routes	Lane Lost Time	Lane Regain Time
11/28/2018 2:00:00 PM	11/29/2018 3:45:00 AM	TP5A0101	11/29/2018 1:00:00 AM	11/29/2018 5:00:00 AM
12/1/2018 4:00:00 PM	12/2/2018 11:00:00 AM	TP5A0101	12/1/2018 5:00:00 PM	12/1/2018 6:00:00 PM
12/26/2018 8:30:00 PM	12/27/2018 6:00:00 AM	TP5A0101	12/26/2018 9:30:00 PM	12/27/2018 4:30:00 AM
12/27/2018 8:45:00 PM	12/28/2018 6:00:00 AM	TP5A0101	12/27/2018 9:30:00 PM	12/28/2018 4:30:00 AM
1/27/2019 6:30:00 PM	1/28/2019 8:00:00 AM	TP5A0101	1/27/2019 8:00:00 PM	1/28/2019 10:00:00 AM
2/5/2019 8:30:00 AM	2/5/2019 8:00:00 PM	TP5A0101	2/5/2019 9:30:00 AM	2/5/2019 3:00:00 PM
2/6/2019 8:00:00 PM	2/7/2019 8:30:00 PM	TP5A0101	2/6/2019 8:20:00 PM	2/7/2019 3:00:00 AM
2/10/2019 7:00:00 AM	2/10/2019 5:30:00 PM	TP5A0101	2/10/2019 9:30:00 AM	2/10/2019 7:30:00 PM
2/11/2019 11:30:00 PM	2/12/2019 4:30:00 PM	TP5A0101	2/12/2019 1:00:00 AM	2/12/2019 5:30:00 PM
2/20/2019 4:00:00 AM	2/21/2019 12:00:00 AM	TP5A0101	2/20/2019 4:40:00 AM	2/21/2019 1:00:00 AM
2/23/2019 2:00:00 AM	2/23/2019 7:00:00 AM	TP5A0101	2/23/2019 2:30:00 AM	2/23/2019 8:00:00 AM
2/23/2019 8:30:00 PM	2/24/2019 4:00:00 AM	TP5A0101	2/23/2019 10:30:00 PM	2/24/2019 11:00:00 PM
2/26/2019 11:30:00 PM	2/27/2019 5:30:00 AM	TP5A0101	2/26/2019 12:30:00 PM	2/27/2019 7:30:00 AM
3/1/2019 10:30:00 AM	3/1/2019 4:00:00 PM	TP5A0101	3/1/2019 11:15:00 AM	3/2/2019 8:00:00 AM
12/27/2018 10:30:00 PM	12/28/2018 2:00:00 AM	TP5H0941	12/28/2018 1:00:00 AM	12/28/2018 4:30:00 AM
12/26/2018 7:00:00 PM	12/27/2018 1:00:00 AM	TP5H0941	12/26/2018 8:00:00 PM	12/27/2018 4:00:00 AM
12/22/2018 10:00:00 PM	12/23/2018 1:30:00 AM	TP5H0941	12/22/2018 11:00:00 PM	12/23/2018 3:00:00 AM
3/1/2019 9:00:00 AM	3/1/2019 9:00:00 PM	TP5H0941	3/1/2019 10:00:00 AM	3/2/2019 3:00:00 AM
2/23/2019 1:30:00 AM	2/24/2019 3:00:00 AM	TP5H0941	2/23/2019 2:00:00 AM	2/24/2019 7:00:00 AM
2/20/2019 3:00:00 AM	2/20/2019 11:30:00 PM	TP5H0941	2/20/2019 3:30:00 AM	2/20/2019 9:00:00 PM
12/27/2018 10:30:00 PM	12/28/2018 2:00:00 AM	TP5H35W1	12/28/2018 1:00:00 AM	12/28/2018 4:30:00 AM
12/26/2018 7:00:00 PM	12/27/2018 1:00:00 AM	TP5H35W1	12/26/2018 8:00:00 PM	12/27/2018 4:00:00 AM
12/22/2018 10:00:00 PM	12/23/2018 1:30:00 AM	TP5H35W1	12/22/2018 11:00:00 PM	12/23/2018 3:00:00 AM
3/1/2019 9:00:00 AM	3/1/2019 9:00:00 PM	TP5H35W1	3/1/2019 10:00:00 AM	3/2/2019 3:00:00 AM

Figure 2.4.3 A Sample Snow-Event Data for 2018-19 in Excel Format Processed for T-database

populate_snow_event_data - Notepad

File Edit Format View Help

```
import sys
sys.path.append("Server/src")
import global_settings
from pyticas import ticas
from pyticas.infra import Infra
from pyticas_tetres import api_urls_admin

from tetres_data_populator.snow_event_data.snow_event_api_reader import SnowEventAPIReader
from tetres_data_populator.snow_event_data.snow_event_api_writer import SnowEventAPIWriter
from tetres_data_populator.snow_event_data.snow_event_excel_reader import SnowEventExcelReader

if __name__ == "__main__":
    ticas.initialize(global_settings.DATA_PATH)
    print(global_settings.DATA_PATH)
    infra = Infra.get_infra()

    base_url = "http://localhost:5000"

    only_file_name = input("Enter the name of the snow event excel file: ")
    snow_event_filename = "Server/src/tetres_data_populator/excel_data/snow_event_data/{}".format(only_file_name)
    snow_event_excel_reader = SnowEventExcelReader(filename=snow_event_filename)

    # adding snow route data
    snow_event_api_writer = SnowEventAPIWriter(infra)
    snow_event_api_writer.post_data(excel_reader=snow_event_excel_reader,
                                    post_url=base_url + api_urls_admin.SNR_INSERT,
                                    list_url=base_url + api_urls_admin.SNR_LIST,
                                    data_type="snow_route",
                                    api_reader_class=SnowEventAPIReader)

    # adding snow event data
    snow_event_api_writer.post_data(excel_reader=snow_event_excel_reader,
                                    post_url=base_url + api_urls_admin.SNE_INSERT,
                                    list_url=base_url + api_urls_admin.SNE_LIST,
                                    data_type="snow_event",
                                    api_reader_class=SnowEventAPIReader)

    # adding snow management data
    snow_event_api_writer.post_data(excel_reader=snow_event_excel_reader,
                                    post_url=base_url + api_urls_admin.SNM_INSERT,
                                    list_url=base_url + api_urls_admin.SNM_LIST_ALL,
                                    data_type="snow_management",
                                    api_reader_class=SnowEventAPIReader)
```

Figure 2.4.4 The Snippets of the Script for Populating T-database with Snow-Event Data

id [PK] integer	start_time timestamp without time zone	end_time timestamp without time zone	reg_date timestamp without time zone
4768	2021-12-28 10:15:00	2021-12-28 15:30:00	2022-11-28 20:31:30.587804
4767	2021-12-28 09:30:00	2021-12-28 15:00:00	2022-11-28 20:31:28.517967
4766	2021-12-26 14:30:00	2021-12-27 21:30:00	2022-11-28 20:31:26.463734
4765	2021-12-26 18:45:00	2021-12-27 09:00:00	2022-11-28 20:31:24.40492
4764	2021-12-26 19:00:00	2021-12-27 08:15:00	2022-11-28 20:31:22.351324
4763	2021-12-26 18:45:00	2021-12-27 08:00:00	2022-11-28 20:31:20.29718
4762	2021-12-26 18:45:00	2021-12-27 07:30:00	2022-11-28 20:31:18.243063
4761	2021-12-26 18:30:00	2021-12-27 07:30:00	2022-11-28 20:31:16.200203
4760	2021-12-26 19:00:00	2021-12-27 07:00:00	2022-11-28 20:31:13.480339
4759	2021-12-26 19:15:00	2021-12-27 07:00:00	2022-11-28 20:31:11.430401
4758	2021-12-26 19:00:00	2021-12-27 06:30:00	2022-11-28 20:31:09.367235
4757	2021-12-26 18:05:00	2021-12-27 06:30:00	2022-11-28 20:31:06.692537
4756	2021-12-26 17:30:00	2021-12-27 06:00:00	2022-11-28 20:31:04.630459
4755	2021-12-26 17:15:00	2021-12-27 06:00:00	2022-11-28 20:31:02.570199
4754	2021-12-26 18:45:00	2021-12-27 06:00:00	2022-11-28 20:31:00.408383
4753	2021-12-26 17:50:00	2021-12-27 06:00:00	2022-11-28 20:30:58.363742
4752	2021-12-26 18:05:00	2021-12-27 06:00:00	2022-11-28 20:30:55.950984

Figure 2.4.5 Screenshot of T-database with a Portion of Populated Snow-Event Data

2.5 Collection and Processing of Incident Data

Figure 2.5.1 shows the structure of the incident data processing module developed in the previous phase of this study. As noted in the figure, the current process for populating the T-database with the metro-freeway requires the incident data from two external sources, i.e., IRIS (Intelligent Road Information System) from RTMC, MnDOT, and CAD (Computer-Aided Dispatch) system from the Department of Public Safety. After both IRIS and CAD incident-database files are imported and integrated in a combined data format, the Incident-Impact data, i.e., lane-closure status, and the Lane-type information are extracted from the IRIS-Incident database and merged onto the data from the CAD system, which is considered as the main data source for incidents. The integrated-incident data is then stored in the T-database. Figure 2.5.2 includes the snippets of the incident-data script, designed to read the imported database files, and to populate the T-database with the extracted data from both databases.

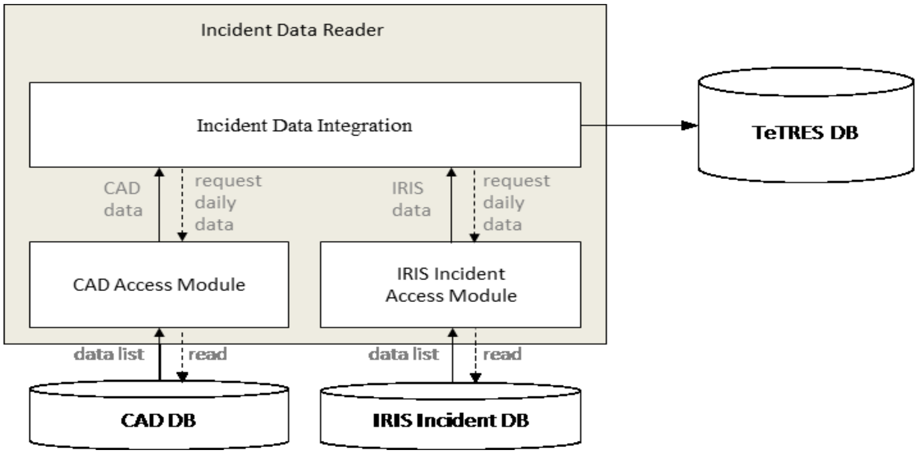

Figure 2.5.1 Structure of the Incident Data Reader/T-Database Population Module

```
sys.path.append("Server/src")
import global_settings
import dbinfo

if __name__ == '__main__':
    print('')
    print(
        '!! Do not run multiple instances of this program. (DB sync problem can be caused in bulk-insertion and deletion)')
    print('!! Stop TeTRES Server if it is running.')
    print('')
    print('# combines cad and iris data to load incident data into tetres system')
    print('')

    sdt_str = input('# Enter start date to load data (e.g. 2015-01-01) : ')
    sdate = datetime.datetime.strptime(sdt_str, '%Y-%m-%d').date()

    edt_str = input('# Enter end date to load data (e.g. 2017-12-31) : ')
    edate = datetime.datetime.strptime(edt_str, '%Y-%m-%d').date()

    print('')
    print('!! Data during the given time period will be deleted.')
    res = input('!! Do you want to proceed data loading process ? [N/y] : ')
    if res.lower() not in ['y', 'ye', 'yes']:
        print('\nAborted!')
        exit(1)

    from pyticas import ticas
    from pyticas.infra import Infra
    from pyticas_tetres.db.cad import conn as conn_cad
    from pyticas_tetres.db.iris import conn as conn_iris
    from pyticas_tetres.db.tetres import conn

    ticas.initialize(global_settings.DATA_PATH)
    infra = Infra.get_infra()

    conn.connect(dbinfo.tetres_db_info())
    conn_cad.connect(dbinfo.cad_db_info())
    conn_iris.connect(dbinfo.iris_incident_db_info())

    time.sleep(1)

    from pyticas_tetres.systasks import initial_data_maker

    try:
        initial_data_maker.load_incident_data(sdate, edate)
    except Exception as ex:
        print('exception:', ex)
```

Figure 2.5.2 Snippets of the Script for Populating T-database with Incident data

In this study, after examining both IRIS and CAD-incident database files, it was noticed that the formats of both database files were changed from those used in the previous phase of this study. As shown in Figure 2.5.3, the CAD database used in the previous phase had 11 columns, while the CAD database provided by RTMC, MnDOT, for the current study, has 16 columns. Further, the recent database from IRIS, i.e., tms database, was noted to have one more schema, named as ‘cap’, than the 2020-version of the tms database. Therefore, in this study, those additional columns and schema were deleted from the recent IRIS and CAD databases, so that the current script can be applicable for populating T-database with the new data sets. Figure 2.5.4 shows a portion of the T-database populated with the new set of the incident data. The updated T-database contains the incident data for the metro freeways from 1/2010 until December 2023.

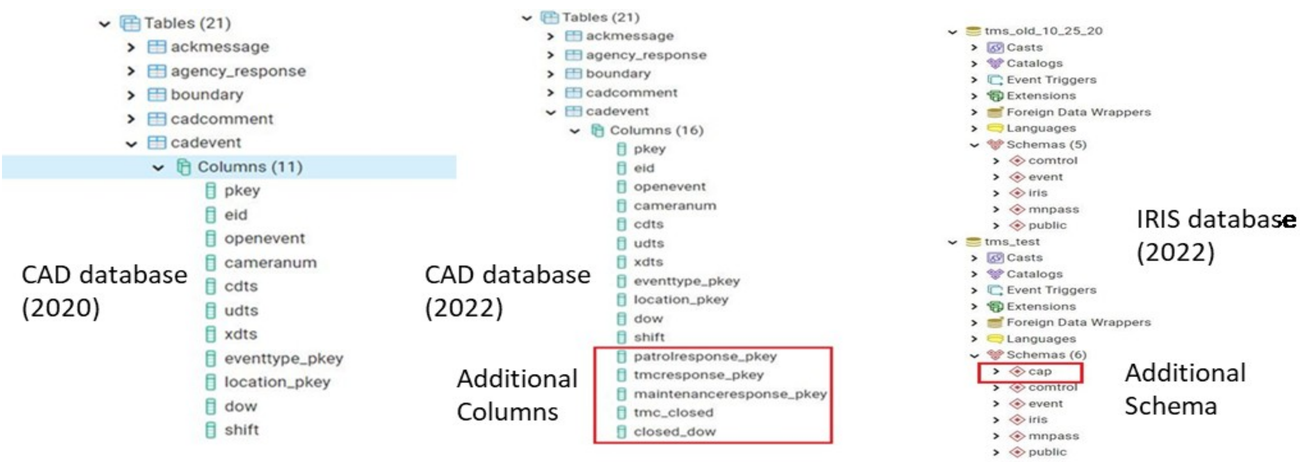

Figure 2.5.3 Format Changes in CAD and IRIS Incident Databases

cdts timestamp without time zone	udts timestamp without time zone	xdts timestamp without time zone	lat double precision	lon double precision	xstreet1 character varying (40)	xstreet2 character varying (40)
2022-09-30 20:15:44	2022-09-30 20:15:58	2022-09-30 20:42:52	44.96675	-93.08932	SB 35E I	CAYUGA ST E
2022-09-30 20:07:50	2022-09-30 20:08:16	2022-10-03 12:50:32	44.40554	-95.12763	71 HWY	68 HWY
2022-09-30 20:06:36	2022-09-30 20:06:57	2022-09-30 20:37:45	44.96569	-93.26254	NB 35W I	CHICAGO AVE S
2022-09-30 20:05:14	2022-09-30 20:06:32	2022-09-30 20:37:44	45.05031	-93.03594	NB 61 HWY	244 HWY
2022-09-30 20:03:31	2022-09-30 20:03:48	2022-10-03 12:52:49	45.13992	-95.00592	SB 71 HWY TO WB 12 HWY ...	CIVIC CENTER DR
2022-09-30 20:02:32	2022-09-30 20:03:01	2022-10-03 12:52:50	45.45423	-94.0067	70TH AVE SE	75TH AVE
2022-09-30 20:01:47	2022-09-30 20:02:03	2022-10-03 12:52:50	46.57558	-95.54408	WB 10 HWY TO 78 HWY RMP	80 CR
2022-09-30 20:01:33	2022-09-30 20:02:20	2022-09-30 21:09:20	44.68131	-93.29359	SB 35 I	185TH ST W
2022-09-30 20:00:57	2022-09-30 20:13:34	2022-10-03 12:52:50	44.18588	-91.85198	CHANNEL VIEW RD	BENNETT AVE
2022-09-30 20:00:15	2022-09-30 20:16:23	2022-10-03 12:52:50	45.2815	-93.549	WB 10 HWY NW	171ST AVE NW
2022-09-30 19:58:10	2022-09-30 20:36:42	2022-10-03 12:52:51	47.00427	-93.26094	65 HWY	200 HWY
2022-09-30 19:56:25	2022-09-30 20:04:39	2022-10-03 12:52:51	46.93471	-95.91028	59 HWY	12 CR
2022-09-30 19:44:17	2022-09-30 19:45:42	2022-10-03 12:52:51	46.35774	-93.74939	37 CR	PINE LAKE RD
2022-09-30 19:42:02	2022-09-30 19:42:39	2022-09-30 20:32:28	45.65086	-93.19324	65 HWY	FJELDHEIM RD NE
2022-09-30 19:35:23	2022-09-30 19:37:40	2022-09-30 23:41:35	45.07616	-93.35565	EB 694 I	ZANE AVE N

Figure 2.5.4 A Screenshot of T-database Showing a Portion of Populated Incident Data

2.6 Collection and Processing of Weather Data

As noted previously, in TeTRES, the weather data is directly downloaded from the data archive of the NOAA, *National Oceanic and Atmospheric Administration,* to the T-database. Figure 2.6.1 shows the script used for downloading the weather data for the period of 11/2020 – 12/2023. from the weather-data stations in the metro-freeway network and for populating the T-database. A screenshot of the sample weather data downloaded into the T-database is shown in Figure 2.6.2.

load_weather_data - Notepad

File Edit Format View Help

```
# -*- coding: utf-8 -*-
__author__ = 'Chongmyung Park (chongmyung.park@gmail.com)'

import datetime
import time
import sys

sys.path.append("Server/src")
import global_settings
import dbinfo

if __name__ == '__main__':
    print('')
    print(
        '!! Do not run multiple instances of this program. (DB sync problem can be caused in bulk-insertion and deletion)')
    print('!! Stop TeTRES Server if it is running.')
    print('')
    print('# loads weather data for the given time period')
    print('')

    sdt_str = input('# Enter start date to load data (e.g. 2015-01-01) : ')
    sdate = datetime.datetime.strptime(sdt_str, '%Y-%m-%d').date()

    edt_str = input('# Enter end date to load data (e.g. 2017-12-31) : ')
    edate = datetime.datetime.strptime(edt_str, '%Y-%m-%d').date()

    print('')
    print('!! Data during the given time period will be deleted.')
    res = input('!! Do you want to proceed data loading process ? [N/y] : ')
    if res.lower() not in ['y', 'ye', 'yes']:
        print('\nAborted!')
        exit(1)

    from pyticas import ticas
    from pyticas.infra import Infra
    from pyticas_tetres.db.cad import conn as conn_cad
    from pyticas_tetres.db.iris import conn as conn_iris
```

Figure 2.6.1 The Snippets of Script for Downloading Weather Data and Populating T-Database

dtime timestamp without time zone	precip double precision	precip_type character varying (4)	precip_intensity character varying (4)	precip_qc character varying (4)	visibility double precision	visibility_qc character varying (4)	obscuration character varying (4)	descriptor character varying (4)	air_temp double precision	air_temp_qc character varying (4)
2022-08-29 21:55:00	[null]	99	9	3	9.999723503	5	9	9	64.4	C
2022-08-29 21:15:00	[null]	99	9	3	9.999723503	5	9	9	64.4	5
2022-08-29 20:55:00	[null]	99	9	3	9.999723503	5	9	9	66.2	C
2022-08-29 19:55:00	[null]	99	9	3	9.999723503	5	9	9	66.2	C
2022-08-29 19:35:00	[null]	99	9	3	9.999723503	5	9	9	68	5
2022-08-29 19:15:00	[null]	99	9	3	9.999723503	5	9	9	69.8	5
2022-08-29 18:55:00	[null]	99	9	3	9.999723503	5	9	9	69.8	C
2022-08-29 18:15:00	[null]	99	9	3	9.999723503	5	9	9	71.6	5
2022-08-29 17:35:00	[null]	99	9	3	9.999723503	5	9	9	73.4	5
2022-08-29 17:15:00	[null]	99	9	3	9.999723503	5	9	9	75.2	5
2022-08-29 16:55:00	[null]	99	9	3	9.999723503	5	9	9	75.2	C
2022-08-29 16:35:00	[null]	99	9	3	9.999723503	5	9	9	75.2	5
2022-08-29 15:35:00	[null]	99	9	3	9.999723503	1	9	9	77	1
2022-08-29 15:15:00	[null]	99	9	3	9.999723503	1	9	9	75.2	1
2022-08-29 14:55:00	[null]	99	9	3	9.999723503	1	9	9	75.2	1

Figure 2.6.2 A screenshot of T-Database Showing a Portion of Populated Weather Data

2.7 Summary

As described in the previous sections, in this study, the TeTRES database was populated with a new set of data to continuously cover the period from the end of the previous phase until December 2023. The resulting, updated TeTRES database contains the following data sets:

- Special-event data: Sport-Events for 1/2012-12/2023, Non-Sport Event for 2016 - 2023
- Work-zone data from 4/2012 – 12/2023
- Winter-road condition data for Metro Freeway-Plow Routes from 10/2012 – 12/2023
- Weather data from NOAA for 1/2010 – 912/2023
- Incident data from CAD/IRIS database for 1/2010 – 12/2023
- Traffic-detector data (stored separately in a local hard disk): 1/2010 – 12/2023.

The TeTRES database updated with the above datasets is applied for estimating the travel-time reliability and traffic-flow measures at the metro freeway corridors in the next chapter.

Chapter 3: ESTIMATION AND ANALYSIS OF TRAVEL-TIME TTR MEASURES AND TRENDS FOR THE METRO FREEWAY CORRIDORS AND NETWORK

3.1 Introduction

In this chapter, the updated TeTRES database, populated with the new sets of the traffic and non-traffic data up to December 2023, is applied to estimate the travel-time reliability (TTR) and traffic-flow measures of the freeway corridors in the metro network. Figure 3.1.1 shows a total of 37 corridors with 76 directional routes, whose monthly and yearly TTR and traffic-flow measures of effectiveness (MoE) are estimated during morning or afternoon peak periods from January 2018 to December 2023. It needs to be noted that each corridor has two directional routes for morning and afternoon peak periods, while the I-94 Corridor between St. Paul and Minneapolis downtowns have a total of 4 directional routes, i.e., each direction has both morning and afternoon peak periods. It is further noted that the boundaries of each directional route have been determined in cooperation with the technical advisory panel of this study. Table 3.1.1 includes the detector-station IDs at the boundaries of each directional route.

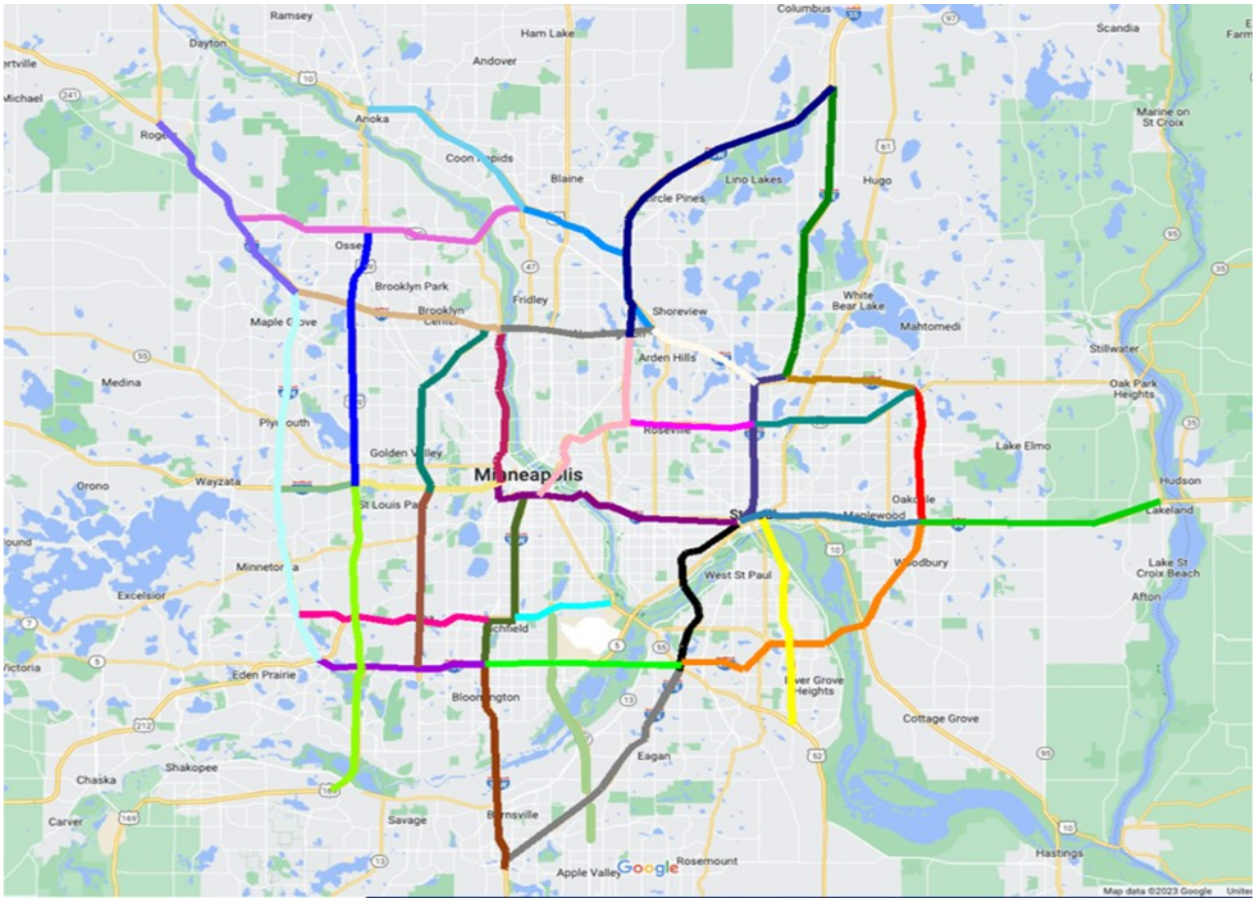

Figure 3.1.1 Freeway Corridors defined for TTR and Traffic-Flow MoE Estimation

Table 3.1.1 Start/End Stations of Each Corridor Directional Route

Corridor	Description	Start	End	Length (Miles)
I-394 (EB)	I494 to TH169	S269	S274	2.7
I-394 (EB)	TH169 to MPLS DT	S274	S290	5.5
I-494 (SB)	I694 to TH212	S209	S473	15.5
I-494 (WB)	I94 to I35E	S1029	S864	12.4
I-494 (WB)	I35E to I35W	S864	S119	7.8
I-494 (WB)	I35W to TH212	S119	S483	5.9
I-694 (NB)	I94 to TH36	S1027	S1418	4.9
I-694 (WB)	TH36 to I35E	S1419	S1459	6.5
I-694 (WB)	I35E to TH10	S1461	S1089	3.8
I-694 (WB)	TH10 to TH252	S1089	S144	5.5
I-94 (EB)	Rogers to I494	S1115	S211	9.1

I-94 (EB)	MPLS DT to SP DT	S110	S499	8.4
I-94 (EB)	MPLS DT to SP DT	S110	S499	8.4
I-94 (EB)	SP DT to I694	S499	S2151	7.3
I-94 (EB)	I694 to TH95	S2151	S1358	9.2
I-94 (EB)	I494 to TH252	S211	S170	8
I-94 (EB)	TH252 to MPLS DT	S170	S110	8.1
I-94 (WB)	I494 to Rogers	S208	S1112	8.4
I-94 (WB)	SP DT to MPLS DT	S500	S1943	8.5
I-94 (WB)	SP DT to MPLS DT	S500	S1943	8.5
I-94 (WB)	TH95 to I694	S1359	S1062	9
I-94 (WB)	I694 to SP DT	S1062	S500	7.5
I-94 (WB)	MPLS DT to TH252	S76	S159	8
I-94 (WB)	TH252 to I494	S159	S216	7.1
T.H.10 (EB)	TH169 to TH610	S940	S954	7.5
T.H.10 (EB)	TH610 to I694	S954	S1825	7.3
T.H.100 (SB)	I694 to I394	S1615	S405	6.8
T.H.100 (SB)	I394 to I494	S405	S421	7.7
T.H.36 (WB)	I35E to I35W	S609	S618	4.4
T.H.36 (WB)	I694 to I35E	S1425	S608	6.4
T.H.52 (NB)	TH55 to SP DT	S1166	S1178	8.2
T.H.610 (EB)	I94 to TH10	S1954	S966	11.7
T.H.62 (WB)	I35W to I494	S127	S369	6.7
T.H.62 (WB)	TH55 to I35W	S330	S127	4.2
T.H.77 (NB)	127th to TH62	S799	S531	6.1
U.S.169 (SB)	TH610 to I394	S1795	S448	10.9
U.S.169 (SB)	I394 to TH13	S448	S1626	16.2

For each directional route of the individual corridors shown in Figure 3.1.1, the TTR measures, based on the travel times calculated every 5-minute interval for each route, were estimated using TeTRES under different operating conditions, and their monthly and yearly trends were analyzed. It needs to be noted that, in this analysis, only regular non-holiday weekdays, i.e., Tuesdays, Wednesdays, Thursdays, were included for estimating TTR measures. In addition, a set of the commonly used traffic-flow MoEs were also estimated and presented for each route. The specific measures and operating conditions used in this analysis are as follows:

Travel-time TTR Measures:

Buffer Index (BI, 95^{th} %ile) = (95^{th} %ile Travel Time – Average Travel Time)/(Average Travel Time)

Planning Index (PI, 95^{th} %ile) = 95^{th} %ile Travel Time / Free-Flow Travel Time

Travel Rate (TR, 95^{th} %ile, minutes/mile) = 95^{th} %ile Travel Time / Route Length

Operating Conditions

Weather: All, Dry, Rain, Snow

Incident: All, No-Incident (N), Property Damage Only (PD), Severe/Fatal (INJ, FA)

Work Zone: All, No-Work Zone (N), Light Impact-WZ (L), Medium-Heavy Effect WZ (M, H)

Special Event: No-Event, Small (< 20,000 attendees), Medium-Large (≥ 20,000 attendees) events

***Peak Periods**: Morning: 6:00 – 9:00 a.m. Afternoon: 3:30 – 6:30 p.m.*

***Traffic-Flow Measures of Effectiveness**: VMT (Vehicle-Miles Traveled), VHT (Vehicle-Hours Traveled), DVH (Delayed Vehicle-Hours)*

Further, the monthly and yearly values of the network-wide, weighted-average TTR measures, using the VMT of each route as the weight, under 'All' conditions were calculated to analyze the network-wide TTR trends for both morning and evening routes. For example, the 'network-wide average buffer index' is calculated as follows:

Network-wide Average Buffer Index (BI) = $\frac{\boldsymbol{R1\,VMT*R1\,BI+R2\,VMT*R2\,BI+ ----- \ +RnVMT*Rn\,BI}}{\boldsymbol{R1\,VMT+R2\,VMT+ ------ \ +Rn\,VMT}}$

where Ri VMT = VMT of Route i,

Ri BI = Buffer Index of Route i

Also, the monthly and yearly total values of the traffic-flow MOEs for morning and afternoon routes were estimated to observe the network-wide traffic-flow trends. The rest of this chapter summarizes the monthly and yearly variation trends of the travel-time reliability and traffic-flow MOE values, estimated under all conditions, for both morning and afternoon networks from January 2018 to December 2023. Further, the yearly vulnerability trends of the individual routes are analyzed by combining the yearly estimates of the buffer index and the travel rate of each route. In addition, the effects of the geometric configuration of each route on its TTR and traffic-flow MoEs are also assessed by analyzing the relationships between the geometric friction factor, defined in the previous phase of this study, and the TTR and traffic-flow MoEs of each route. The monthly and yearly trends of the TTR and traffic-flow MOEs of each directional route under different operating conditions are included in the Appendix.

3.2 Network-wide Traffic-Flow Performance and Travel-Time Reliability Trends

NETWORK-WIDE TRENDS OF TRAFFIC-FLOW MEASURES OF EFFECTIVENESS (MOE)

Figure 3.2.1 shows the monthly variations of the network-wide traffic-flow measures of effectiveness (MoE), which consisted with Vehicle-Miles-Traveled (VMT), Vehicle-Hours-Traveled (VHT) and Delayed-Vehicle-Hours (DVH), for both morning and afternoon routes. The yearly variations of the same traffic-flow MoEs are shown in Figure 3.2.2. As can be noted in this figure, both morning and afternoon VMT and VHT values substantially dropped in April 2020, when the state-wide traffic-restriction started because of COVID-19, resulting in substantial reduction of DVH. It can be also seen that all those three measures have been slowly, but continuously increasing since April 2020, however, as of December 2023, all the traffic-flow measures show significantly lower values than those of the pre-pandemic period. It is also noted that, while the overall traffic-flow patterns in the afternoon network are similar to those in the morning network, the afternoon network exhibits significantly higher DVH values than those of the morning network, which is consistent with the pre-pandemic period.

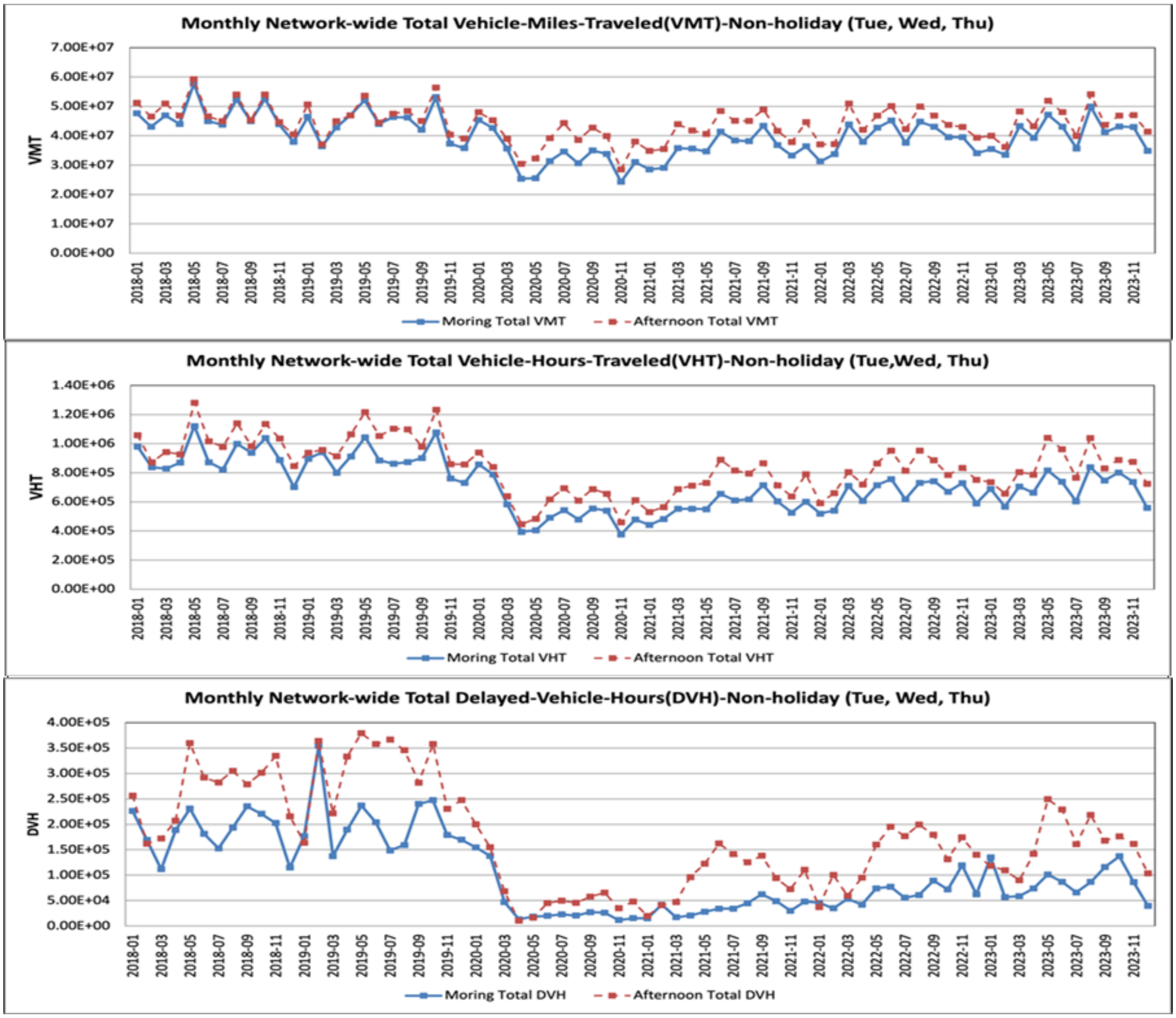

Figure 3.2.1 Network-wide Monthly Variations of Traffic-Flow Measures of Effectiveness

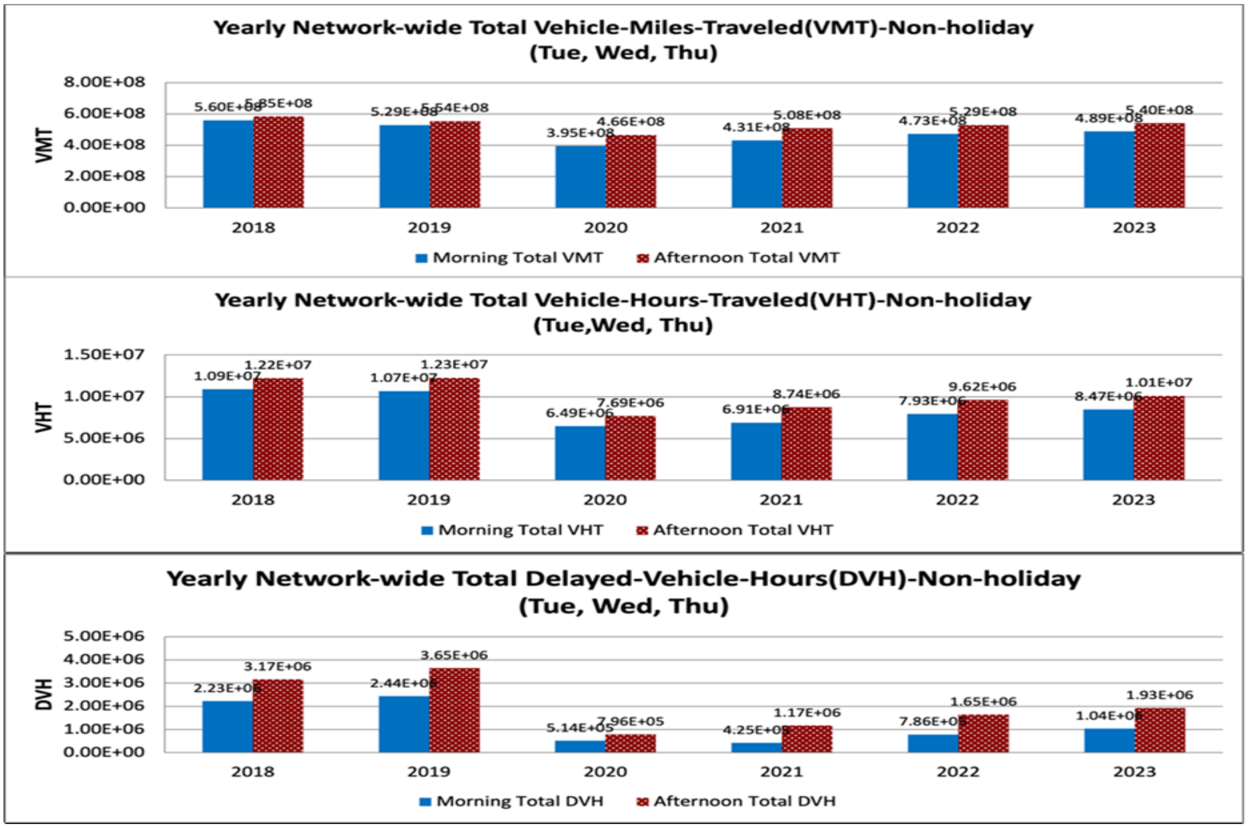

Figure 3.2.2 Network-wide Yearly Variations of Traffic-Flow MoEs for Morning and Afternoon Routes

NETWORK-WIDE TRENDS FOR TRAVEL-TIME RELIABILITY

Figure 3.2.3 shows the monthly variations of the network-wide, weighted average TTR values, including buffer index, planning index and travel rate, for both morning and afternoon networks. The yearly trends of these indices are shown in Figure 3.2.4. As can be seen in these figures, there is a clear difference in those TTR trends before and after April 2020, when the COVID-19 traffic restriction started. I.e., the network-wide travel-time reliability was significantly improved after April 2020, i.e., those TTR measures show substantially lower values than those of the before-pandemic period. It's also noted that, the yearly TTR values of the morning network show slowly but continuously increasing trends from 2020 to 2023, while the afternoon network in 2023 has slightly lower TTR values than those of the 2022 afternoon network. However, as of December 2023, all the network-wide reliability indices for both morning and afternoon networks are significantly lower than those of the pre-pandemic period. Further, in 2023, the buffer index of the afternoon network has smaller value than that of the morning network, while both planning index and travel rate show higher values than those in the morning network. This indicates the overall higher level of congestion in the afternoon network, resulting in less fluctuations in travel times than the morning network, in 2023.

The above analysis of the network-wide trends for both Travel-Time Reliability and Traffic-Flow MoEs indicates that, as of December 2023, the traffic-flows in the metro freeway network are still in the process of recovery from COVID-19.

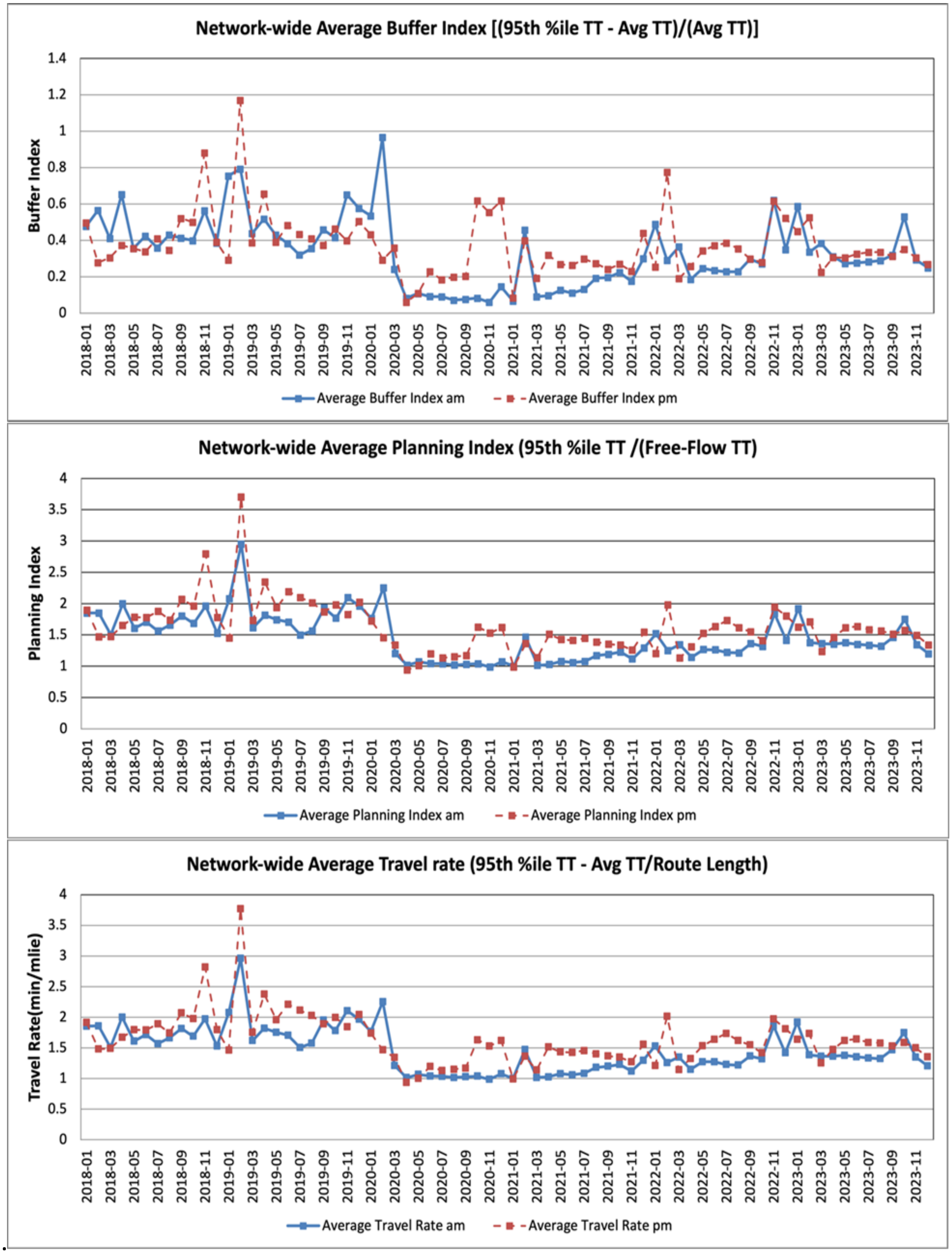

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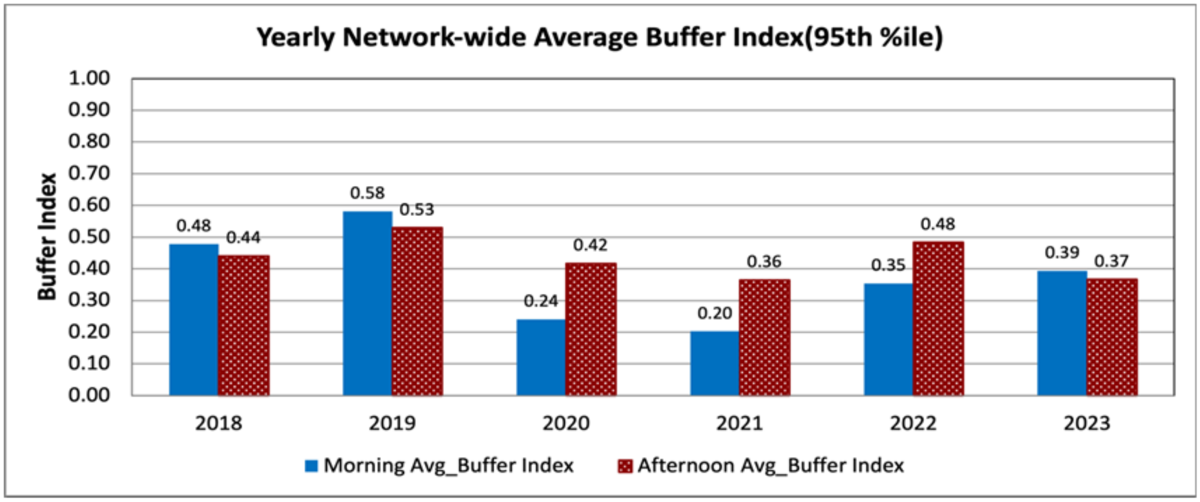
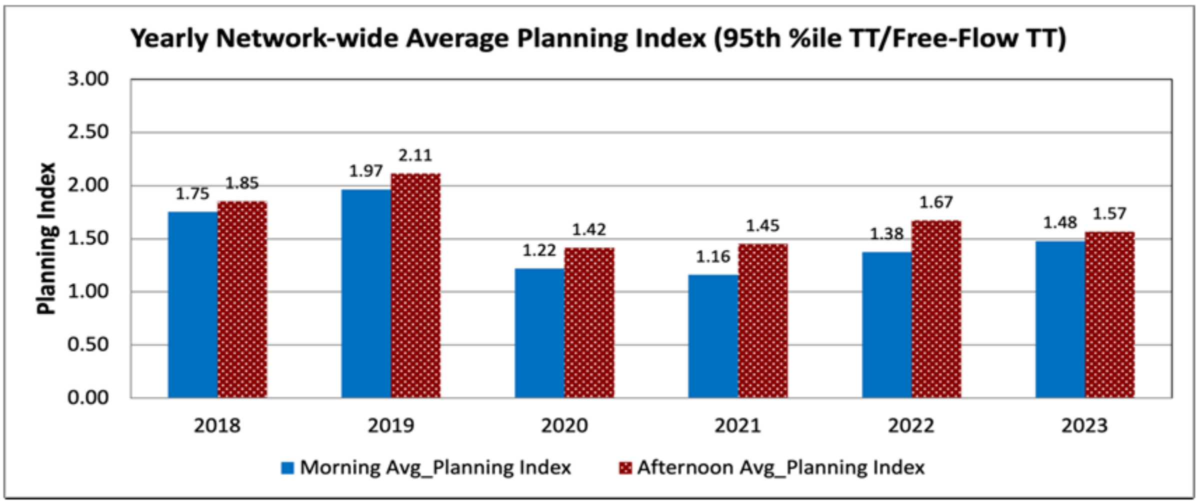
Figure 3.2.3 Monthly Network-wide TTR Trends for Morning and Afternoon Routes





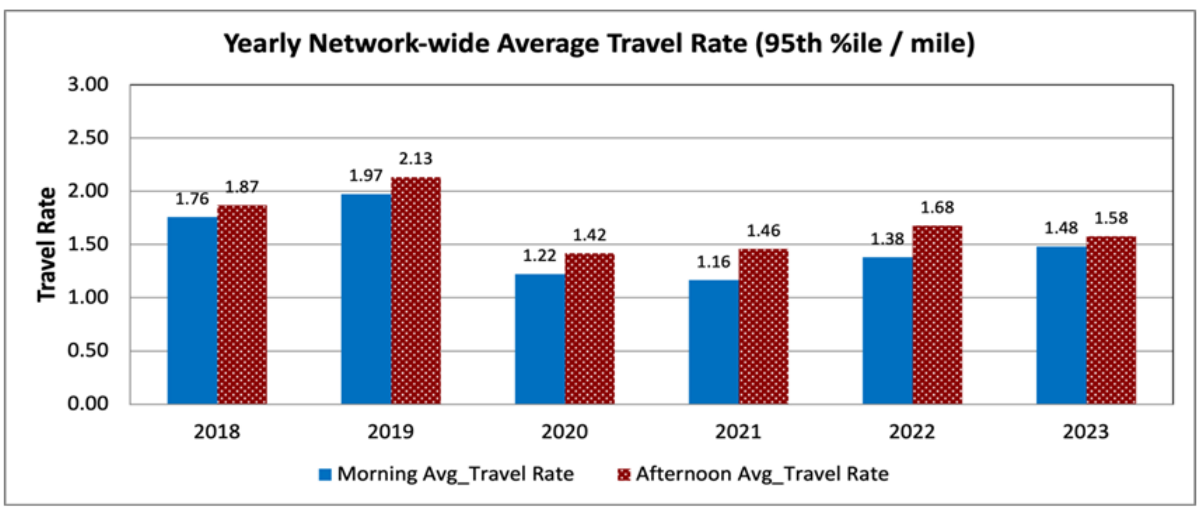


Figure 3.2.4 Yearly Network-wide TTR Trends for Morning and Afternoon Routes

3.3 Yearly Trends of Travel-Time Reliability on Individual Directional Routes

In this section, the yearly TTR trends of each directional route are analyzed with the TTR measures estimated under all operating conditions. First, to assess the overall reliability status of each route, the Vulnerability Level of a given route is determined with two travel-time TTR measures, i.e., Buffer Index (BI) and Travel Rate (TR), whose formula are shown below:

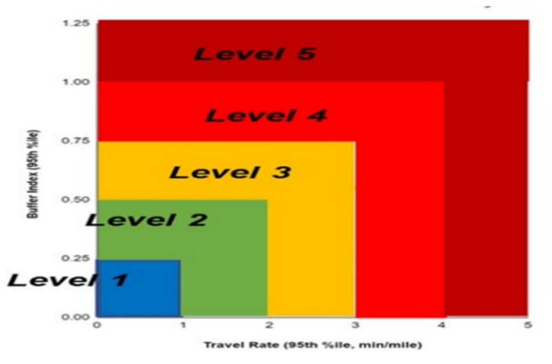
$$\text{BI} = \frac{(95th\ percentile\ Travel\ Time - Average\ Travel\ Time)}{Average\ Travel\ Time}$$

$$\text{TR (min/mile)} = \frac{(95th\ percential\ Travel\ Time)}{(Route\ Length)}$$

As indicated in the above formula, BI quantifies the variability of travel times, while TR measures the excessiveness of travel times for a given route during a given period. By plotting each route's BI and TR values in a BI—TR space, as shown in Figure 3.3.1, the combined reliability, defined as vulnerability (VI), level of each route in terms of the variability and excessiveness of travel times can be assessed and compared with those of other routes.

In this study, 5 VI levels are defined in the BI-TR space, as shown in Figure 3.3.1, and each route's VI level was determined with the BI and TR values from 2018 to 2023. Figures 3.3.2 - 3.3.13 show the yearly BI-TR relationships of the morning and afternoon routes from 2018 until 2023. Further, Tables 3.3.1 - 3.3.4 include the BI and TR values, and the resulting VI levels, of each route, from 2018 to 2023. It can be noted that the slope-steepness of the data points in the BI-TR space could indicate the overall congestion and reliability status of each period, i.e., a low slope indicates higher level of congestion with lower fluctuations in travel times than those with high slopes. For example, the BI-TR relationships of the afternoon routes generally show lower slopes, i.e., higher congestion, than those of the morning routes, consistent with the network-wide TTR and traffic-flow MoE trends discussed in the previous section. Finally, Table 3.3.5 and Figure 3.3.14 summarize the yearly variation trends of the VI levels for both morning and afternoon routes from 2018 to 2023.

As can be seen from the above figures and tables, the overall vulnerability conditions of both morning and afternoon routes exhibit clear improvements in 2020, i.e., during the pandemic period, compared to those in 2018 – 2019, while the 2021-2023 VI trends indicate the traffic conditions of the metro freeway routes have not reached the pre-pandemic level.



Level	BI (95th %-ile)	TR (95th %-ile)
1	BI < 0.25	< 1.0
2	0.25 ≤ BI < 0.5	1.0 ≤ TR < 2.0
3	0.5 ≤ BI < 0.75	2.0 ≤ TR < 3.0
4	0.75 ≤ BI < 1.0	3.0 ≤ TR < 4.0
5	1.0 ≤ BI	4.0 ≤ TR

Figure 3.3.1 Vulnerability Level Definitions in a BI-TR Space

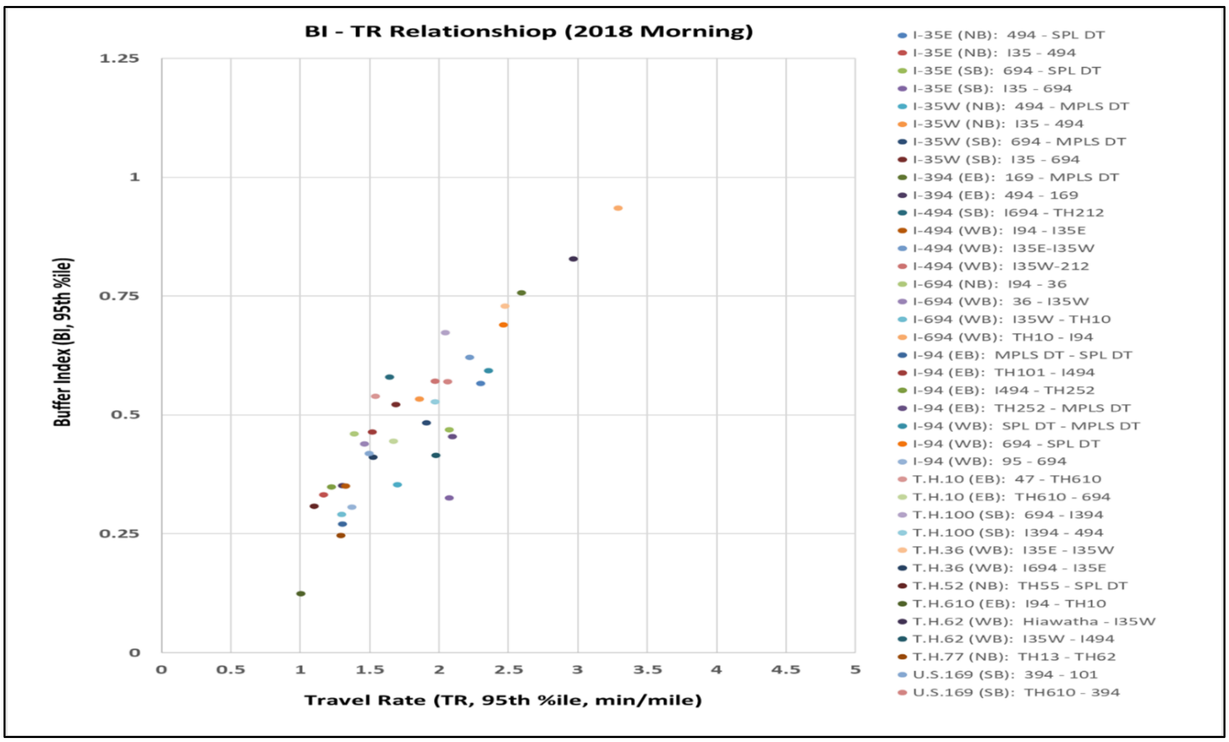


Figure 3.3.2 BI-TR Relationship - 2018 Morning Routes

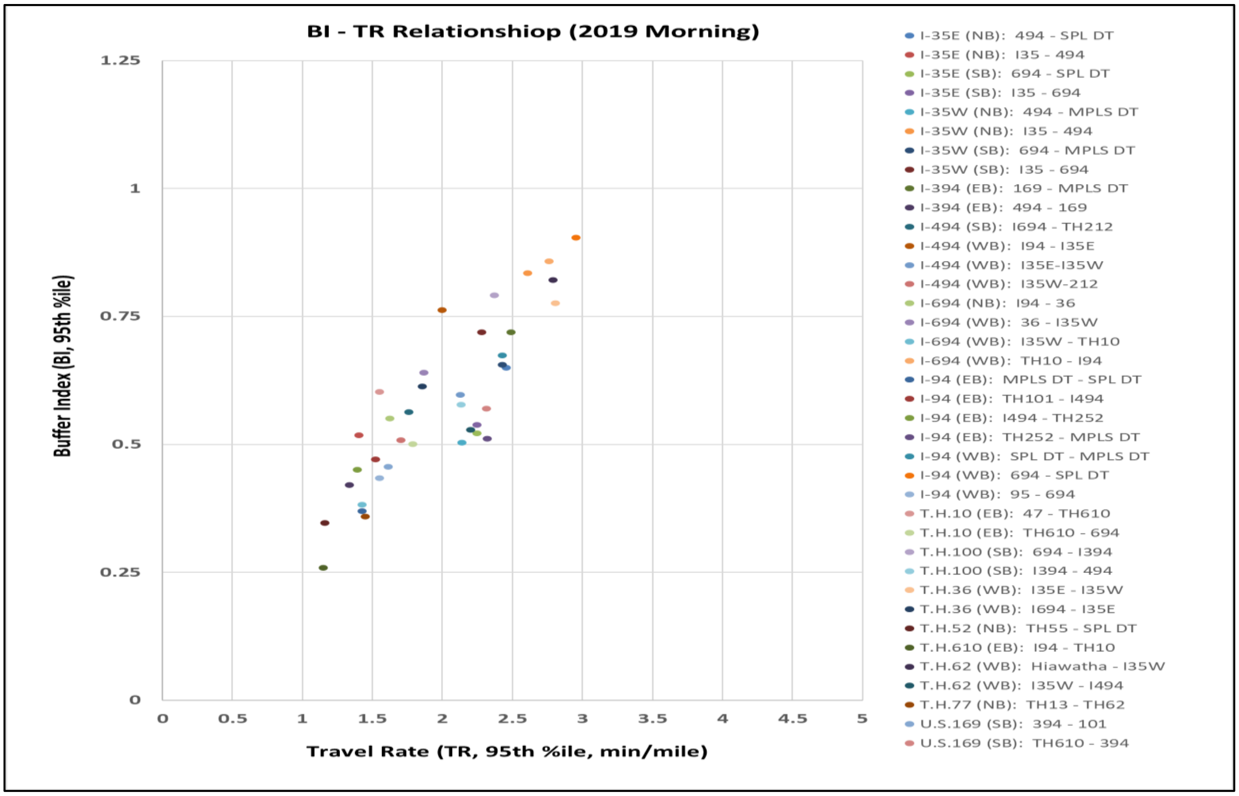


Figure 3.3.3 BI-TR Relationship - 2019 Morning Routes

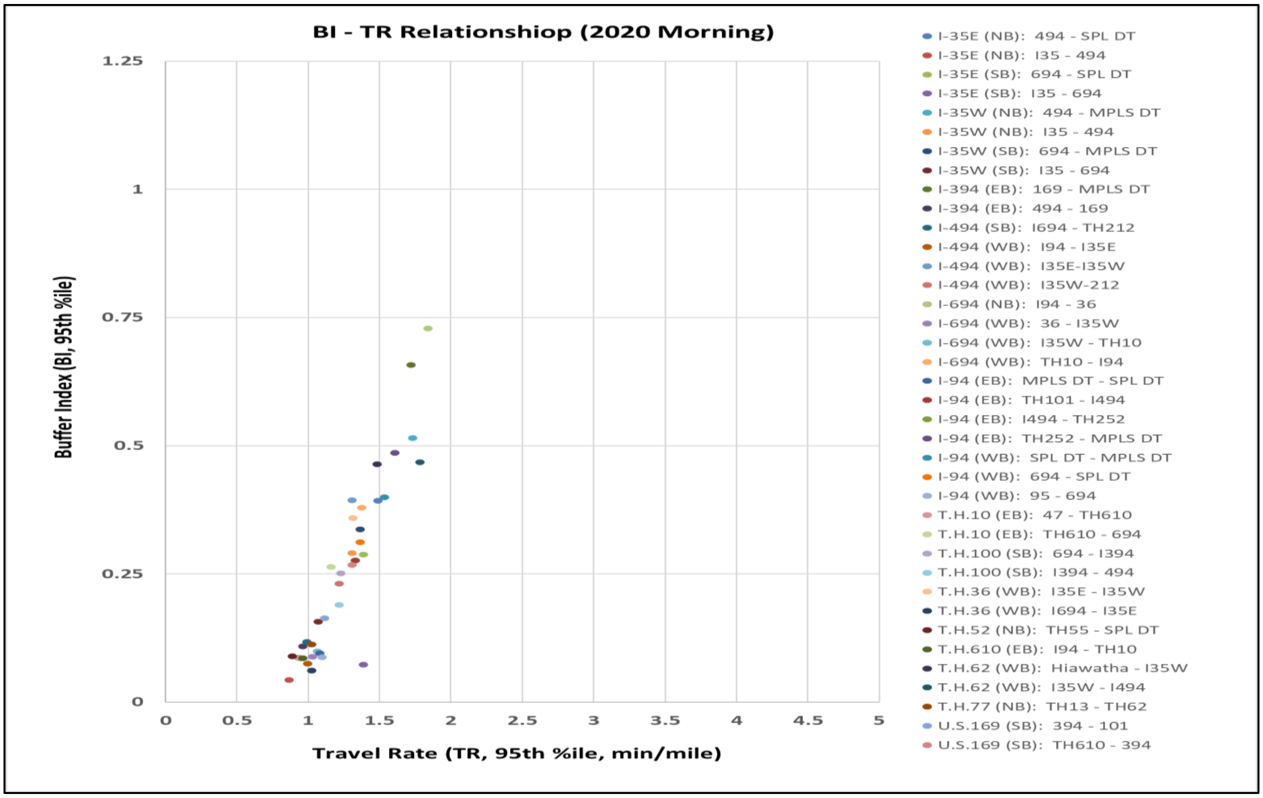


Figure 3.3.4 BI-TR Relationship - 2020 Morning Routes

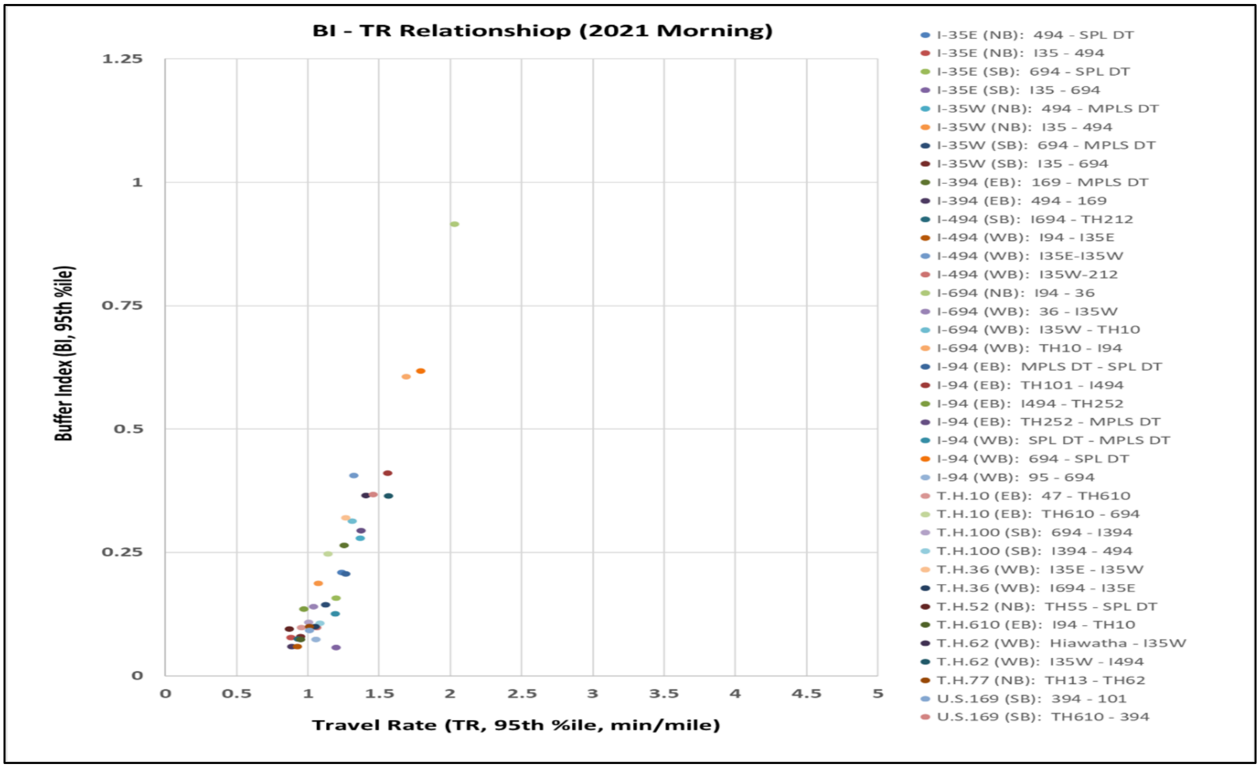


Figure 3.3.5 BI-TR Relationship - 2021 Morning Routes

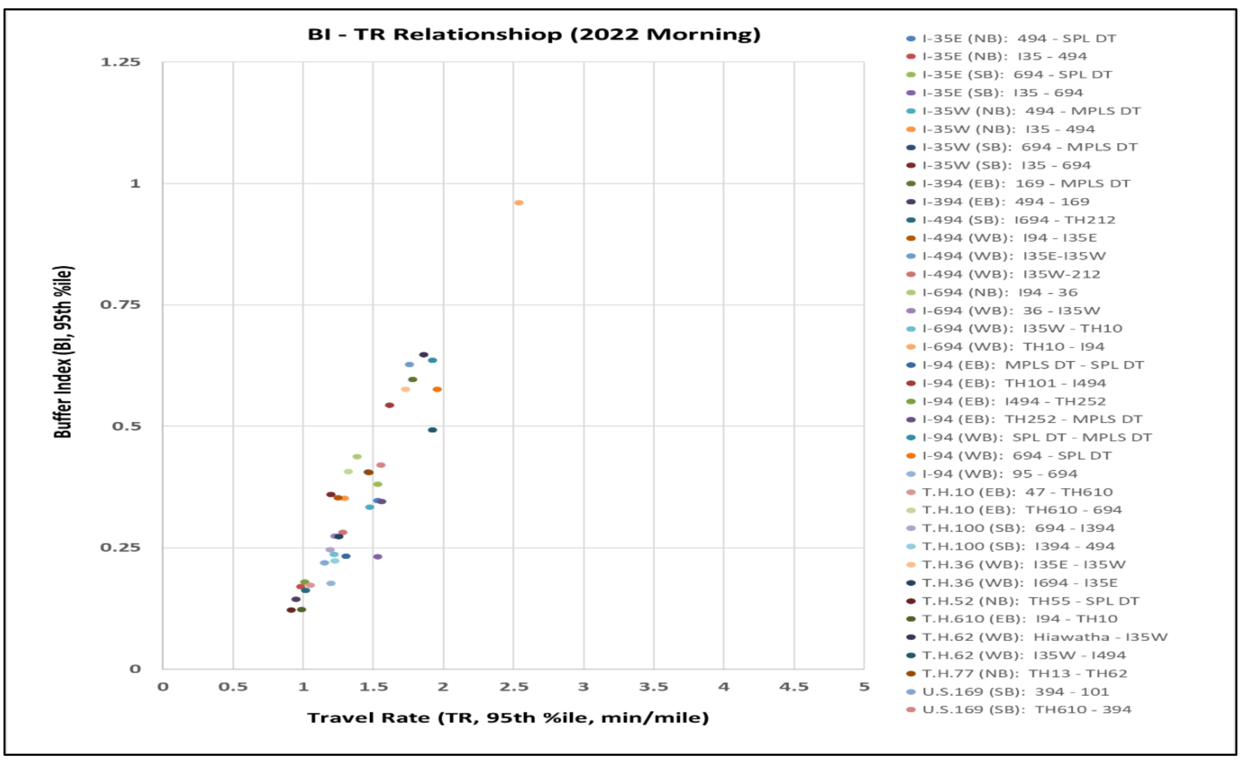


Figure 3.3.6 BI-TR Relationship - 2022 Morning Routes

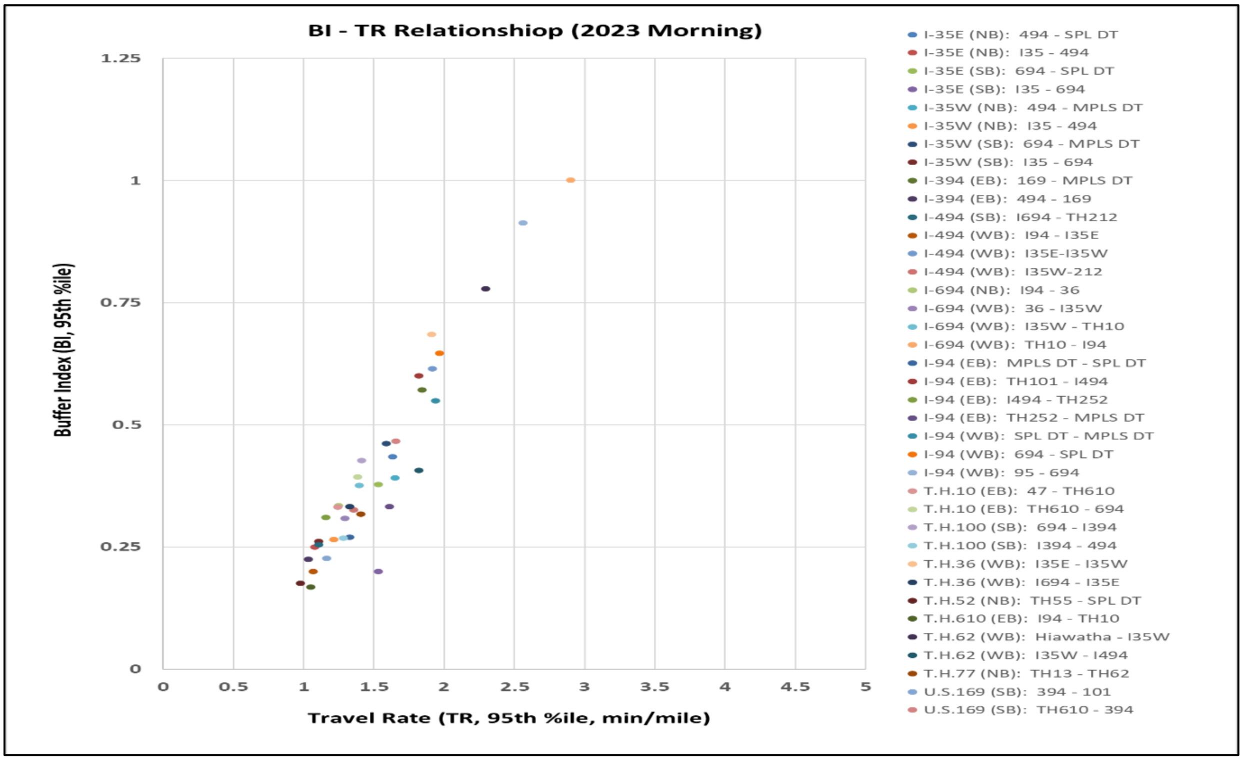


Figure 3.3.7 BI-TR Relationship - 2023 Morning Routes

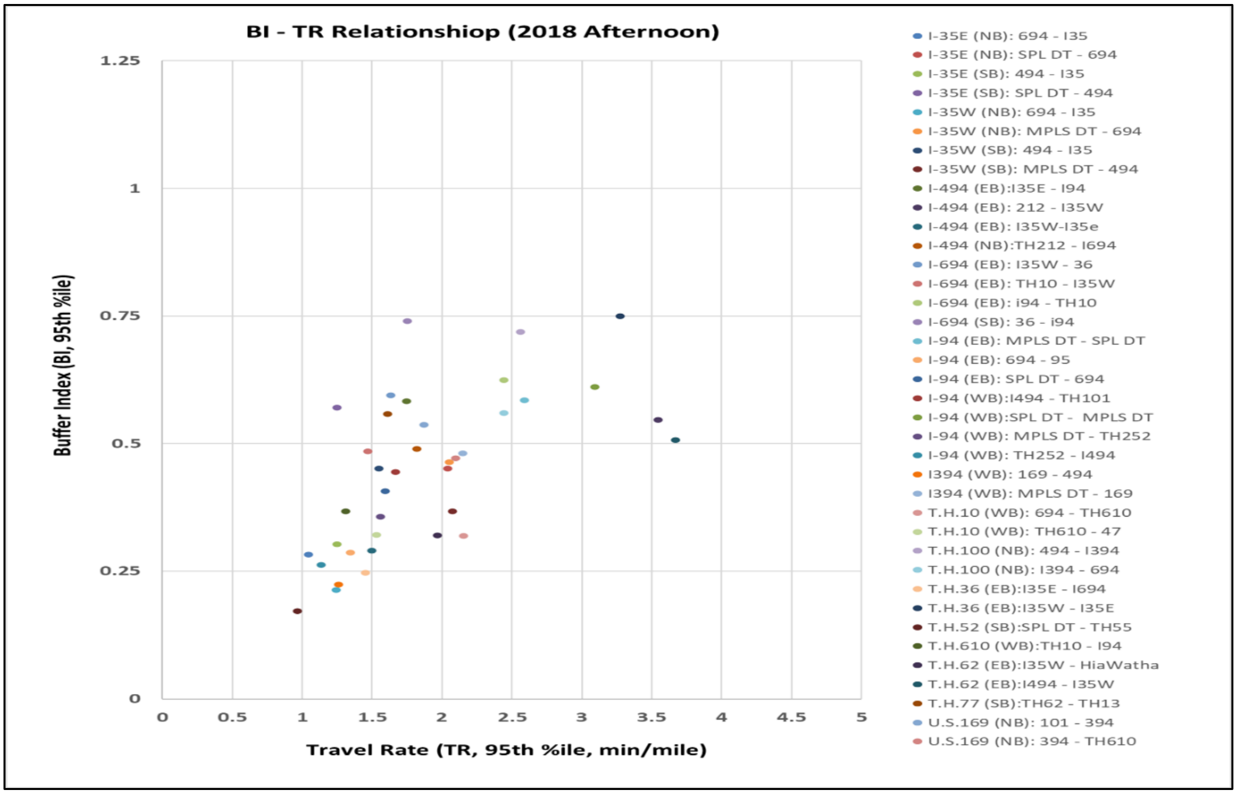


Figure 3.3.8 BI-TR Relationships – 2018 Afternoon Routes

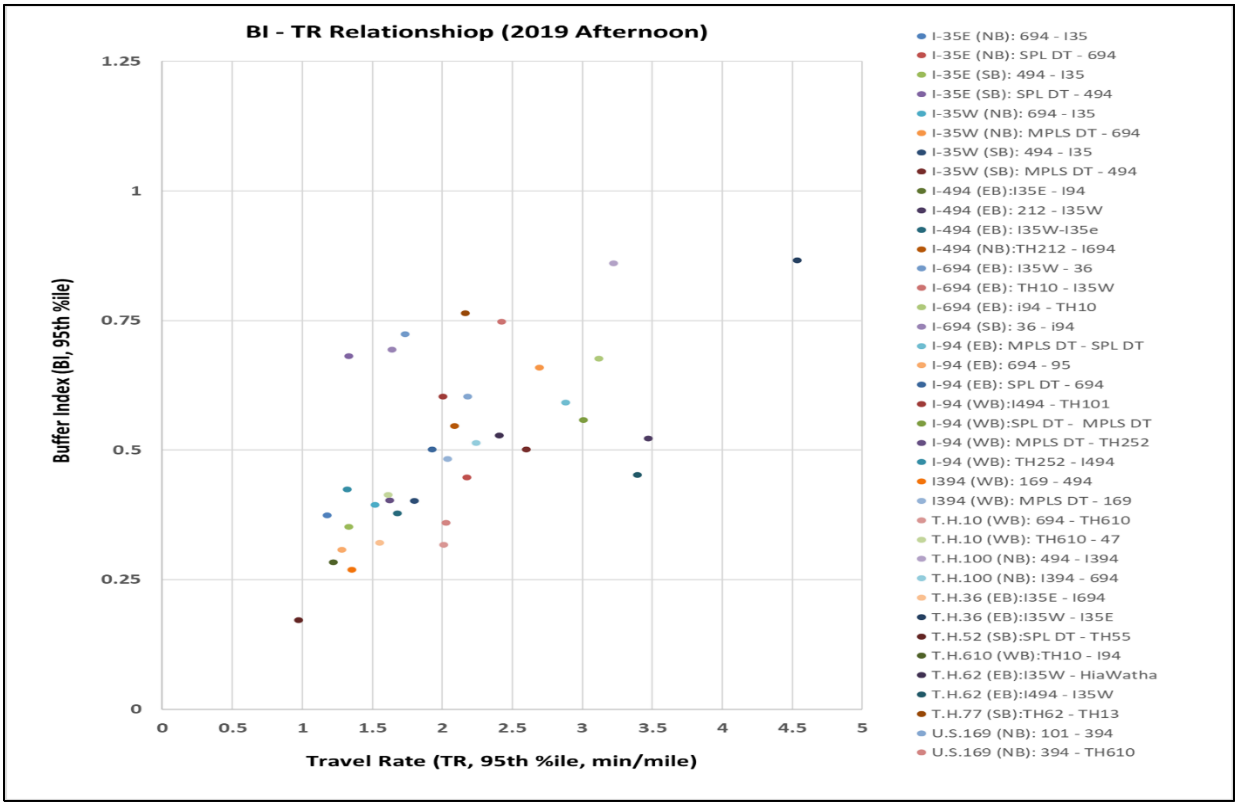


Figure 3.3.9 BI-TR Relationships – 2019 Afternoon Routes

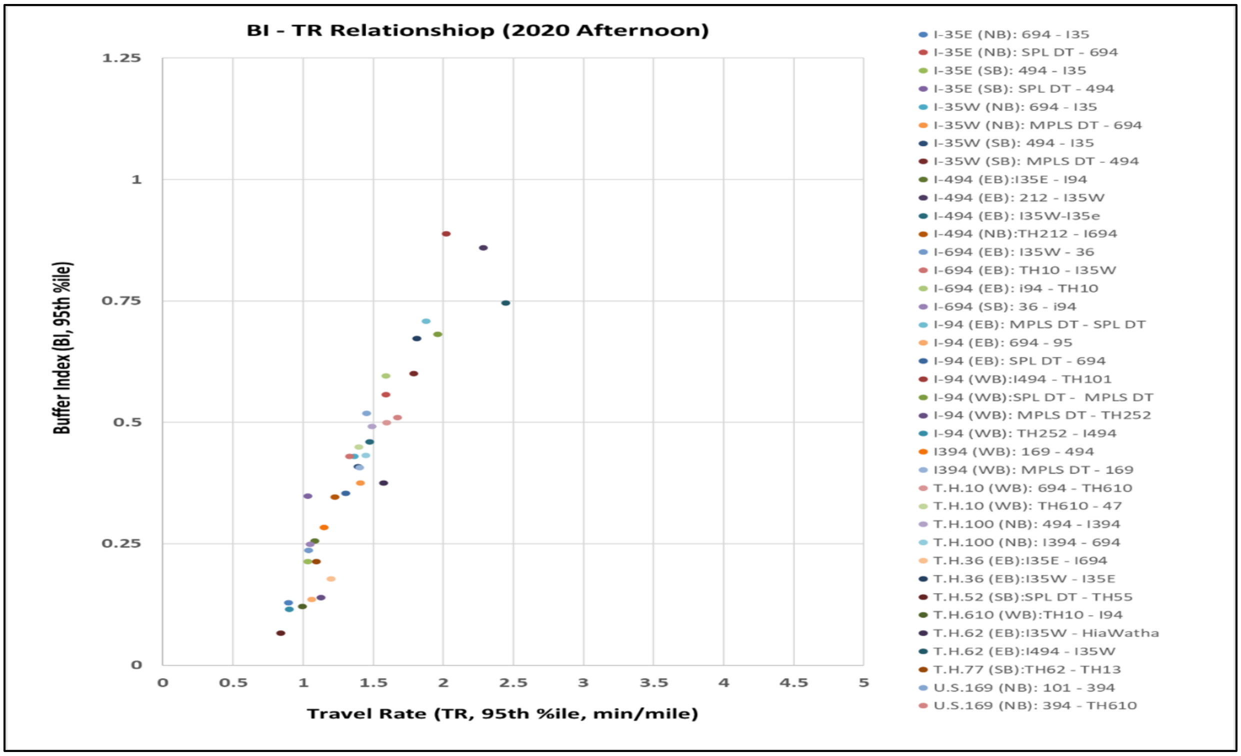


Figure 3.3.10 BI-TR Relationships – 2020 Afternoon Routes

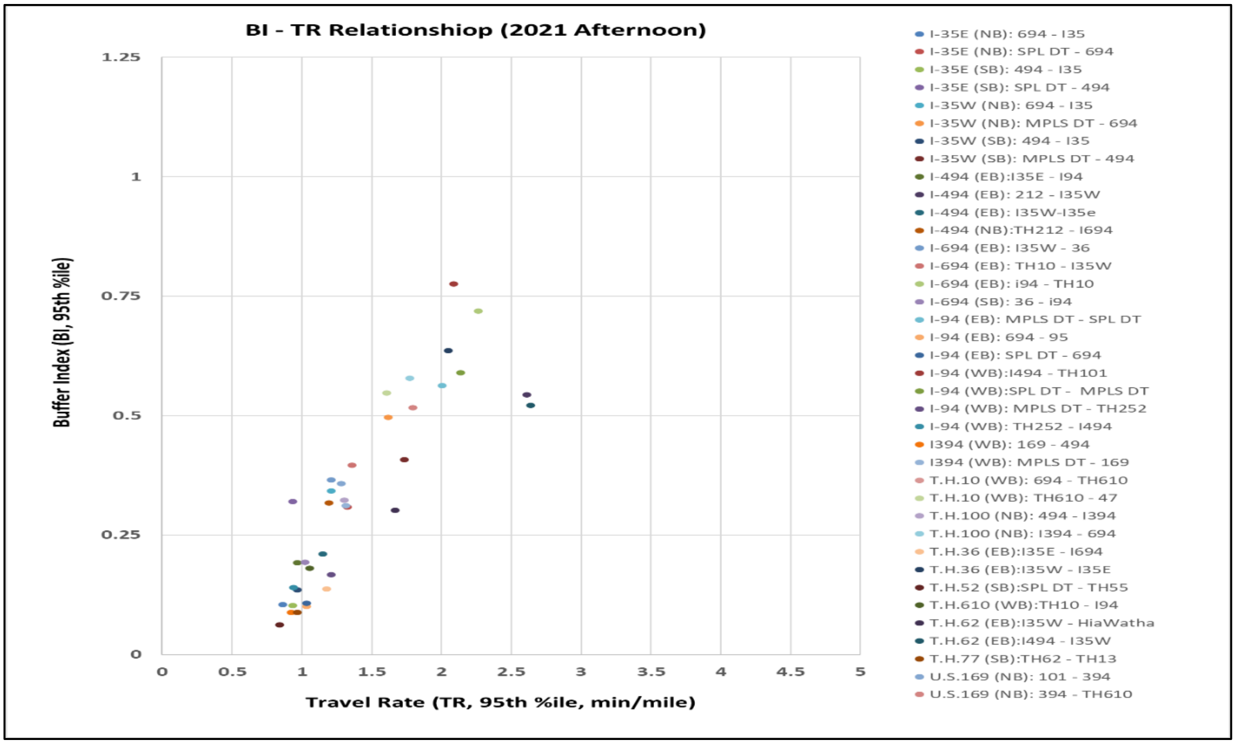


Figure 3.3.11 BI-TR Relationships – 2021 Afternoon Routes

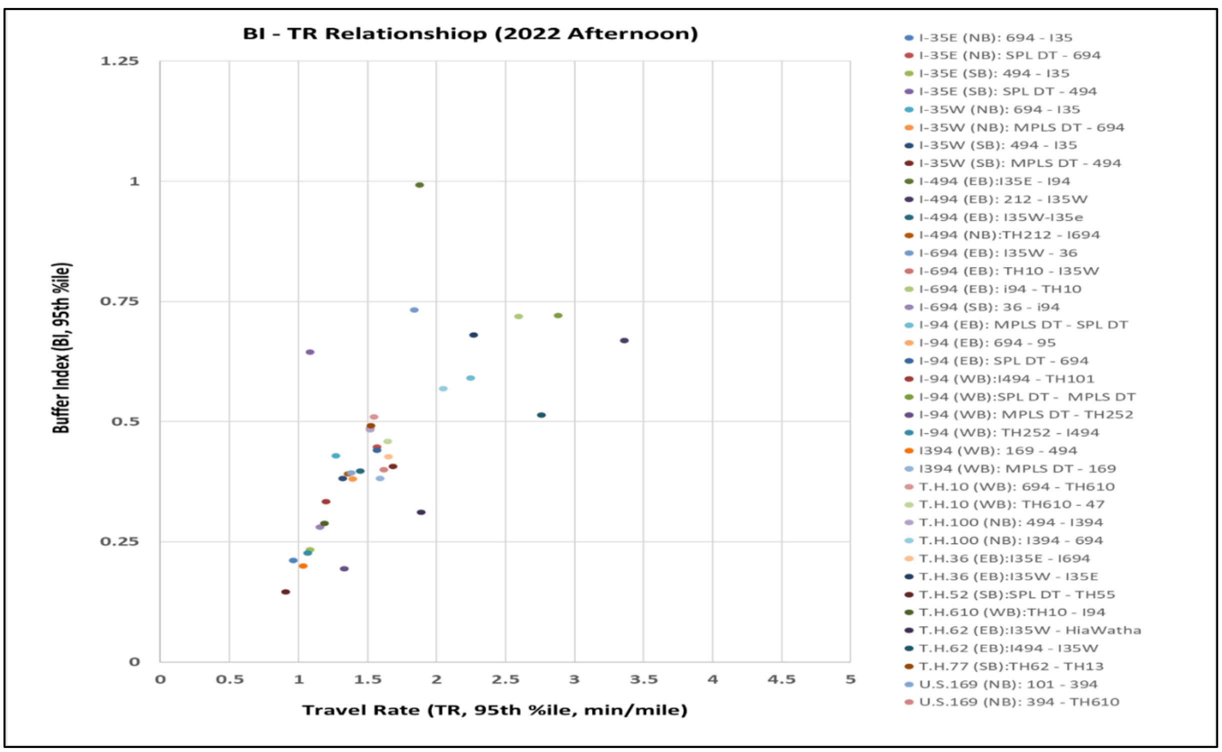


Figure 3.3.12 BI-TR Relationships – 2022 Afternoon Routes

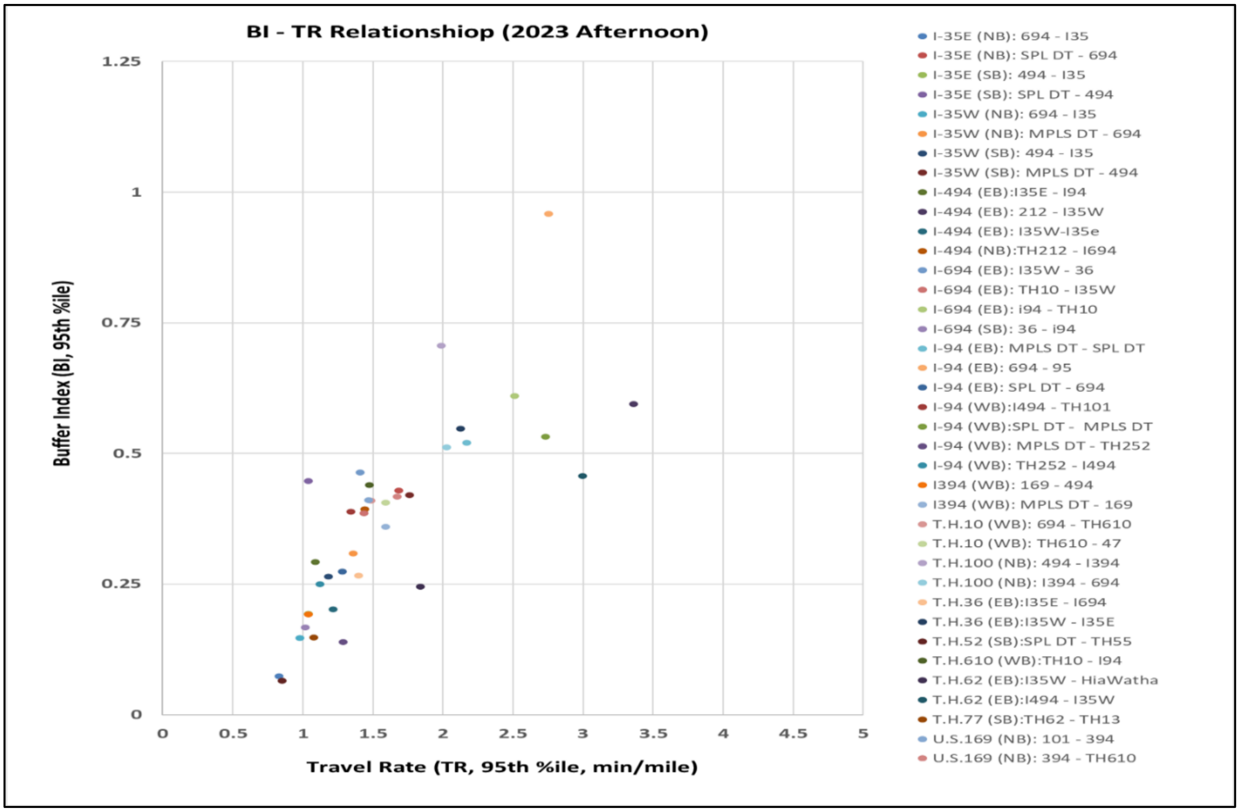


Figure 3.3.13 BI-TR Relationships - 2023 Afternoon Routes

Table 3.3.1 Yearly BI-TR and VI Levels for Morning Routes (2018-2020)

2018 Morning				2019 Morning				2020 Morning			
Route	BI	TR	VI Level	Route	BI	TR	VI Level	Route	BI	TR	VI Level
I-394 (EB): 169 - MPLS DT	0.76	2.59	4	I-35W (NB): I35 - 494	0.83	2.61	4	I-35W (NB): 494 - MPLS DT	0.52	1.73	3
I-694 (WB): TH10 - I94	0.76	3.29	4	I-494 (WB): I94 - I35E	0.76	1.99	4	I-394 (EB): 169 - MPLS DT	0.66	1.72	3
T.H.62 (WB): Hiawatha - I35W	0.76	2.97	4	I-694 (WB): TH10 - I94	0.86	2.76	4	I-694 (NB): I94 - 36	0.73	1.84	3
I-35E (NB): 494 - SPL DT	0.76	2.3	3	I-94 (WB): 694 - SPL DT	0.9	2.95	4	I-35E (NB): 494 - SPL DT	0.39	1.49	2
I-35E (SB): 694 - SPL DT	0.76	2.07	3	T.H.100 (SB): 694 - I394	0.79	2.37	4	I-35E (SB): 694 - SPL DT	0.29	1.38	2
I-35W (NB): I35 - 494	0.76	1.86	3	T.H.36 (WB): I35E - I35W	0.78	2.81	4	I-35W (NB): I35 - 494	0.29	1.31	2
I-35W (SB): I35 - 694	0.76	1.69	3	T.H.62 (WB): Hiawatha - I35W	0.82	2.79	4	I-35W (SB): 694 - MPLS DT	0.34	1.37	2
I-494 (SB): I694 - TH212	0.76	1.64	3	I-35E (NB): 494 - SPL DT	0.65	2.46	3	I-35W (SB): I35 - 694	0.16	1.07	2
I-494 (WB): I35e-I35W	0.76	2.22	3	I-35E (NB): I35 - 494	0.52	1.4	3	I-494 (WB): I35e-I35W	0.39	1.31	2
I-494 (WB): I35W-212	0.76	1.97	3	I-35E (SB): 694 - SPL DT	0.52	2.24	3	I-494 (WB): I35W-212	0.23	1.22	2
I-94 (EB): TH252 - MPLS DT	0.76	2.09	3	I-35E (SB): I35 - 694	0.54	1.43	3	I-694 (WB): 36 - I35W	0.09	1.03	2
I-94 (WB): SPL DT - MPLS DT	0.76	2.36	3	I-35W (NB): 494 - MPLS DT	0.5	2.14	3	I-694 (WB): I35W - TH10	0.10	1.06	2
I-94 (WB): 694 - SPL DT	0.76	2.46	3	I-35W (SB): 694 - MPLS DT	0.66	2.43	3	I-694 (WB): TH10 - I94	0.38	1.38	2
T.H.10 (EB): 47 - TH610	0.76	1.54	3	I-35W (SB): I35 - 694	0.72	2.28	3	I-94 (EB): MPLS DT - SPL DT	0.10	1.08	2
T.H.100 (SB): 694 - I394	0.76	2.05	3	I-394 (EB): 169 - MPLS DT	0.72	2.49	3	I-94 (EB): TH101 - I494	0.28	1.33	2
T.H.100 (SB): I394 - 494	0.76	1.97	3	I-494 (SB): I694 - TH212	0.56	1.76	3	I-94 (EB): TH252 - MPLS DT	0.49	1.61	2
T.H.36 (WB): I35E - I35W	0.76	2.47	3	I-494 (WB): I35e-I35W	0.6	2.13	3	I-94 (WB): SPL DT - MPLS DT	0.40	1.53	2
U.S.169 (SB): TH610 - 394	0.76	2.06	3	I-494 (WB): I35W-212	0.51	1.7	3	I-94 (WB): 694 - SPL DT	0.31	1.36	2
I-35E (NB): I35 - 494	0.76	1.17	2	I-694 (NB): I94 - 36	0.55	1.63	3	I-94 (WB): 95 - 694	0.09	1.10	2
I-35E (SB): I35 - 694	0.76	1.16	2	I-694 (WB): 36 - I35W	0.64	1.87	3	T.H.10 (EB): TH610 - 694	0.26	1.16	2
I-35W (NB): 494 - MPLS DT	0.76	1.7	2	I-94 (EB): TH252 - MPLS DT	0.51	2.32	3	T.H.100 (SB): 694 - I394	0.25	1.23	2
I-35W (SB): 694 - MPLS DT	0.76	1.91	2	I-94 (WB): SPL DT - MPLS DT	0.67	2.43	3	T.H.100 (SB): I394 - 494	0.19	1.22	2
I-394 (EB): 494 - 169	0.76	1.3	2	T.H.10 (EB): 47 - TH610	0.6	1.55	3	T.H.36 (WB): I35E - I35W	0.36	1.31	2
I-494 (WB): I94 - I35E	0.76	1.33	2	T.H.10 (EB): TH610 - 694	0.5	1.79	3	T.H.36 (WB): I694 - I35E	0.06	1.03	2
I-694 (NB): I94 - 36	0.76	1.39	2	T.H.100 (SB): I394 - 494	0.58	2.13	3	T.H.62 (WB): Hiawatha - I35W	0.46	1.48	2

I-694 (WB): 36 - I35W	0.76	1.46	2	T.H.36 (WB): I694 - I35E	0.61	1.86	3	T.H.62 (WB): I35W - I494	0.47	1.78	2
I-694 (WB): I35W - TH10	0.76	1.3	2	T.H.62 (WB): I35W - I494	0.53	2.2	3	T.H.77 (NB): TH13 - TH62	0.11	1.02	2
I-94 (EB): MPLS DT - SPL DT	0.76	1.3	2	U.S.169 (SB): TH610 - 394	0.57	2.31	3	U.S.169 (SB): 394 - 101	0.16	1.11	2
I-94 (EB): TH101 - I494	0.76	1.52	2	I-394 (EB): 494 - 169	0.42	1.34	2	U.S.169 (SB): TH610 - 394	0.27	1.31	2
I-94 (EB): I494 - TH252	0.76	1.22	2	I-694 (WB): I35W - TH10	0.38	1.43	2	I-35E (NB): I35 - 494	0.04	0.86	1
I-94 (WB): 95 - 694	0.76	1.37	2	I-94 (EB): MPLS DT - SPL DT	0.37	1.42	2	I-35E (SB): I35 - 694	0.07	0.85	1
T.H.10 (EB): TH610 - 694	0.76	1.67	2	I-94 (EB): TH101 - I494	0.47	1.52	2	I-394 (EB): 494 - 169	0.11	0.96	1
T.H.36 (WB): I694 - I35E	0.76	1.52	2	I-94 (EB): I494 - TH252	0.45	1.39	2	I-494 (SB): I694 - TH212	0.12	0.99	1
T.H.52 (NB): TH55 - SPL DT	0.76	1.1	2	I-94 (WB): 95 - 694	0.43	1.55	2	I-494 (WB): I94 - I35E	0.08	0.99	1
T.H.610 (EB): I94 - TH10	0.76	1	2	T.H.52 (NB): TH55 - SPL DT	0.35	1.16	2	I-94 (EB): I494 - TH252	0.09	0.93	1
T.H.62 (WB): I35W - I494	0.76	1.98	2	T.H.610 (EB): I94 - TH10	0.26	1.15	2	T.H.10 (EB): 47 - TH610	0.09	0.94	1
T.H.77 (NB): TH13 - TH62	0.76	1.29	2	T.H.77 (NB): TH13 - TH62	0.36	1.45	2	T.H.52 (NB): TH55 - SPL DT	0.09	0.89	1
U.S.169 (SB): 394 - 101	0.76	1.5	2	U.S.169 (SB): 394 - 101	0.46	1.61	2	T.H.610 (EB): I94 - TH10	0.09	0.96	1

Table 3.3.2 Yearly BI-TR and VI Levels for Morning Routes (2021-2023)

2021 Morning				2022 Morning				2023 Morning			
Route	**BI**	**TR**	**VI Level**	**Route**	**BI**	**TR**	**VI Level**	**Route**	**BI**	**TR**	**VI Level**
I-694 (NB): I94 - 36	0.91	2.03	4	I-694 (WB): TH10 - I94	0.96	2.54	4	I-694 (WB): TH10 - I94	1.00	2.90	5
I-694 (WB): TH10 - I94	0.61	1.69	3	I-394 (EB): 169 - MPLS DT	0.60	1.78	3	I-94 (WB): 95 - 694	0.91	2.56	4
I-94 (WB): 694 - SPL DT	0.62	1.79	3	I-494 (WB): I35e-I35W	0.63	1.76	3	T.H.62 (WB): Hiawatha - I35W	0.78	2.29	4
I-35E (NB): 494 - SPL DT	0.21	1.24	2	I-94 (EB): TH101 - I494	0.54	1.61	3	I-394 (EB): 169 - MPLS DT	0.57	1.84	3
I-35E (SB): 694 - SPL DT	0.16	1.20	2	I-94 (WB): SPL DT - MPLS DT	0.64	1.92	3	I-494 (WB): I35e-I35W	0.61	1.91	3
I-35W (NB): 494 - MPLS DT	0.28	1.37	2	I-94 (WB): 694 - SPL DT	0.58	1.96	3	I-94 (EB): TH101 - I494	0.60	1.82	3
I-35W (NB): I35 - 494	0.19	1.08	2	T.H.36 (WB): I35E - I35W	0.58	1.73	3	I-94 (WB): SPL DT - MPLS DT	0.55	1.94	3
I-35W (SB): 694 - MPLS DT	0.14	1.12	2	T.H.62 (WB): Hiawatha - I35W	0.65	1.86	3	I-94 (WB): 694 - SPL DT	0.65	1.96	3
I-394 (EB): 169 - MPLS DT	0.26	1.26	2	I-35E (NB): 494 - SPL DT	0.35	1.53	2	T.H.36 (WB): I35E - I35W	0.68	1.91	3
I-494 (WB): I35e-I35W	0.41	1.32	2	I-35E (SB): 694 - SPL DT	0.38	1.53	2	I-35E (NB): 494 - SPL DT	0.43	1.63	2
I-494 (WB): I35W-212	0.10	1.06	2	I-35W (NB): 494 - MPLS DT	0.33	1.47	2	I-35E (NB): I35 - 494	0.25	1.08	2
I-694 (WB): 36 - I35W	0.14	1.04	2	I-35W (NB): I35 - 494	0.35	1.29	2	I-35E (SB): 694 - SPL DT	0.38	1.53	2

I-694 (WB): I35W - TH10	0.31	1.31	2	I-35W (SB): 694 - MPLS DT	0.41	1.46	2	I-35W (NB): 494 - MPLS DT	0.39	1.65	2
I-94 (EB): MPLS DT - SPL DT	0.21	1.26	2	I-35W (SB): I35 - 694	0.36	1.20	2	I-35W (NB): I35 - 494	0.26	1.21	2
I-94 (EB): TH101 - I494	0.41	1.56	2	I-494 (SB): I694 - TH212	0.16	1.02	2	I-35W (SB): 694 - MPLS DT	0.46	1.59	2
I-94 (EB): TH252 - MPLS DT	0.29	1.37	2	I-494 (WB): I94 - I35E	0.35	1.25	2	I-35W (SB): I35 - 694	0.26	1.11	2
I-94 (WB): SPL DT - MPLS DT	0.13	1.19	2	I-494 (WB): I35W-212	0.28	1.28	2	I-394 (EB): 494 - 169	0.22	1.03	2
I-94 (WB): 95 - 694	0.07	1.05	2	I-694 (NB): I94 - 36	0.44	1.38	2	I-494 (SB): I694 - TH212	0.25	1.11	2
T.H.10 (EB): TH610 - 694	0.25	1.14	2	I-694 (WB): 36 - I35W	0.27	1.23	2	I-494 (WB): I94 - I35E	0.20	1.07	2
T.H.100 (SB): 694 - I394	0.11	1.01	2	I-694 (WB): I35W - TH10	0.24	1.22	2	I-494 (WB): I35W-212	0.33	1.36	2
T.H.100 (SB): I394 - 494	0.11	1.09	2	I-94 (EB): MPLS DT - SPL DT	0.23	1.30	2	I-694 (NB): I94 - 36	0.33	1.25	2
T.H.36 (WB): I35E - I35W	0.32	1.27	2	I-94 (EB): I494 - TH252	0.18	1.01	2	I-694 (WB): 36 - I35W	0.31	1.29	2
T.H.36 (WB): I694 - I35E	0.10	1.05	2	I-94 (EB): TH252 - MPLS DT	0.35	1.56	2	I-694 (WB): I35W - TH10	0.38	1.39	2
T.H.62 (WB): Hiawatha - I35W	0.37	1.41	2	I-94 (WB): 95 - 694	0.18	1.20	2	I-94 (EB): MPLS DT - SPL DT	0.27	1.33	2
T.H.62 (WB): I35W - I494	0.36	1.57	2	T.H.10 (EB): 47 - TH610	0.17	1.05	2	I-94 (EB): I494 - TH252	0.31	1.16	2
T.H.77 (NB): TH13 - TH62	0.10	1.01	2	T.H.10 (EB): TH610 - 694	0.41	1.32	2	I-94 (EB): TH252 - MPLS DT	0.33	1.61	2
U.S.169 (SB): 394 - 101	0.09	1.01	2	T.H.100 (SB): 694 - I394	0.25	1.19	2	T.H.10 (EB): 47 - TH610	0.33	1.24	2
U.S.169 (SB): TH610 - 394	0.37	1.46	2	T.H.100 (SB): I394 - 494	0.22	1.23	2	T.H.10 (EB): TH610 - 694	0.39	1.38	2
I-35E (NB): I35 - 494	0.08	0.88	1	T.H.36 (WB): I694 - I35E	0.27	1.25	2	T.H.100 (SB): 694 - I394	0.43	1.41	2
I-35E (SB): I35 - 694	0.06	0.83	1	T.H.62 (WB): I35W - I494	0.49	1.92	2	T.H.100 (SB): I394 - 494	0.27	1.28	2
I-35W (SB): I35 - 694	0.08	0.95	1	T.H.77 (NB): TH13 - TH62	0.41	1.47	2	T.H.36 (WB): I694 - I35E	0.33	1.33	2
I-394 (EB): 494 - 169	0.06	0.89	1	U.S.169 (SB): 394 - 101	0.22	1.15	2	T.H.610 (EB): I94 - TH10	0.17	1.05	2
I-494 (SB): I694 - TH212	0.07	0.93	1	U.S.169 (SB): TH610 - 394	0.42	1.55	2	T.H.62 (WB): I35W - I494	0.41	1.82	2
I-494 (WB): I94 - I35E	0.06	0.93	1	I-35E (NB): I35 - 494	0.17	0.98	1	T.H.77 (NB): TH13 - TH62	0.32	1.41	2
I-94 (EB): I494 - TH252	0.14	0.97	1	I-35E (SB): I35 - 694	0.23	0.99	1	U.S.169 (SB): 394 - 101	0.23	1.16	2
T.H.10 (EB): 47 - TH610	0.10	0.95	1	I-394 (EB): 494 - 169	0.14	0.95	1	U.S.169 (SB): TH610 - 394	0.47	1.65	2
T.H.52 (NB): TH55 - SPL DT	0.09	0.87	1	T.H.52 (NB): TH55 - SPL DT	0.12	0.91	1	I-35E (SB): I35 - 694	0.20	0.98	1
T.H.610 (EB): I94 - TH10	0.07	0.95	1	T.H.610 (EB): I94 - TH10	0.12	0.99	1	T.H.52 (NB): TH55 - SPL DT	0.18	0.98	1

Table 3.3.3 Yearly BI-TR and VI Levels for Afternoon Routes (2018-2020)

2018 Afternoon				2019 Afternoon				2020 Afternoon			
Route	BI	TR	VI Level	Route	BI	TR	VI Level	Route	BI	TR	VI Level
I-494 (EB): 212 - I35W	0.55	3.55	4	T.H.36 (EB):I35W - I35E	0.87	4.53	5	I-494 (EB): 212 - I35W	0.86	2.28	4
I-94 (WB):SPL DT - MPLS DT	0.61	3.09	4	I-494 (EB):I35E - I94	1.25	3.23	4	I-94 (WB):I494 - TH101	0.89	2.02	4
T.H.36 (EB):I35W - I35E	0.75	3.28	4	I-494 (EB): 212 - I35W	0.52	3.47	4	T.H.62 (EB):I494 - I35W	0.75	2.44	4
T.H.62 (EB):I494 - I35W	0.51	3.67	4	I-694 (EB): i94 - TH10	0.68	3.12	4	I-35E (NB): SPL DT - 694	0.56	1.59	3
I-35E (NB): SPL DT - 694	0.45	2.04	3	I-94 (WB):SPL DT - MPLS DT	0.56	3.01	4	I-35W (SB): MPLS DT - 494	0.60	1.79	3
I-35E (SB): SPL DT - 494	0.57	2.35	3	T.H.100 (NB): 494 - I394	0.86	3.22	4	I-694 (EB): i94 - TH10	0.60	1.59	3
I-35W (NB): MPLS DT - 694	0.46	2.05	3	T.H.62 (EB):I494 - I35W	0.45	3.39	4	I-94 (EB): MPLS DT - SPL DT	0.71	1.88	3
I-35W (SB): MPLS DT - 494	0.37	2.07	3	T.H.77 (SB):TH62 - TH13	0.76	2.17	4	I-94 (WB):SPL DT - MPLS DT	0.68	1.96	3
I-494 (EB):I35E - I94	0.58	1.75	3	I-35E (NB): SPL DT - 694	0.45	2.18	3	T.H.36 (EB):I35W - I35E	0.67	1.81	3
I-694 (EB): I35W - 36	0.59	1.63	3	I-35E (SB): SPL DT - 494	0.68	2.55	3	U.S.169 (NB): 101 - 394	0.52	1.45	3
I-694 (EB): i94 - TH10	0.62	2.44	3	I-35W (NB): MPLS DT - 694	0.66	2.69	3	U.S.169 (NB): 394 - TH610	0.51	1.67	3
I-694 (SB): 36 - i94	0.74	1.75	3	I-35W (SB): MPLS DT - 494	0.50	2.60	3	I-35E (SB): 494 - I35	0.21	1.03	2
I-94 (EB): MPLS DT - SPL DT	0.58	2.59	3	I-494 (NB):TH212 - I694	0.55	2.09	3	I-35E (SB): SPL DT - 494	0.35	1.38	2
I394 (WB): MPLS DT - 169	0.48	2.15	3	I-694 (EB): I35W - 36	0.72	1.73	3	I-35W (NB): 694 - I35	0.43	1.37	2
T.H.10 (WB): 694 - TH610	0.32	2.15	3	I-694 (EB): TH10 - I35W	0.75	2.42	3	I-35W (NB): MPLS DT - 694	0.38	1.41	2
T.H.100 (NB): 494 - I394	0.72	2.56	3	I-694 (SB): 36 - i94	0.69	1.64	3	I-35W (SB): 494 - I35	0.41	1.39	2
T.H.100 (NB): I394 - 694	0.56	2.44	3	I-94 (EB): MPLS DT - SPL DT	0.59	2.88	3	I-494 (EB):I35E - I94	0.26	1.08	2
T.H.77 (SB):TH62 - TH13	0.56	1.61	3	I-94 (EB): SPL DT - 694	0.50	1.93	3	I-494 (EB): I35W-I35e	0.46	1.47	2
U.S.169 (NB): 101 - 394	0.54	1.87	3	I-94 (WB):I494 - TH101	0.60	2.00	3	I-494 (NB):TH212 - I694	0.35	1.23	2
U.S.169 (NB): 394 - TH610	0.47	2.10	3	I394 (WB): MPLS DT - 169	0.48	2.04	3	I-694 (EB): I35W - 36	0.24	1.04	2
I-35E (NB): 694 - I35	0.28	1.05	2	T.H.10 (WB): 694 - TH610	0.32	2.01	3	I-694 (EB): TH10 - I35W	0.43	1.33	2
I-35E (SB): 494 - I35	0.30	1.25	2	T.H.100 (NB): I394 - 694	0.51	2.24	3	I-694 (SB): 36 - i94	0.25	1.05	2
I-35W (NB): 694 - I35	0.21	1.24	2	T.H.62 (EB):I35W - HiaWatha	0.53	2.41	3	I-94 (EB): 694 - 95	0.14	1.06	2
I-35W (SB): 494 - I35	0.45	1.55	2	U.S.169 (NB): 101 - 394	0.60	2.18	3	I-94 (EB): SPL DT - 694	0.35	1.30	2
I-494 (EB): I35W-I35e	0.29	1.50	2	U.S.169 (NB): 394 - TH610	0.36	2.03	3	I-94 (WB): MPLS DT - TH252	0.14	1.13	2
I-494 (NB):TH212 - I694	0.49	1.82	2	I-35E (NB): 694 - I35	0.37	1.18	2	I394 (WB): 169 - 494	0.28	1.15	2
I-694 (EB): TH10 - I35W	0.48	1.47	2	I-35E (SB): 494 - I35	0.35	1.33	2	I394 (WB): MPLS DT - 169	0.41	1.41	2

I-94 (EB): 694 - 95	0.29	1.35	2	I-35W (NB): 694 - I35	0.39	1.52	2	T.H.10 (WB): 694 - TH610	0.50	1.60	2
I-94 (EB): SPL DT - 694	0.41	1.59	2	I-35W (SB): 494 - I35	0.40	1.80	2	T.H.10 (WB): TH610 - 47	0.45	1.40	2
I-94 (WB):I494 - TH101	0.44	1.67	2	I-494 (EB): I35W-I35e	0.38	1.68	2	T.H.100 (NB): 494 - I394	0.49	1.49	2
I-94 (WB): MPLS DT - TH252	0.36	1.56	2	I-94 (EB): 694 - 95	0.31	1.28	2	T.H.100 (NB): I394 - 694	0.43	1.45	2
I-94 (WB): TH252 - I494	0.26	1.14	2	I-94 (WB): MPLS DT - TH252	0.40	1.62	2	T.H.36 (EB):I35E - I694	0.18	1.20	2
I394 (WB): 169 - 494	0.22	1.26	2	I-94 (WB): TH252 - I494	0.42	1.32	2	T.H.62 (EB):I35W - HiaWatha	0.37	1.57	2
T.H.10 (WB): TH610 - 47	0.32	1.53	2	I394 (WB): 169 - 494	0.27	1.35	2	T.H.77 (SB):TH62 - TH13	0.21	1.10	2
T.H.36 (EB):I35E - I694	0.25	1.45	2	T.H.10 (WB): TH610 - 47	0.41	1.61	2	I-35E (NB): 694 - I35	0.13	0.90	1
T.H.610 (WB):TH10 - I94	0.37	1.31	2	T.H.36 (EB):I35E - I694	0.32	1.55	2	I-94 (WB): TH252 - I494	0.11	0.90	1
T.H.62 (EB):I35W - HiaWatha	0.32	1.97	2	T.H.610 (WB):TH10 - I94	0.28	1.22	2	T.H.52 (SB):SPL DT - TH55	0.07	0.84	1
T.H.52 (SB):SPL DT - TH55	0.17	0.96	1	T.H.52 (SB):SPL DT - TH55	0.17	0.97	1	T.H.610 (WB):TH10 - I94	0.12	1.00	1

Table 3.3.4 Yearly BI-TR and VI Levels for Afternoon Routes (2021-2023)

2021 Afternoon				2022 Afternoon				2023 Afternoon			
Route	BI	TR	VI Level	Route	BI	TR	VI Level	Route	BI	TR	VI Level
T.H.10 (WB): 694 - TH610	1.51	3.35	5	I-94 (EB): 694 - 95	1.60	3.46	5	I-494 (EB): 212 - I35W	0.59	3.36	4
I-494 (EB): 212 - I35W	0.54	2.61	3	I-494 (EB):I35E - I94	0.99	1.88	4	I-694 (EB): i94 - TH10	0.61	2.51	3
I-694 (EB): i94 - TH10	0.72	2.27	3	I-494 (EB): 212 - I35W	0.67	3.36	4	I-94 (EB): MPLS DT - SPL DT	0.52	2.17	3
I-94 (EB): MPLS DT - SPL DT	0.56	2.00	3	I-35E (SB): SPL DT - 494	0.64	1.97	3	I-94 (EB): 694 - 95	0.96	2.76	3
I-94 (WB):I494 - TH101	0.78	2.09	3	I-694 (EB): I35W - 36	0.73	1.84	3	I-94 (WB):SPL DT - MPLS DT	0.53	2.73	3
I-94 (WB):SPL DT - MPLS DT	0.59	2.14	3	I-694 (EB): i94 - TH10	0.72	2.59	3	T.H.100 (NB): 494 - I394	0.71	1.98	3
T.H.100 (NB): I394 - 694	0.58	1.77	3	I-94 (EB): MPLS DT - SPL DT	0.59	2.25	3	T.H.100 (NB): I394 - 694	0.51	2.03	3
T.H.36 (EB):I35W - I35E	0.64	2.05	3	I-94 (WB):SPL DT - MPLS DT	0.72	2.88	3	T.H.36 (EB):I35W - I35E	0.55	2.12	3
T.H.62 (EB):I494 - I35W	0.52	2.64	3	T.H.10 (WB): 694 - TH610	0.51	1.54	3	T.H.62 (EB):I494 - I35W	0.46	3.00	3
U.S.169 (NB): 394 - TH610	0.52	1.80	3	T.H.100 (NB): I394 - 694	0.57	2.05	3	I-35E (NB): SPL DT - 694	0.43	1.69	2
I-35E (NB): SPL DT - 694	0.31	1.33	2	T.H.36 (EB):I35W - I35E	0.68	2.27	3	I-35E (SB): 494 - I35	0.19	1.04	2
I-35E (SB): SPL DT - 494	0.32	1.43	2	T.H.62 (EB):I494 - I35W	0.51	2.76	3	I-35E (SB): SPL DT - 494	0.45	1.80	2
I-35W (NB): 694 - I35	0.34	1.21	2	I-35E (NB): SPL DT - 694	0.45	1.57	2	I-35W (NB): MPLS DT - 694	0.31	1.36	2
I-35W (NB): MPLS DT - 694	0.50	1.62	2	I-35E (SB): 494 - I35	0.23	1.08	2	I-35W (SB): 494 - I35	0.26	1.18	2
I-35W (SB): MPLS DT - 494	0.41	1.73	2	I-35W (NB): 694 - I35	0.43	1.27	2	I-35W (SB): MPLS DT - 494	0.42	1.76	2
I-494 (EB): I35W-I35e	0.21	1.15	2	I-35W (NB): MPLS DT - 694	0.38	1.39	2	I-494 (EB):I35E - I94	0.29	1.09	2
I-494 (NB):TH212 - I694	0.32	1.19	2	I-35W (SB): 494 - I35	0.38	1.32	2	I-494 (EB): I35W-I35e	0.2	1.22	2

I-694 (EB): I35W - 36	0.37	1.21	2	I-35W (SB): MPLS DT - 494	0.41	1.69	2	I-494 (NB):TH212 - I694	0.39	1.44	2
I-694 (EB): TH10 - I35W	0.40	1.36	2	I-494 (EB): I35W-I35e	0.40	1.45	2	I-694 (EB): I35W - 36	0.46	1.41	2
I-694 (SB): 36 - i94	0.19	1.02	2	I-494 (NB):TH212 - I694	0.39	1.36	2	I-694 (EB): TH10 - I35W	0.39	1.44	2
I-94 (EB): 694 - 95	0.10	1.03	2	I-694 (EB): TH10 - I35W	0.49	1.52	2	I-694 (SB): 36 - i94	0.17	1.02	2
I-94 (EB): SPL DT - 694	0.11	1.03	2	I-694 (SB): 36 - i94	0.28	1.16	2	I-94 (EB): SPL DT - 694	0.27	1.28	2
I-94 (WB): MPLS DT - TH252	0.17	1.21	2	I-94 (EB): SPL DT - 694	0.44	1.57	2	I-94 (WB):I494 - TH101	0.39	1.34	2
I394 (WB): MPLS DT - 169	0.31	1.31	2	I-94 (WB):I494 - TH101	0.33	1.20	2	I-94 (WB): MPLS DT - TH252	0.14	1.29	2
T.H.10 (WB): TH610 - 47	0.55	1.61	2	I-94 (WB): MPLS DT - TH252	0.19	1.33	2	I-94 (WB): TH252 - I494	0.25	1.12	2
T.H.100 (NB): 494 - I394	0.32	1.30	2	I-94 (WB): TH252 - I494	0.23	1.06	2	I394 (WB): 169 - 494	0.19	1.04	2
T.H.36 (EB):I35E - I694	0.14	1.18	2	I394 (WB): 169 - 494	0.20	1.03	2	I394 (WB): MPLS DT - 169	0.36	1.59	2
T.H.610 (WB):TH10 - I94	0.18	1.05	2	I394 (WB): MPLS DT - 169	0.38	1.59	2	T.H.10 (WB): 694 - TH610	0.41	1.48	2
T.H.62 (EB):I35W - HiaWatha	0.30	1.67	2	T.H.10 (WB): TH610 - 47	0.46	1.64	2	T.H.10 (WB): TH610 - 47	0.41	1.59	2
U.S.169 (NB): 101 - 394	0.36	1.28	2	T.H.100 (NB): 494 - I394	0.48	1.52	2	T.H.36 (EB):I35E - I694	0.27	1.40	2
I-35E (NB): 694 - I35	0.10	0.87	1	T.H.36 (EB):I35E - I694	0.43	1.65	2	T.H.610 (WB):TH10 - I94	0.44	1.47	2
I-35E (SB): 494 - I35	0.10	0.93	1	T.H.610 (WB):TH10 - I94	0.29	1.19	2	T.H.62 (EB):I35W - HiaWatha	0.25	1.84	2
I-35W (SB): 494 - I35	0.14	0.97	1	T.H.62 (EB):I35W - HiaWatha	0.31	1.89	2	T.H.77 (SB):TH62 - TH13	0.15	1.08	2
I-494 (EB):I35E - I94	0.19	0.97	1	T.H.77 (SB):TH62 - TH13	0.49	1.52	2	U.S.169 (NB): 101 - 394	0.41	1.47	2
I-94 (WB): TH252 - I494	0.14	0.94	1	U.S.169 (NB): 101 - 394	0.39	1.38	2	U.S.169 (NB): 394 - TH610	0.42	1.67	2
I394 (WB): 169 - 494	0.09	0.93	1	U.S.169 (NB): 394 - TH610	0.40	1.62	2	I-35E (NB): 694 - I35	0.07	0.83	1
T.H.52 (SB):SPL DT - TH55	0.06	0.84	1	I-35E (NB): 694 - I35	0.21	0.96	1	I-35W (NB): 694 - I35	0.15	0.98	1
T.H.77 (SB):TH62 - TH13	0.09	0.97	1	T.H.52 (SB):SPL DT - TH55	0.15	0.91	1	T.H.52 (SB):SPL DT - TH55	0.07	0.85	1

Table 3.3.5 Yearly Variations of Vulnerability Levels for Morning and Afternoon Routes

Morning							**Afternoon**						
	2018	**2019**	**2020**	**2021**	**2022**	**2023**		**2018**	**2019**	**2020**	**2021**	**2022**	**2023**
level 1	0	0	9	10	5	2	**level 1**	1	1	4	8	2	3
level 2	20	10	26	25	25	27	**level 2**	17	12	23	20	24	26
level 3	15	21	3	2	7	6	**level 3**	16	17	8	9	9	8
level 4	3	7	0	1	1	2	**level 4**	4	7	3	0	2	1
level 5	0	0	0	0	0	1	**level 5**	0	1	0	1	1	0

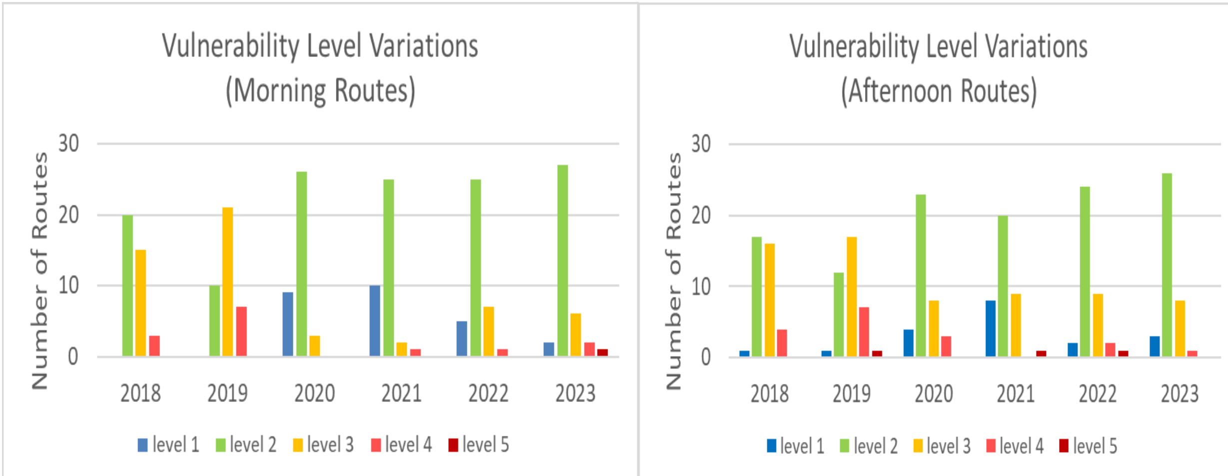


Figure 3.3.14 Yearly Variations of Vulnerability Levels (Morning/Afternoon Routes)

3.4 Effects of Geometric Configuration on Travel-Time Reliability and Traffic-Flow Measures

In this section, the potential effects of the route-wide geometric configuration on the travel-time reliability (TTR) and traffic-flow measures are analyzed. The previous phase of this study modeled the 'strength' of the route-wide geometric structure, G, in terms of handling the traffic flows going through a given corridor as follows:

$$G = \frac{G1*G3*G4}{G2}$$

where, G: Geometric Friction Index of a given route,

G1: Number of Exit Ramps per mile (G1) in a given route,

G2: Number of Entrance Ramps per mile (G2) for a given route,

G3: Proportion of the total non-weaving section length in a given route,

= 1 – [Σ (lengths of all weaving sections) / route length],

G4: Average number of through lanes for a given route weighted with the distance from upstream boundary.

In the above formula, the numerator reflects the combined effects of the geometric features facilitating through movements, while the denominator represents the potential interruption caused by the entering volumes to the route-wide, through-traffic flows. Therefore, the routes with high G values can be considered to have less friction to through-traffic flows than those with low G values.

In this study, the G values of all 74 directional routes were calculated with the geometry values extracted from the Google-earth map. Further, the potential effects of the geometric friction on TTR are analyzed by examining the relationships between G and the yearly TTR values, i.e., Buffer Index (BI) and Planning Index (PI), of each route. It can be expected that the routes with less geometric friction (high G values), have generally better TTR, i.e., low values of BI and PI resulting from less fluctuations in travel times with lower levels of congestion, than those with high friction (low G values).

Figures 3.4.1 - 3.4.24 show the yearly variations of G - BI and G - PI relationships estimated for both morning and afternoon routes from 2018 to 2023. As noted from these figures, the G - BI and G - PI patterns of the metro freeways generally follow the expected relationships, i.e., as G value increases, both BI and PI values tend to decrease. It can be also noted that there are multiple route groups with slightly different G-BI/PI slopes, indicating the need for further enhancement of the G model. However, no notable pattern is observed for both morning and afternoon routes in 2020, when there was substantial reduction in traffic flows because of the pandemic.

The effects of the geometric configuration on the traffic-flow measures of effectiveness, i.e., Vehicle-Miles-Traveled (VMT) and Vehicle-Hours-Traveled (VHT), are shown in Figures 3.4.25 - and 3.4.48, which include the yearly variations of G-VMT/mile and G-VHT/mile relationships for both morning and afternoon routes. As expected, the routes with high G values, i.e., low levels of friction to through traffic, exhibit higher values of VMT/mile and VHT/mile than those with low G values.

The above observations can provide the basis for future geometric changes of the freeway corridors in terms of improving the efficiency of traffic flows and travel-time reliability.

Buffer Index (BI) vs Geometric-Friction Index (G) - 2018 -2023: Morning Routes

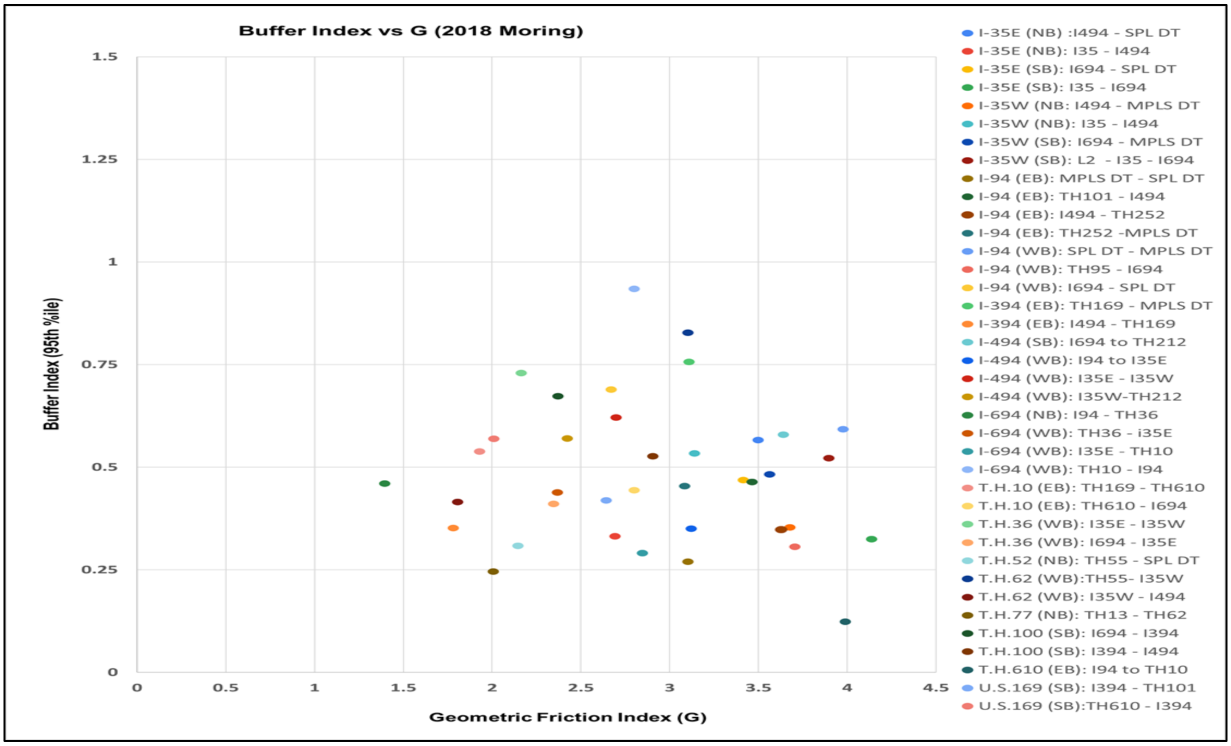


Figure 3.4.1 BI – G Relationship (2018 Morning Routes)

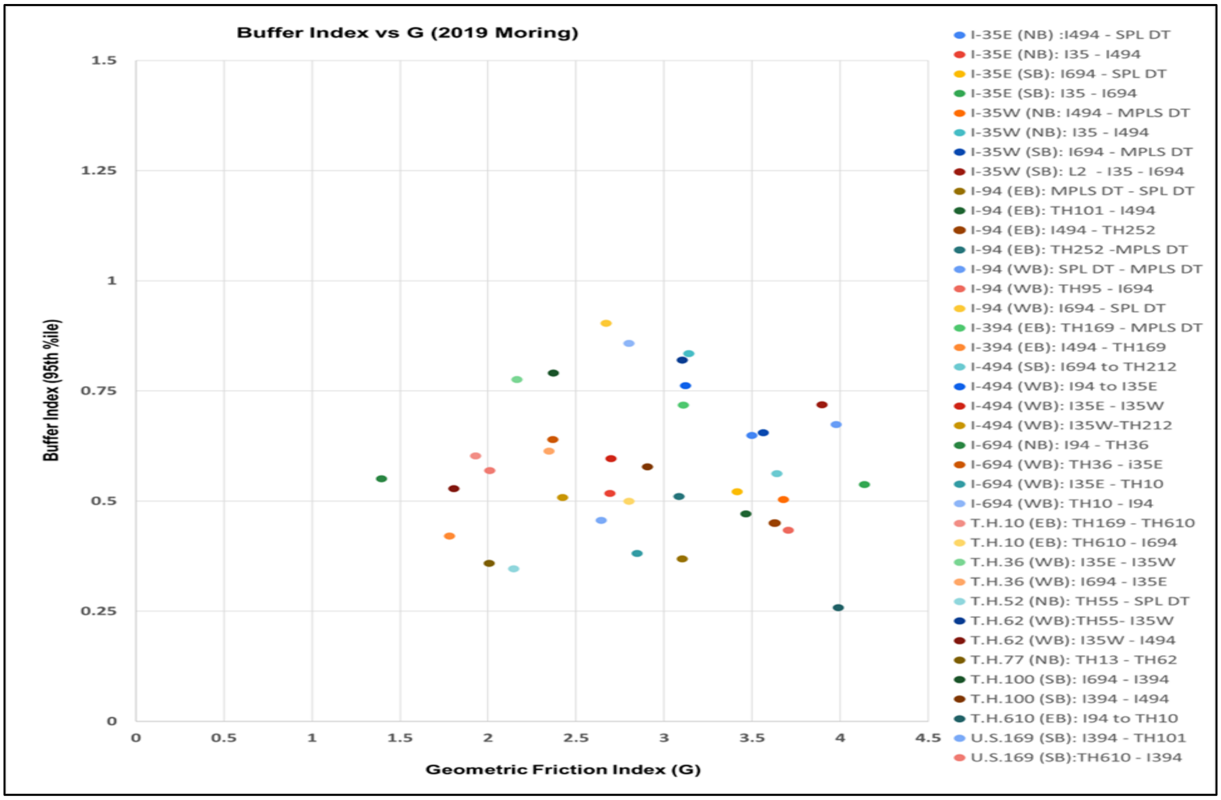


Figure 3.4.2 BI – G Relationship (2019 Morning Routes)

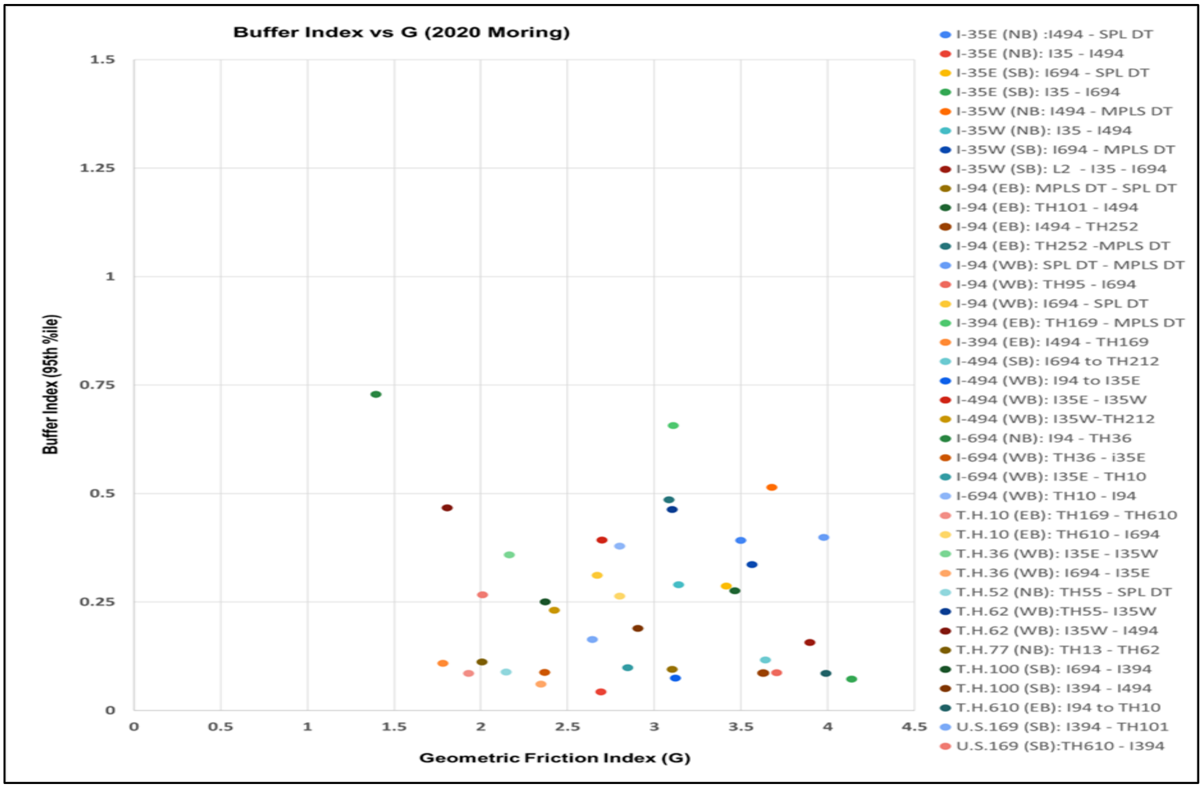


Figure 3.4.3 BI – G Relationship (2020 Morning Routes)

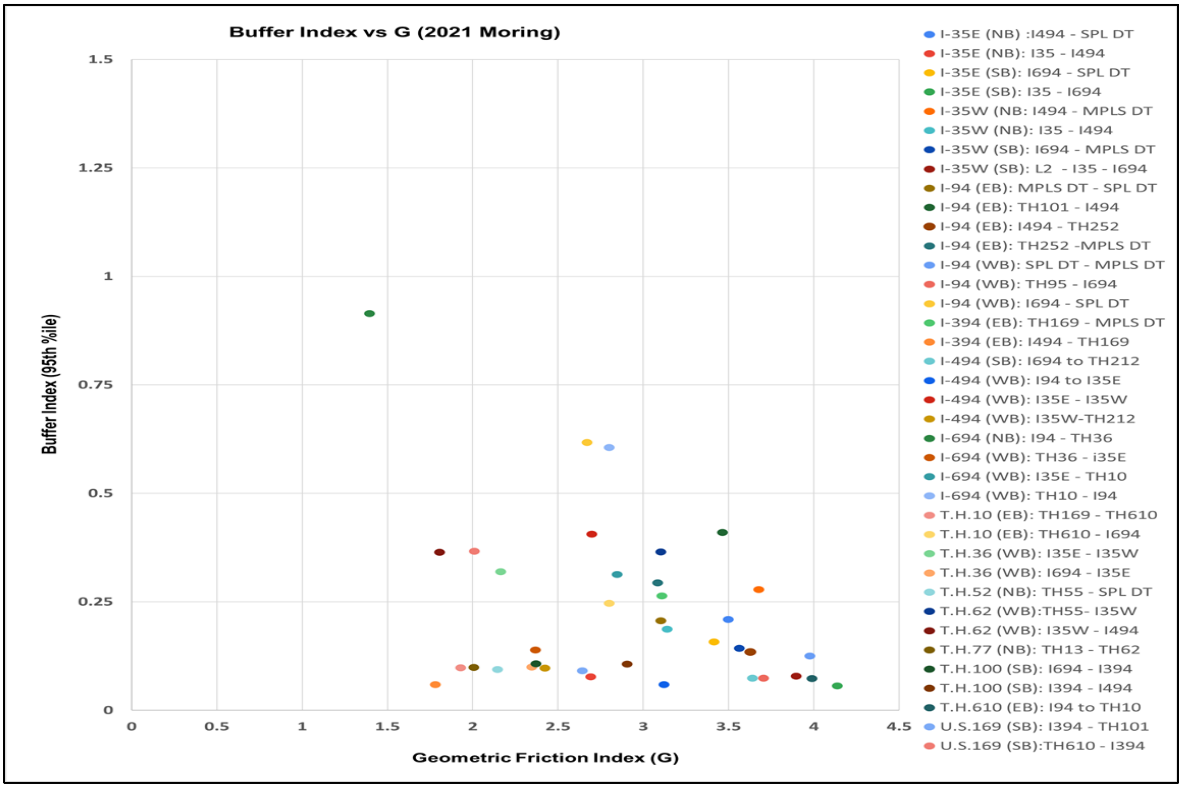


Figure 3.4.4 BI – G Relationship (2021 Morning Routes)

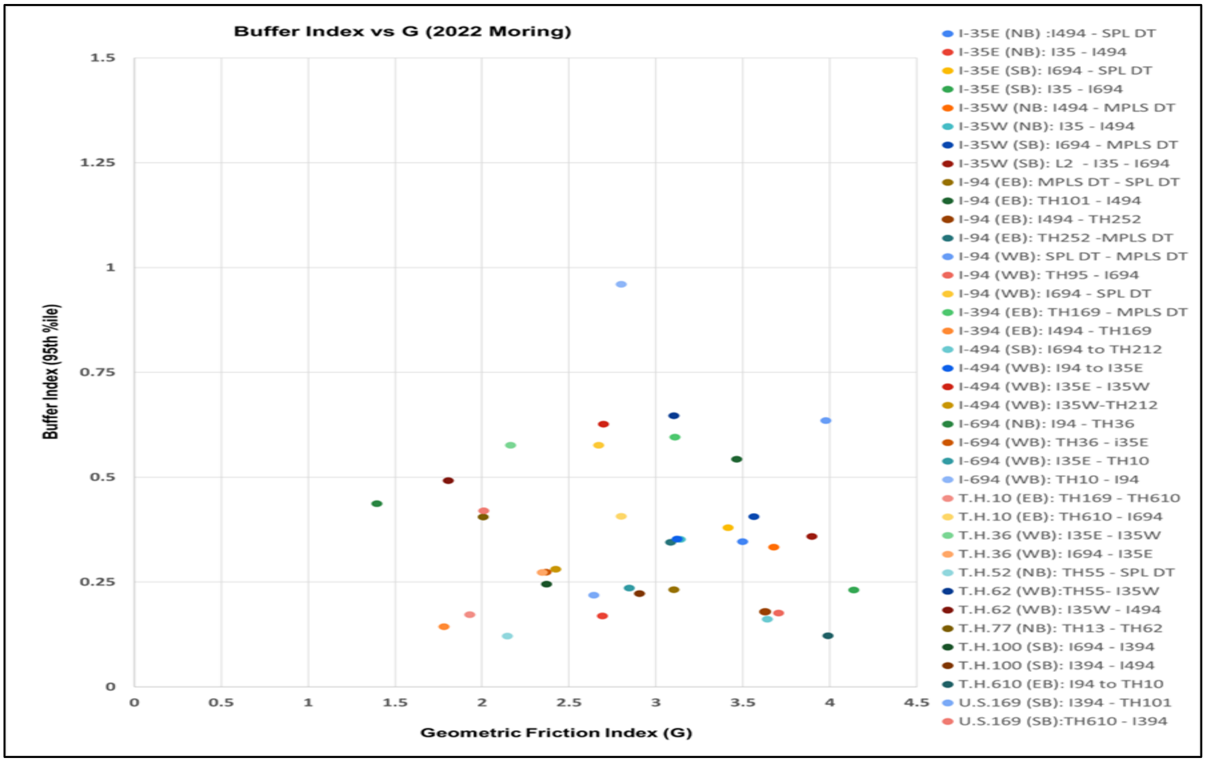


Figure 3.4.5 BI – G Relationship (2022 Morning Routes)

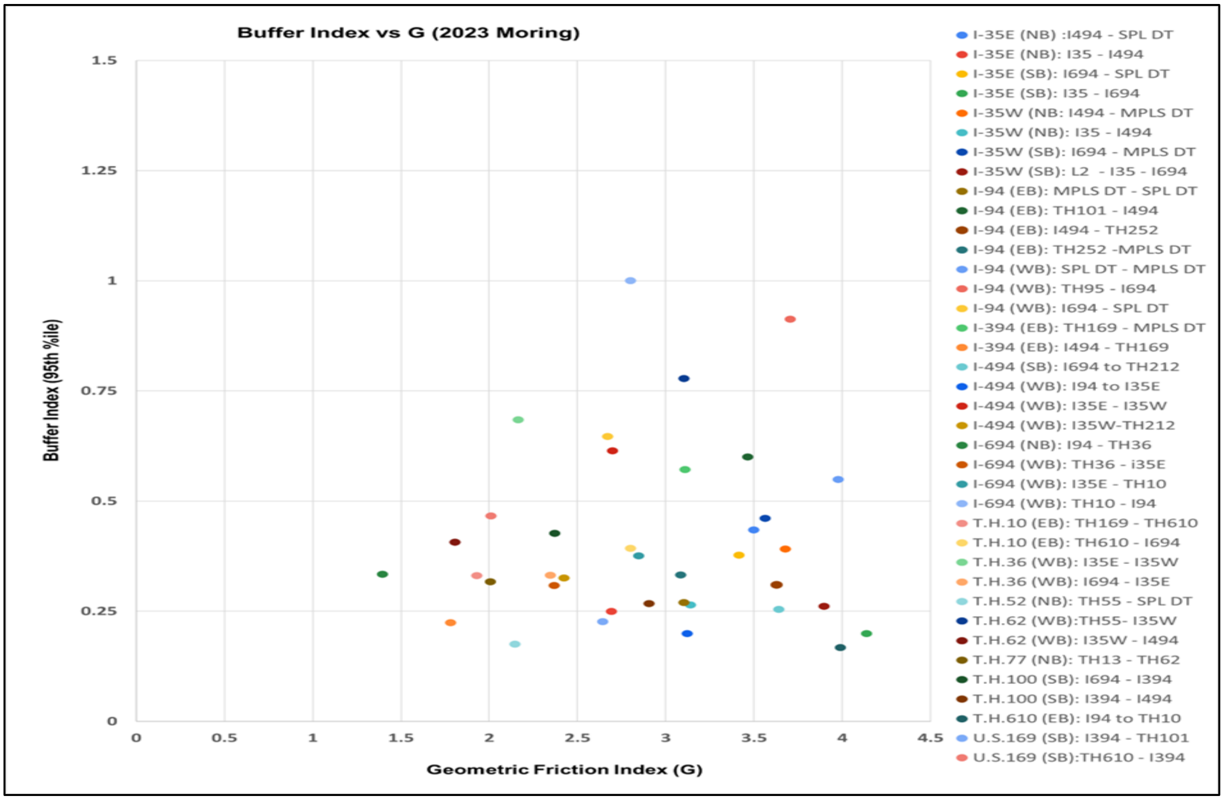


Figure 3.4.6 BI – G Relationship (2023 Morning Routes)

Buffer Index vs Geometric Friction Index (2018 – 2023: Afternoon Routes)

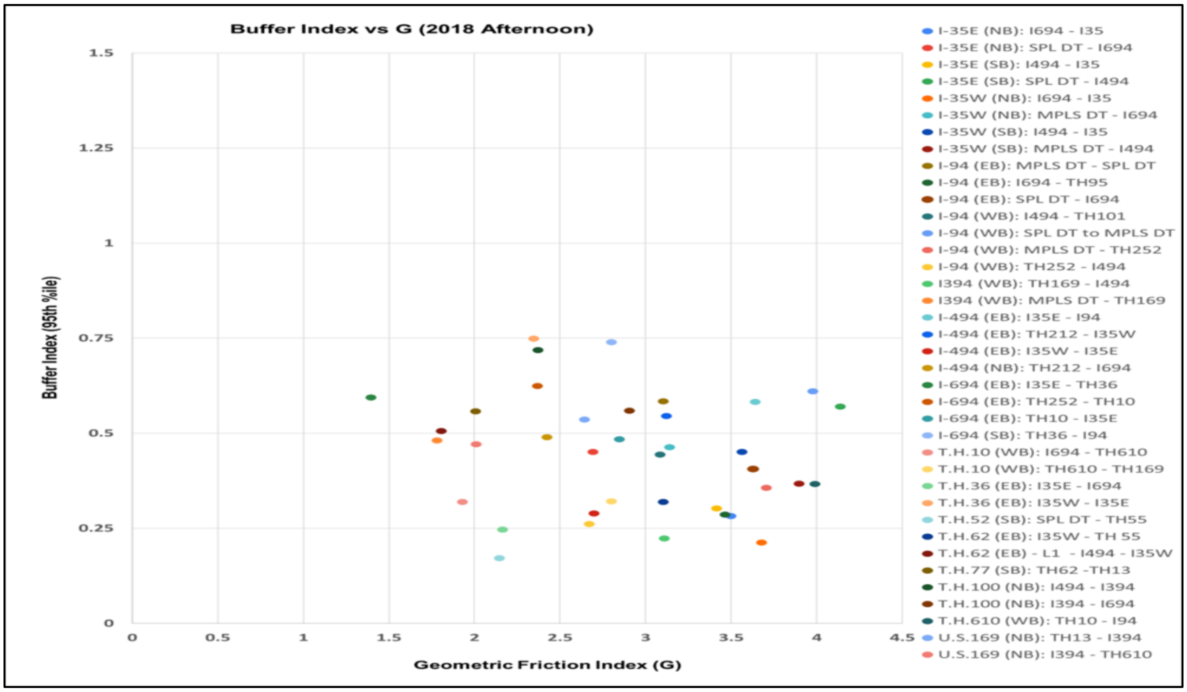


Figure 3.4.7 BI – G Relationship (2018 Afternoon Routes)

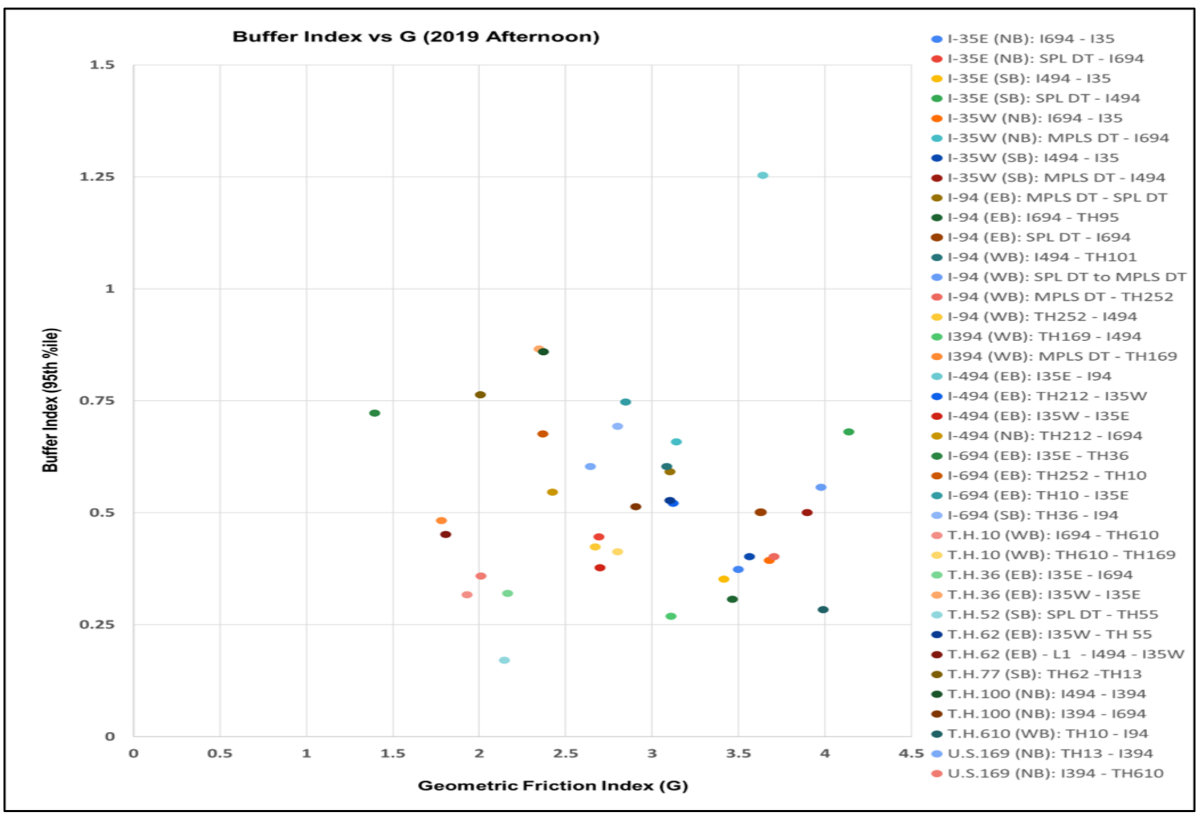


Figure 3.4.8 BI – G Relationship (2019 Afternoon Routes)

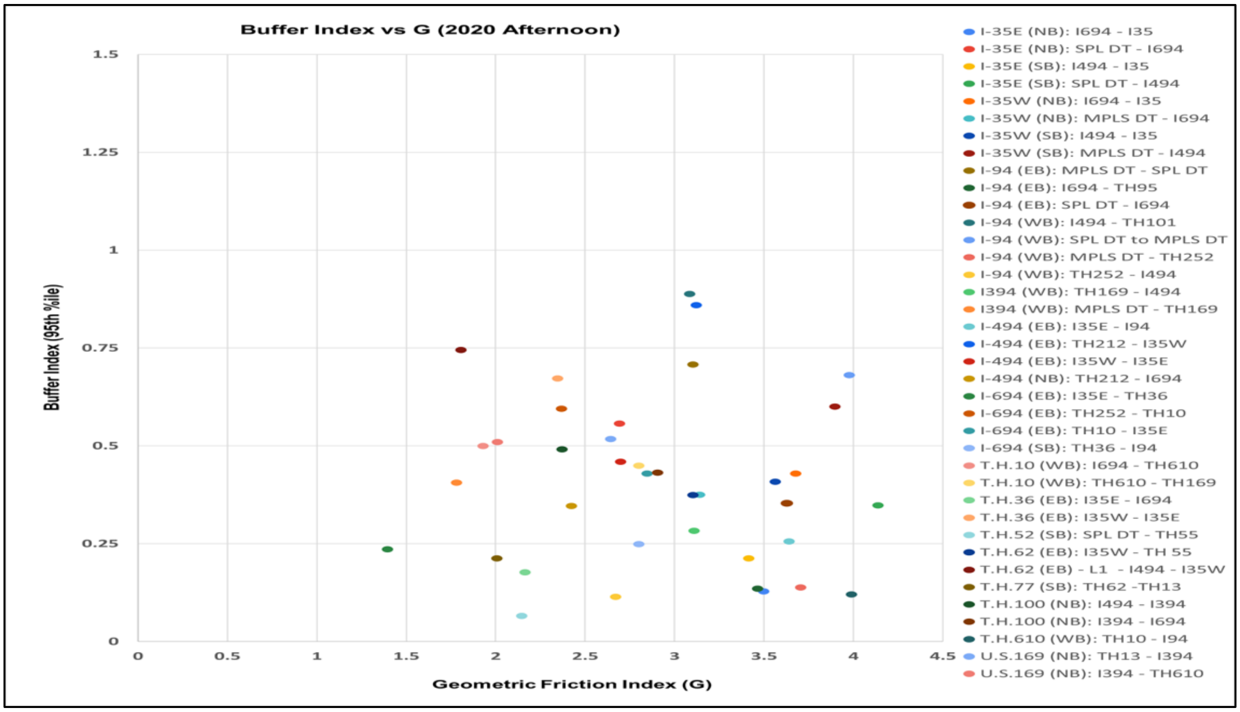


Figure 3.4.9 BI – G Relationship (2020 Afternoon Routes)

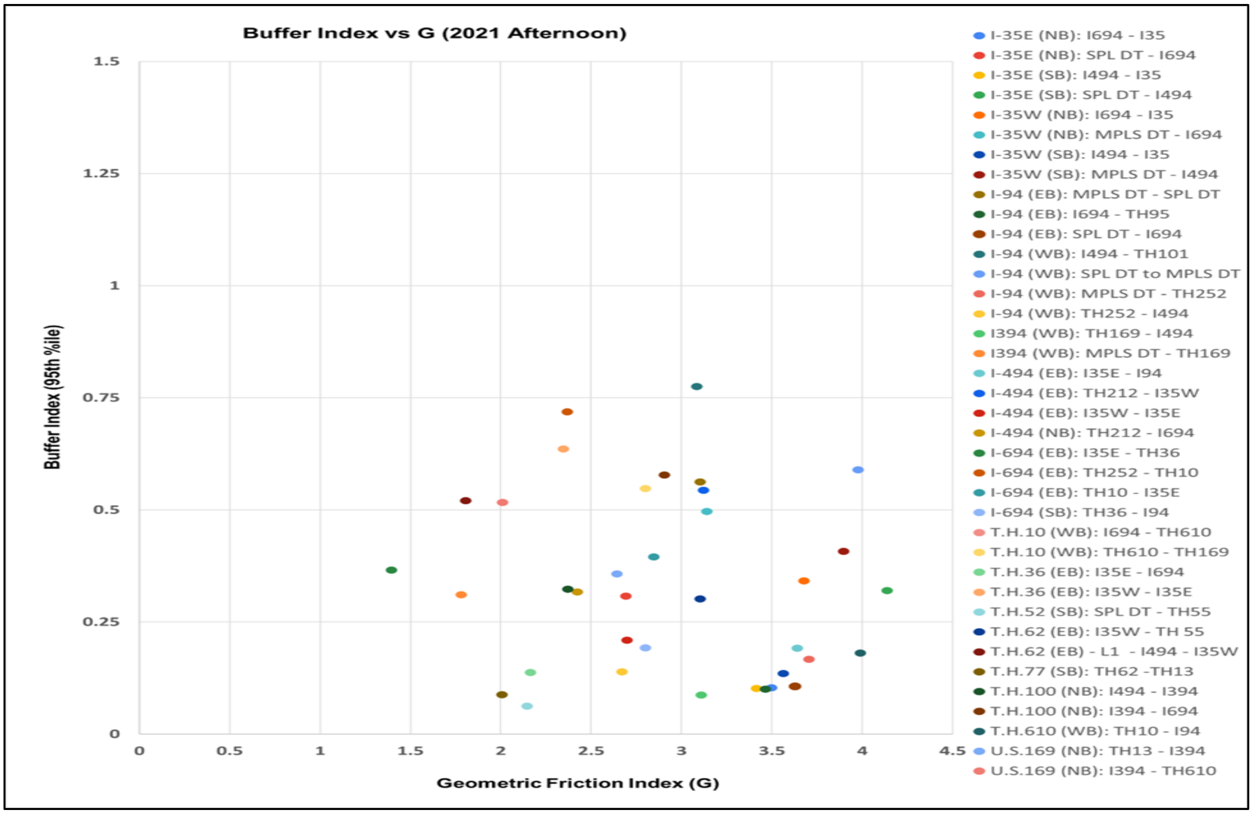


Figure 3.4.10 BI – G Relationship (2021 Afternoon Routes)

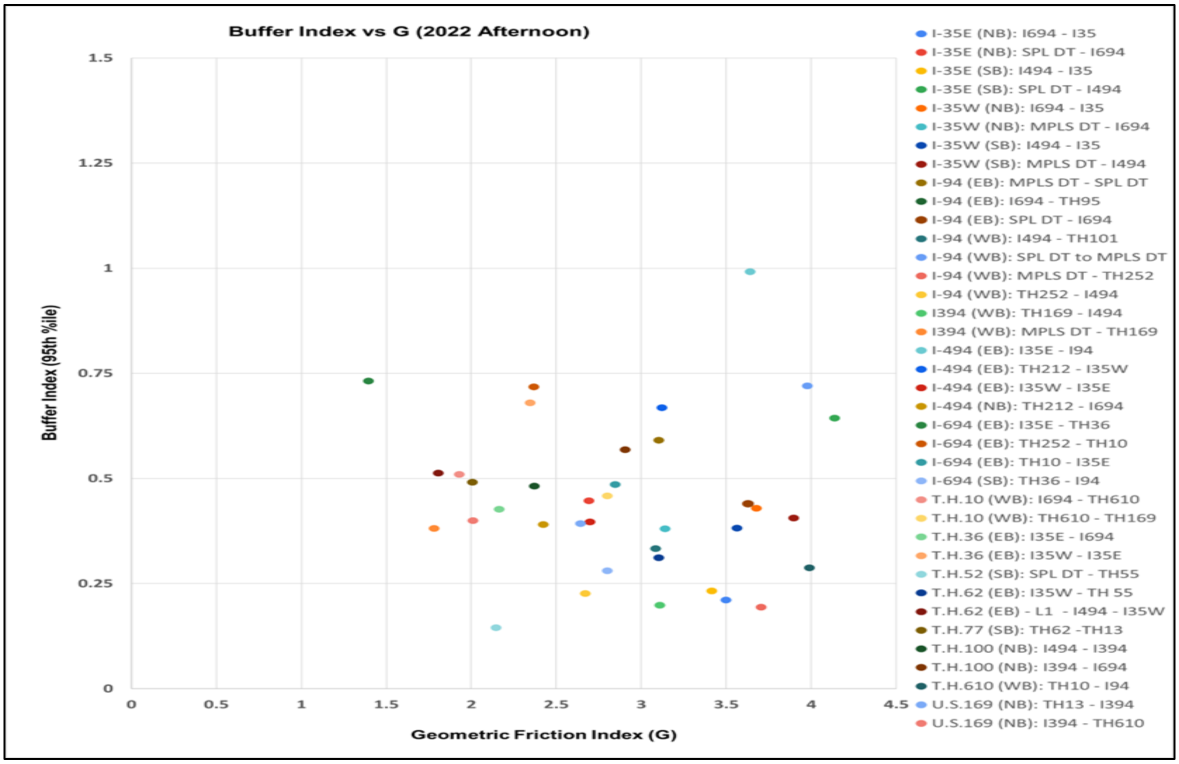


Figure 3.4.11 BI – G Relationship (2022 Afternoon Routes)

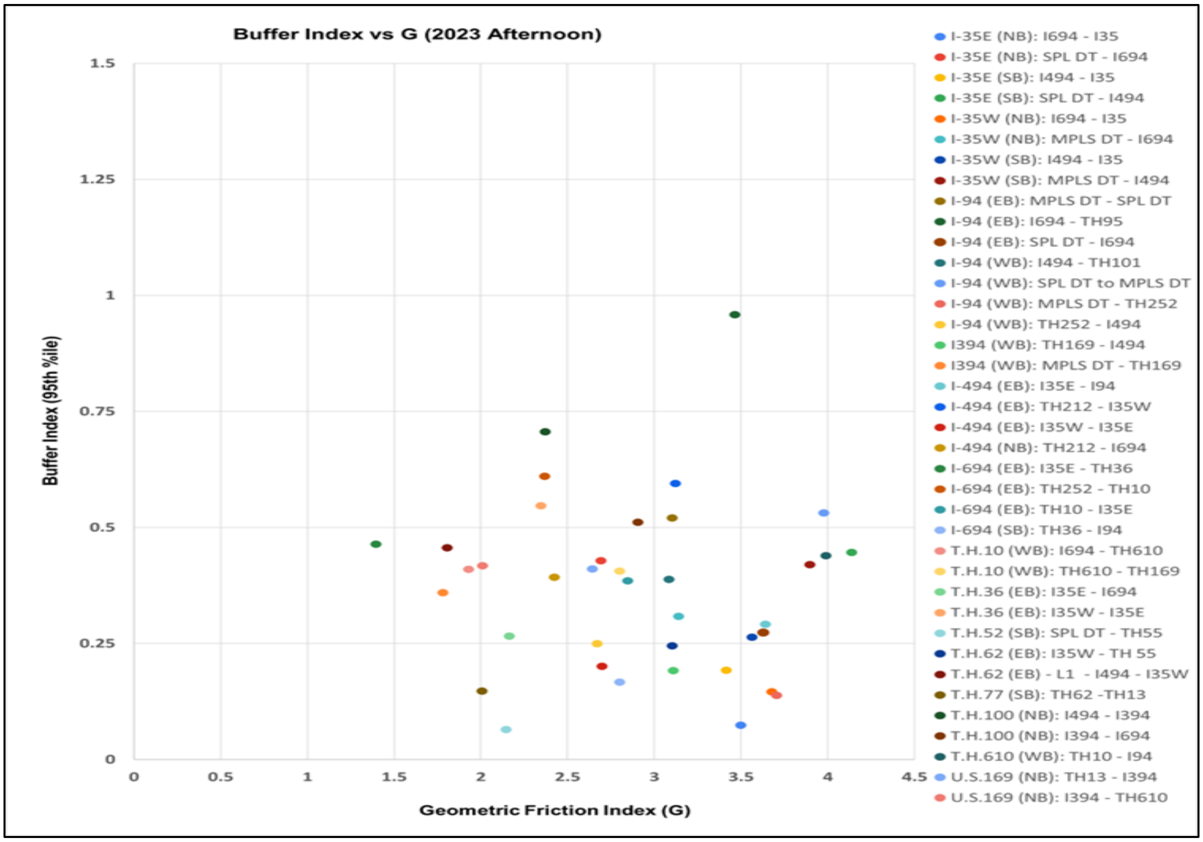


Figure 3.4.12 BI - G Relationship (2023 Afternoon Routes)

Planning Index (PI) vs Geometric Friction Index (G) - 2018 to 2023: Morning Routes

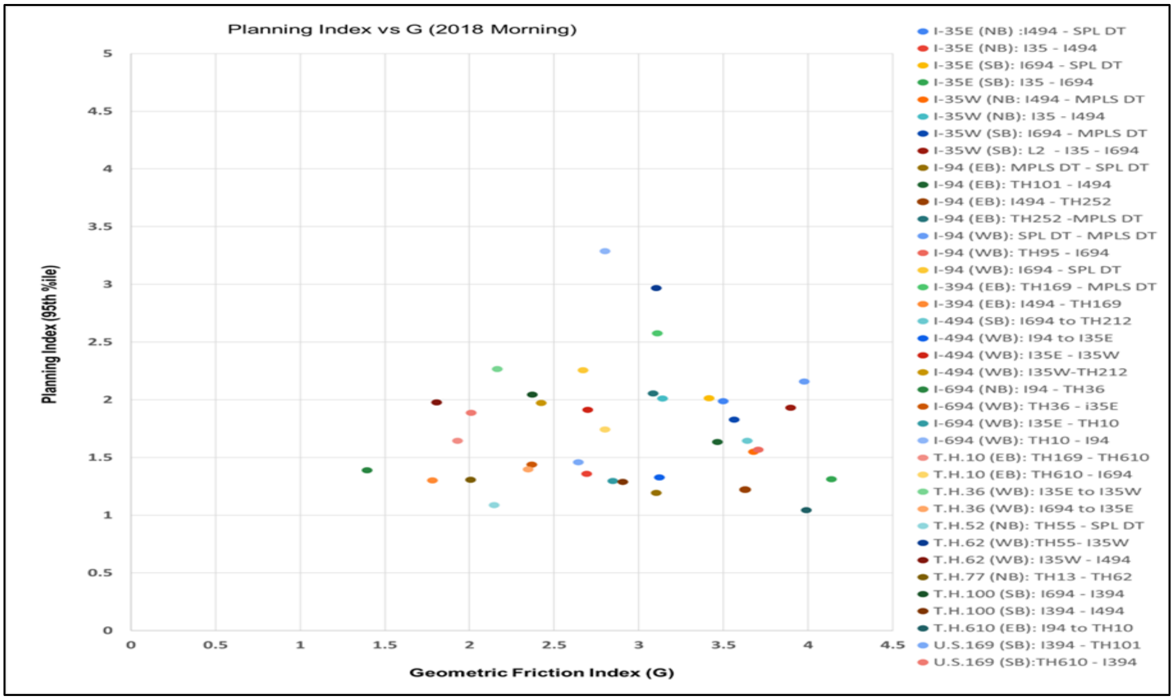


Figure 3.4.13 PI - G Relationship (2018 Morning Routes)

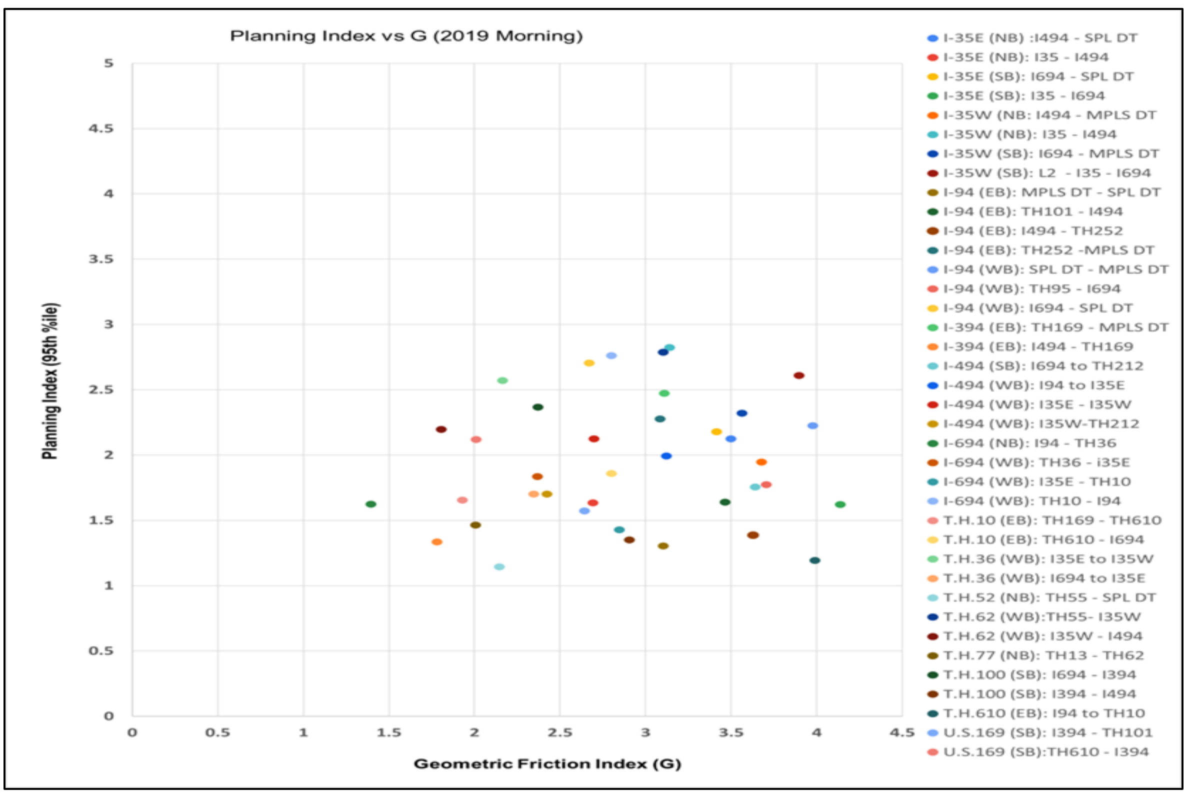


Figure 3.4.14 PI - G Relationship (2019 Morning Routes)

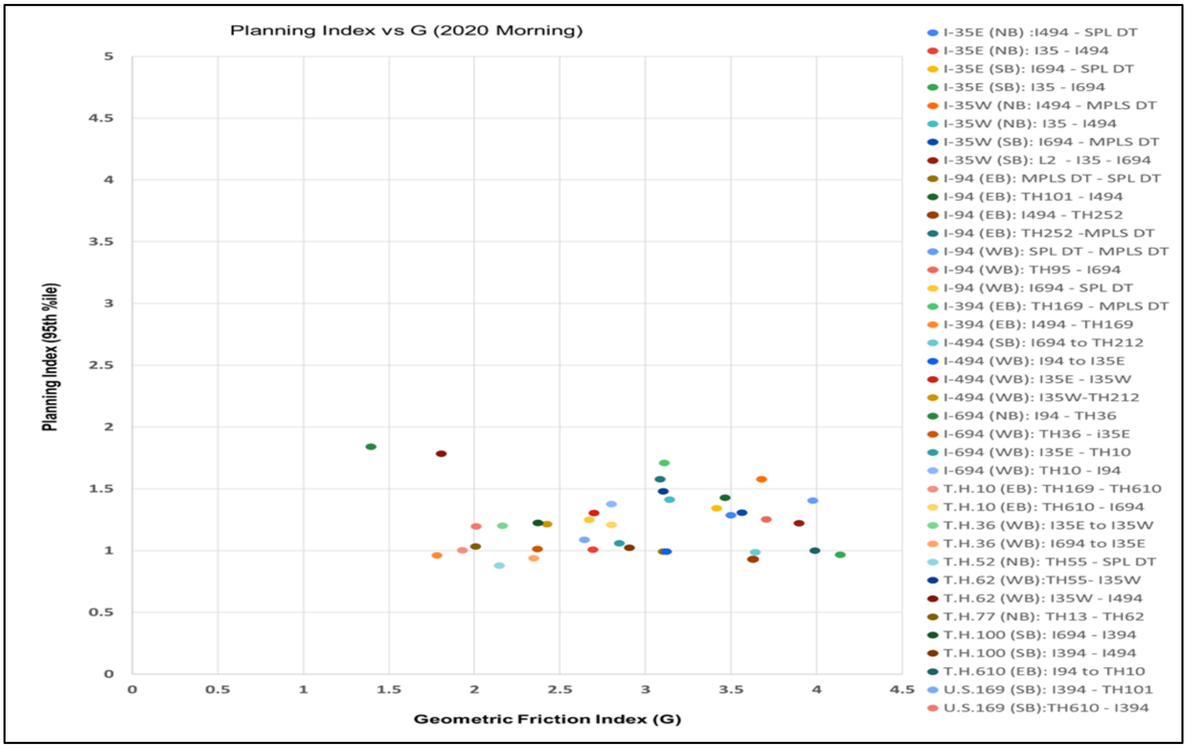


Figure 3.4.15 PI - G Relationship (2020 Morning Routes)

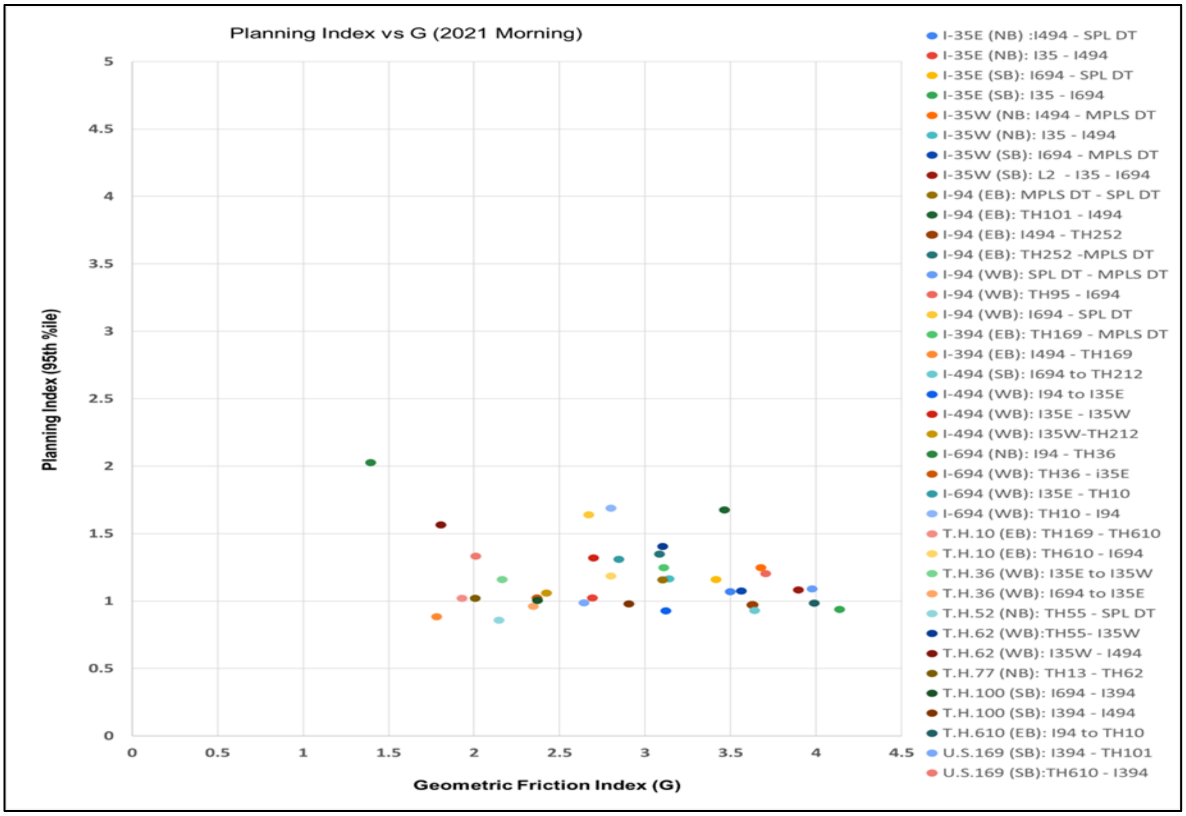


Figure 3.4.16 PI - G Relationship (2021 Morning Routes)

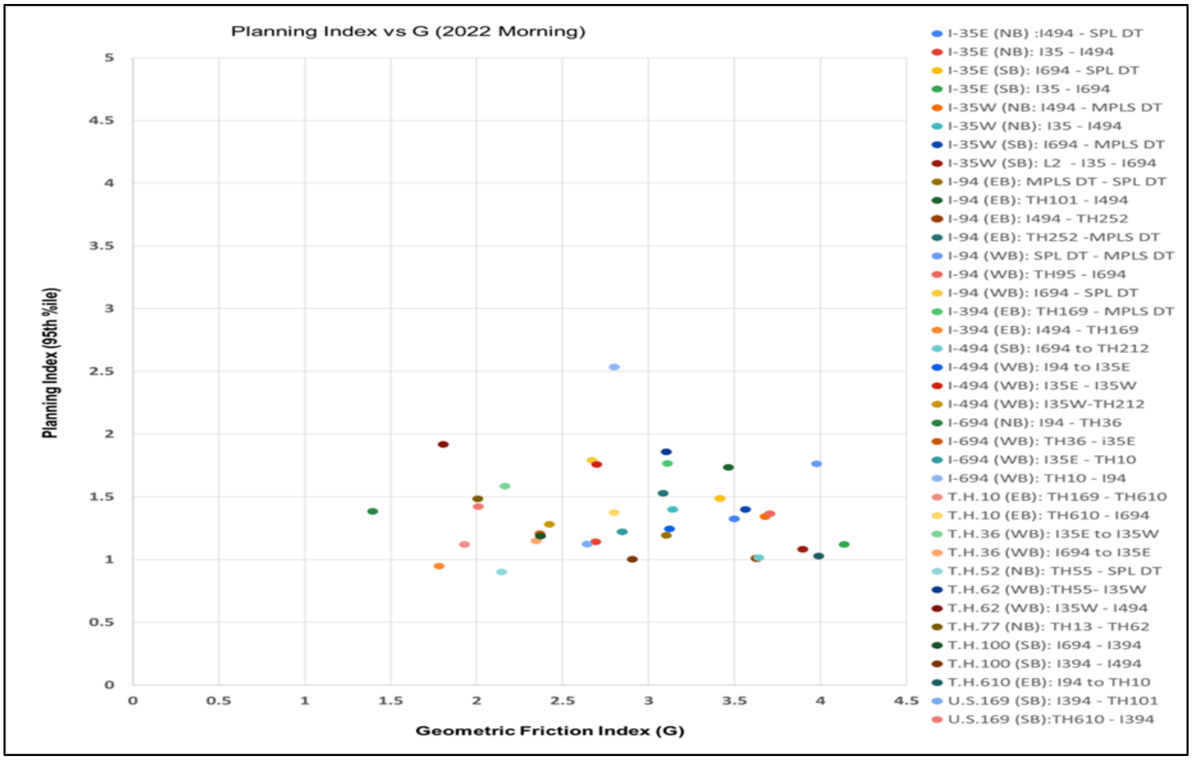


Figure 3.4.17 PI - G Relationship (2022 Morning Routes)

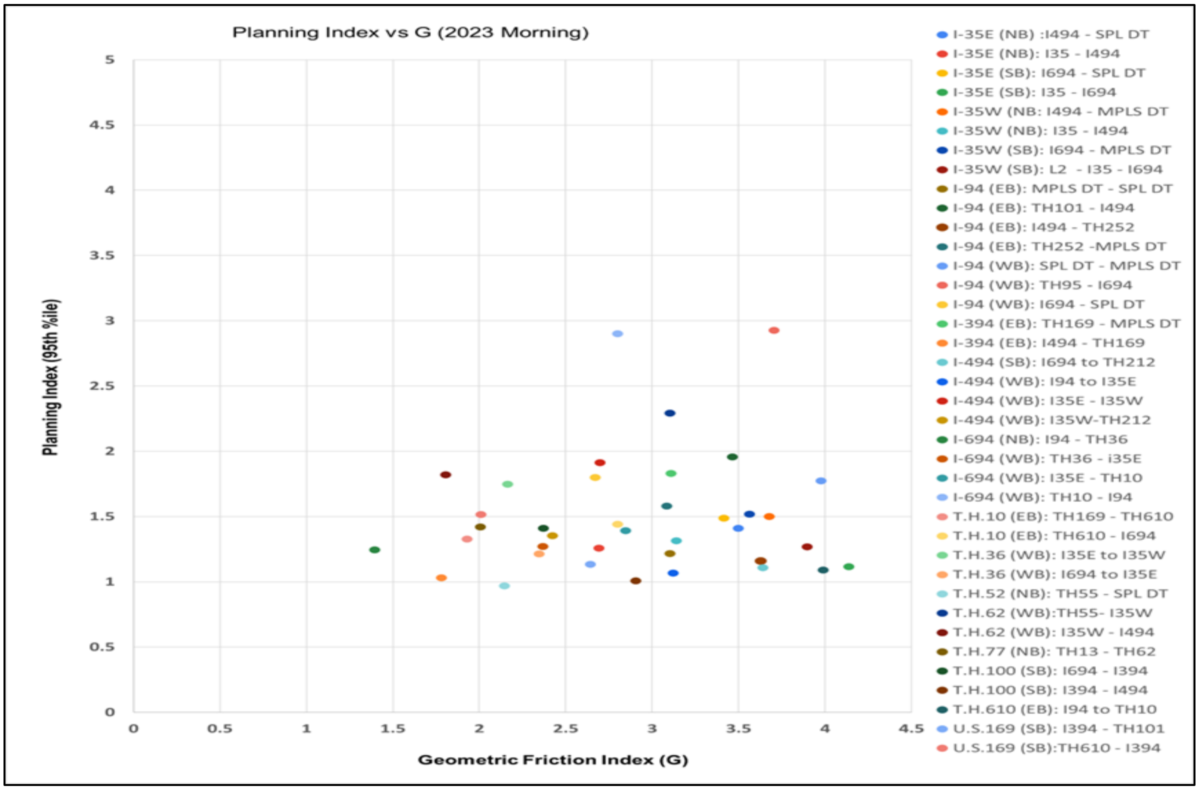


Figure 3.4.18 PI - G Relationship (2023 Morning Routes)

Planning Index (PI) vs Geometric Friction Index (G) - 2018 to 2023: Afternoon Routes

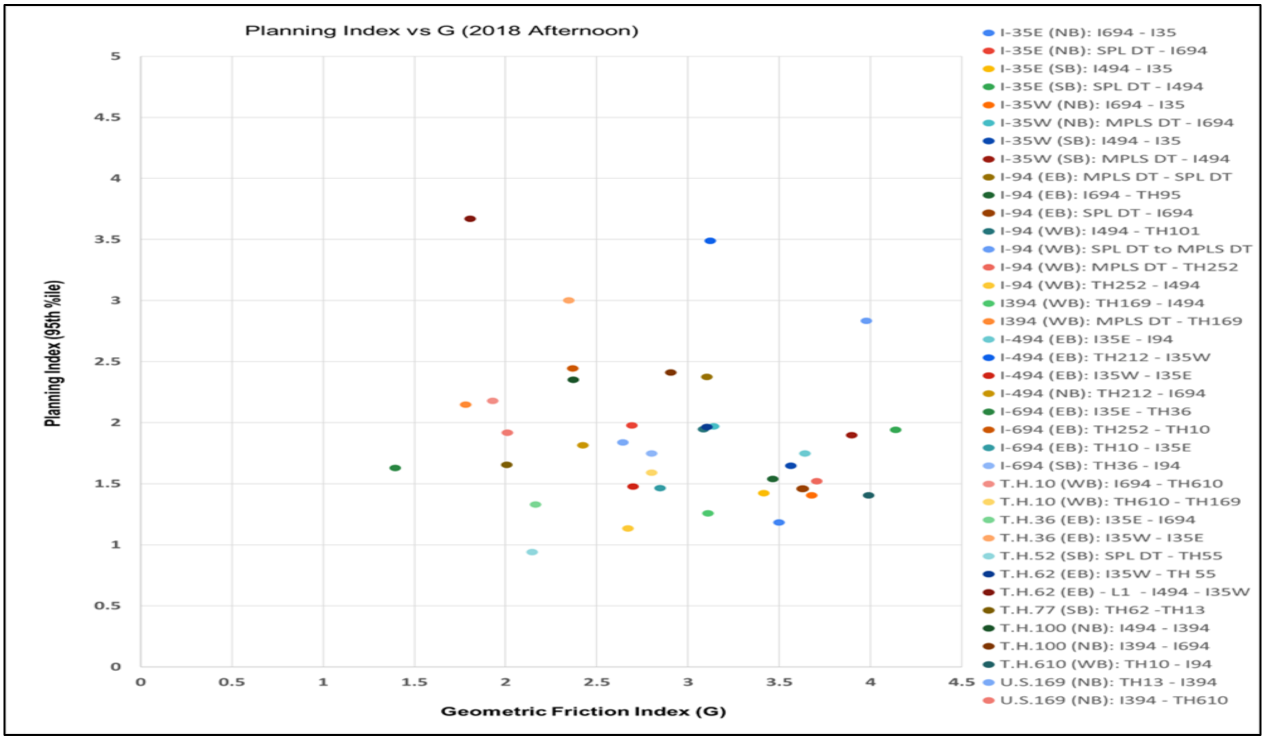


Figure 3.4.19 PI - G Relationship (2018 Afternoon Routes)

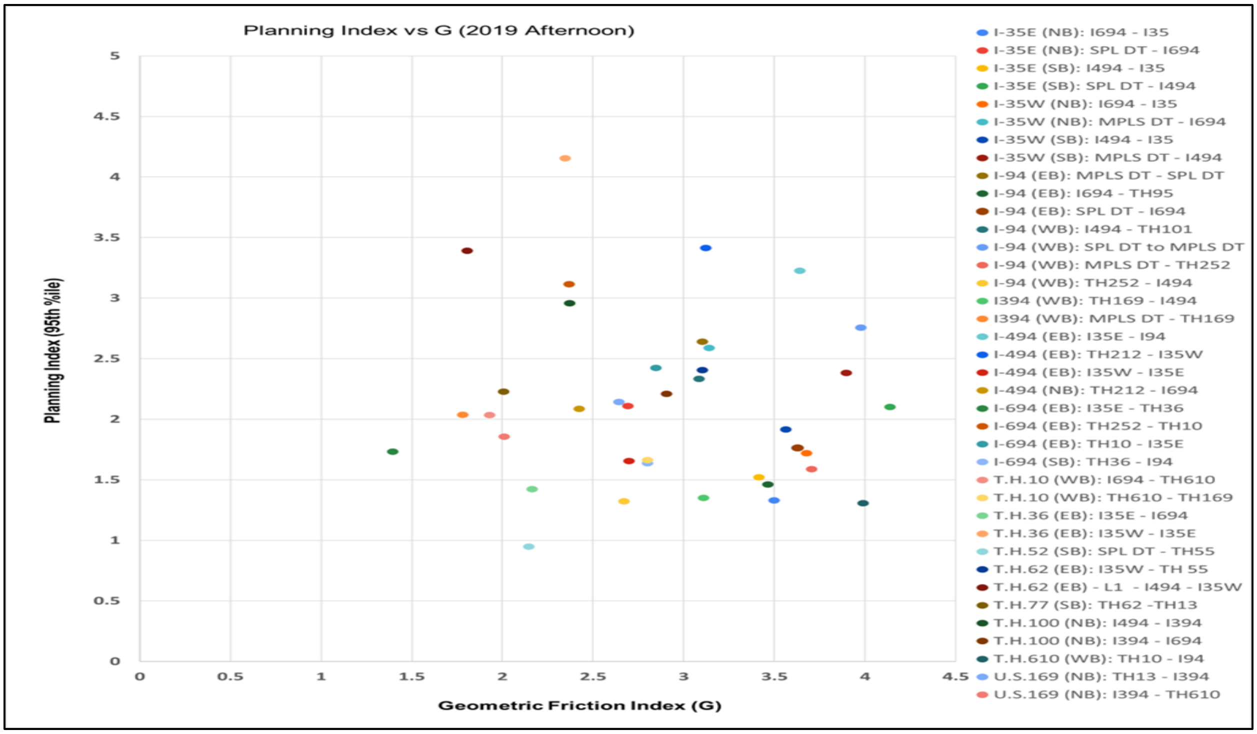


Figure 3.4.20 PI - G Relationship (2019 Afternoon Routes)

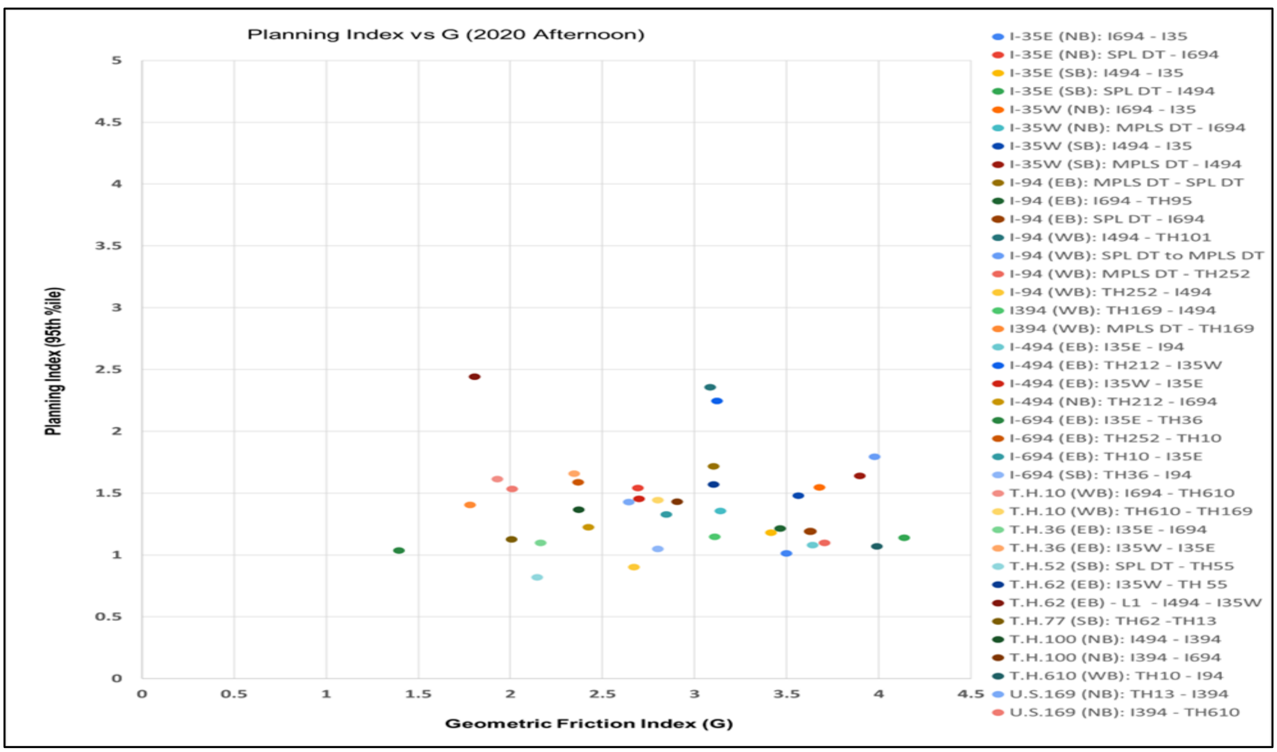


Figure 3.4.21 PI - G Relationship (2020 Afternoon Routes)

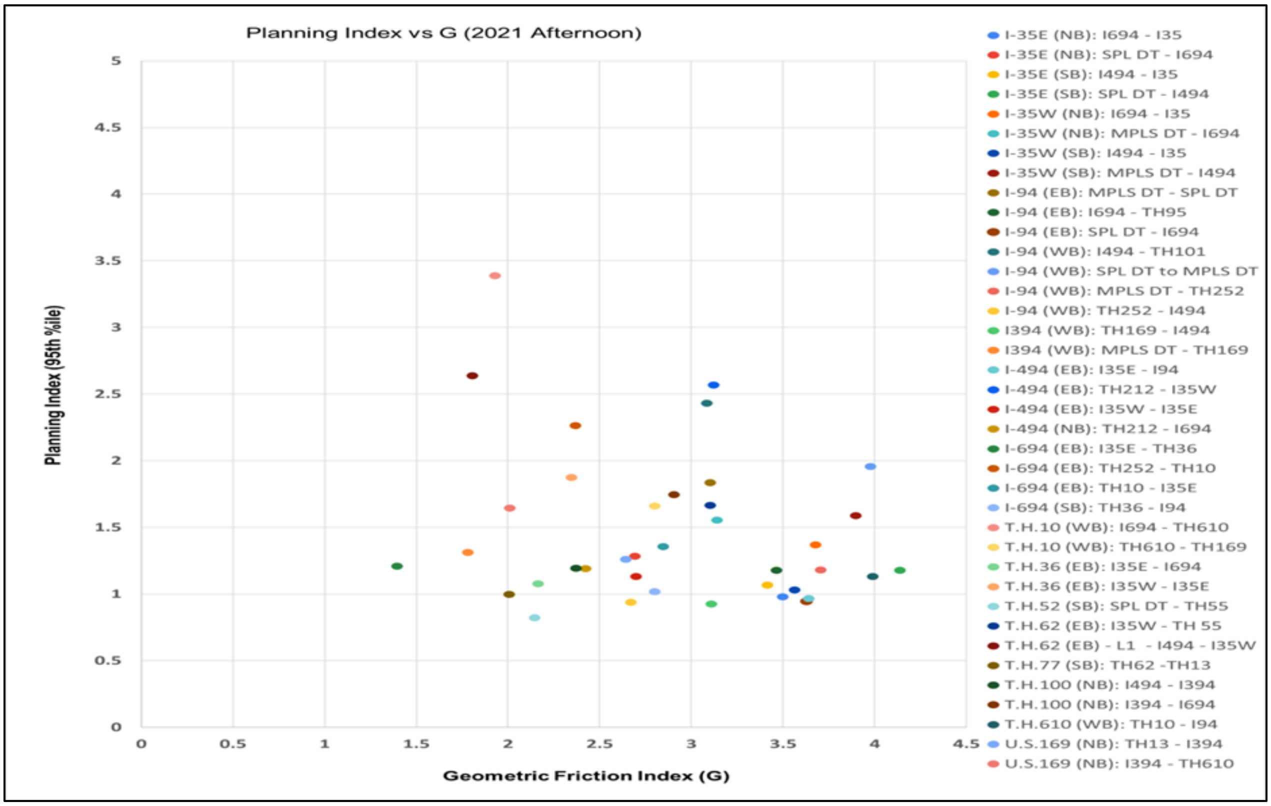


Figure 3.4.22 PI - G Relationship (2021 Afternoon Routes)

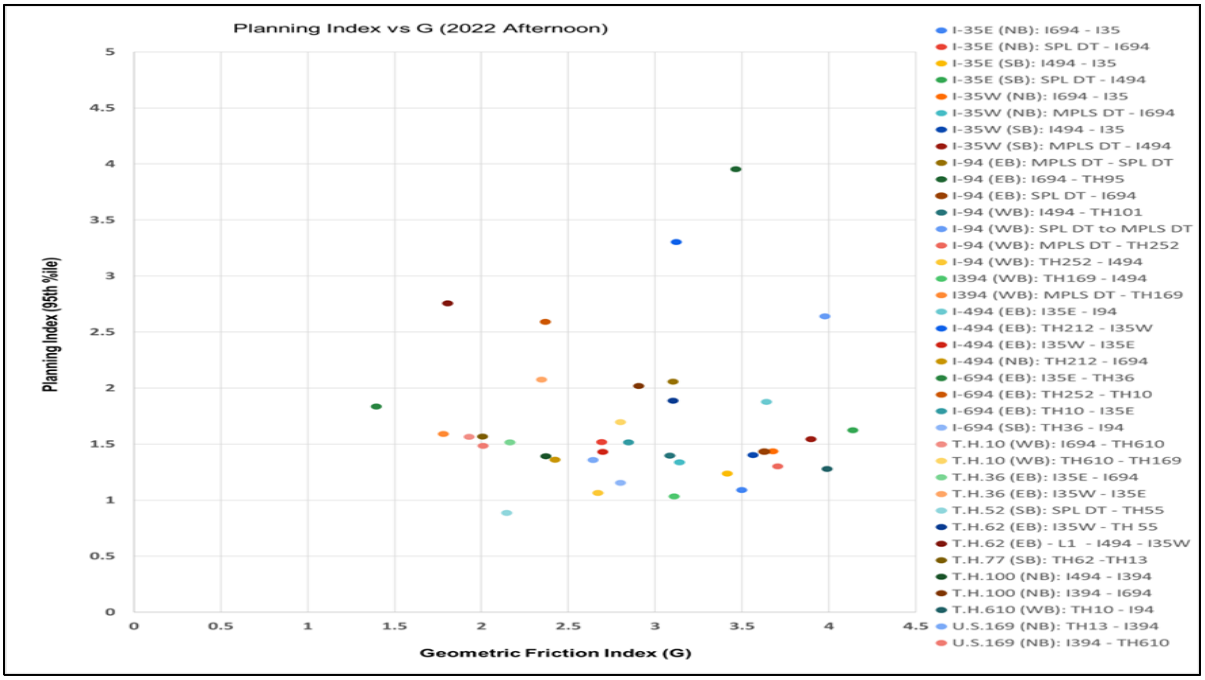


Figure 3.4.23 PI - G Relationship (2022 Afternoon Routes)

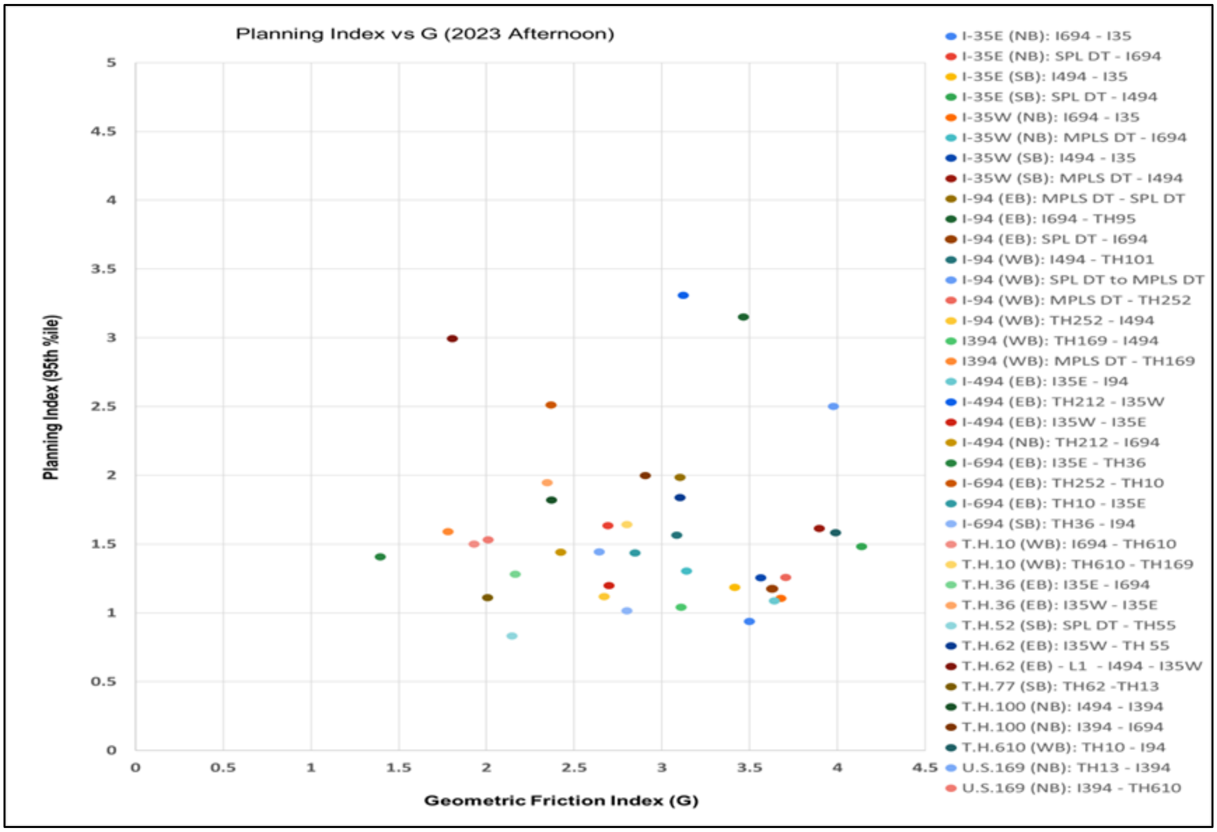


Figure 3.4.24 PI - G Relationship (2023 Afternoon Routes)

Vehicle-Miles-Traveled (VMT)mile vs Geometric-Friction Index (G) - 2018 – 2023: Morning Routes

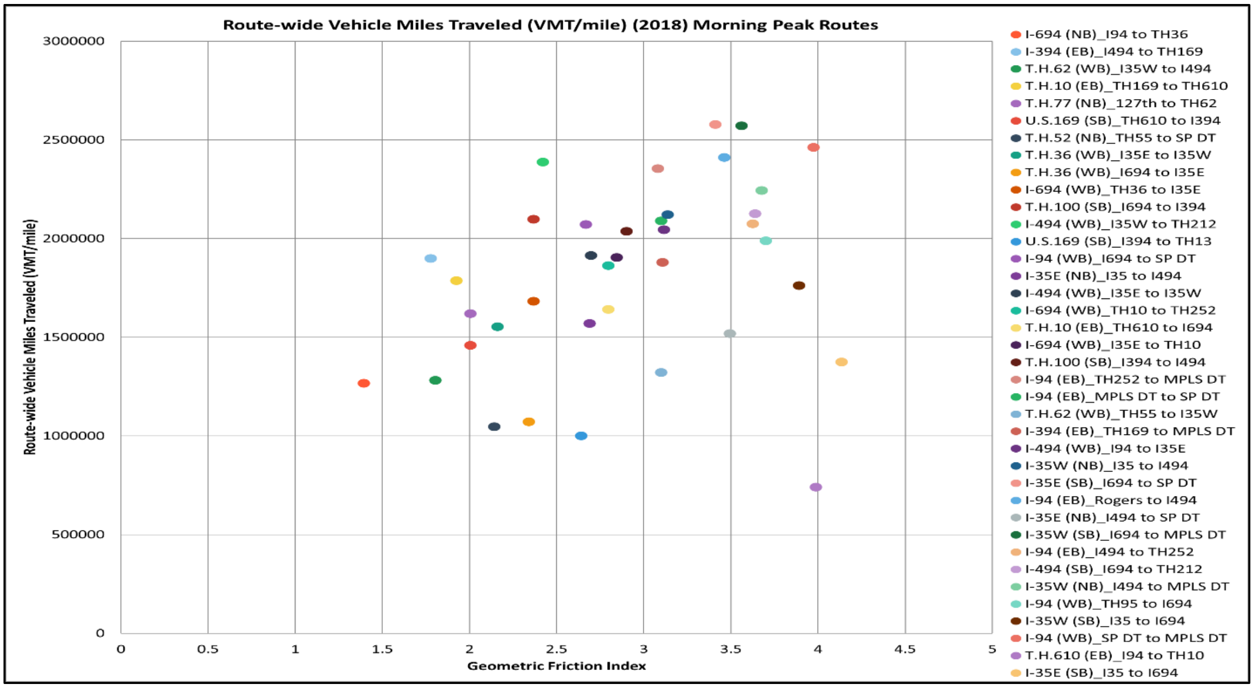


Figure 3.4.25 VMT/mile - G Relationship (2018 Morning Routes)

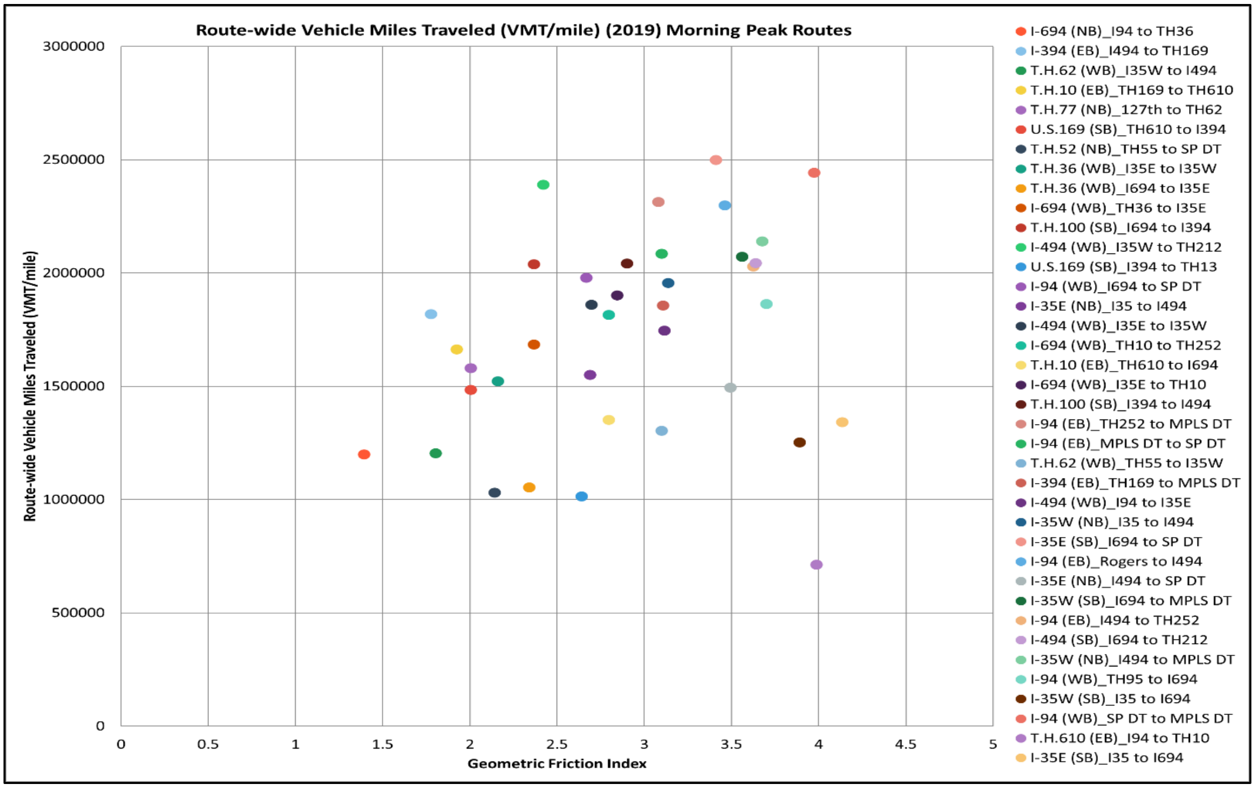


Figure 3.4.26 VMT/mile - G Relationship (2019 Morning Routes)

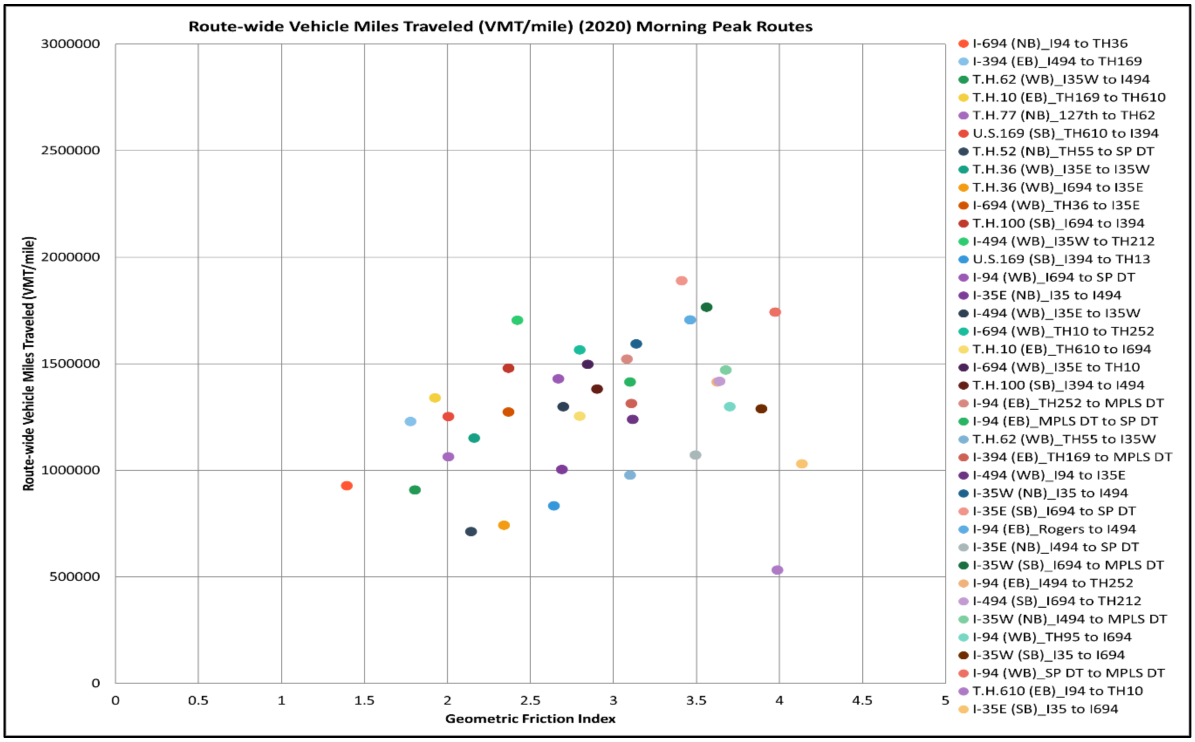


Figure 3.4.27 VMT/mile - G Relationship (2020 Morning Routes)

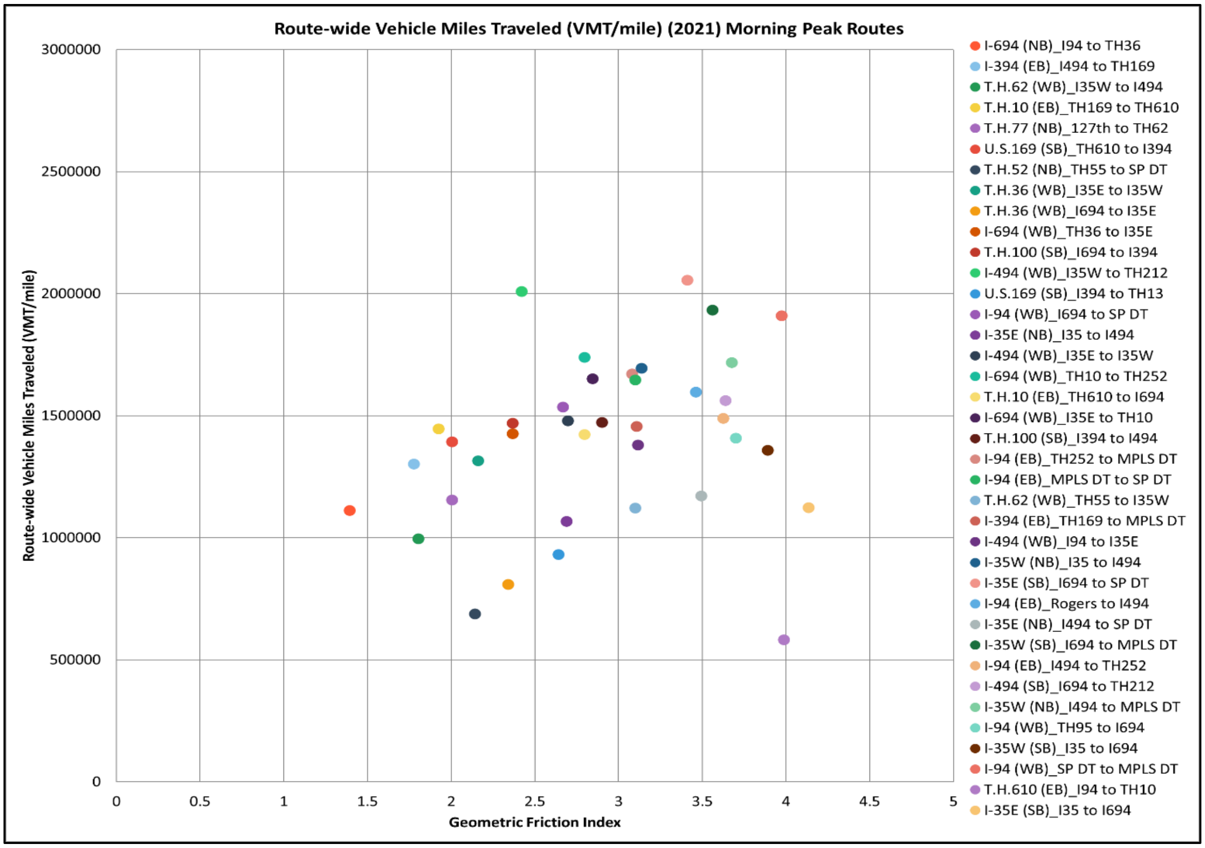


Figure 3.4.28 VMT/mile - G Relationship (2021 Morning Routes)

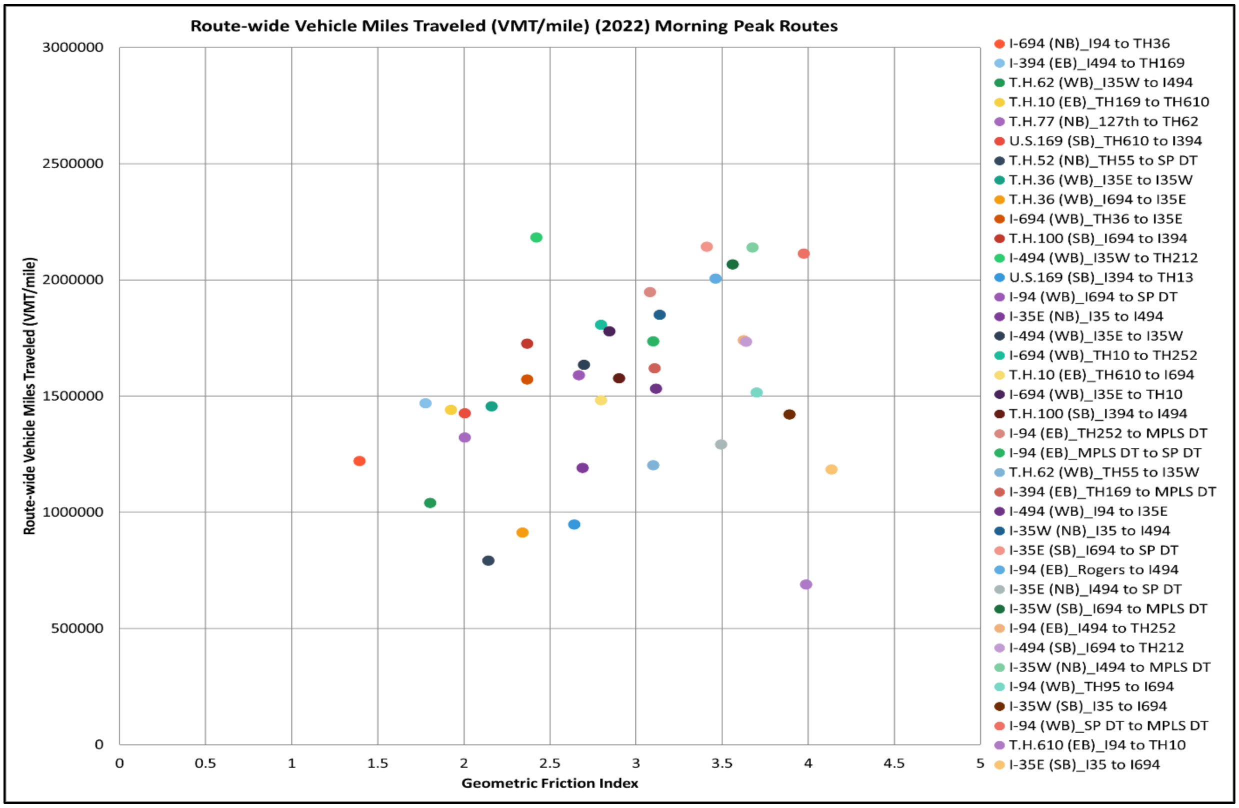


Figure 3.4.29 VMT/mile - G Relationship (2022 Morning Routes)

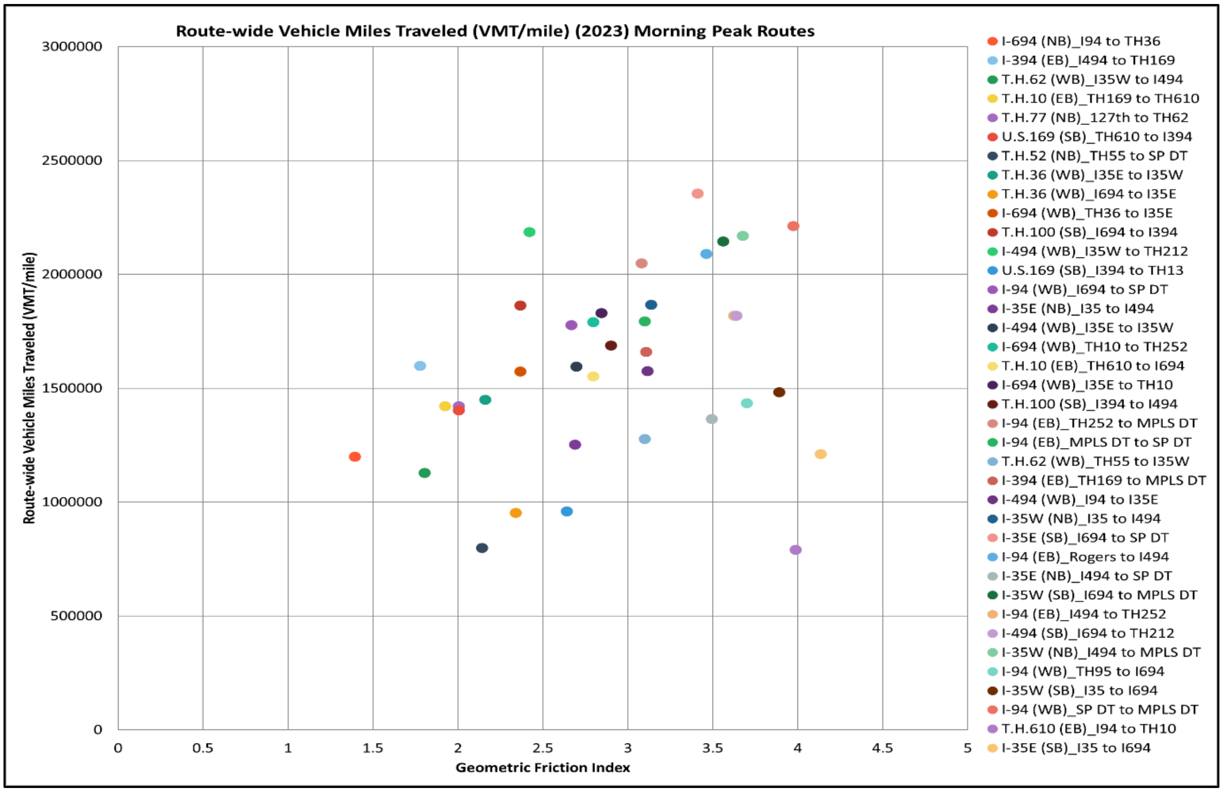


Figure 3.4.30 VMT/mile - G Relationship (2023 Morning Routes)

Vehicle-Miles-Traveled (VMT)/mile vs Geometric-Friction Index (G) - 2018 – 2023: Afternoon Routes

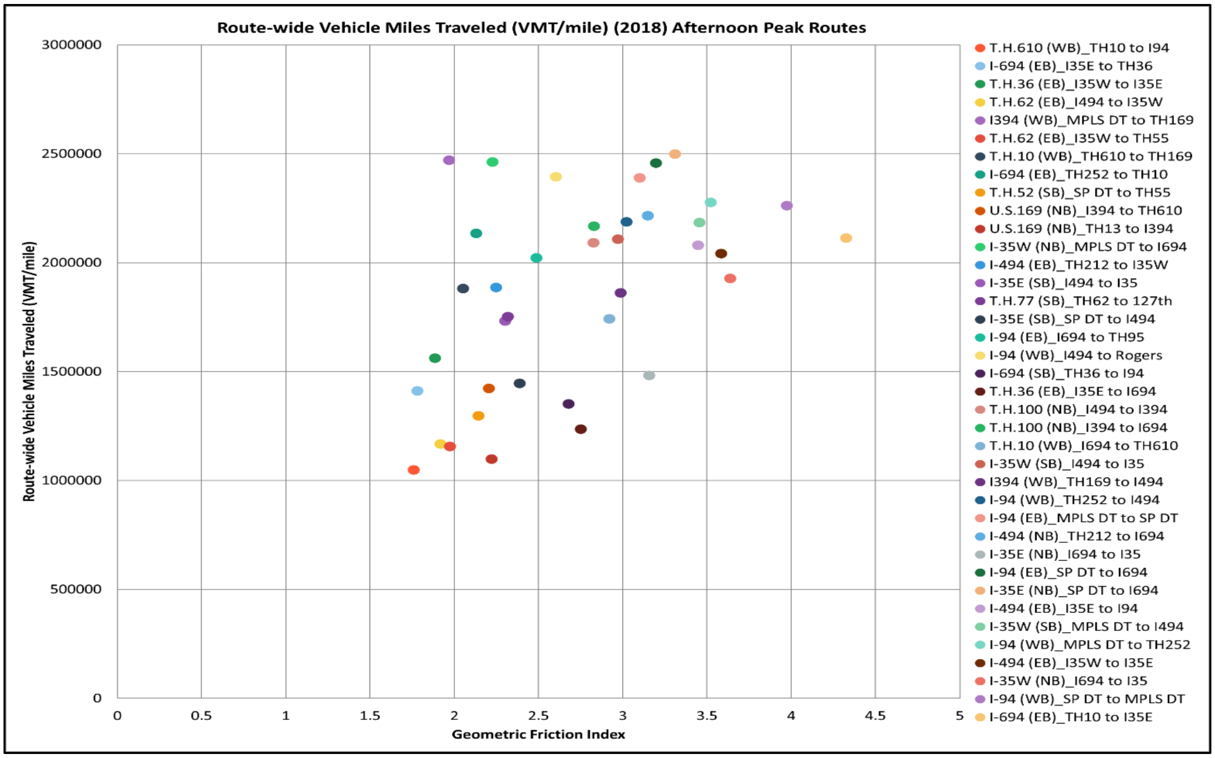


Figure 3.4.31 VMT/mile - G Relationship (2018 Afternoon Routes)

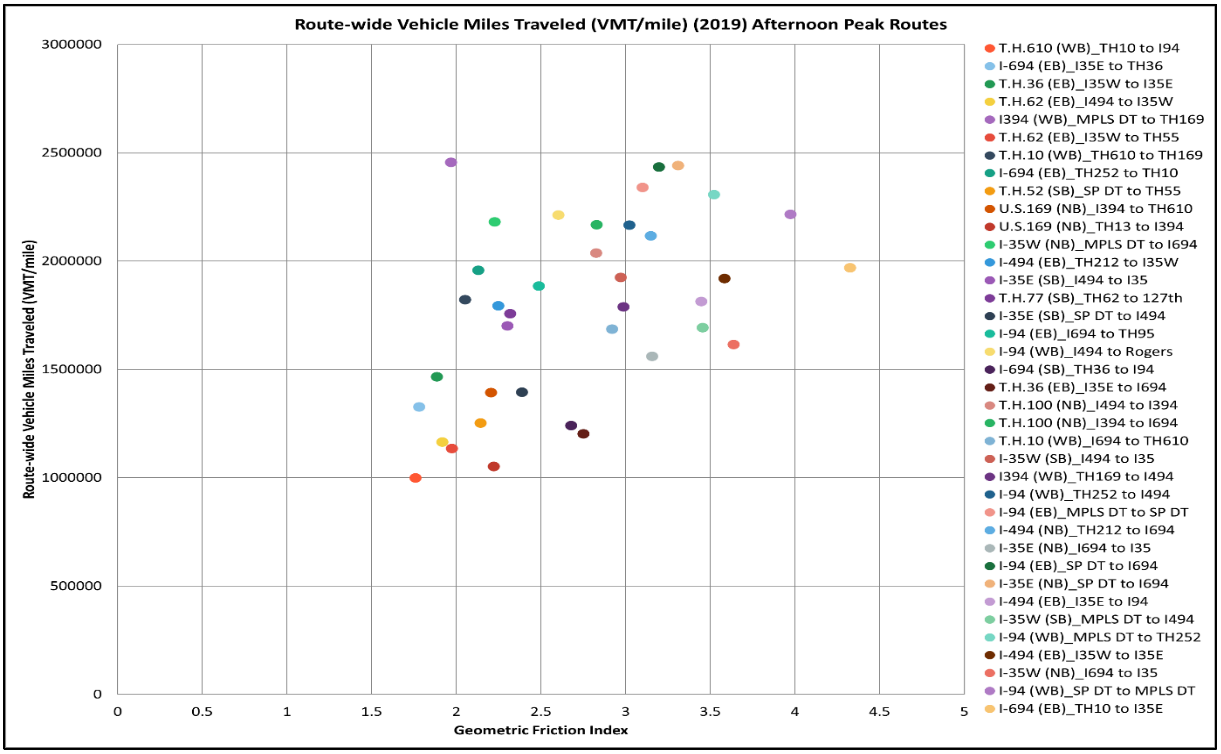


Figure 3.4.32 VMT/mile - G Relationship (2019 Afternoon Routes)

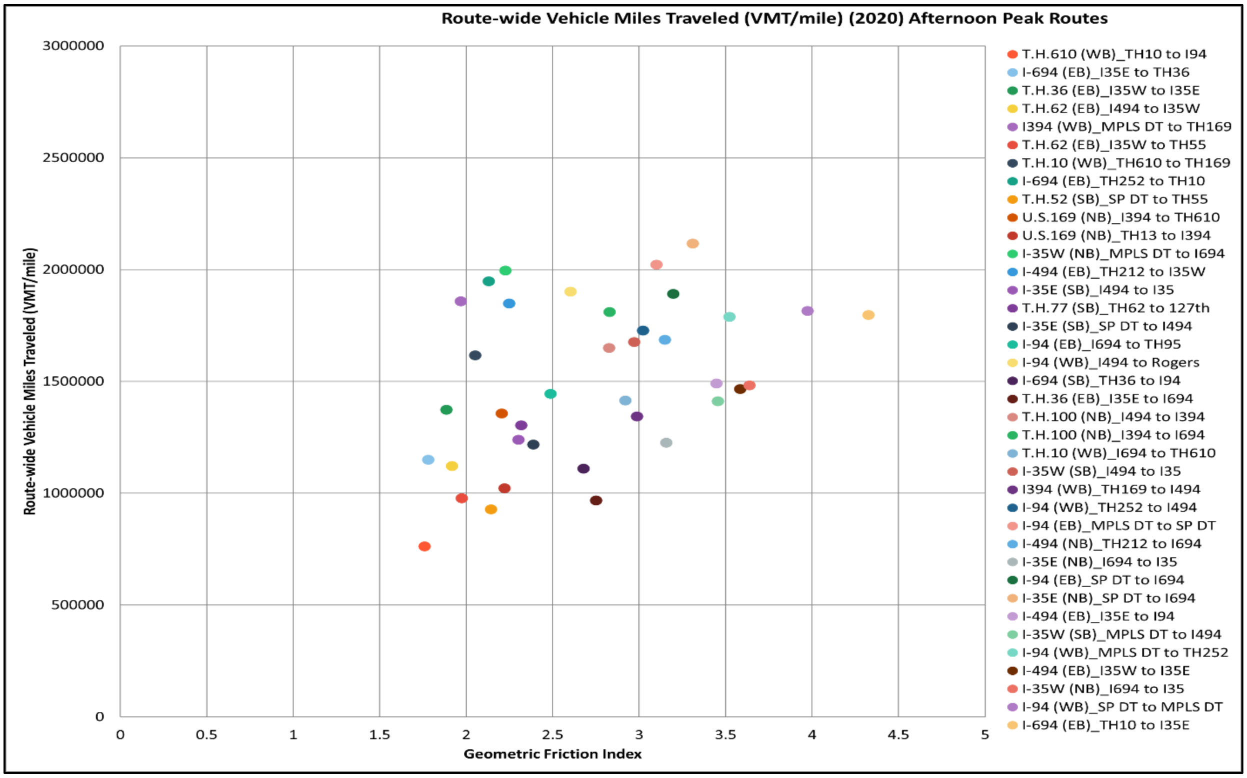


Figure 3.4.33 VMT/mile - G Relationship (2020 Afternoon Routes)

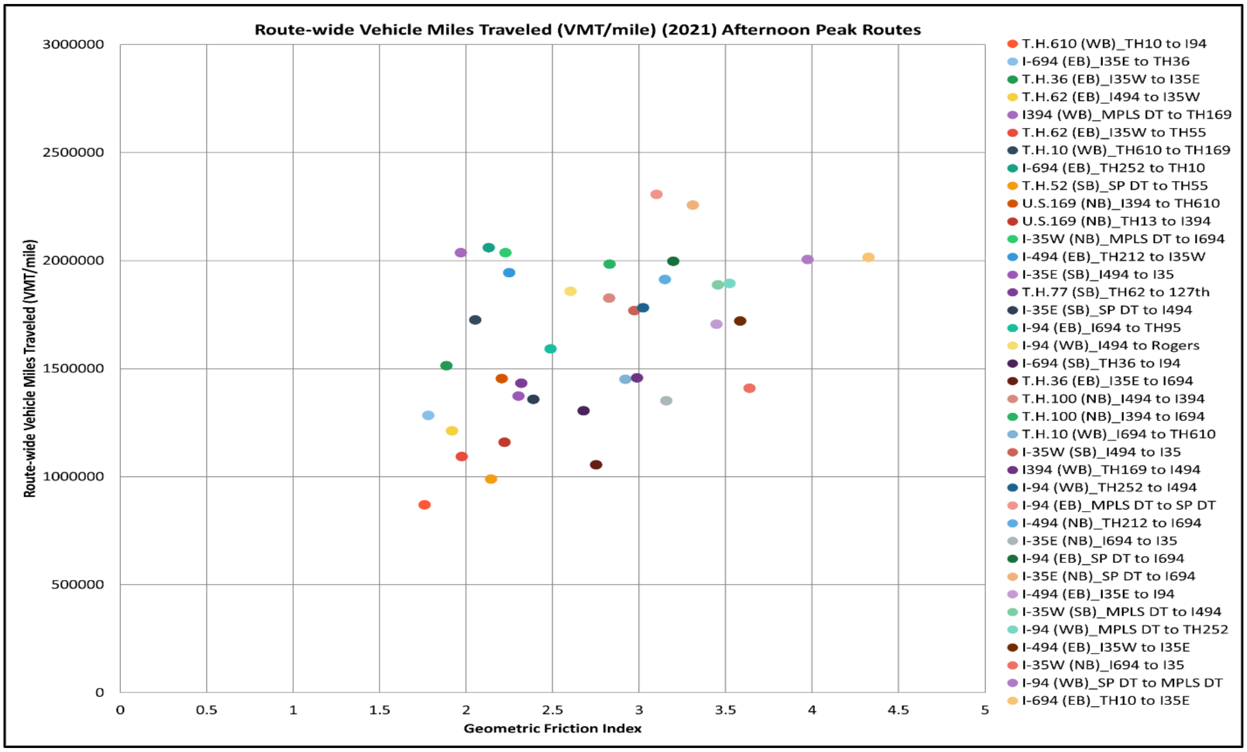


Figure 3.4.34 VMT/mile - G Relationship (2021 Afternoon Routes)

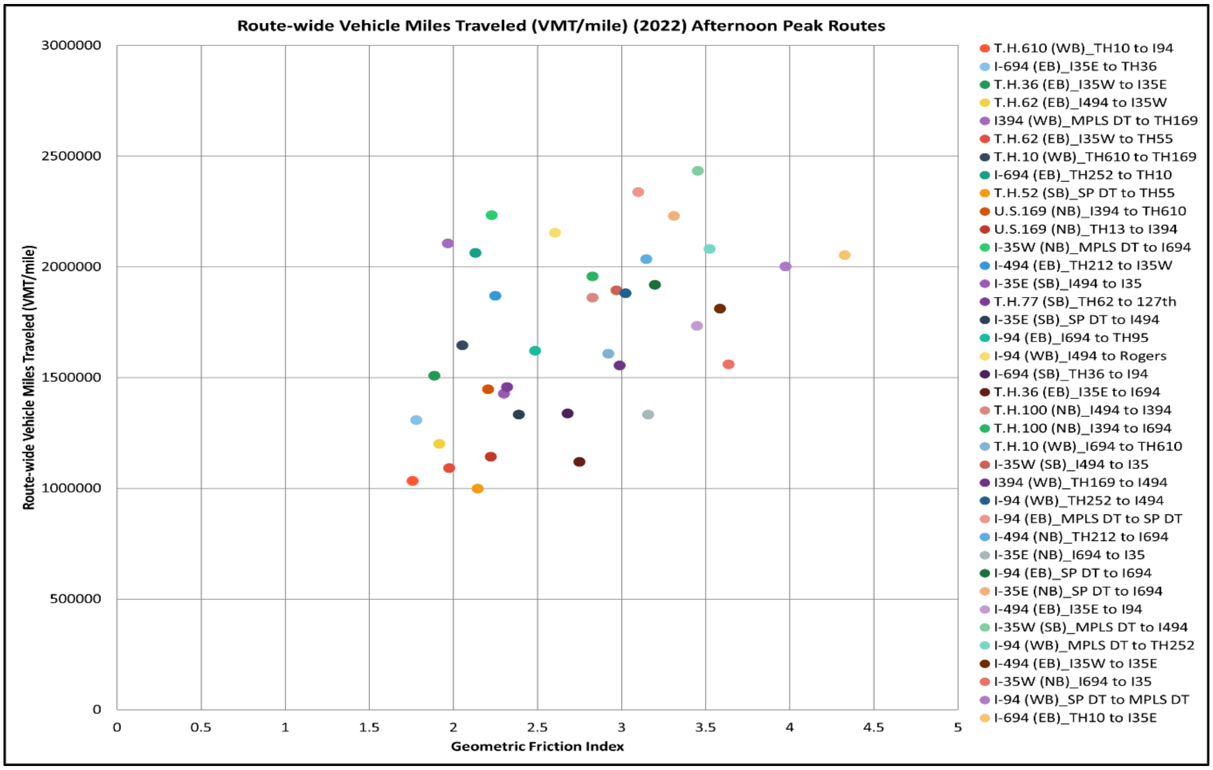


Figure 3.4.35 VMT/mile - G Relationship (2022 Afternoon Routes)

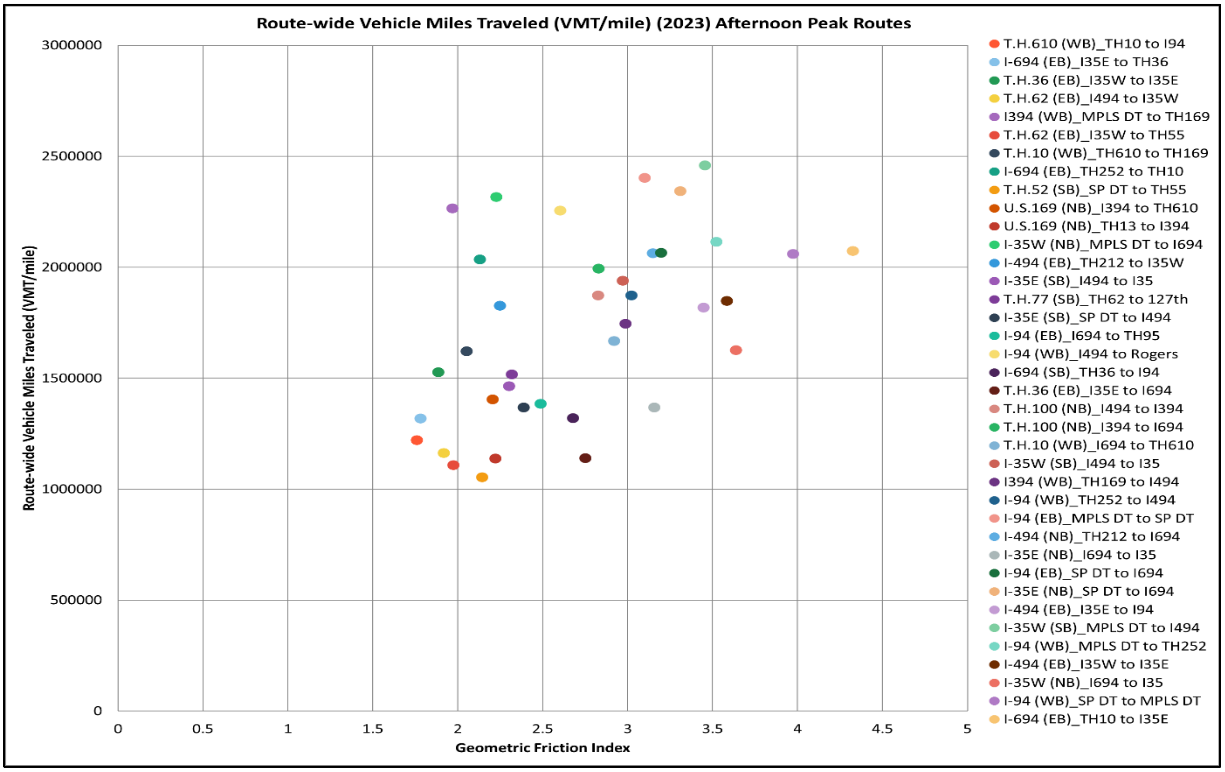


Figure 3.4.36 VMT/mile - G Relationship (2023 Afternoon Routes)

Vehicle-Hours-Traveled (VHT)/mile vs Geometric-Friction Index (G) - 2018-2023: Morning Routes

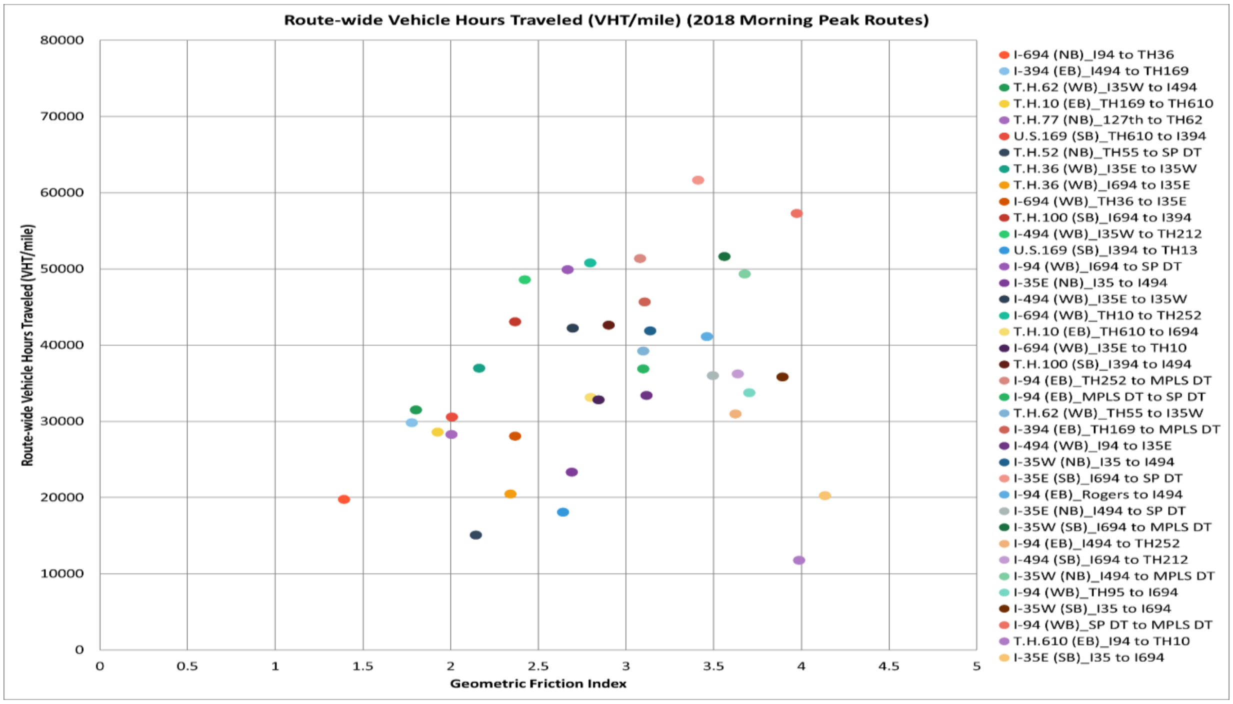


Figure 3.4.37 VHT/mile - G Relationship (2018 Morning Routes)

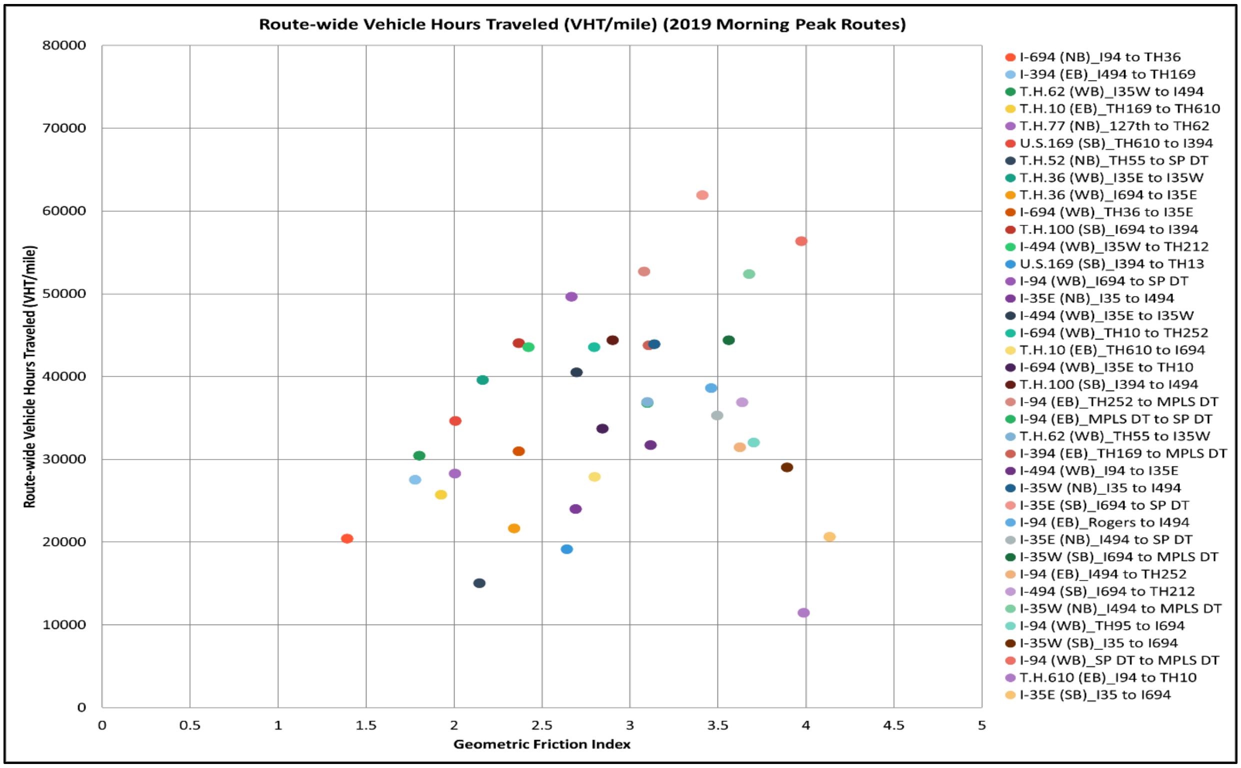


Figure 3.4.38 VHT/mile - G Relationship (2019 Morning Routes)

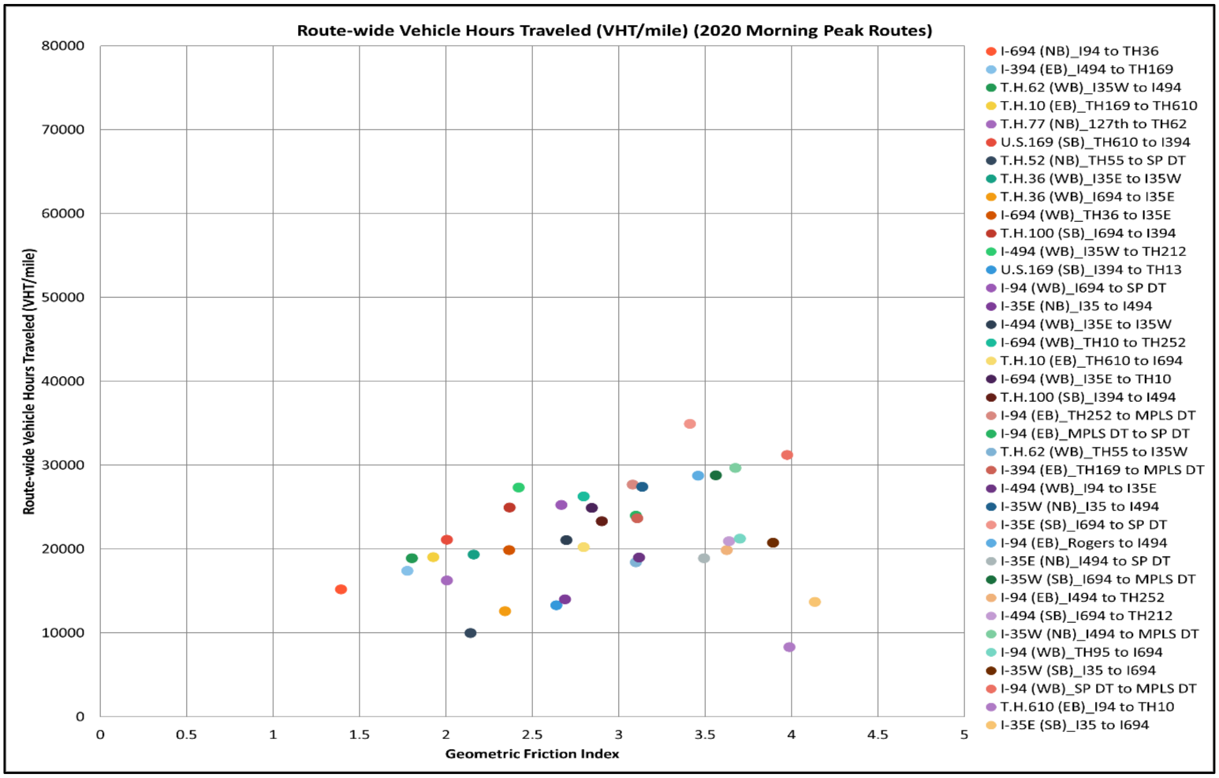


Figure 3.4.39 VHT/mile - G Relationship (2020 Morning Routes)

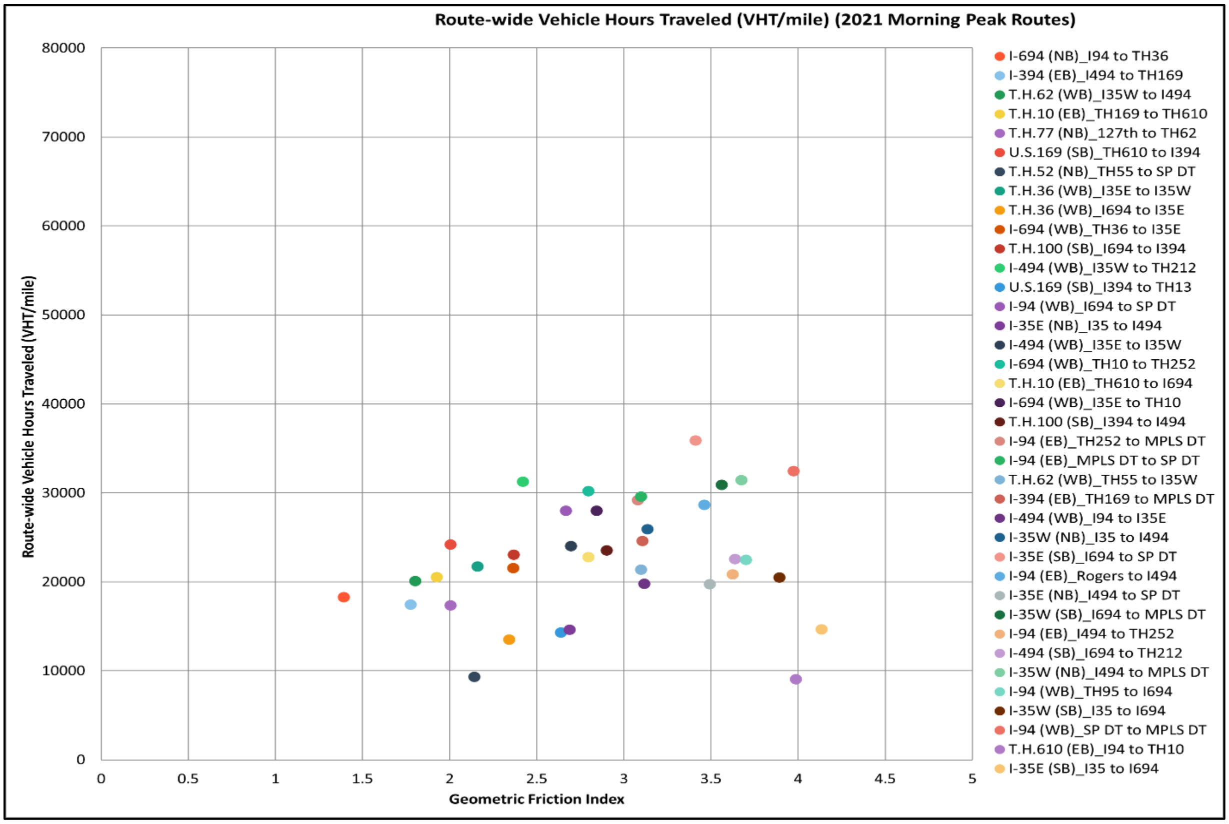


Figure 3.4.40 VHT/mile - G Relationship (2021 Morning Routes)

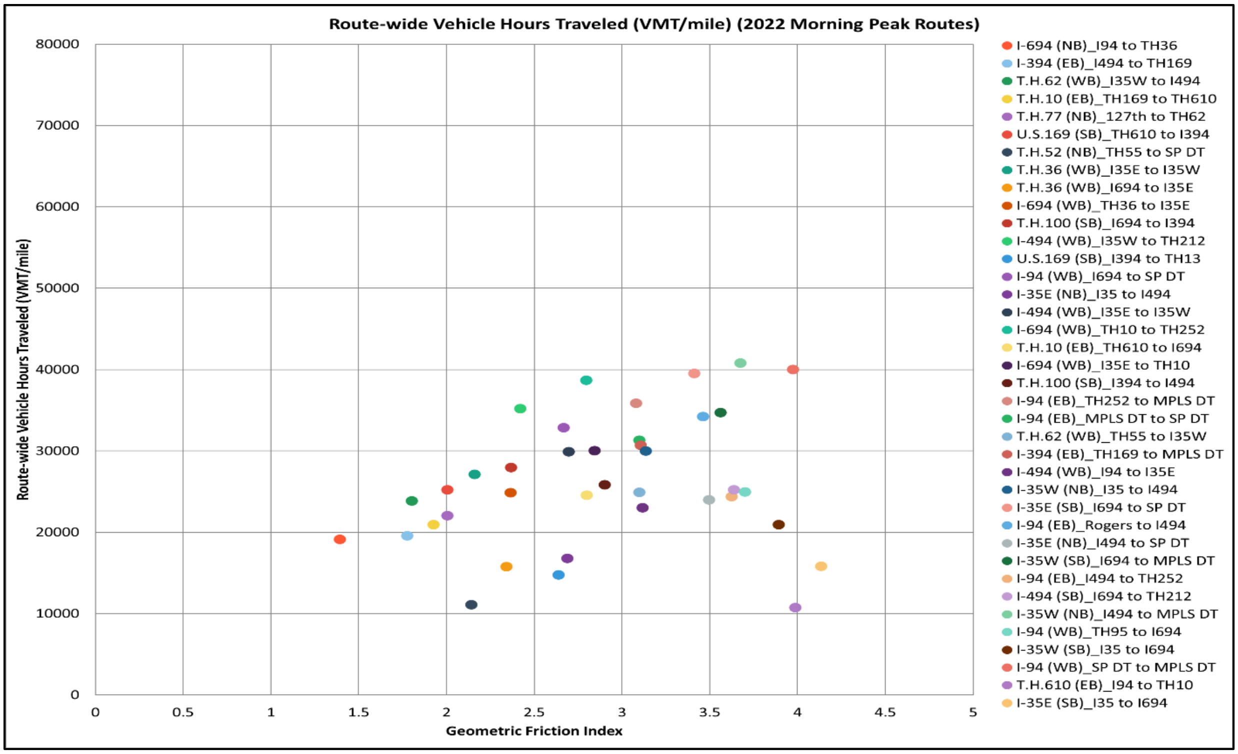


Figure 3.4.41 VHT/mile - G Relationship (2022 Morning Routes)

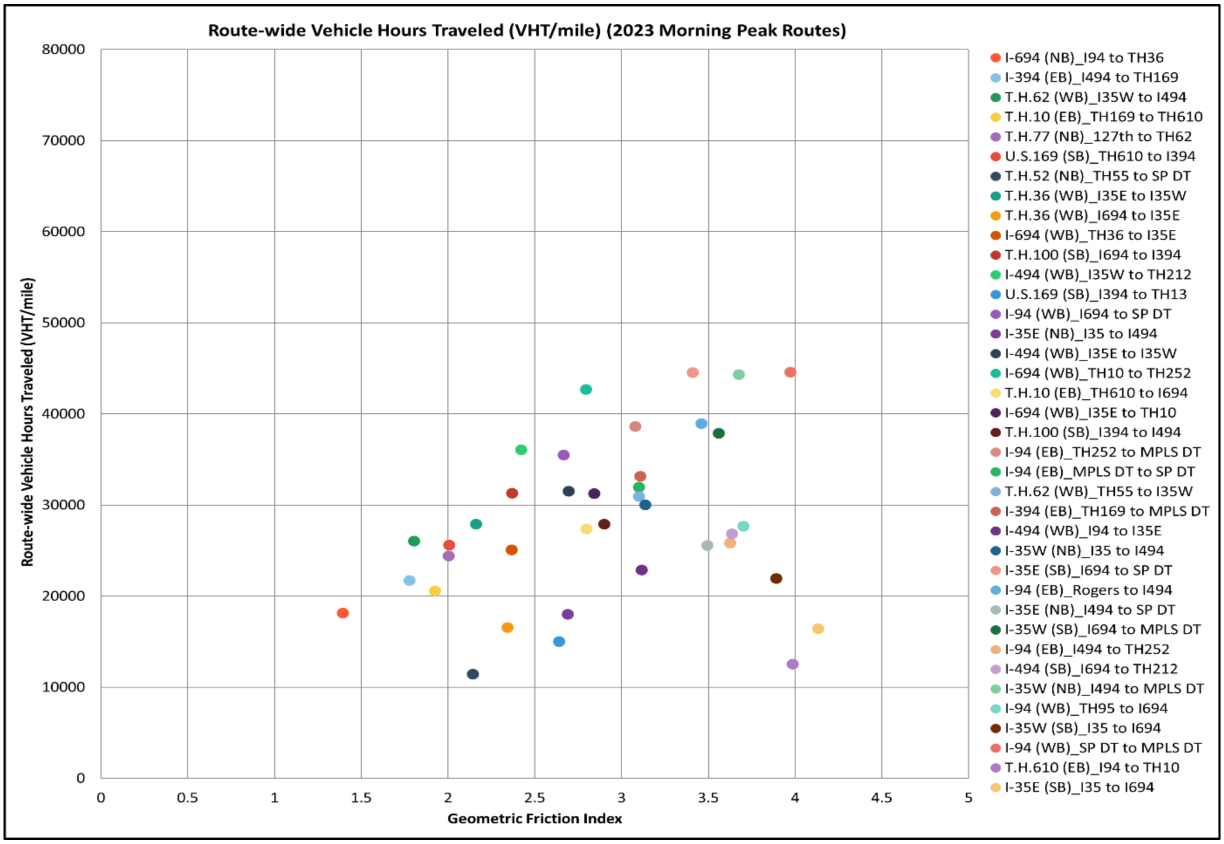


Figure 3.4.42 VHT/mile - G Relationship (2023 Morning Routes)

Vehicle-Hours-Traveled (VHT)/mile vs Geometric-Friction Index (G) - 2018-2023: Afternoon Routes

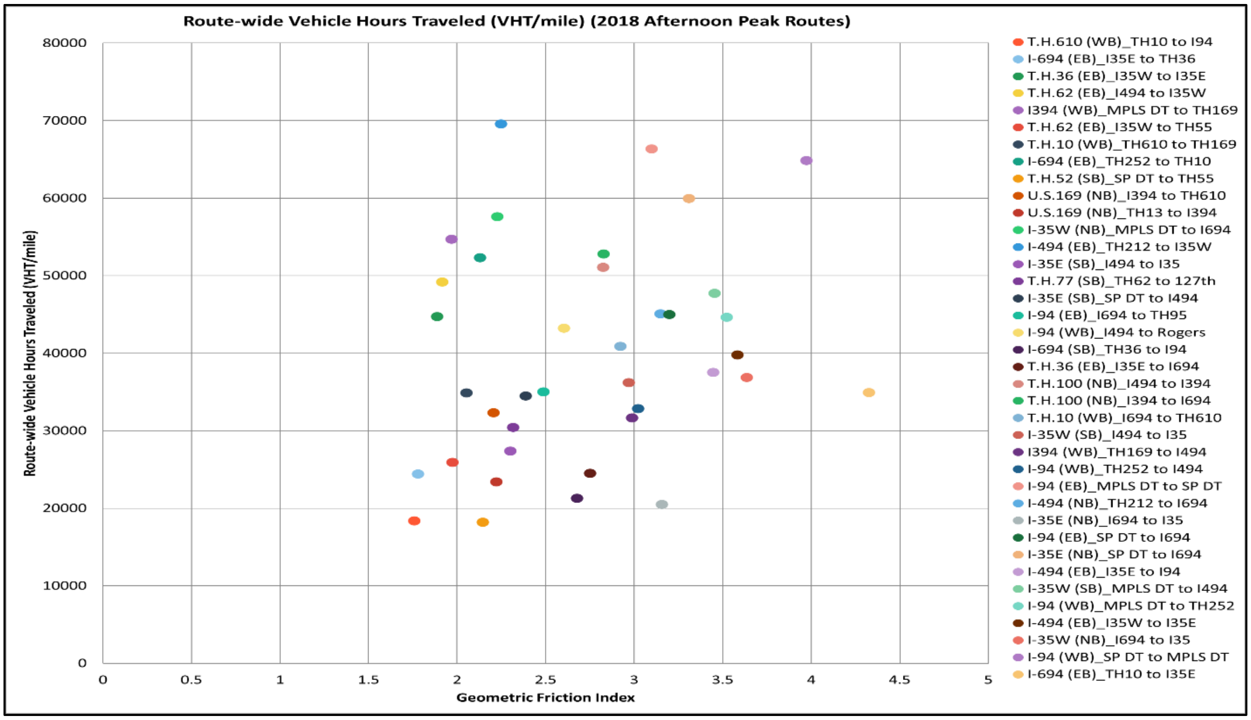


Figure 3.4.43 VHT/mile - G Relationship (2018 Afternoon Routes)

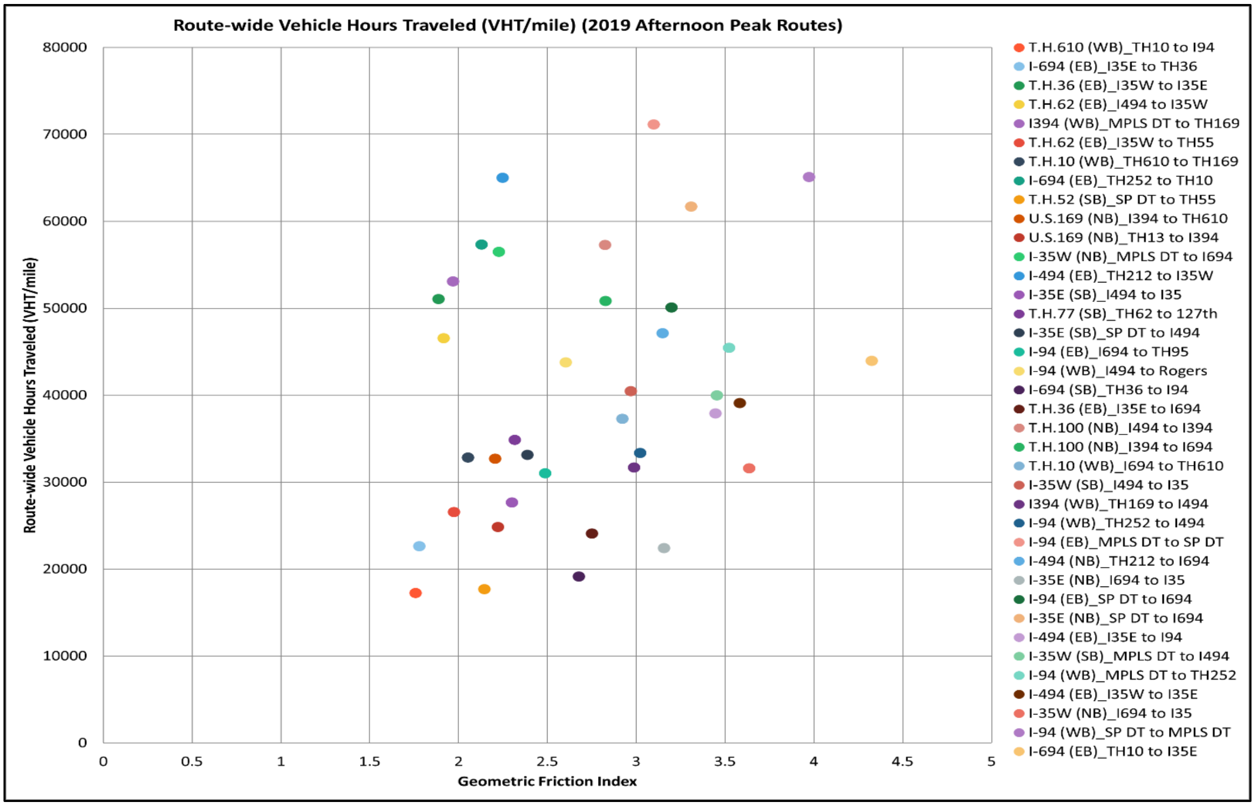


Figure 3.4.44 VHT/mile - G Relationship (2019 Afternoon Routes)

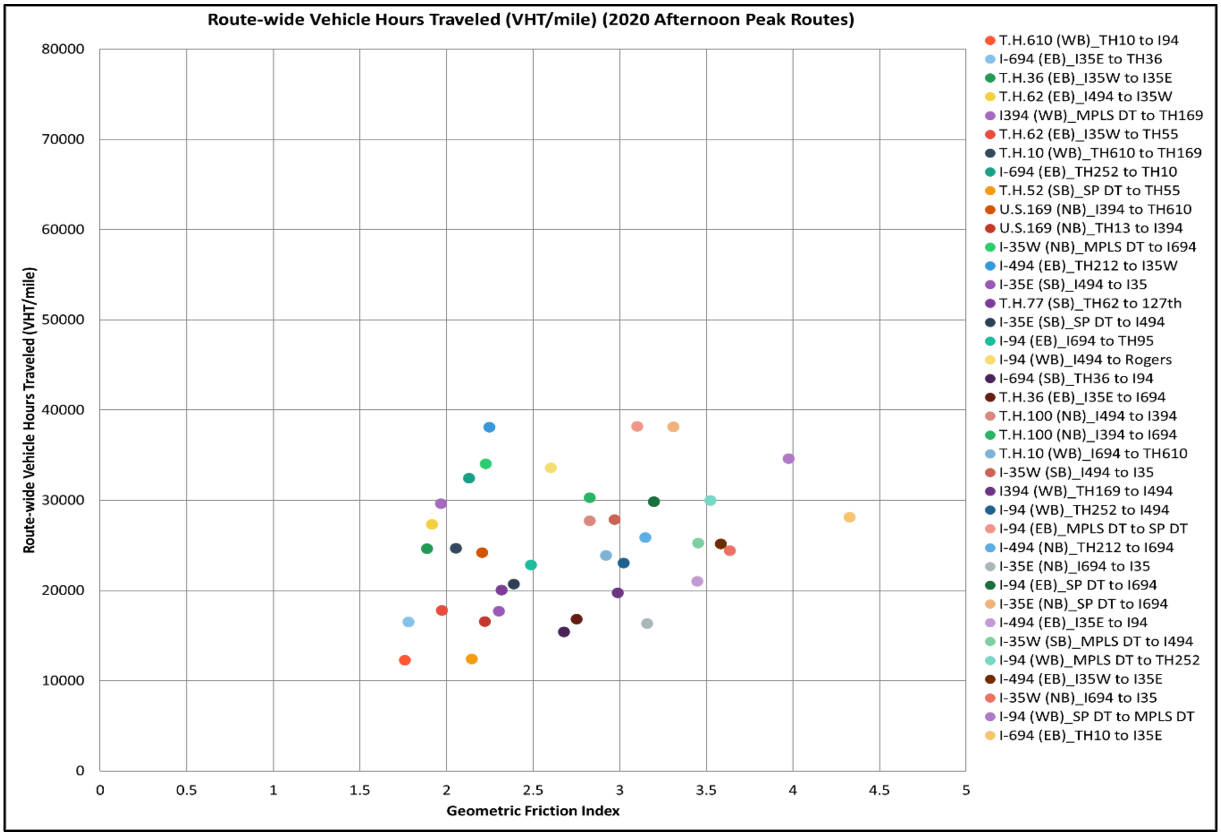


Figure 3.4.45 VHT/mile - G Relationship (2020 Afternoon Routes)

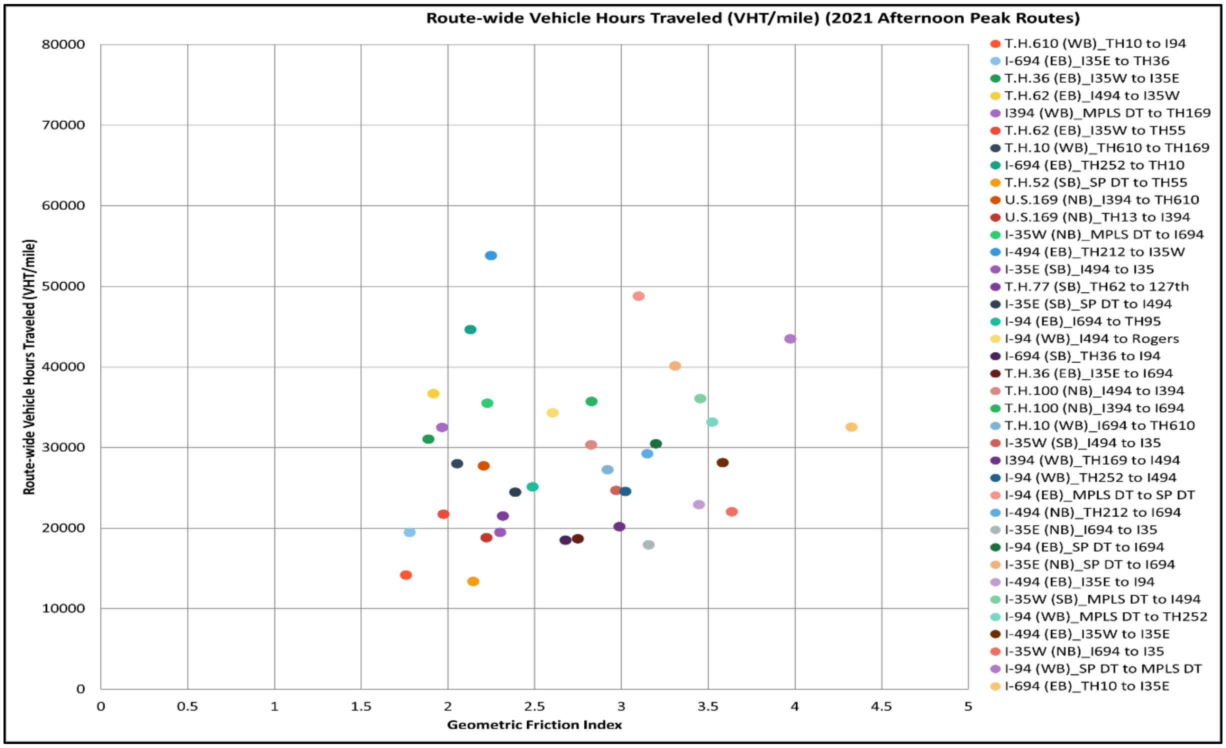


Figure 3.4.46 VHT/mile - G Relationship (2021 Afternoon Routes)

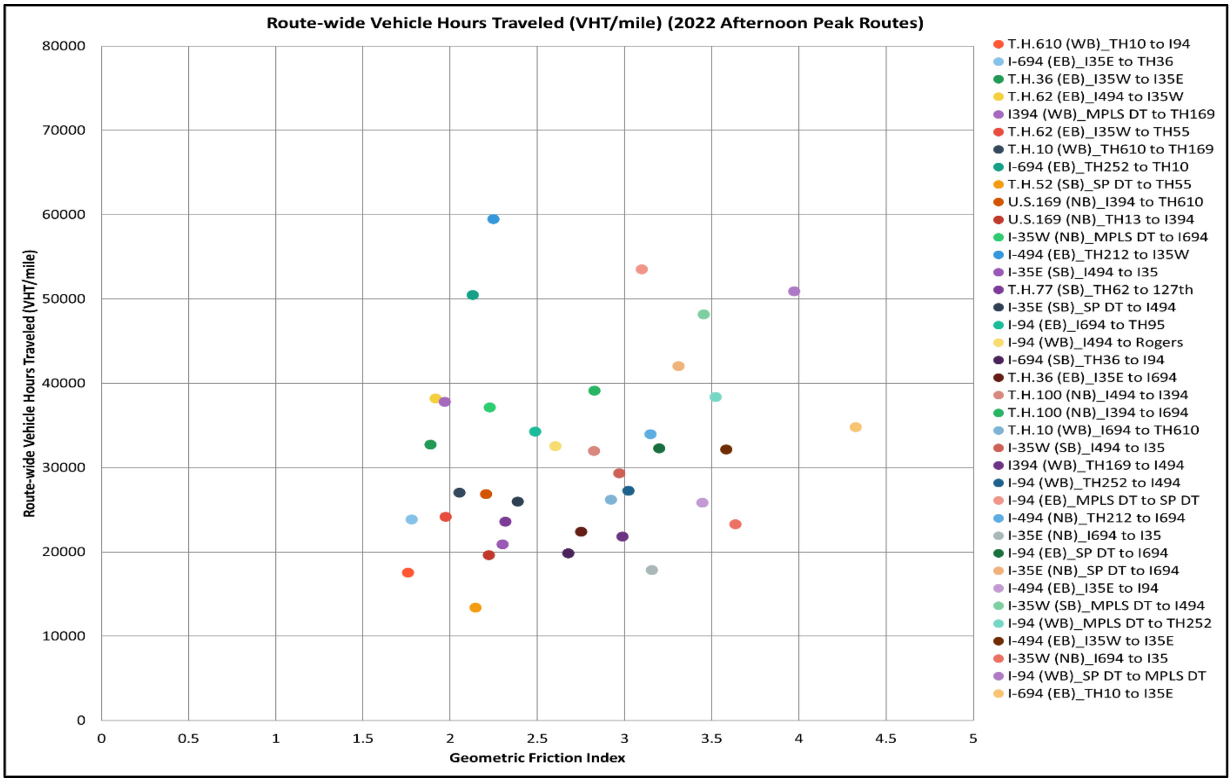


Figure 3.4.47 VHT/mile - G Relationship (2022 Afternoon Routes)

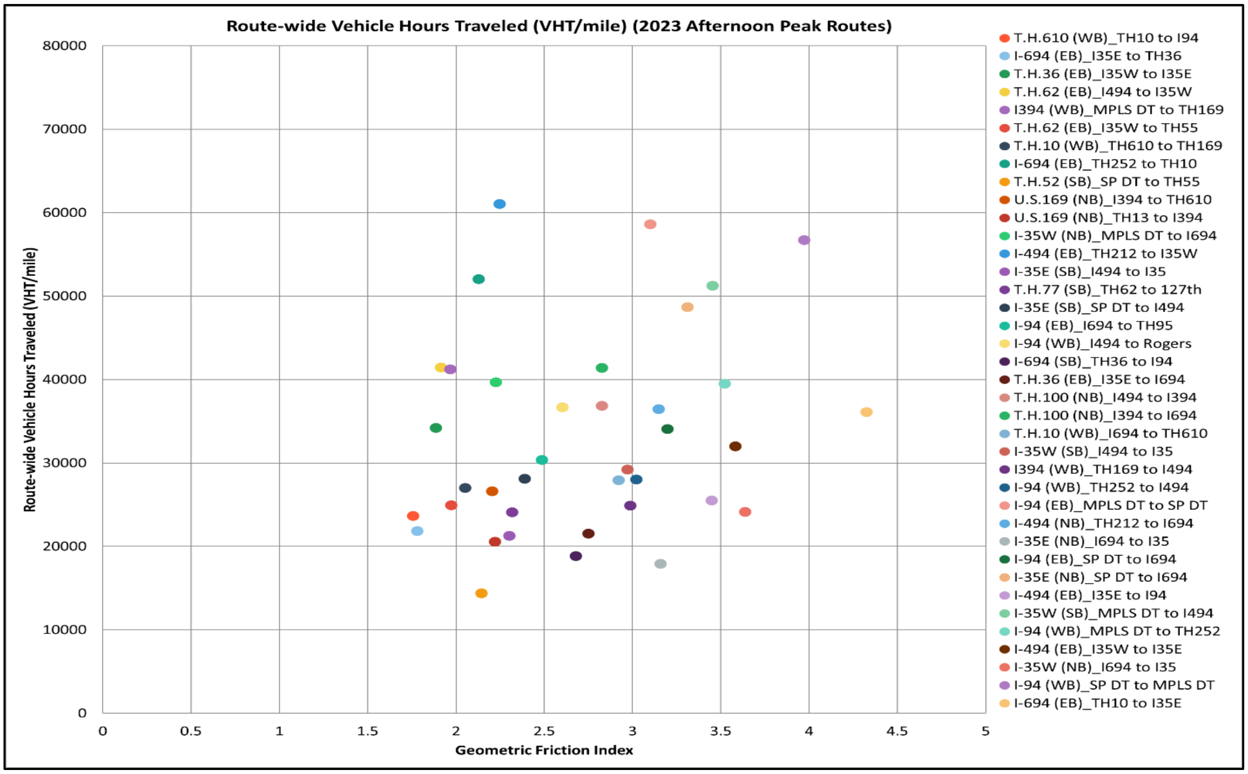


Figure 3.4.48 VHT/mile - G Relationship (2023 Afternoon Routes)

3.5 Monthly and Yearly Trends of Travel-Time Reliability and Traffic-Flow Measures at Individual

ROUTES

As described earlier, this study also analyzed the monthly and yearly trends of individual travel-time reliability (TTR) and traffic-flow measures of effectiveness (MoE) from January 2018 until December 2023. In this section, a sample output for such an individual-route analysis for the 169 northbound (NB) route is presented. Figures 3.5.1 – 3.5.9 show the monthly and yearly variations of the TTR and traffic-flow MoE measures at the example route. The results of all other routes are included in the Appendix.

MONTHLY RELIABILITY TRENDS OF US-169 NB ROUTE (TH 101 < -- > I-394) FOR AFTERNOON-PEAK PERIOD

Figure 3.5.1 Location of 169 NB Route

Effects of Weather conditions on Travel-Time Reliability (TTR)

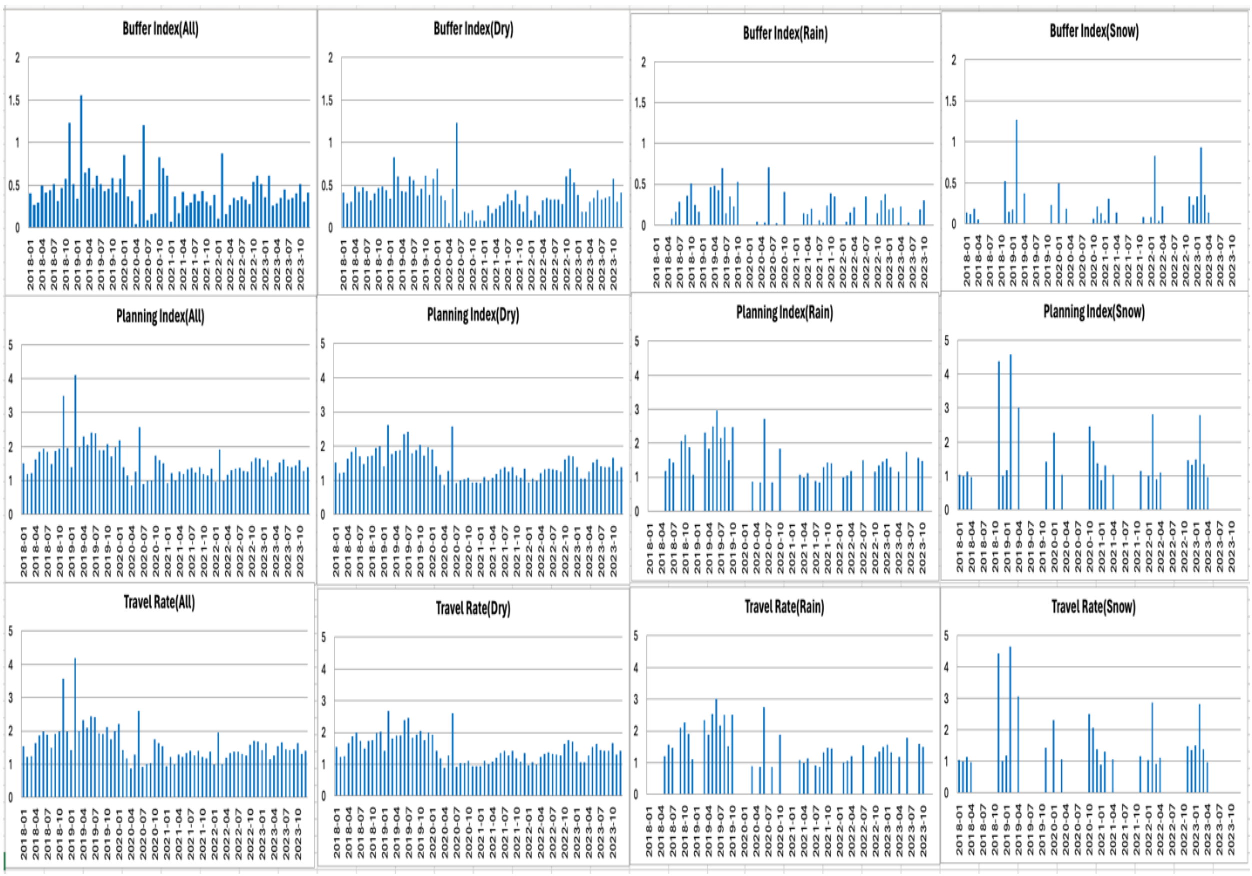


Figure 3.5.2 Monthly Variations of TTR Measures under Different Weather Conditions (169 NB)

Effects of Incidents

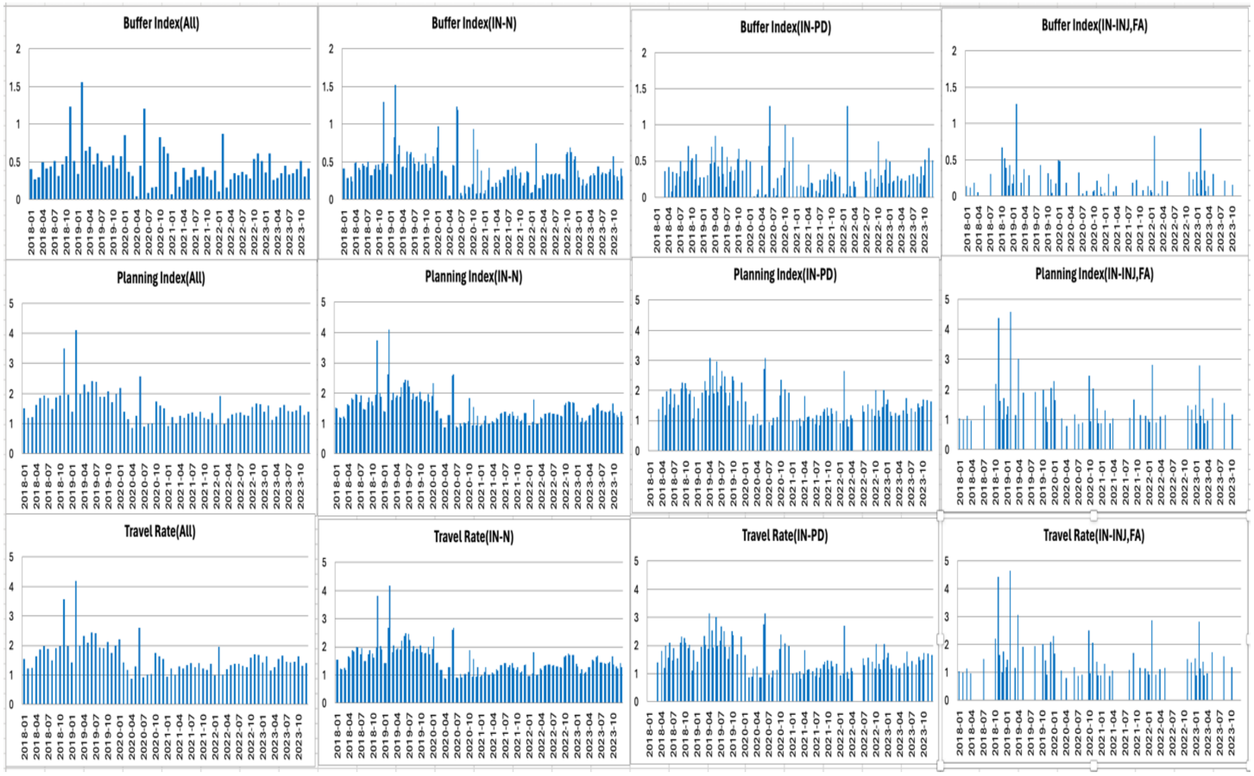


Figure 3.5.3 Monthly Variations of TTR Measures under Different Incident Conditions (169 NB)

Effects of Work Zones

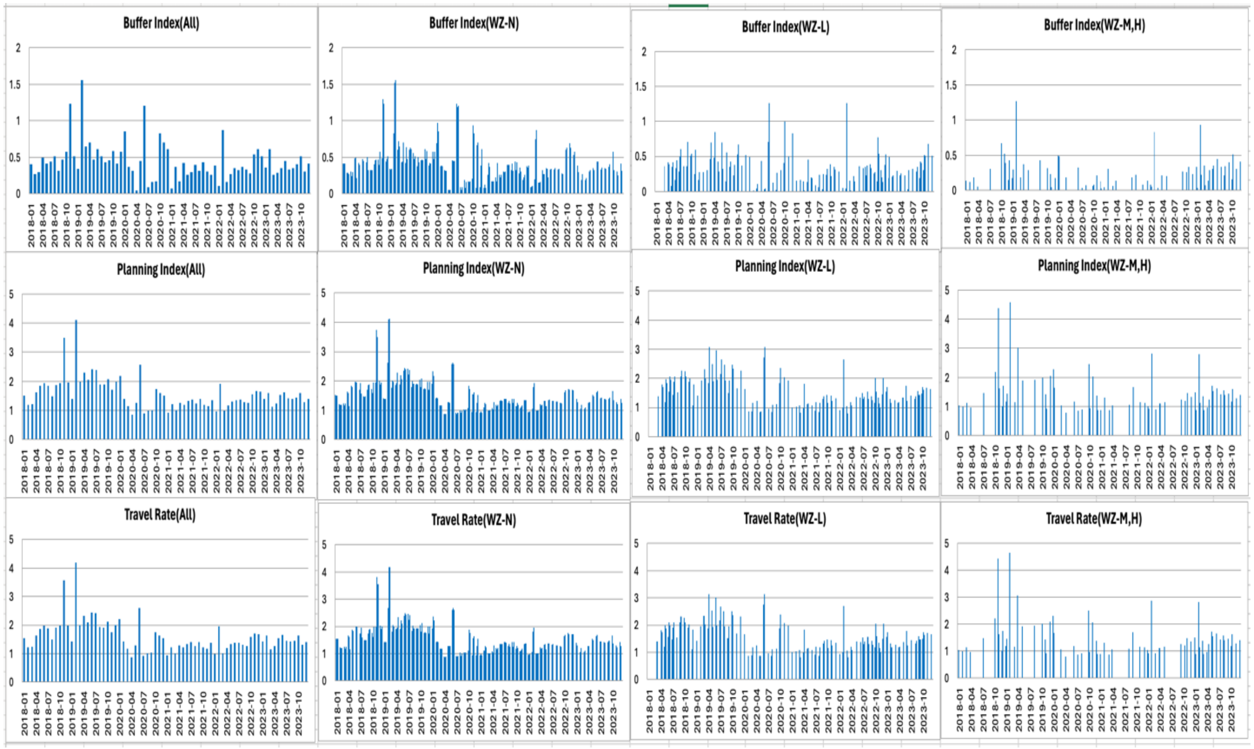


Figure 3.5.4 Monthly Variations of TTR Measures under Different Work-Zone Conditions (169 NB)

Yearly Variations of TTR - *Weather Effects*

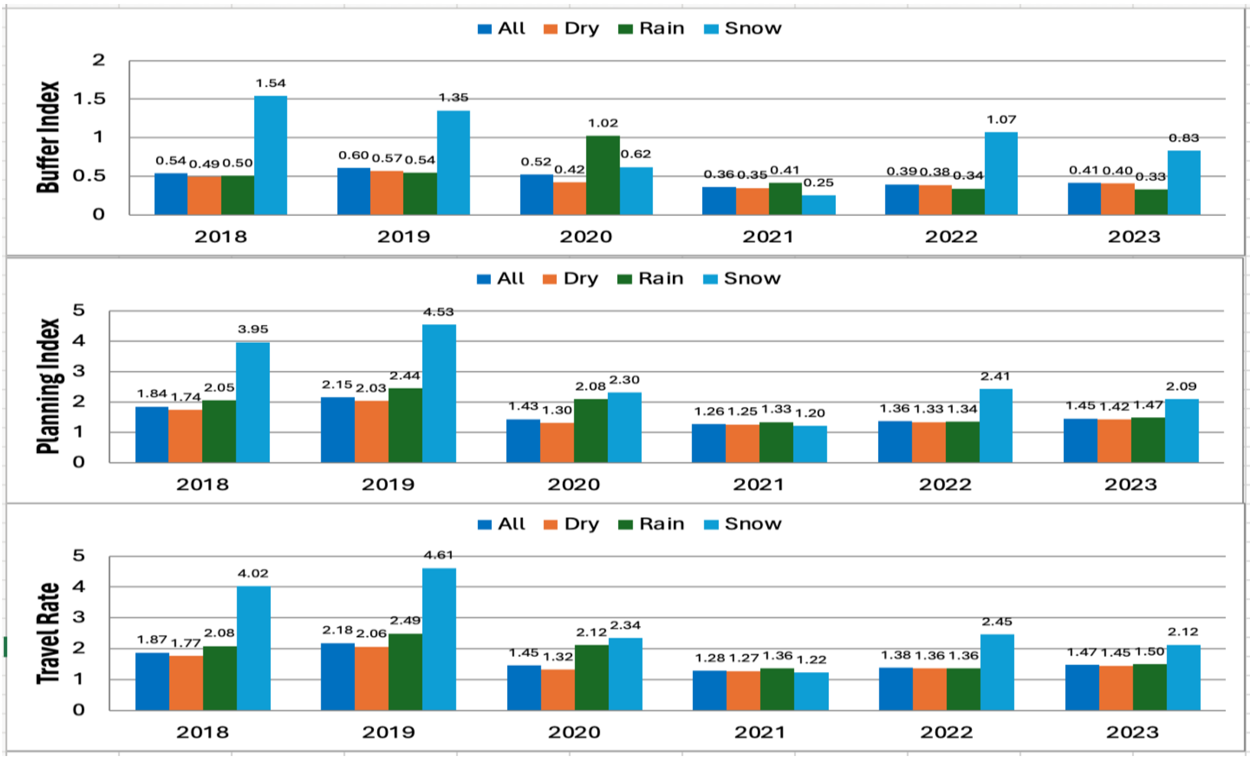


Figure 3.5.5 Yearly Variations of TTR Measures under Different Weather Conditions (169 NB)

Incident Effects

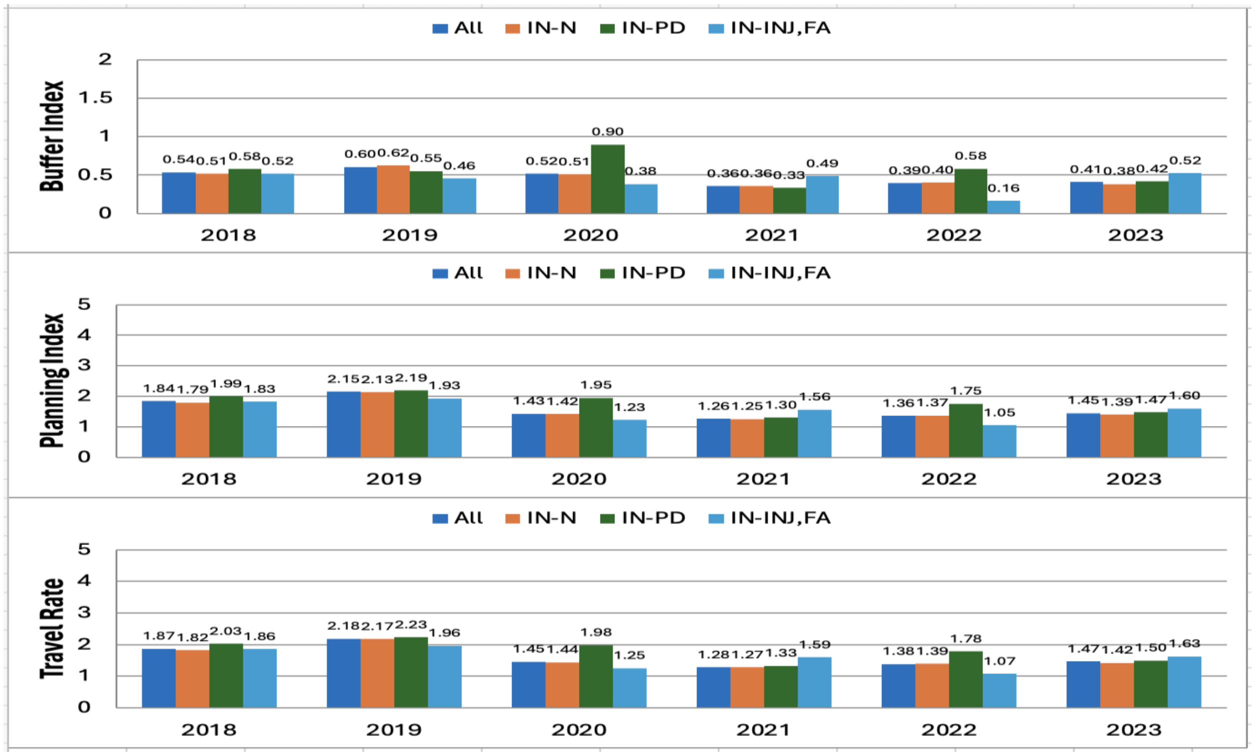


Figure 3.5.6 Yearly Variations of TTR Measures under Different Incident Conditions (169 NB)

Work-Zone Effects

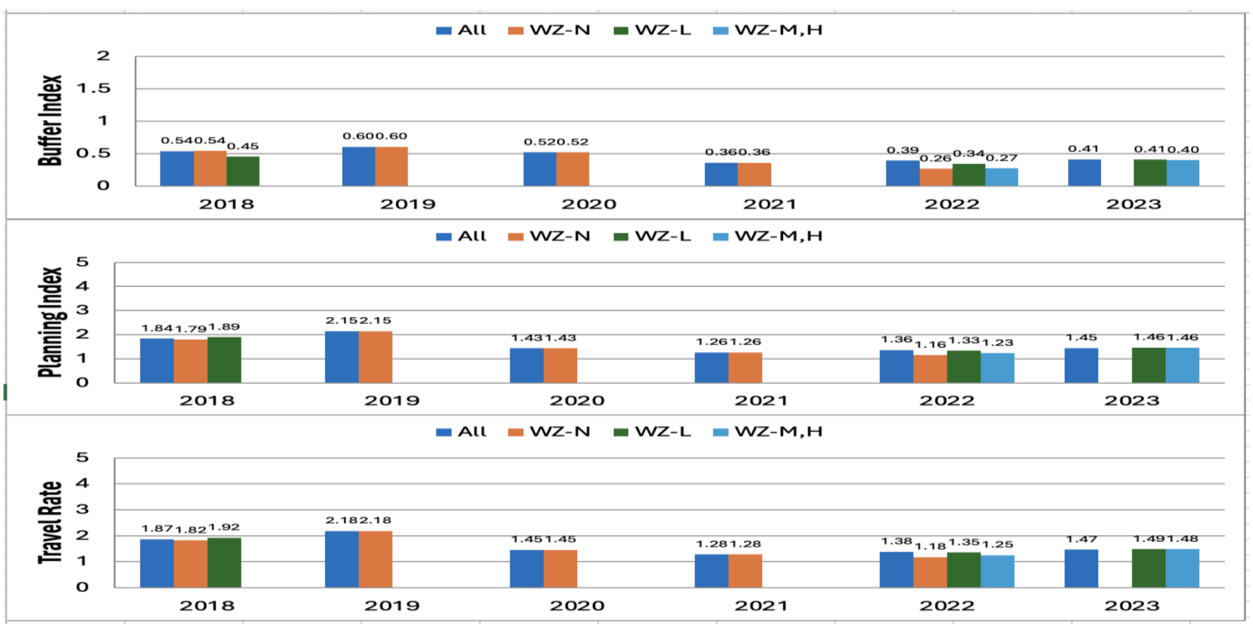


Figure 3.5.7 Yearly Variations of TTR Measures under Different Work-Zone Conditions (169 NB)

Yearly Variations of Buffer Index - Travel Rate Relationships

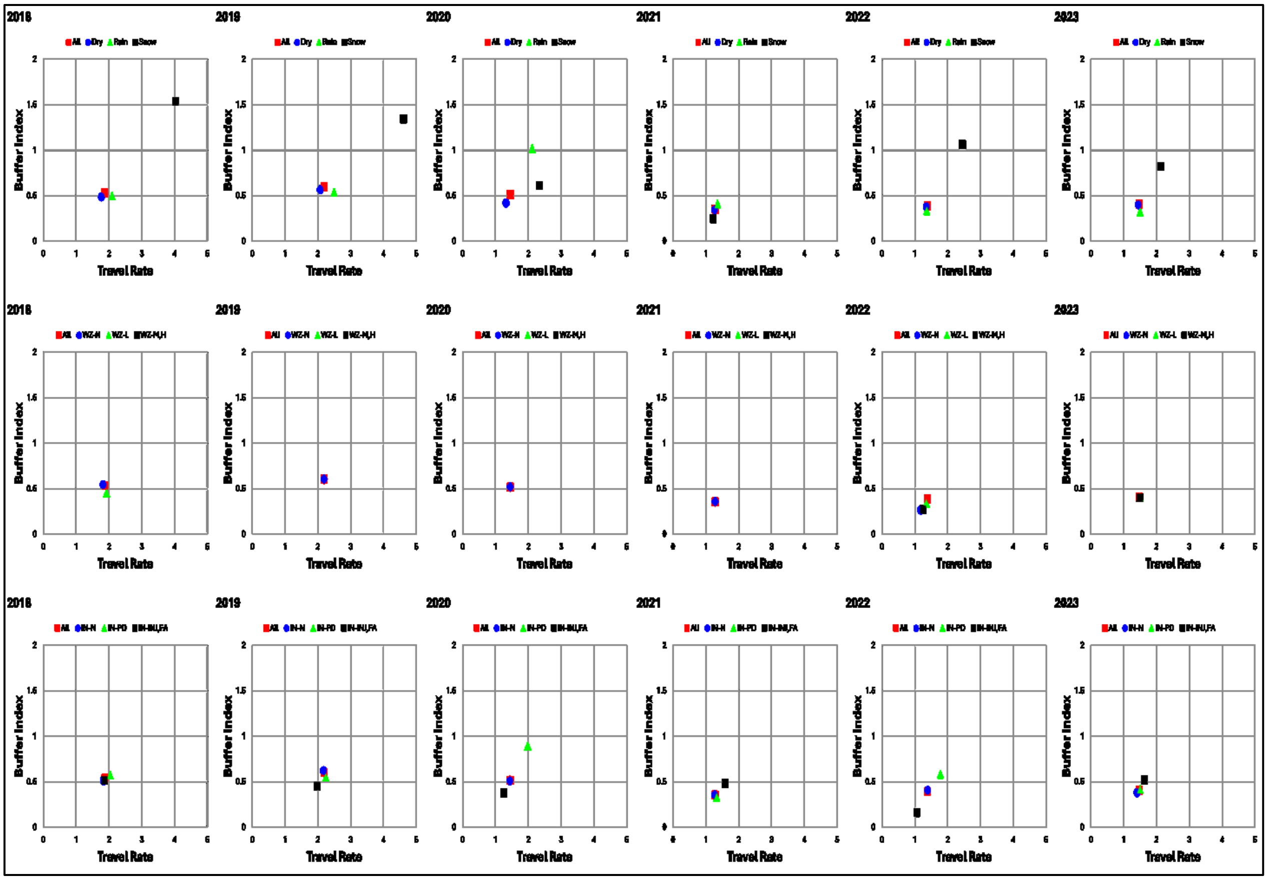


Figure 3.5.8 Yearly Variations of Buffer-Index vs Travel-Rate Relationships (169 NB)

Variations of Traffic-Flow Measures

Figure 3.5.9 Yearly Variations of Traffic-Flow Measures (169 NB)

Trends Summary for 169 NB Route

- The congestion on this route had been increasing before the pandemic as shown in the Delayed-Vehicle-Hour (DVH) and Buffer/Planning Index trends for the 2018-2019 period.
- The pandemic-induced traffic restriction in 2020 resulted in significant reduction in VMT and improvements in travel-time TTR measures. While the total DVH has been continuously increasing since 2020, the DVH in December 2023 is still significantly lower than the pre-pandemic level.
- While weather is the major factor affecting travel-time reliability, the effects of snow are significantly larger than those of rain on this route with high levels of traffic flow.

3.6 Summary

This chapter summarizes the analysis results for the travel-time reliability (TTR) and traffic-flow performance trends of the metro freeway network, which consists of 37 corridors and 74 directional routes. First, for each directional route, a set of the monthly/yearly TTR indices and traffic-flow measures of effectiveness (MoE) for morning and afternoon peak periods were estimated from 2018 until 2023 under various operating conditions. Next, the results from the individual-route analysis were used to determine the network-wide trends for the TTR and traffic-flow MoEs before and after April 2020, when the COVID-19 traffic-restriction started. The trends analysis showed that, after the sudden reduction in traffic flows in April 2020, the traffic flows in the metro freeway network have been slowly but continuously increasing, however, as of December 2023, they have not reached the pre-pandemic level. As a result, the network-wide TTR measures after April 2020 showed continuously better reliability conditions than those of the pre-pandemic period in both morning and afternoon networks.

The results from the individual route analysis were also used to determine the overall reliability conditions, defined as vulnerability (VI), of each route and their yearly trends. Specifically, the yearly values of the buffer index and travel rate are used to determine the vulnerability level of each route, and the most vulnerable routes were identified each year from 2018 until 2023. Further, the effects of the route-wide geometric configuration, quantified as the geometric friction factor, G, on the TTR and traffic-flow measures of each route were also analyzed by examining the graphical relationships between G and TTR/traffic-flow MoEs, whose yearly plots exhibited the expected patterns, i.e., the routes with low friction handled higher traffic flows with less fluctuations in travel times than those with high friction geometry.

The findings in this chapter provide the overall traffic conditions and trends of the metro freeway network as well as those of individual routes. Further, the analysis results of route vulnerability and the geometric effects on both TTR and traffic-flow measures could provide the basis for future improvements of freeway corridors.

Chapter 4: ENHANCEMENT OF THE OPERATIONAL-RESILIENCE MODEL FOR FREEWAY CORRIDORS

4.1 Introduction and Overview of Preliminary Resilience Model

This chapter summarizes the process to enhance the preliminary model, developed in the previous phase, to quantify the corridor-wide operational resilience, which is defined as the inherent capability of a freeway traffic system to maintain its functionality by absorbing various levels of traffic disturbances and to recover from congestion with maximum efficiency under given geometry and operating conditions. Figure 4.1.1 shows the conceptual framework, described in the previous phase, of the corridor-wide traffic process, where the time-variant congestion levels, e.g., delayed-vehicle-hours, can be considered as the results from the interaction between the corridor-wide resilience and external disturbances to a given system.

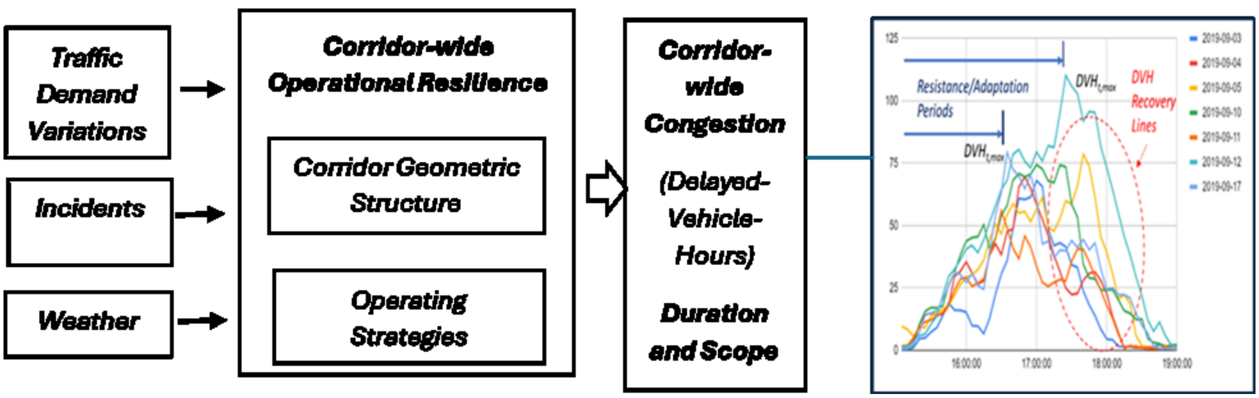


Figure 4.1.1 Conceptual Framework of Corridor-wide Traffic Process

Based on the above conceptual relationship, a preliminary model to quantify the operational resilience of a given freeway directional corridor was developed in the previous phase as follows:

$$CORI_i = \frac{\sum_t (DVH_t * A_t)}{(\sum_t V_{E,t}) * \sigma}$$

where, $CORI_i$ = *Operational Resilience Index of Corridor i*

DVH_t = *Corridor-wide delayed-vehicle-hours during t,*

= $\Sigma\ [(TT_{i,t} - FF\_TT_i) * K_{i,t} * L_i]$ for all segment *i* in a given route,

where, $TT_{i,t}$ = *Estimated travel time of segment i during t,*

FF_TT_i = *Free-Flow travel time of segment i, estimated with the speed limit at a given roadway section,*

$K_{i,t}$ = *Traffic density of segment i during t,* L_i = *Length of segment i.*

$V_{E,t}$ = *Corridor-wide total entering volume during t,*

= *(Upstream Boundary Station Volume)*$_t$ + *Σ (All Entrance Ramp Volumes)*$_t$

σ = *Standard deviation of* $V_{E,t}$ *during a peak period.*

A_t = *Proportion of weighted average number of through lanes during t,*

$$= \frac{Average\ Weighted\ Number\ of\ Through\ Lanes\ -\ (Number\ of\ Lanes\ Blocked)_t}{Average\ Weighted\ \ Number\ of\ Through\ Lanes}$$

As noted from the above formulation, the preliminary model tries to quantify the operational resilience of a given directional corridor as its capability to minimize delay under given time-variant traffic demand and through capacity, i.e., a smaller CORI index indicates a stronger resilience level for a given corridor. It also needs to be noted that, in the preliminary modeling, the *'Average Weighted-Number of Through Lanes*' is used as a surrogate measure of the through capacity for a given route. In particular, a set of the assumed values for blocked lanes, derived from the historical data, were used to reflect the incident effects on the through capacity.

The preliminary model was tested with the traffic data collected from a total of 8 sample routes for the period of September-October 2019 and the daily estimates of the Corridor-wide Operational Resilience Index (CORI) values for each route were calculated for the dry days. Figure 4.1.3 shows the locations of those sample routes. The daily estimates of CORI values for each sample route showed relatively consistent values as reported in the previous phase (2). Further, the potential relationship between the corridor-wide operational resilience and the geometric structure of each corridor was also studied in the previous phase by examining the relationships between the 'Geometric-Friction Index', G, described in the previous chapter as the quantification of the 'strength' of the geometric structure of a given corridor in terms of facilitating through traffic movements. Figure 4.1.3 shows the relationship between Geometric Friction Factor and CORI, Corridor-wide Operational Resilience Index, estimated with the preliminary model for the sample routes.

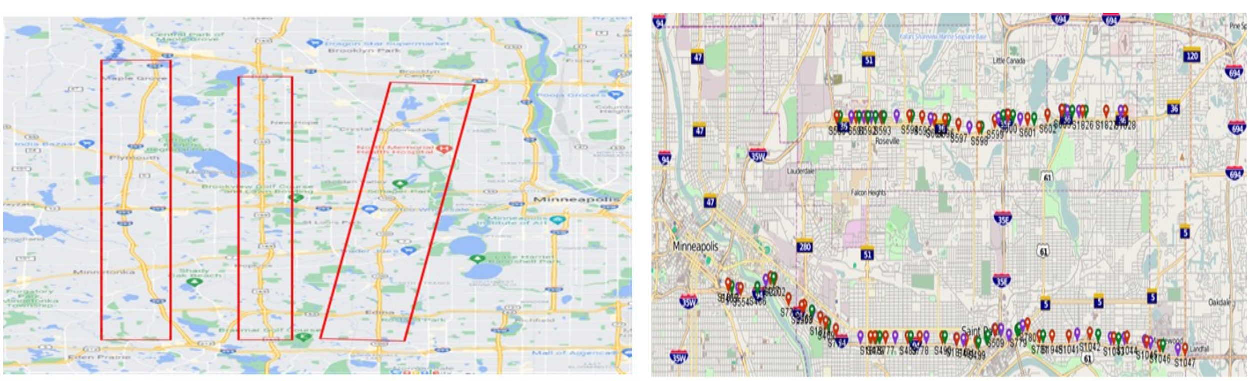


Figure 4.1.2 Locations of the Sample Routes (5 Corridors/8 Directional Routes)

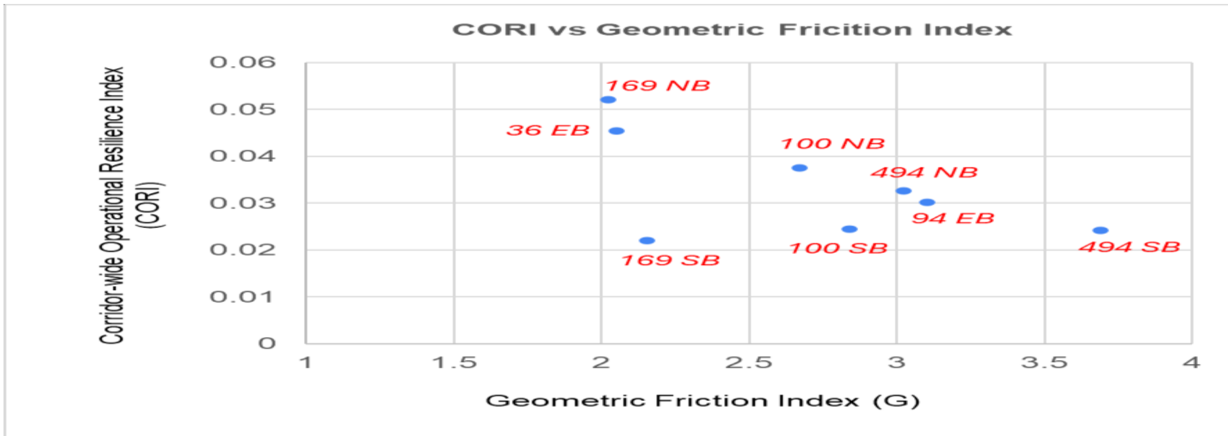


Figure 4.1.3 Operational Resilience (Preliminary Model) vs G for Sample Routes

4.2 Enhancements of the Preliminary Model for Operational Resilience of Freeway Corridors

As described in the previous section, the testing results of the preliminary model with the data collected from the sample routes showed relatively consistent daily estimates of CORI values for each sample route. Further, it also showed promising possibilities in quantifying the operational resilience of a given corridor traffic system as a function of its geometric configuration. However, the following issues were identified for the preliminary resilience model to be applied for field operations:

- The preliminary model is based on the Delayed-Vehicle-Hours (DVH) as the system performance measure. While DVH through time can reflect the interaction between the external input to a corridor-traffic system and its operational resilience, the values of DVH through time can vary depending on the number of lanes and length of a given route, i.e., DVH values for a given route are not normalized and cannot be used for direct comparison with other routes.

- In the preliminary model, a set of assumed values were used for the number of blocked lanes for different types of accident. However, it has been found that those values can vary for the same type of accident depending on the traffic level and surrounding conditions, e.g., the effects of a shoulder-block incident on the light traffic flows may not be the same as those on the medium to heavy traffic flows at a same location. Therefore, applying a set of the fixed values of blocked lanes may not correctly capture the effects of incidents on the resilience.

- It has been noted that most freeway routes in the current metro network contain some entrance ramps with missing detector data. The lack of some entrance-ramp data directly affects the accuracy of the 'total entering-volume through time', an important parameter in the preliminary model. Further, those missing ramp-flow rates could not be estimated correctly through imputation if adjacent detector data are not available.

To address the above issues, the following enhancements have been made to the preliminary model:

First, the route-wide Space-Mean Speed, U_t, is used as the main performance measure, which is estimated through time using only the mainline detector-station data as follows:

$U_t = (VMT)_t / (VHT)_t$

where, U_t = *Route-wide space-mean speed (mph) during t,*

$(VMT)_t$ = *Route-wide Vehicle-Miles-Traveled during t,*

$= \Sigma (Q_{i,t} * T * L_i)$ *for all i, t*

where, $Q_{i,t}$: *Flow-Rate of Segment i during t, T: Time duration of t,* L_i: *Length of Segment, i*

$(VHT)_t$ = *Route-wide Vehicle-Hours-Traveled during t*

$= \Sigma (K_{i,t} * L_i * t_i)$ *for all* L_i, t_i *where,* $K_{i,t}$: *Density of Segment i, during t*

In the above formulation, the Flow Rate and Density of Segment i through time are estimated with the traffic data from the field detector stations on the mainline in each route. Figure 4.2.1 shows the U_t variations through time at the I-494 NB and the 100 NB routes, two of the sample routes used in this study, for the same weekdays. As indicated in this figure, the U_t-time variations on each weekday clearly exhibit the route-wide resilience patterns in terms of resistance/adaptation and recovery periods. It can also be noted that the route-wide space-mean speed is a normalized measure that can be directly used for comparing the traffic performance of multiple routes.

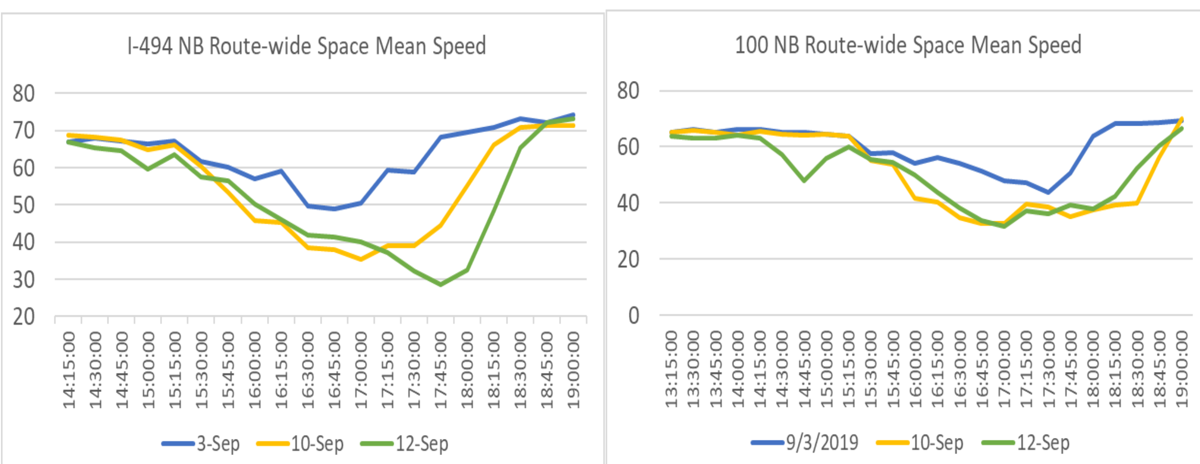


Figure 4.2.1 Space-Mean-Speed, Ut, Variations through time at I-494 NB and 100 NB Routes

Next, a new route-wide measure, *Total Number of Mainline Vehicles on a Given Route during t*, V_t, is added to the modeling. V_t captures the combined effects of the interaction among all the entrance/exit ramp volumes and the mainline volume during t on a given route, i.e.,

$V_t = \Sigma (K_{i,t} * L_i)$ *for all segment i,* L_i: *Length of segment i*

Figure 4.2.2 shows the variations of V_t and U_t on a weekday at the I-494 NB route, which had a crash accident from 16:55 until 18:00. As indicated in this figure, Ut directly responds to the variations of V_t. In particular, the V_t - U_t variations during the crash period shows that the V_t variations can directly reflect the effects of an incident, i.e., the resilience of a given route responding to an incident could be captured by the interrelationship between V_t and U_t.

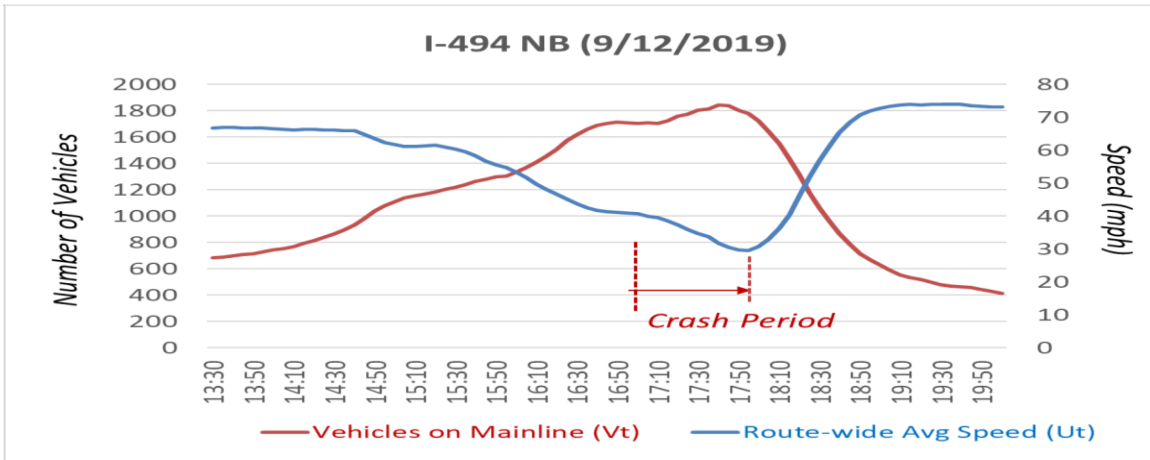


Figure 4.2.2 Vt and Ut Variations through time at I-494 NB Route

Based on the above analysis, two alternative models are developed in this study as the potential enhancements of the preliminary model to quantify the operational resilience of freeway corridors and tested with the same set of data used in the previous phase as follows:

Model 1: $CORI_i = \frac{\sum_{t,i}(\Delta U_t * t_i) * \sum_t(V_t)}{\sum_t(E_t)}$

where *CORI: Corridor-wide (directional) Operational Resilience Index*

ΔU_t: $U_f - U_t$, where U_f: Free-Flow Speed (estimated with the speed limit at a given location),

t_i: Duration of time interval: i => 0 – T, T: Total Time Period,

ΣV_t: Total Number of Vehicles on the Mainline during t,

E_t : Total Route-wide Entering Volume during t,

Model 2: $CORI_i = \frac{\sum_{t,i} (\Delta U_t * t_i)}{(\sum_t v_t)}$

where v_t: Total Number of Vehicles on the Mainline per mile during t, i.e., V_t / (Route Length)

In the above formulations, *(ΔU_t * t_i)* quantifies the functional loss of the route-wide traffic system during *t*. In *Model 1 (M1),* the operational resilience of a directional corridor is measured as the total route-wide functional loss per entering vehicle, while *Model 2 (M2)* determines the total functional loss per mainline vehicle as a measure of the CORI for a given route. In both models, the smaller value of CORI indicates stronger resilience for a given corridor traffic system. It can also be noted that in both models the number of blocked lanes because of an incident is not included, i.e., the resilience of a given route responding to an incident is designed to be captured through the interaction between V_t and U_t.

In this study, both *M1* and *M2* models are tested with the same set of data, i.e., the traffic data for the dry weekdays in September-October 2019, used in the previous phase for developing the preliminary model. Figures 4.2.3 and 4.2.4 show the daily CORI estimates for the sample routes for the same days with *M1* and *M2*. The daily CORI estimates with *M2* are also compared with those from the preliminary model as shown in Figure 4.2.5. As noted from these figures, the CORI estimates with *M2* exhibit significantly consistent daily values, i.e., substantially less day-to-day variations, than those from either the preliminary model or M1 for both afternoon and morning peak routes. It can be noted that M2 does not include the '*Total Entering Volume, E_t'*, which has potential accuracy issues depending on the availability of entrance ramp data.

Figure 4.2.6 shows the relationships between the Geometric Friction Index, G, and the CORI values estimated with both M1 and M2. It can be observed that the CORI-G pattern resulting from M2 exhibits a very high value of R^2, i.e., 92%, indicating the possibility of estimating the corridor operational resilience as a function of the geometric features of a given route.

Finally, M2 is applied to estimate the CORI values of the sample routes for the rainy days during the same period, i.e., September-October 2019, and each route's rainy day-CORI values are plotted in the CORI-G space, as shown in Figure 4.2.7. As can be seen in this figure, the rainy-day CORI-G relationship shows consistently higher CORI values than those of the dry days for the same routes, while maintaining the same structural pattern as the dry-day one, i.e., during rainy days, a freeway corridor system is less resilient than dry days. Further, the high R^2 value of the rainy-day CORI-G pattern indicates the potential applicability of Model 2 to different weather conditions.

Based on the above, in this study, M2 is selected as the enhanced operational-resilience model, which will be applied to the expanded metro freeway network in the subsequent chapter.

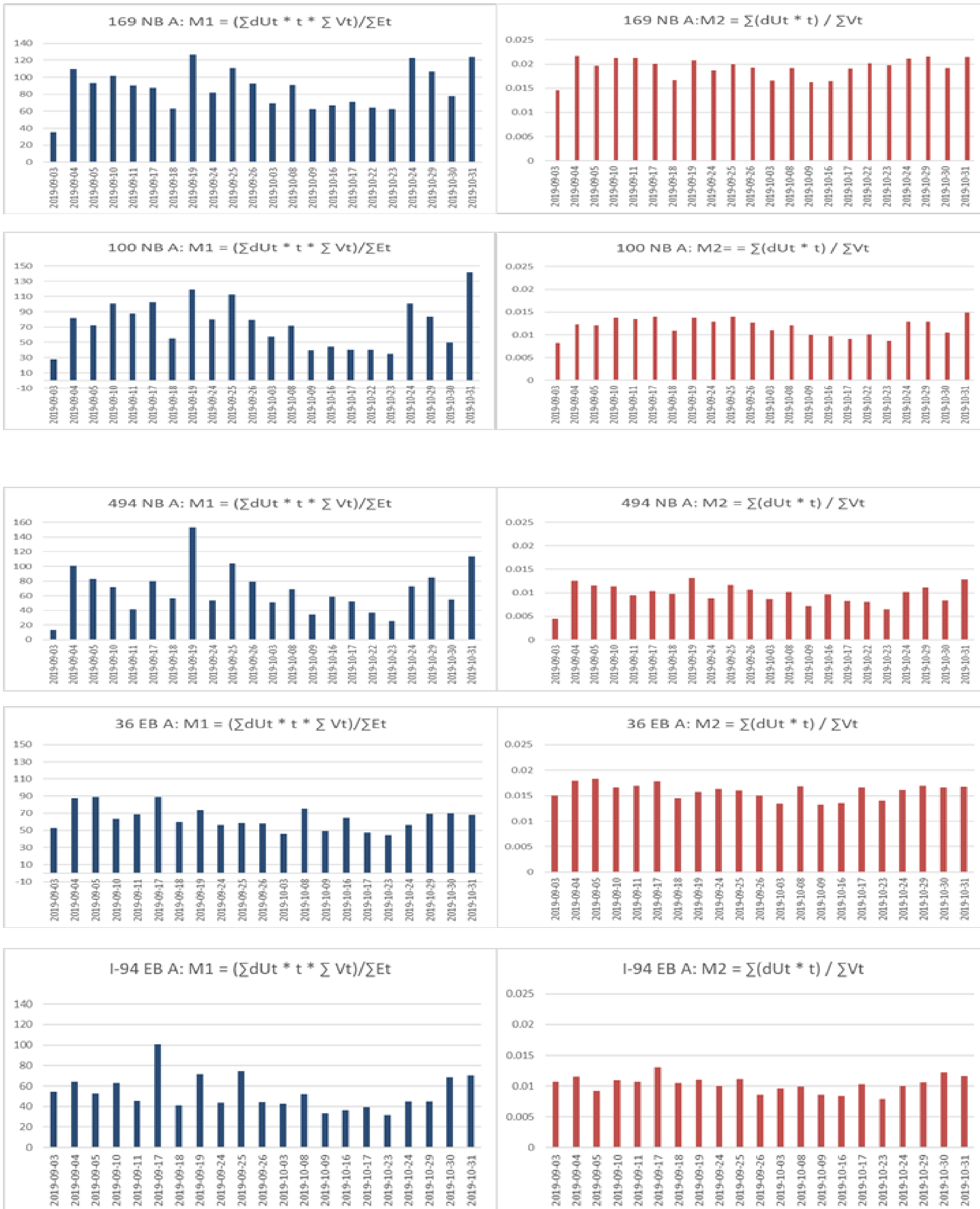


Figure 4.2.3 Comparison of Daily Estimates of CORI from M1 and M2 (Afternoon-Peak Routes)

Figure 4.2.4 Comparison of Daily Estimates of CORI from M 1 and M 2 (Morning-Peak Routes)

Figure 4.2.5 Comparison of Daily CORI Estimates with Preliminary Model and Enhanced Model (M2)

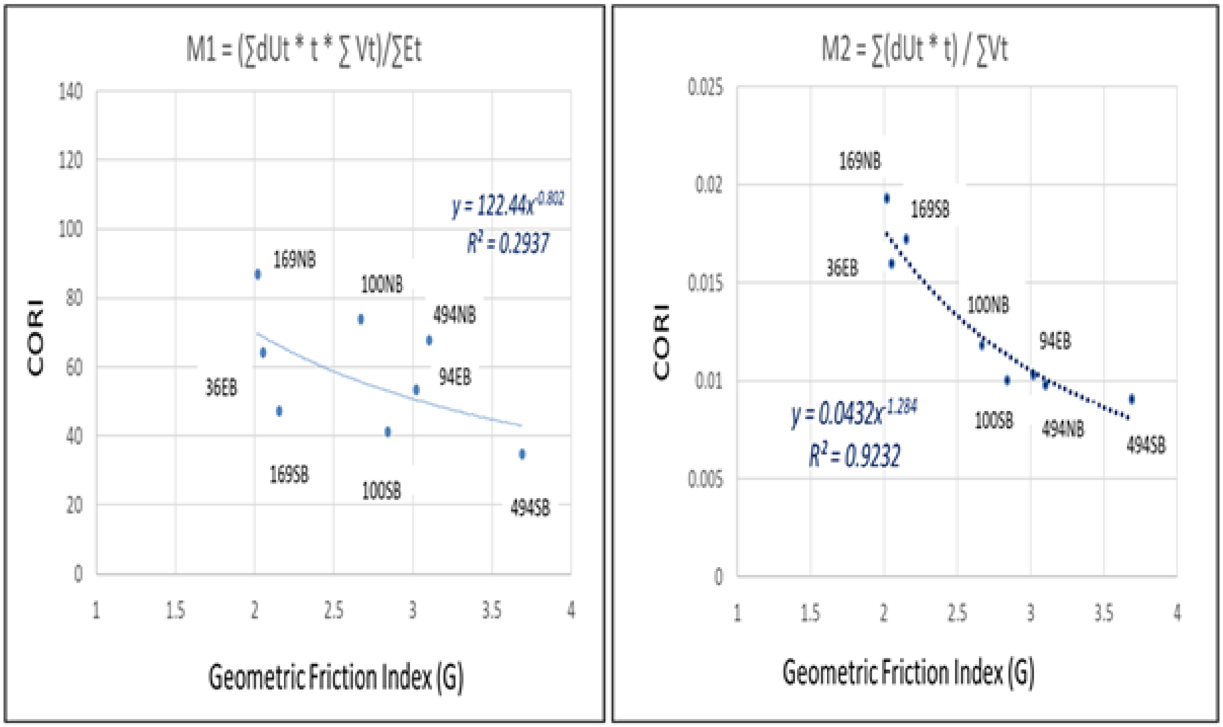


Figure 4.2.6 CORI vs Geometric Friction Index (G) with Model 1 and Model 2

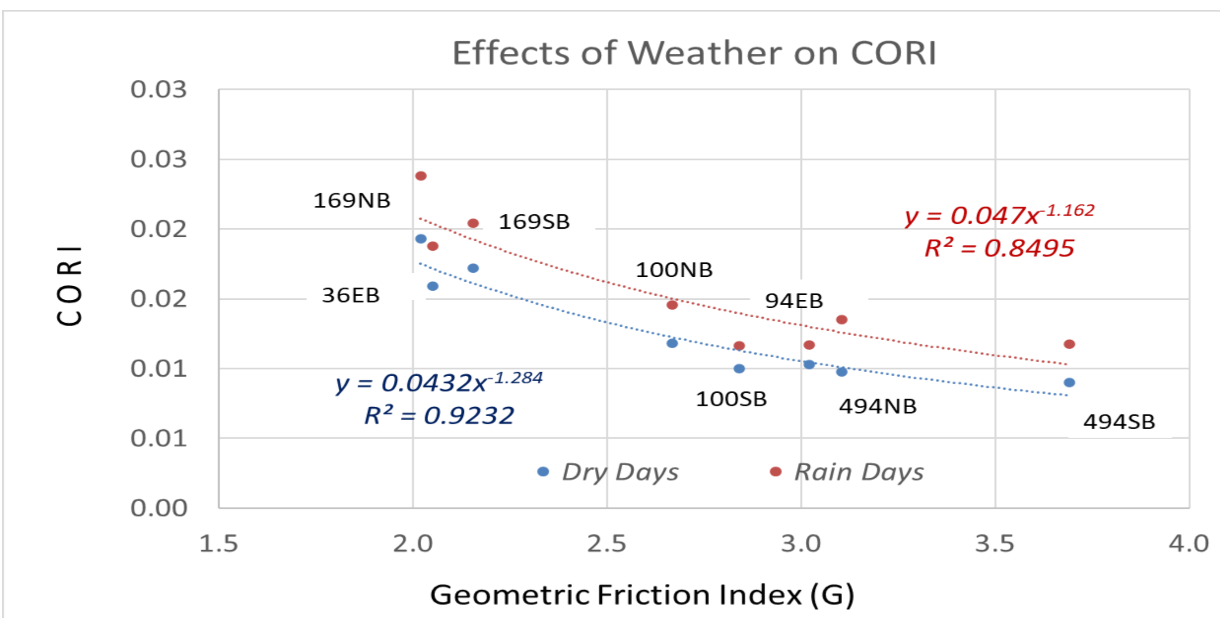


Figure 4.2.7 Comparison of Dry-Day and Rainy-Day CORI Estimates with Model 2

4.3 Summary

This chapter summarized the results from the enhancement and testing of the preliminary model to quantify the operational resilience of freeway corridors. The enhanced model developed in this study considers the time-variant, route-wide space-mean speed as the system performance measure and estimates the resilience of a given route as its capability to resist the route-wide speed reduction and to recover to the free-flow speed in response to the route-wide, mainline volume variations through time. Further, only mainline-traffic data are used in the enhanced model in estimating the operational resilience of a given route, i.e., the enhanced model does not depend on the entrance ramp volumes that may have potential detection issues.

The enhanced model was tested with the same set of data collected from the sample routes used for developing the preliminary model in the previous phase. The test results of the enhanced model showed significantly better performance than those from the preliminary model, i.e., the daily estimates of the operational resilience for the sample routes exhibit consistently less variations than those of the preliminary model. Further, the CORI-Geometric Friction Index (G) relationships for the sample routes have a clear pattern with substantially high correlation, indicating the possibility for developing a functional relationship between the operational resilience and the geometric feature of a given route. The application results of the enhanced model for the rainy days also resulted in the expected CORI-G pattern with strong correlation, i.e., during rainy days, a corridor-traffic system becomes less resilient than dry days.

The enhanced resilience model developed in this chapter is applied in the subsequent chapter to estimate the resilience of the individual corridors in the metro network. Further, the relationships between the resilience estimates and traffic-flow measures of each corridor are also analyzed in the following chapter.

Chapter 5: ASSESSMENT OF OPERATIONAL RESILIENCE OF INDIVIDUAL CORRIDORS AND THEIR EFFECTS ON TRAFFIC-FLOW PERFORMANCE IN THE METRO NETWORK

5.1 Introduction

In this chapter, the corridor-wide operational-resilience model, enhanced in the previous chapter, is applied to the metro freeway network, and the operational resilience of individual directional corridors, both morning and afternoon-peak routes, are estimated with the field traffic data collected over the weekdays of September-October period in 2018, 2019 and 2023. These periods were selected to ensure most freeway corridors in the metro network have experienced certain levels of congestion during peak periods. Further, the relationships between the route-wide geometric configuration and operational resilience are also analyzed in this chapter. The effects of the operational resilience on the traffic-flow performance and the travel-time reliability (TTR) measures at each corridor are analyzed in the subsequent chapter.

5.2 Estimation of Operational Resilience of Individual Directional Corridors in the Metro Network

Figure 5.2.1 shows the configuration of the total 37 individual corridors with 74 directional routes whose corridor-wide operational resilience indices (CORI) were estimated and analyzed in this chapter. First, the daily CORI values of each directional corridor during peak periods for the 2-month period, i.e., from September to October, for 2018, 2019 and 2023 were estimated under dry-weather conditions with the field traffic-detector data. It needs to be noted that, in calculating the daily CORI value of each directional corridor, only those days with at least 40 % of valid detector data were included in this study to minimize the effects of detector-malfunction issues. Next, the average daily CORI value of each directional corridor for the two-month period of each year was determined and shown in Tables 5.2.1 – 5.2.6, which includes the sorted corridor list with the CORI values from low to high for both morning and afternoon routes under dry-weather conditions.

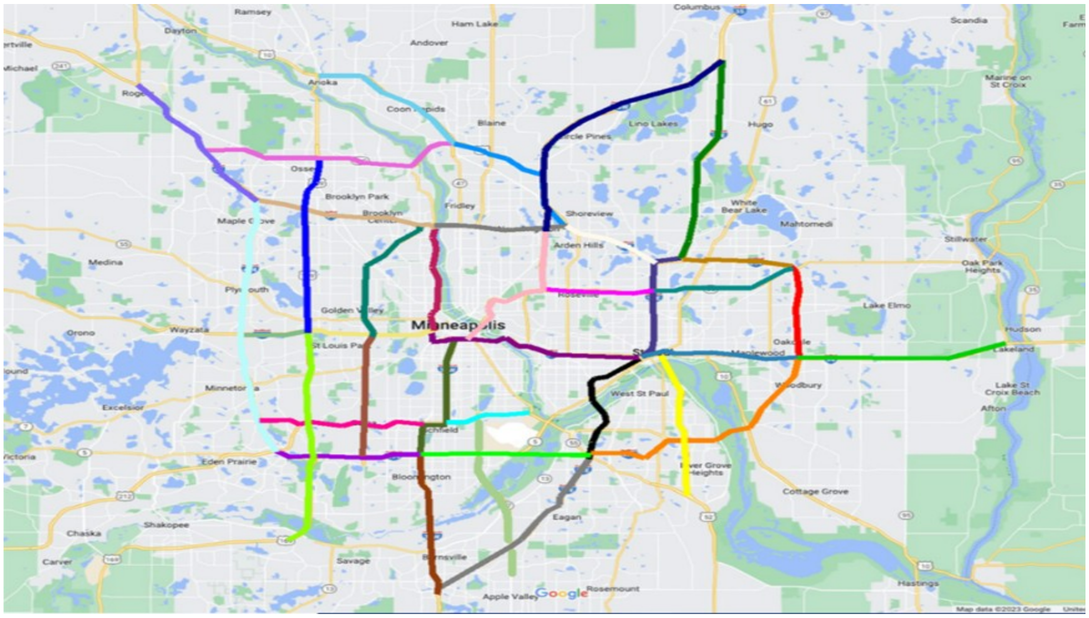


Figure 5.2.1 Configuration of Individual Corridors for the Metro Freeway Network

It needs to be noted that smaller values of CORI indicate higher levels of resilience, i.e., more resilient corridors. Further, the CORI values of all the directional corridors are grouped into 6 color-coded levels as follows:

Level 1: 0 ≤ CORI < 0.005

Level 2: 0.005 ≤ CORI < 0.01

Level 3: 0.01 ≤ CORI < 0.015

Level 4: 0.015 ≤ CORI < 0.02

Level 5: 0.02 ≤ CORI < 0.025

Level 6: 0.025 ≤ CORI

Figures 5.2.2 – 5.2.7 show the color-coded CORI level of each directional corridor under dry-weather conditions for both morning and afternoon peak periods in 2018, 2019 and 2023. As noted in those tables and figures, the CORI levels of the individual corridors in the metro freeway network mostly belong to Level 2 and 3 over the selected 3-year period, while a group of certain routes have consistently exhibited higher CORI values, i.e., Level 4 or higher, indicating relatively weaker resilience levels than other corridors. Tables 5.2.7 and 5.2.8 include the list of those individual corridors whose CORI levels have been greater than or equal to Level 4 at least once during the 3-year study period.

EFFECTS OF GEOMETRY ON OPERATIONAL RESILIENCE

Finally, the effects of the geometric configuration on the corridor-wide operational resilience are also analyzed in this chapter by examining the relationships between the Geometric Friction (G) Factor, described in the previous chapter, and the CORI values of each directional corridor, both morning and afternoon-peak routes. Figures 5.2.8 – 5.2.13 show the G-CORI plots over the 3-year period. As can be noted in these figures, there exists a clear pattern between the G and CORI values of individual corridors, i.e., as the corridor-G values increase, the CORI values decrease, i.e., the corridors with low geometric friction to through traffic have strong resilience than those with high level of interruption.

Table 5.2.1 CORI Values (2018, AM, Dry Days)

	Corridor	Length (Miles)	Geometric Friction Index (G)	Operational Resilience Index (R)
1	I-94 (EB)_MPLS DT to SP DT	8.4	3.10	**0.0020**
2	I-35E (NB)_I35 to I494	10.9	2.69	**0.0048**
3	I-494 (WB)_I94 to I35E	12.4	3.12	**0.0049**
4	I-694 (WB)_I35E to TH10	3.8	2.84	**0.0056**
5	T.H.10 (EB)_TH169 to TH610	7.5	1.93	**0.0064**
6	I-35E (SB)_I35 to I694	13.5	4.14	**0.0068**
7	I-694 (WB)_TH36 to I35E	6.5	2.37	**0.0068**
8	I-94 (EB)_I494 to TH252	8	3.63	**0.0068**
9	I-394 (EB)_I494 to TH169	2.7	1.78	**0.0077**
10	T.H.52 (NB)_TH55 to SP DT	8.2	2.14	**0.0087**
11	I-35E (SB)_I694 to SP DT	6	3.41	**0.0089**
12	I-35W (SB)_I694 to MPLS DT	9.1	3.56	**0.0089**
13	I-35W (NB)_I494 to MPLS DT	9.2	3.68	**0.0093**
14	I-94 (WB)_SP DT to MPLS DT	8.5	3.97	**0.0094**
15	I-494 (WB)_I35W to TH212	5.9	2.42	**0.0097**
16	T.H.100 (SB)_I694 to I394	6.8	2.37	**0.0099**
17	T.H.100 (SB)_I394 to I494	7.7	2.90	**0.0100**
18	T.H.610 (EB)_I94 to TH10	11.7	3.99	**0.0100**
19	I-94 (EB)_TH252 to MPLS DT	8.1	3.08	**0.0102**

20	T.H.77 (NB)_127th to TH62	6.1	2.01	0.0104
21	I-494 (SB)_I694 to TH212	15.5	3.64	0.0106
22	I-35W (NB)_I35 to I494	8.4	3.14	0.0114
23	I-94 (WB)_I694 to SP DT	7.5	2.67	0.0124
24	I-494 (WB)_I35E to I35W	7.8	2.70	0.0128
25	I-394 (EB)_TH169 to MPLS DT	5.5	3.11	0.0132
26	T.H.10 (EB)_TH610 to I694	7.3	2.80	0.0134
27	I-35W (SB)_I35 to I694	14.8	3.89	0.0134
28	I-694 (NB)_I94 to TH36	4.9	1.39	0.0136
29	I-35E (NB)_I494 to SP DT	7.6	3.50	0.0138
30	T.H.36 (WB)_I694 to I35E	6.4	2.34	0.0145
31	I-694 (WB)_TH10 to TH252	5.5	2.80	0.0155
32	U.S.169 (SB)_TH610 to I394	10.9	2.01	0.0167
33	T.H.62 (WB)_TH55 to I35W	4.2	3.10	0.0176
34	T.H.36 (WB)_I35E to I35W	4.4	2.16	0.0177
35	T.H.62 (WB)_I35W to I494	6.7	1.80	0.0202
36	U.S.169 (SB)_I394 to TH13	16.2	2.64	0.0202

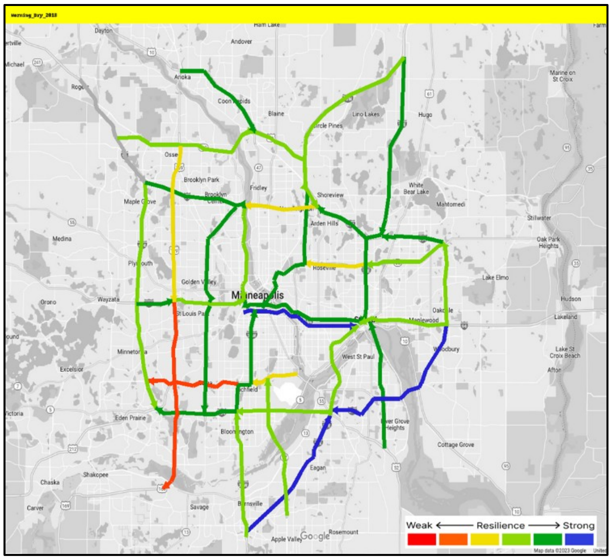


Figure 5.2.2 CORI Levels (2018, AM, Dry Days)

Table 5.2.2 CORI Values (2018, PM, Dry Days)

	Corridor	Length (Miles)	Geometric Friction Index (G)	Operational Resilience Index (R)
1	I-94 (EB)_SP DT to I694	7.3	3.20	0.0044
2	I-94 (WB)_MPLS DT to TH252	8	3.52	0.0051
3	I-94 (WB)_I494 to Rogers	8.4	2.60	0.0056
4	I394 (WB)_TH169 to I494	3.3	2.99	0.0056
5	T.H.610 (WB)_TH10 to I94	11.3	1.76	0.0063
6	I-35E (SB)_I494 to I35	11	2.30	0.0067
7	I-35W (SB)_I494 to I35	8.6	2.97	0.0069
8	I-494 (EB)_I35W to I35E	7.8	3.58	0.0071
9	I-694 (EB)_TH10 to I35E	4.7	4.33	0.0076
10	T.H.77 (SB)_TH62 to 127th	8.2	2.32	0.0080
11	T.H.10 (WB)_TH610 to TH169	7.6	2.05	0.0081
12	I-494 (NB)_TH212 to I694	14.4	3.15	0.0084
13	I394 (WB)_MPLS DT to TH169	5.6	1.97	0.0090
14	I-94 (EB)_MPLS DT to SP DT	8.4	3.10	0.0090

15	T.H.36 (EB)_I35E to I694	6.6	2.75	0.0092
16	I-35W (NB)_MPLS DT to I694	9.2	2.23	0.0092
17	I-35E (NB)_SP DT to I694	5.8	3.31	0.0093
18	T.H.100 (NB)_I394 to I694	6.9	2.83	0.0097
19	I-35W (NB)_I694 to I35	14.7	3.64	0.0105
20	I-494 (EB)_I35E to I94	12.4	3.45	0.0108
21	T.H.100 (NB)_I494 to I394	7.6	2.83	0.0120
22	I-694 (EB)_TH252 to TH10	5.4	2.13	0.0122
23	T.H.62 (EB)_I35W to TH55	4.8	1.98	0.0122
24	I-35W (SB)_MPLS DT to I494	9.1	3.45	0.0124
25	I-94 (WB)_SP DT to MPLS DT	8.5	3.97	0.0127
26	I-694 (SB)_TH36 to I94	5.3	2.68	0.0130
27	T.H.10 (WB)_I694 to TH610	7.7	2.92	0.0135
28	I-694 (EB)_I35E to TH36	5.7	1.78	0.0138
29	I-494 (EB)_TH212 to I35W	6.2	2.25	0.0142
30	I-35E (SB)_SP DT to I494	7.5	2.39	0.0144
31	U.S.169 (NB)_I394 to TH610	11.1	2.21	0.0161
32	T.H.36 (EB)_I35W to I35E	5.2	1.89	0.0165
33	U.S.169 (NB)_TH13 to I394	16	2.22	0.0185
34	T.H.62 (EB)_I494 to I35W	6.9	1.92	0.0246

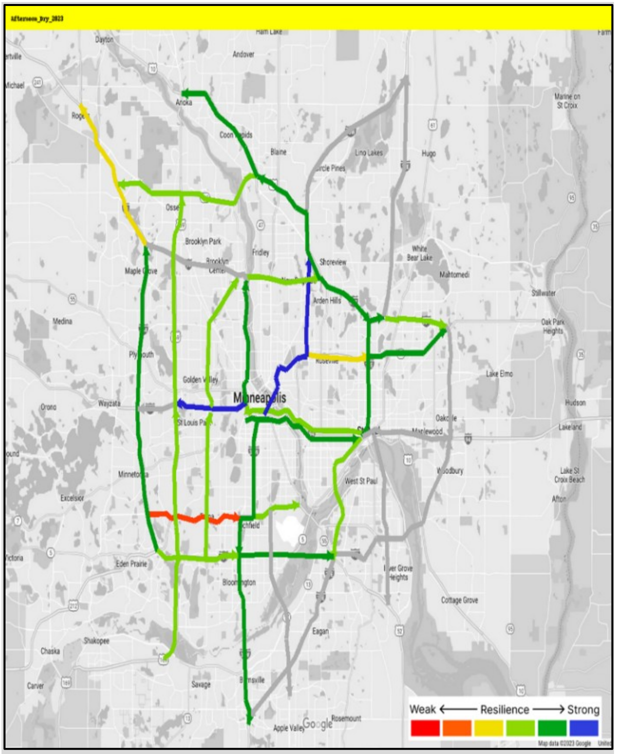


Figure 5.2.3 CORI Levels (2018, PM, Dry Days)

Table 5.2.3 CORI Levels (2018, PM, Dry Days)

	Corridor	Length (Miles)	Geometric Friction Index (G)	Operational Resilience Index (R)
1	I-94 (EB)_MPLS DT to SP DT	8.4	3.10	0.0017
2	I-35E (NB)_I35 to I494	10.9	2.69	0.0052
3	I-394 (EB)_I494 to TH169	2.7	1.78	0.0052
4	I-94 (EB)_I494 to TH252	8	3.63	0.0066
5	I-494 (WB)_I35W to TH212	5.9	2.42	0.0075
6	I-494 (WB)_I94 to I35E	12.4	3.12	0.0075
7	I-94 (WB)_SP DT to MPLS DT	8.5	3.97	0.0081
8	T.H.100 (SB)_I394 to I494	7.7	2.90	0.0087
9	I-494 (SB)_I694 to TH212	15.5	3.64	0.0092
10	I-35E (SB)_I35 to I694	13.5	4.14	0.0093
11	T.H.610 (EB)_I94 to TH10	11.7	3.99	0.0094
12	I-694 (WB)_I35E to TH10	3.8	2.84	0.0095

13	I-35E (SB)_I694 to SP DT	6	3.41	**0.0095**
14	T.H.77 (NB)_127th to TH62	6.1	2.01	**0.0098**
15	T.H.100 (SB)_I694 to I394	6.8	2.37	**0.0103**
16	T.H.10 (EB)_TH169 to TH610	7.5	1.93	**0.0105**
17	I-35W (NB)_I35 to I494	8.4	3.14	**0.0110**
18	I-94 (EB)_TH252 to MPLS DT	8.1	3.08	**0.0111**
19	I-35W (NB)_I494 to MPLS DT	9.2	3.68	**0.0112**
20	I-694 (WB)_TH36 to I35E	6.5	2.37	**0.0117**
21	I-394 (EB)_TH169 to MPLS DT	5.5	3.11	**0.0118**
22	I-35E (NB)_I494 to SP DT	7.6	3.50	**0.0119**
23	I-694 (NB)_I94 to TH36	4.9	1.39	**0.0125**
24	I-94 (WB)_I694 to SP DT	7.5	2.67	**0.0132**
25	I-494 (WB)_I35E to I35W	7.8	2.70	**0.0141**
26	U.S.169 (SB)_I394 to TH13	16.2	2.64	**0.0152**
27	I-694 (WB)_TH10 to TH252	5.5	2.80	**0.0153**
28	T.H.10 (EB)_TH610 to I694	7.3	2.80	**0.0154**
29	I-35W (SB)_I694 to MPLS DT	9.1	3.56	**0.0165**
30	U.S.169 (SB)_TH610 to I394	10.9	2.01	**0.0175**
31	T.H.62 (WB)_TH55 to I35W	4.2	3.10	**0.0177**
32	T.H.36 (WB)_I35E to I35W	4.4	2.16	**0.0184**
33	T.H.62 (WB)_I35W to I494	6.7	1.80	**0.0196**
34	T.H.36 (WB)_I694 to I35E	6.4	2.34	**0.0231**

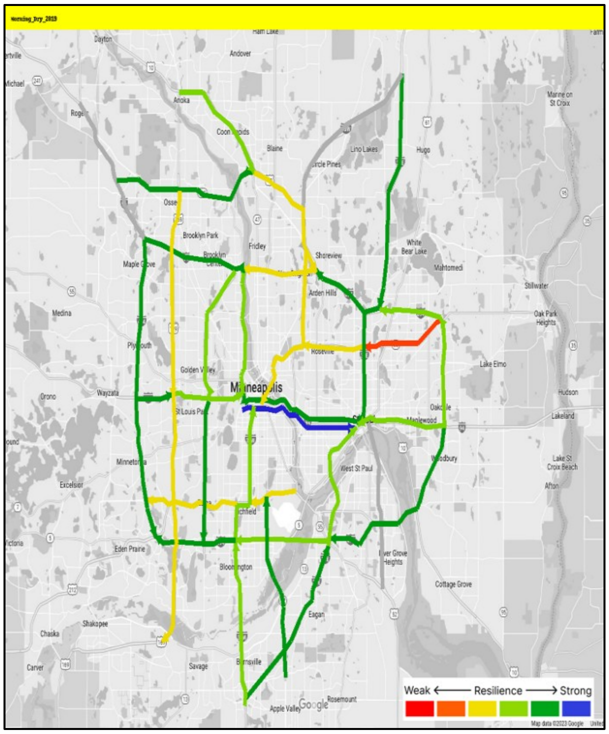


Figure 5.2.4 CORI Levels (2019, AM, Dry Days)

Table 5.2.4 CORI Values (2019, PM, Dry Days)

	Corridor	Length (Miles)	Geometric Friction Index (G)	Operational Resilience Index (R)
1	I-94 (WB)_TH252 to I494	7.1	3.02	0.0050
2	I-35E (SB)_I494 to I35	11	2.30	0.0053
3	I-94 (WB)_MPLS DT to TH252	8	3.52	0.0055
4	I-94 (WB)_I494 to Rogers	8.4	2.60	0.0056
5	I-94 (EB)_SP DT to I694	7.3	3.20	0.0062
6	T.H.610 (WB)_TH10 to I94	11.3	1.76	0.0065
7	T.H.10 (WB)_TH610 to TH169	7.6	2.05	0.0065
8	I394 (WB)_MPLS DT to TH169	5.6	1.97	0.0079
9	I-494 (EB)_I35W to I35E	7.8	3.58	0.0080
10	T.H.36 (EB)_I35E to I694	6.6	2.75	0.0081
11	I-694 (EB)_I35E to TH36	5.7	1.78	0.0090
12	T.H.77 (SB)_TH62 to 127th	8.2	2.32	0.0092
13	I-94 (EB)_MPLS DT to SP DT	8.4	3.10	0.0092
14	I394 (WB)_TH169 to I494	3.3	2.99	0.0095
15	I-35W (SB)_I494 to I35	8.6	2.97	0.0099
16	I-35E (NB)_SP DT to I694	5.8	3.31	0.0099
17	I-35E (NB)_I694 to I35	14	3.16	0.0100
18	I-494 (NB)_TH212 to I694	14.4	3.15	0.0100
19	I-494 (EB)_I35E to I94	12.4	3.45	0.0102
20	I-94 (WB)_SP DT to MPLS DT	8.5	3.97	0.0103
21	T.H.100 (NB)_I394 to I694	6.9	2.83	0.0105
22	I-35W (NB)_MPLS DT to I694	9.2	2.23	0.0110
23	T.H.10 (WB)_I694 to TH610	7.7	2.92	0.0120
24	I-694 (EB)_TH252 to TH10	5.4	2.13	0.0122
25	T.H.100 (NB)_I494 to I394	7.6	2.83	0.0125
26	I-35E (SB)_SP DT to I494	7.5	2.39	0.0127
27	I-694 (EB)_TH10 to I35E	4.7	4.33	0.0137

28	I-694 (SB)_TH36 to I94	5.3	2.68	0.0146
29	T.H.62 (EB)_I35W to TH55	4.8	1.98	0.0148
30	I-35W (SB)_MPLS DT to I494	9.1	3.45	0.0149
31	I-494 (EB)_TH212 to I35W	6.2	2.25	0.0150
32	U.S.169 (NB)_I394 to TH610	11.1	2.21	0.0175
33	T.H.36 (EB)_I35W to I35E	5.2	1.89	0.0175
34	U.S.169 (NB)_TH13 to I394	16	2.22	0.0211
35	T.H.62 (EB)_I494 to I35W	6.9	1.92	0.0238

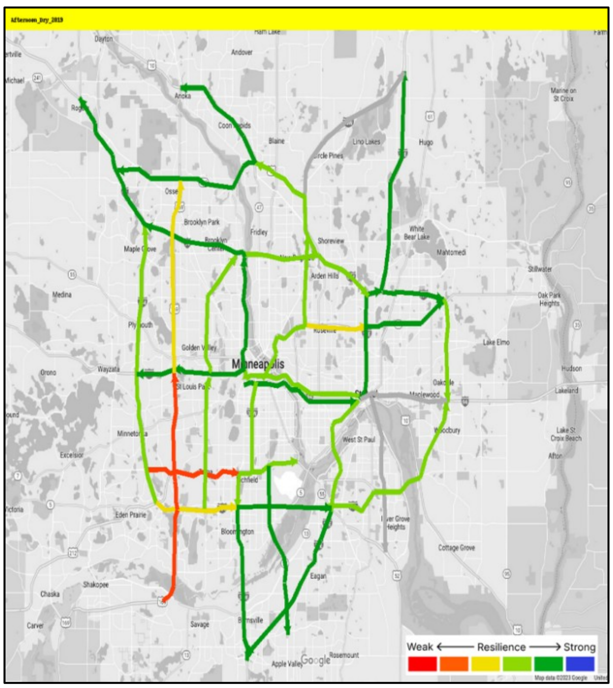


Figure 5.2.5 CORI Levels (2019, PM, Dry Days)

Table 5.2.5 CORI Values (2023, AM, Dry Days)

	Corridor	Length (Miles)	Geometric Friction Index (G)	Operational Resilience Index (R)
1	I-694 (WB)_I35E to TH10	3.8	2.84	0.0054
2	I-94 (EB)_MPLS DT to SP DT	8.4	3.10	0.0056
3	I-35E (SB)_I694 to SP DT	6	3.41	0.0060

4	I-694 (WB)_TH36 to I35E	6.5	2.37	**0.0061**
5	I-94 (EB)_I494 to TH252	8	3.63	**0.0064**
6	I-35W (NB)_I35 to I494	8.4	3.14	**0.0068**
7	T.H.100 (SB)_I394 to I494	7.7	2.90	**0.0068**
8	T.H.100 (SB)_I694 to I394	6.8	2.37	**0.0074**
9	I-494 (WB)_I35W to TH212	5.9	2.42	**0.0074**
10	I-494 (SB)_I694 to TH212	15.5	3.64	**0.0078**
11	I-94 (EB)_TH252 to MPLS DT	8.1	3.08	**0.0082**
12	I-94 (WB)_SP DT to MPLS DT	8.5	3.97	**0.0084**
13	T.H.77 (NB)_127th to TH62	6.1	2.01	**0.0084**
14	I-35W (SB)_I694 to MPLS DT	9.1	3.56	**0.0086**
15	I-35W (NB)_I494 to MPLS DT	9.2	3.68	**0.0105**
16	I-94 (EB)_Rogers to I494	9.1	3.46	**0.0116**
17	I-35W (SB)_I35 to I694	14.8	3.89	**0.0116**
18	I-394 (EB)_TH169 to MPLS DT	5.5	3.11	**0.0119**
19	T.H.10 (EB)_TH610 to I694	7.3	2.80	**0.0121**
20	U.S.169 (SB)_I394 to TH13	16.2	2.64	**0.0123**
21	I-94 (WB)_I694 to SP DT	7.5	2.67	**0.0124**
22	I-694 (NB)_I94 to TH36	4.9	1.39	**0.0131**
23	I-494 (WB)_I35E to I35W	7.8	2.70	**0.0137**
24	I-35E (NB)_I494 to SP DT	7.6	3.50	**0.0137**
25	I-694 (WB)_TH10 to TH252	5.5	2.80	**0.0161**
26	T.H.36 (WB)_I35E to I35W	4.4	2.16	**0.0185**
27	U.S.169 (SB)_TH610 to I394	10.9	2.01	**0.0205**
28	T.H.610 (EB)_I94 to TH10	11.7	3.99	**0.0220**
29	T.H.62 (WB)_TH55 to I35W	4.2	3.10	**0.0220**
30	T.H.36 (WB)_I694 to I35E	6.4	2.34	**0.0242**
31	T.H.62 (WB)_I35W to I494	6.7	1.80	**0.0267**

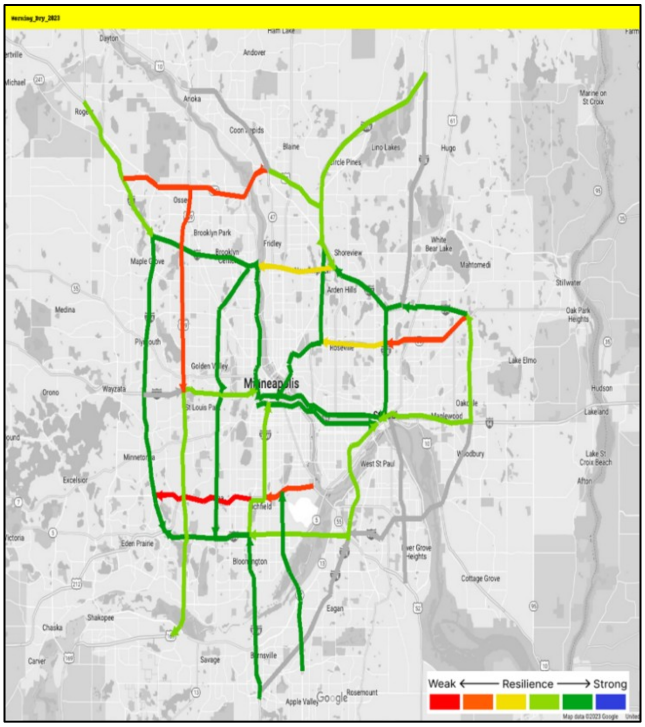


Figure 5.2.6 CORI Levels (2023, AM, Dry Days)

Table 5.2.6 CORI Values (2023, PM, Dry Days)

	Corridor	Length (Miles)	Geometric Friction Index (G)	Operational Resilience Index (R)
1	I-94 (EB)_SP DT to I694	7.3	3.20	0.0037
2	I394 (WB)_MPLS DT to TH169	5.6	1.97	0.0049
3	I-35W (NB)_MPLS DT to I694	9.2	2.23	0.0049
4	I-35W (SB)_I494 to I35	8.6	2.97	0.0055
5	I-494 (EB)_I35W to I35E	7.8	3.58	0.0058
6	I-94 (WB)_MPLS DT to TH252	8	3.52	0.0063
7	T.H.10 (WB)_I694 to TH610	7.7	2.92	0.0066
8	I-35E (NB)_SP DT to I694	5.8	3.31	0.0069
9	I-494 (NB)_TH212 to I694	14.4	3.15	0.0076

10	T.H.10 (WB)_TH610 to TH169	7.6	2.05	**0.0078**
11	I-35W (SB)_MPLS DT to I494	9.1	3.45	**0.0081**
12	I-94 (EB)_MPLS DT to SP DT	8.4	3.10	**0.0083**
13	I-694 (EB)_TH10 to I35E	4.7	4.33	**0.0090**
14	T.H.36 (EB)_I35E to I694	6.6	2.75	**0.0094**
15	I-694 (EB)_I35E to TH36	5.7	1.78	**0.0101**
16	T.H.100 (NB)_I494 to I394	7.6	2.83	**0.0102**
17	T.H.100 (NB)_I394 to I694	6.9	2.83	**0.0103**
18	I-694 (EB)_TH252 to TH10	5.4	2.13	**0.0113**
19	I-94 (WB)_SP DT to MPLS DT	8.5	3.97	**0.0115**
20	U.S.169 (NB)_I394 to TH610	11.1	2.21	**0.0121**
21	T.H.610 (WB)_TH10 to I94	11.3	1.76	**0.0130**
22	T.H.62 (EB)_I35W to TH55	4.8	1.98	**0.0137**
23	U.S.169 (NB)_TH13 to I394	16	2.22	**0.0137**
24	I-35E (SB)_SP DT to I494	7.5	2.39	**0.0143**
25	I-494 (EB)_TH212 to I35W	6.2	2.25	**0.0148**
26	I-94 (WB)_I494 to Rogers	8.4	2.60	**0.0153**
27	T.H.36 (EB)_I35W to I35E	5.2	1.89	**0.0162**
28	T.H.62 (EB)_I494 to I35W	6.9	1.92	**0.0224**

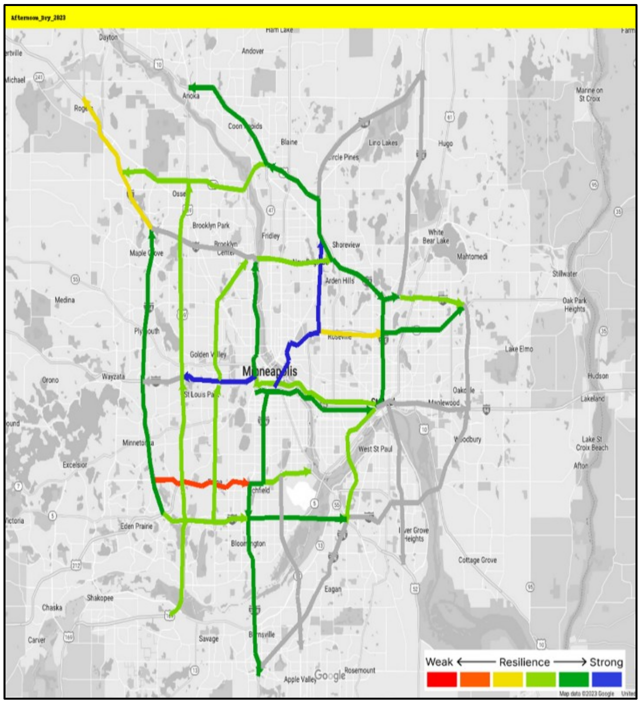


Figure 5.2.7 CORI Levels (2023, PM, Dry Days)

Table 5.2.7 Average CORI Values of Individual Corridors with Level 4 or Higher (Morning-Peak Period)

	Corridor	Length (Miles)	Geometric Friction Index (G)	Operational Resilience Index (R)
1	T.H.36 (WB)_694 to I35E	6.4	2.34	0.0237
2	T.H.62 (WB)_I35W to 494	6.7	1.80	0.0221
3	T.H.610 (EB)_I94 to TH10	11.7	3.99	0.0220
4	T.H.62 (WB)_TH55 to I35W	4.2	3.10	0.0191
5	U.S.169 (SB)_TH610 to 394	10.9	2.01	0.0182
6	T.H.36 (WB)_I35E to I35W	4.4	2.16	0.0182

7	U.S.169 (SB)_394 to 101	16.2	2.64	0.0177
8	I-35W (SB)_694 to MSPL DT	9.1	3.56	0.0165
9	I-694 (WB)_TH10 to I94	5.5	2.80	0.0157
10	T.H.10 (EB)_TH610 to 694	7.3	2.80	0.0154

Table 5.2.8 Average CORI Values of Individual Corridors with Level 4 or Higher (Afternoon-Peak Period)

	Corridor	Length (Miles)	Geometric Friction Index (G)	Operational Resilience Index (R)
1	T.H.62 (EB)_494 to I35W	6.9	1.92	0.0236
2	U.S.169 (NB)_101 to 394	16	2.22	0.0198
3	U.S.169 (NB)_394 to TH610	11.1	2.21	0.0168
4	T.H.36 (EB)_I35W to I35E	5.2	1.89	0.0167
5	I-94 (WB)_I494 to TH610	8.4	2.60	0.0153
6	I-494 (EB)_212 to I35W	6.2	2.25	0.0150

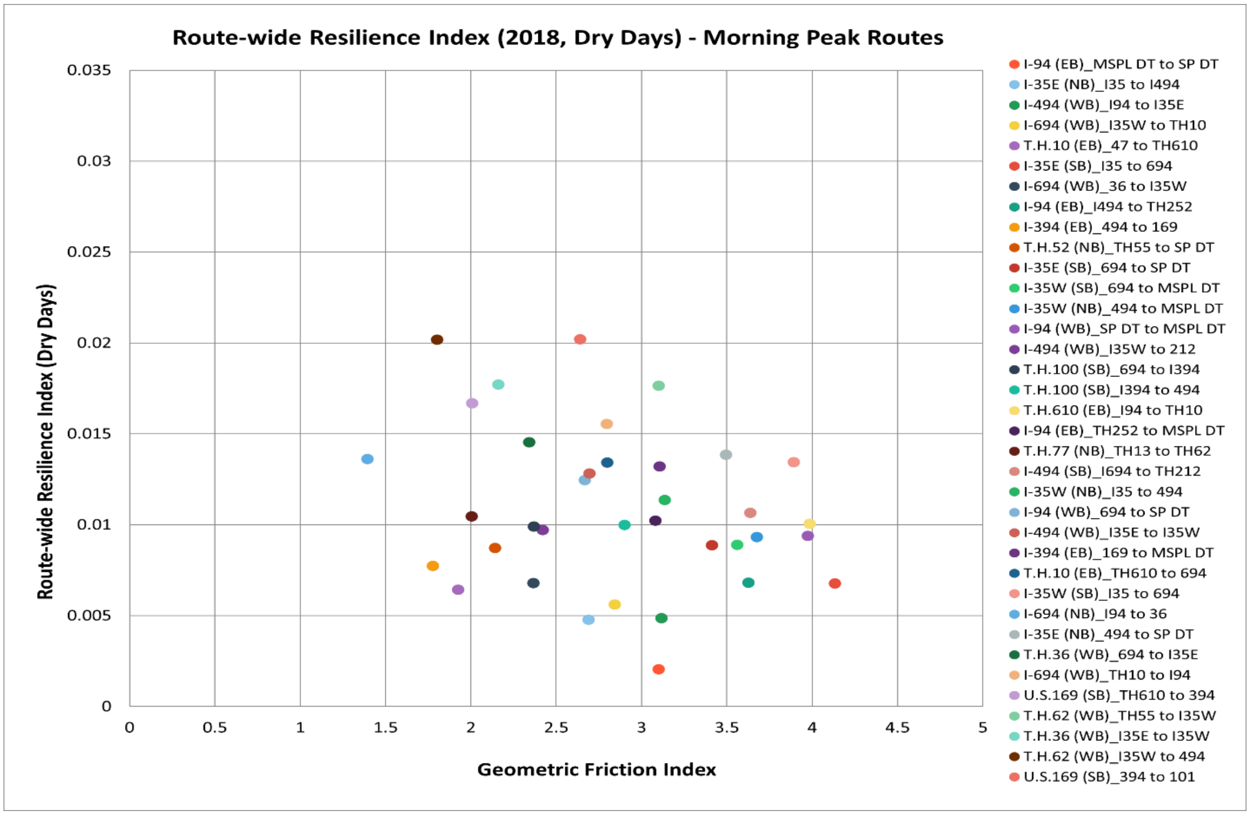


Figure 5.2.8 Route-wide Resilience vs. Geometric Friction Factor (2018, Dry Days, AM-Peak Routes)

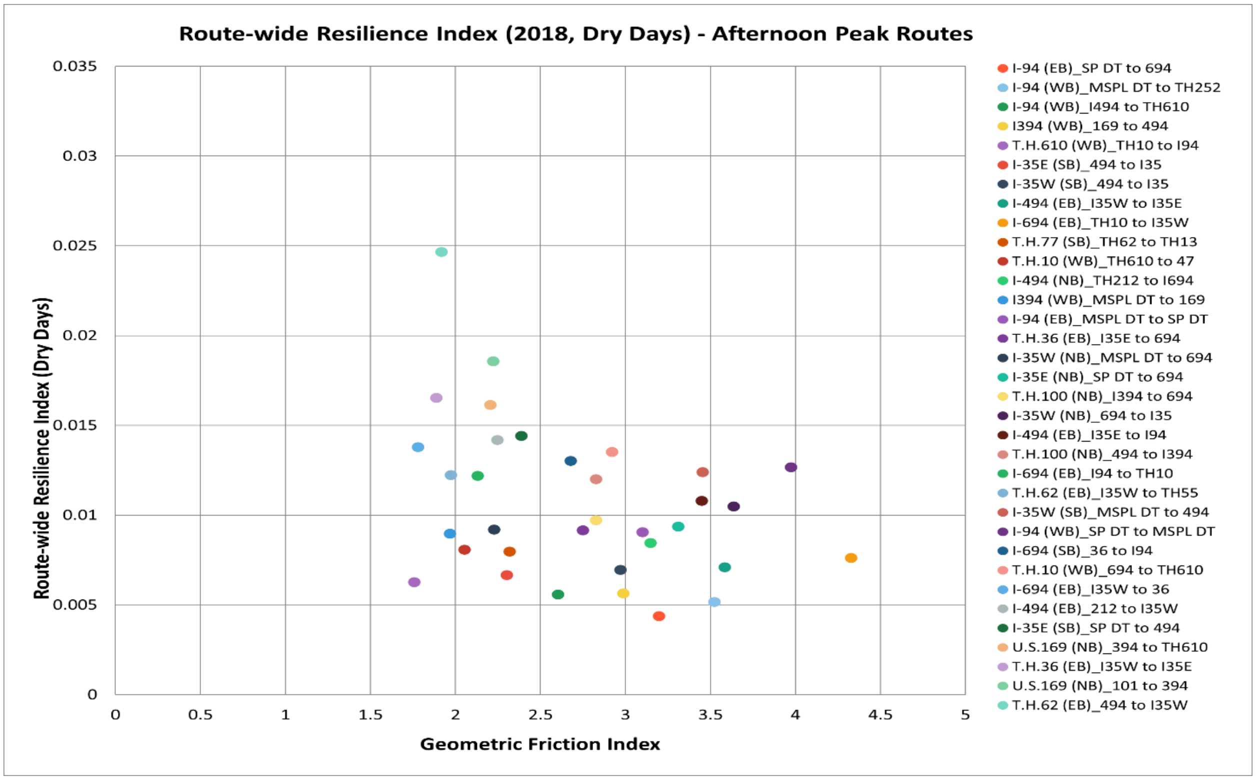


Figure 5.2.9 Route-wide Resilience vs. Geometric Friction Factor (2018, Dry Days, PM-Peak Routes)

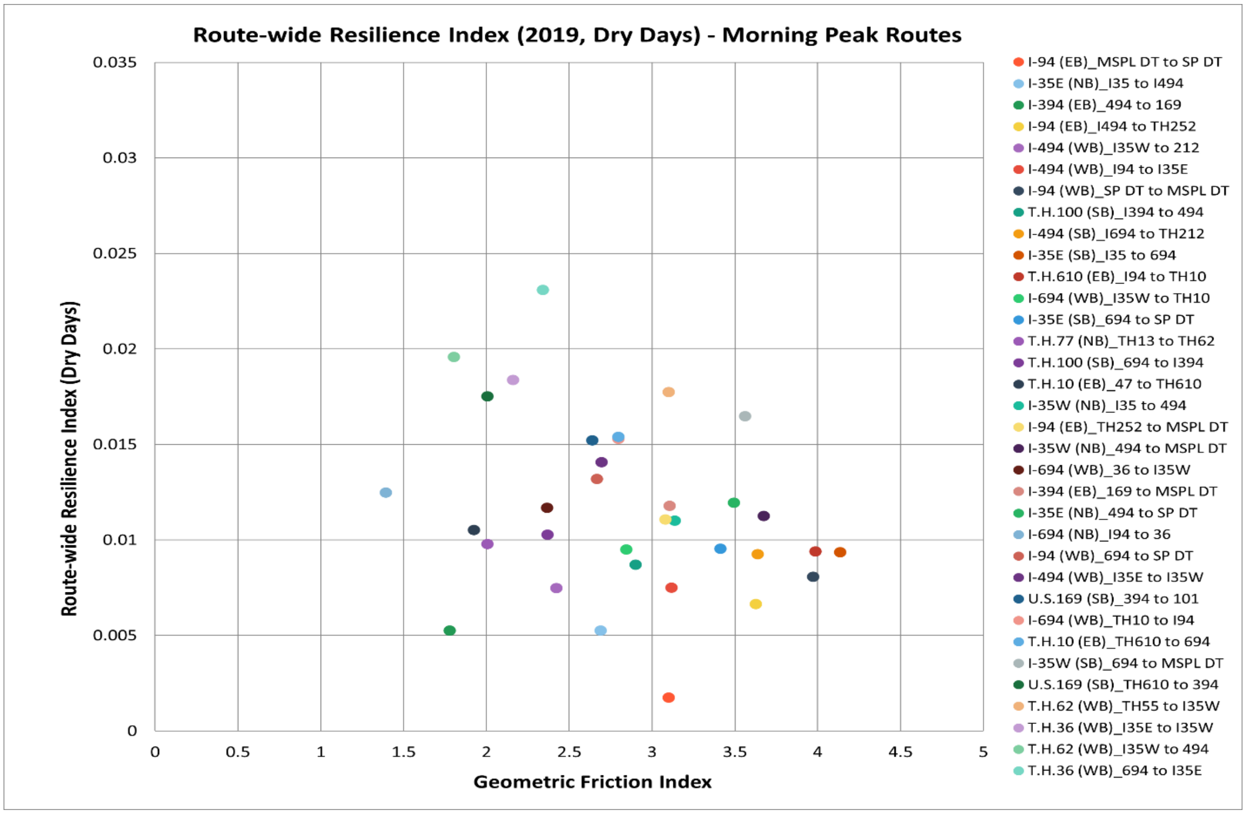


Figure 5.2.10 Route-wide Resilience vs. Geometric Friction Factor (2019, Dry Days, AM-Peak Routes)

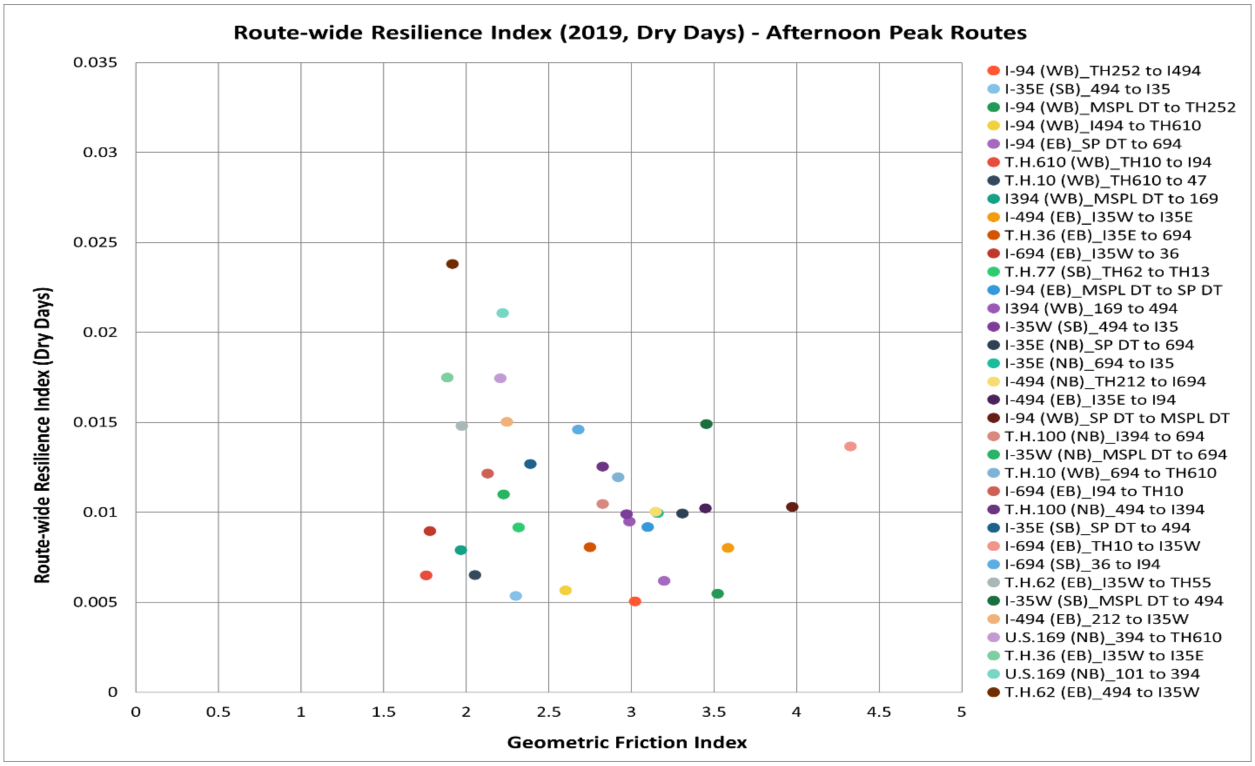


Figure 5.2.11 Route-wide Resilience vs. Geometric Friction Factor (2019, Dry Days, PM-Peak Routes)

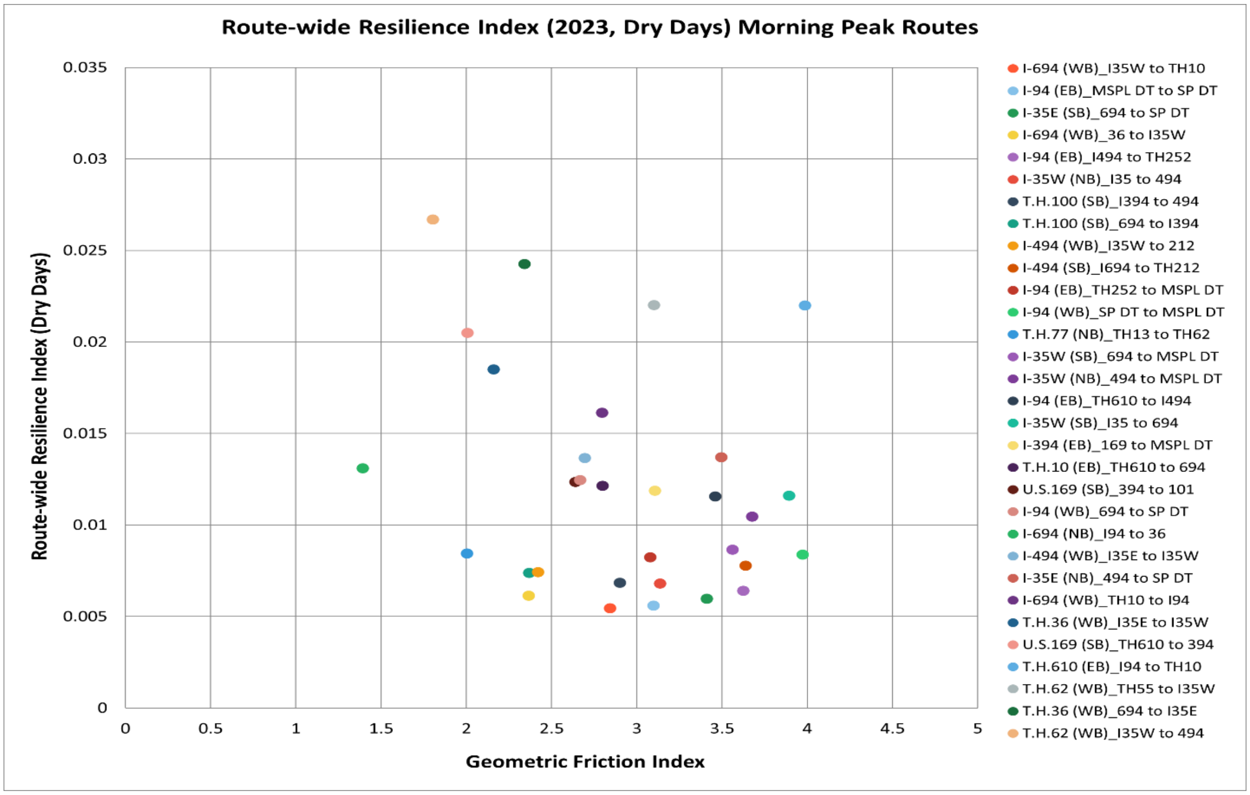


Figure 5.2.12 Route-wide Resilience vs. Geometric Friction Factor (2023, Dry Days, AM-Peak Routes)

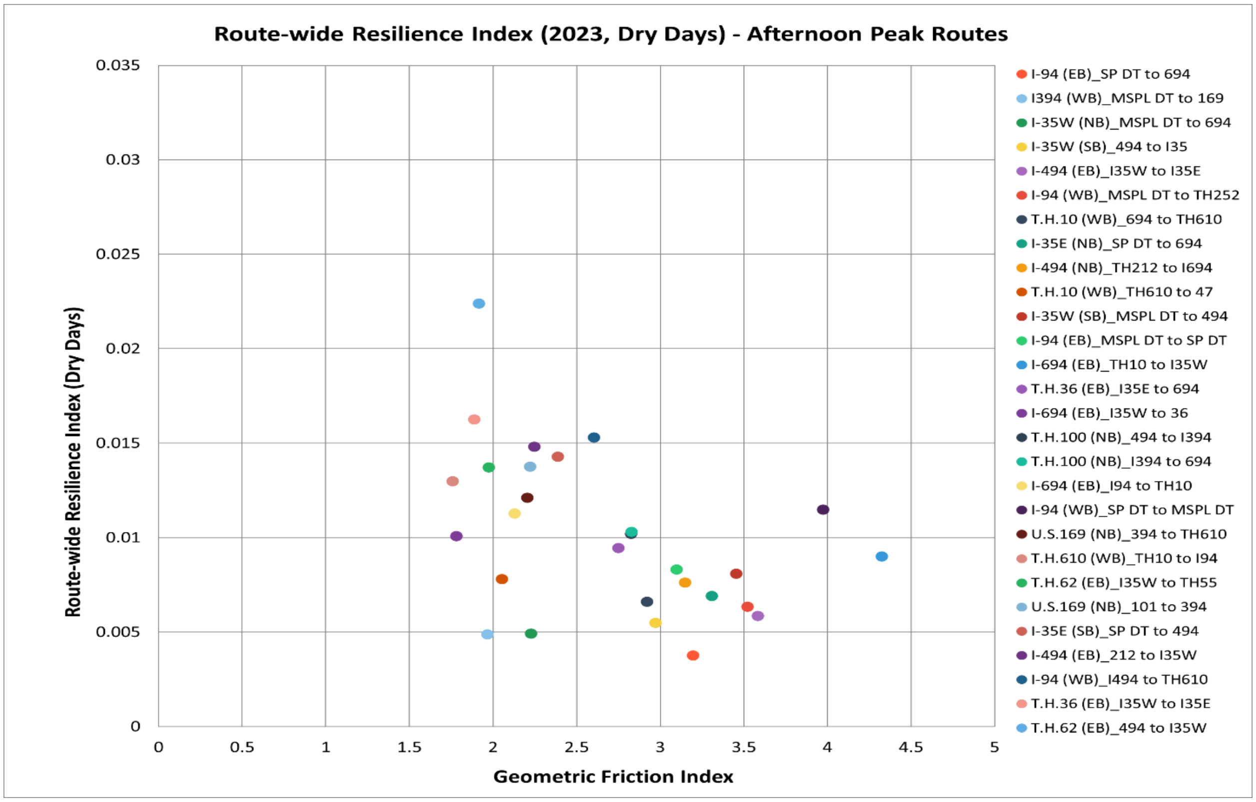


Figure 5.2.13 Route-wide Resilience vs. Geometric Friction Factor (2023, Dry Days, PM-Peak Routes)

5.3 Effects of Operational Resilience on Travel-Time Reliability and Traffic-Flow Measures

In this section, the effects of the operational resilience on the traffic-flow performance and the travel-time TTR Measures at individual directional corridors are analyzed by using the CORI values determined in the previous section. First, for each directional corridor, the yearly estimates of traffic-flow measures, i.e., Vehicle-Miles-Traveled (VMT) and Delayed-Vehicle-Hours (DVH), as well as a set of the travel-time reliability indices are calculated with TeTRES for the 3-year study period of 2018, 2019 and 2023. Next, the relationships between CORI and those traffic-flow measures and travel-time reliability indices are analyzed for each year. The travel-time reliability indices used in this analysis are as follows:

95th %-ile Buffer Index (BI) : (95th %-ile Travel Time – Average Travel Time) /(Average Travel Time)

95th %-ile Planning Index (PI): (95th %-ile Travel Time / Free-Flow Travel Time

EFFECTS OF OPERATIONAL RESILIENCE ON TRAFFIC-FLOW MEASURES

Figures 5.3.1 – 5.3.6 show the relationships between the CORI values and the yearly estimates of VMT/mile for individual directional corridors for the morning and afternoon-peak periods over the 3-year period. In this study, the yearly VMT values of individual directional corridors were normalized by dividing them with the length of each route.

As shown in these figures, there is a clear linear pattern between VMT/mile and CORI. As the CORI value increases, i.e., as the routes become less resilient, the values of VMT/mile also decrease. Further, the VMT/mile-CORI pattern appears to be consistent in both morning and afternoon-peak routes. This indicates the resilience of a directional corridor directly affects the productivity of a given route-traffic system. The above observation is also noted in the relationships between the DVH/mile and CORI, which are shown in Figures 5.3.7 – 5.3.12. As indicated, the routes with smaller CORI values, i.e., the routes with strong resilience, also exhibit smaller values of delayed-vehicle hours per mile than those with weak resilience.

EFFECTS OF OPERATIONAL RESILIENCE ON TRAVEL-TIME TTR MEASURES

Figures 5.3.13 – 5.3.18 show the CORI-Buffer Index (BI) relationships of the morning and afternoon routes for the 3-year study period. As noted in these figures, there is a clear and consistent pattern between CORI and BI, i.e., as CORI increases, BI also increases. This indicates that the routes with high CORI values, i.e., weak resilience, have larger levels of fluctuations in travel times than those with strong resilience, i.e., low CORI values.

The effects of the operational resilience on the congestion level are also analyzed by examining the relationships between CORI and Planning Index (PI), a ratio of 95th percentile travel time to free-flow travel time, at individual directional corridors. Figures 5.3.19 – 5.3.24 show the CORI-PI plots for both morning and afternoon routes during the study period. The CORI-PI relationships noted in these figures exhibit similar patterns shown in the CORI-BI plots, i.e., as CORI increases, PI also increases. This indicates that the routes with low levels of resilience also have high levels of congestion.

As discussed above, the CORI-BI and CORI-PI relationships of the individual directional corridors in the metro freeway network show the expected patterns, i.e., the routes with strong resilience have low levels of travel-time fluctuations and congestion compared to those with weak resilience.

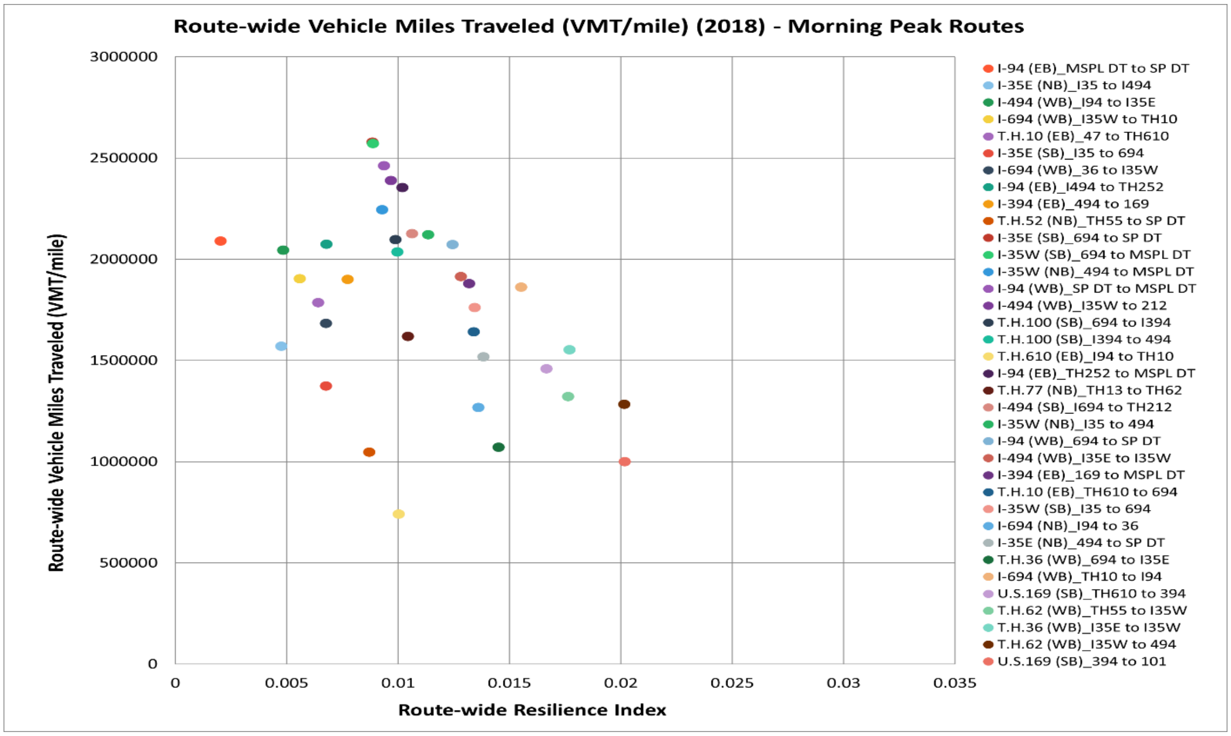


Figure 5.3.1 Route-wide Resilience Index vs VMT/mile (2018, Morning-Peak Routes)

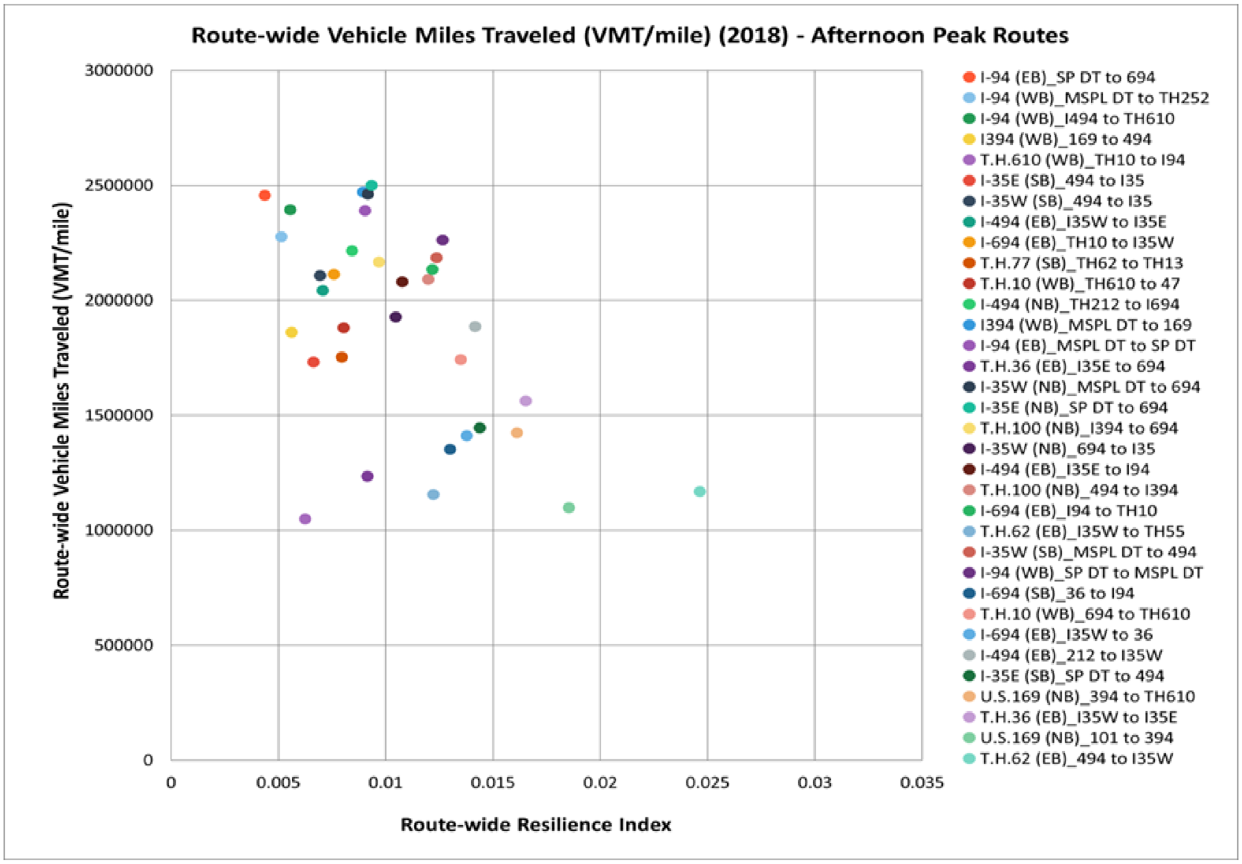


Figure 5.3.2 Route-wide Resilience Index vs VMT/mile (2018, Afternoon-Peak Routes)

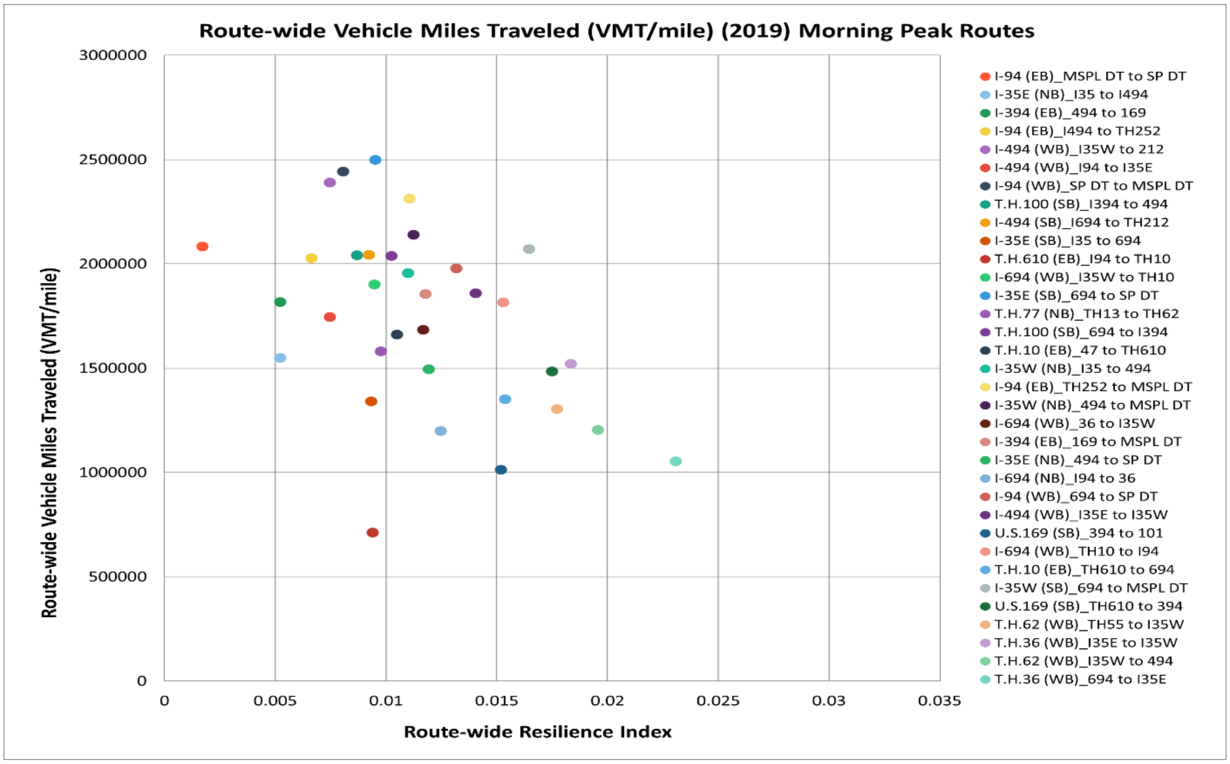


Figure 5.3.3 Route-wide Resilience Index vs VMT/mile (2019, Morning-Peak Routes)

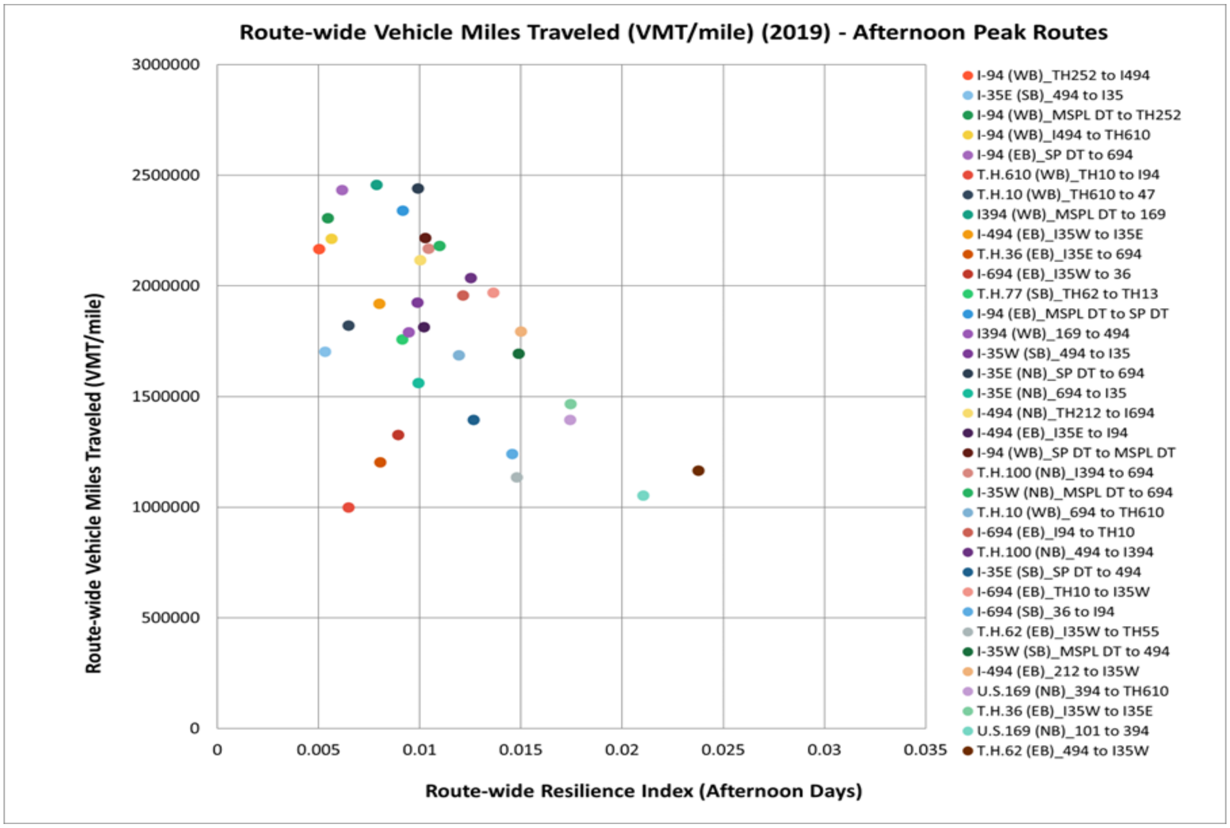


Figure 5.3.4 Route-wide Resilience Index vs VMT/mile (2019, Afternoon-Peak Routes)

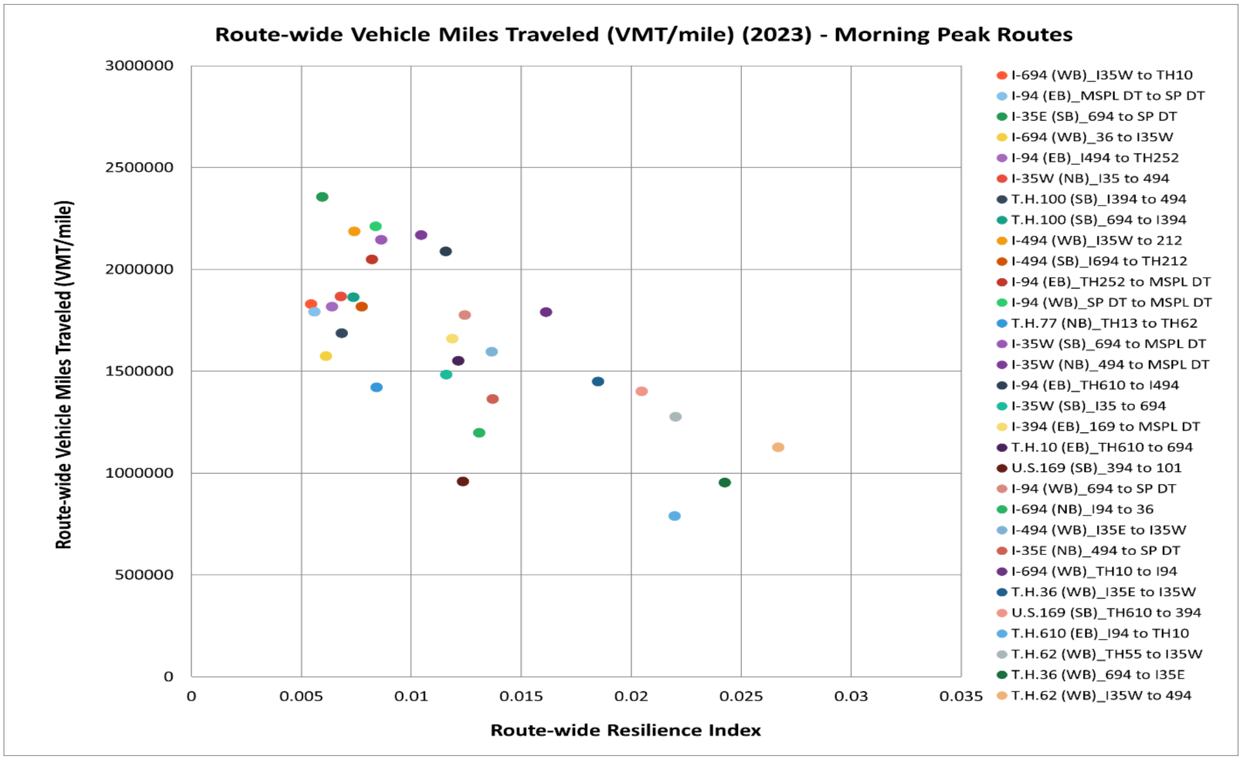


Figure 5.3.5 Route-wide Resilience Index vs VMT/mile (2023, Morning-Peak Routes)

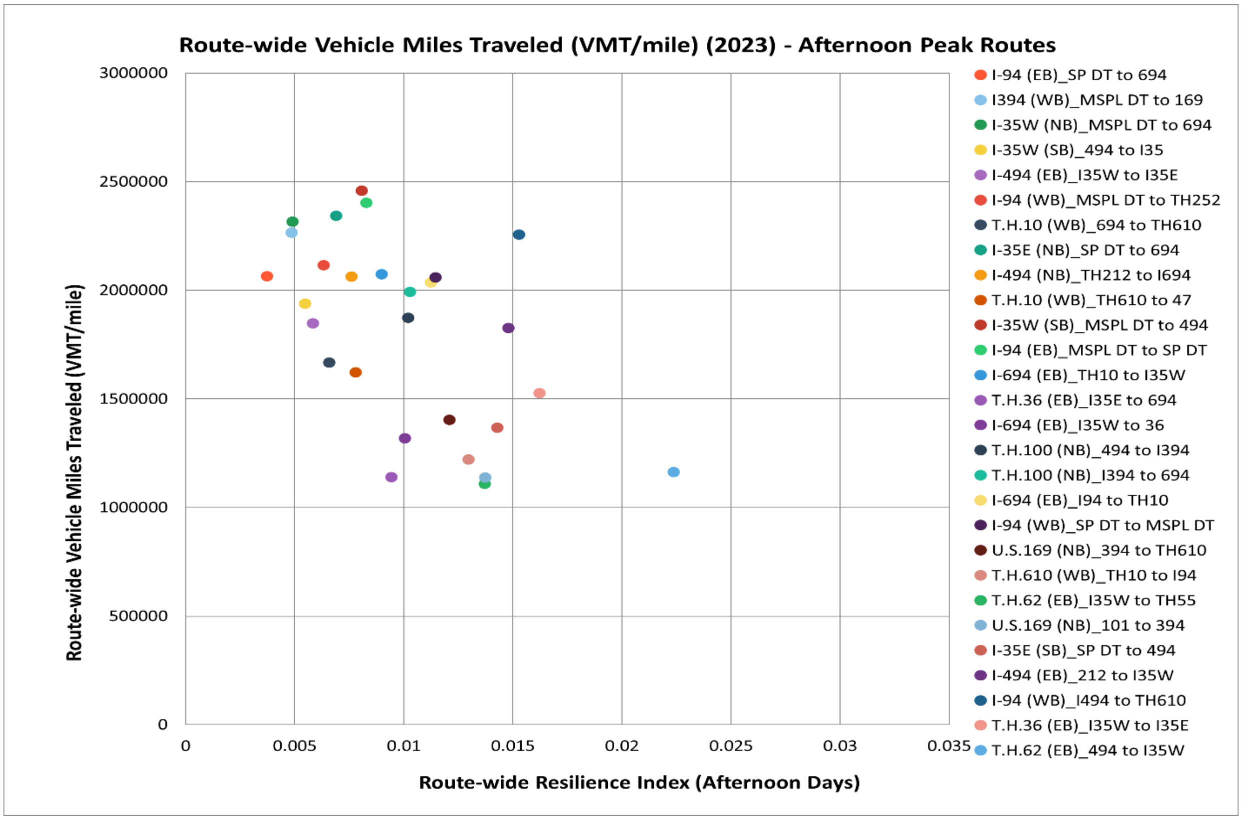


Figure 5.3.6 Route-wide Resilience Index vs VMT/mile (2023, Afternoon-Peak Routes)

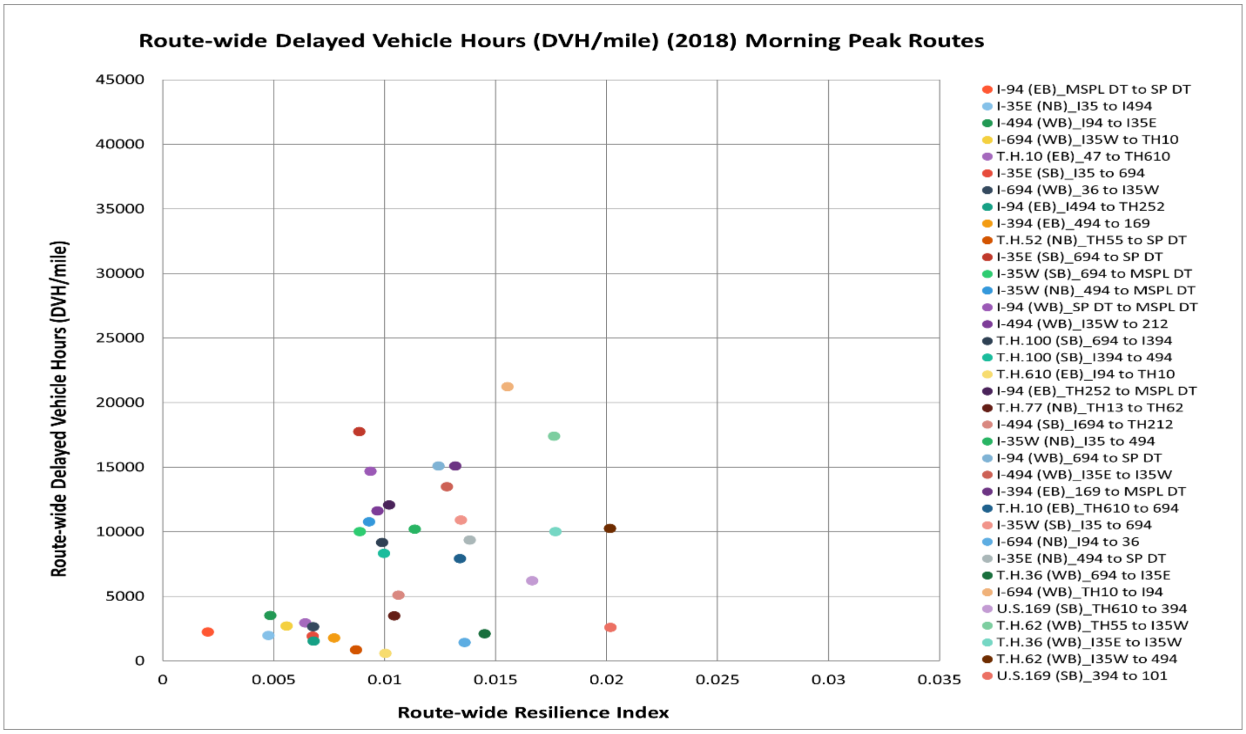


Figure 5.3.7 Route-wide Resilience Index vs DVH/mile (2018, Morning-Peak Routes)

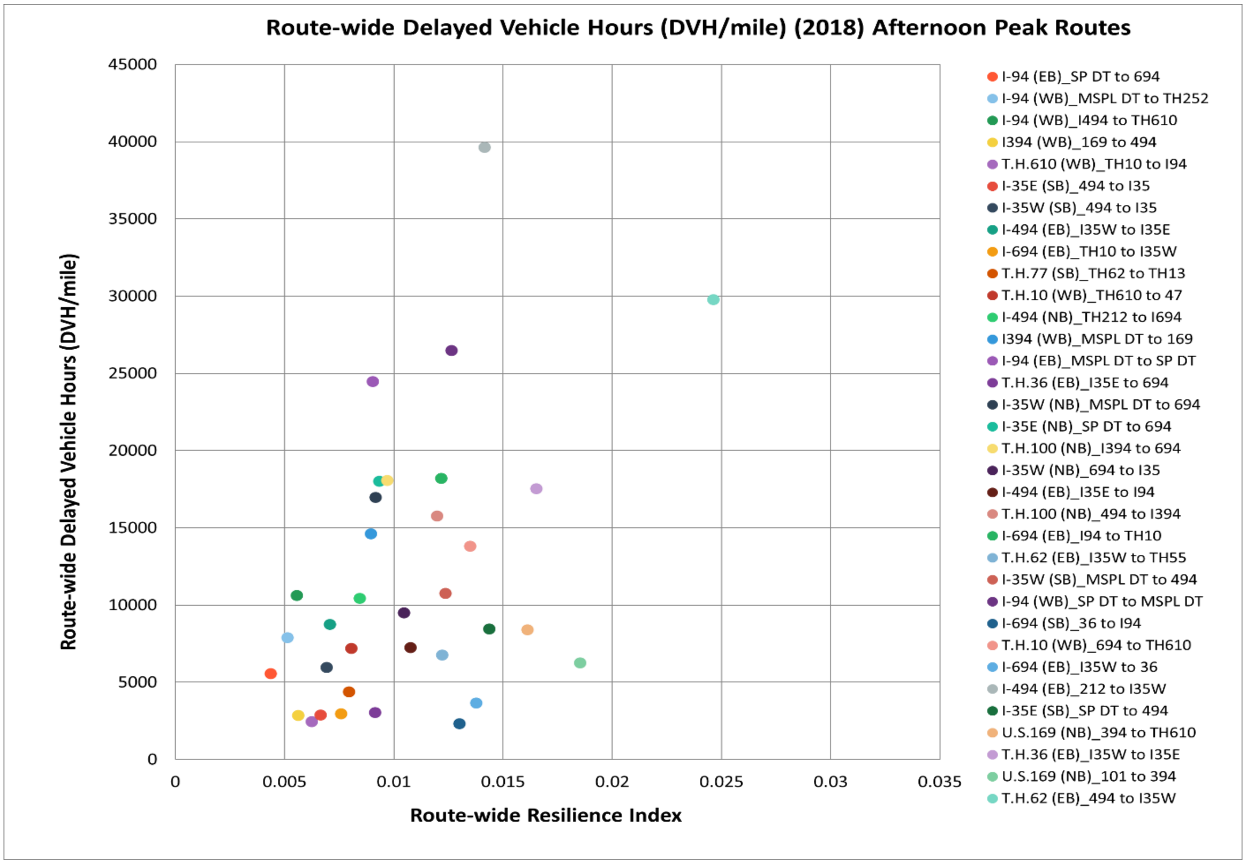


Figure 5.3.8 Route-wide Resilience Index vs DVH/mile (2018, Afternoon-Peak Routes)

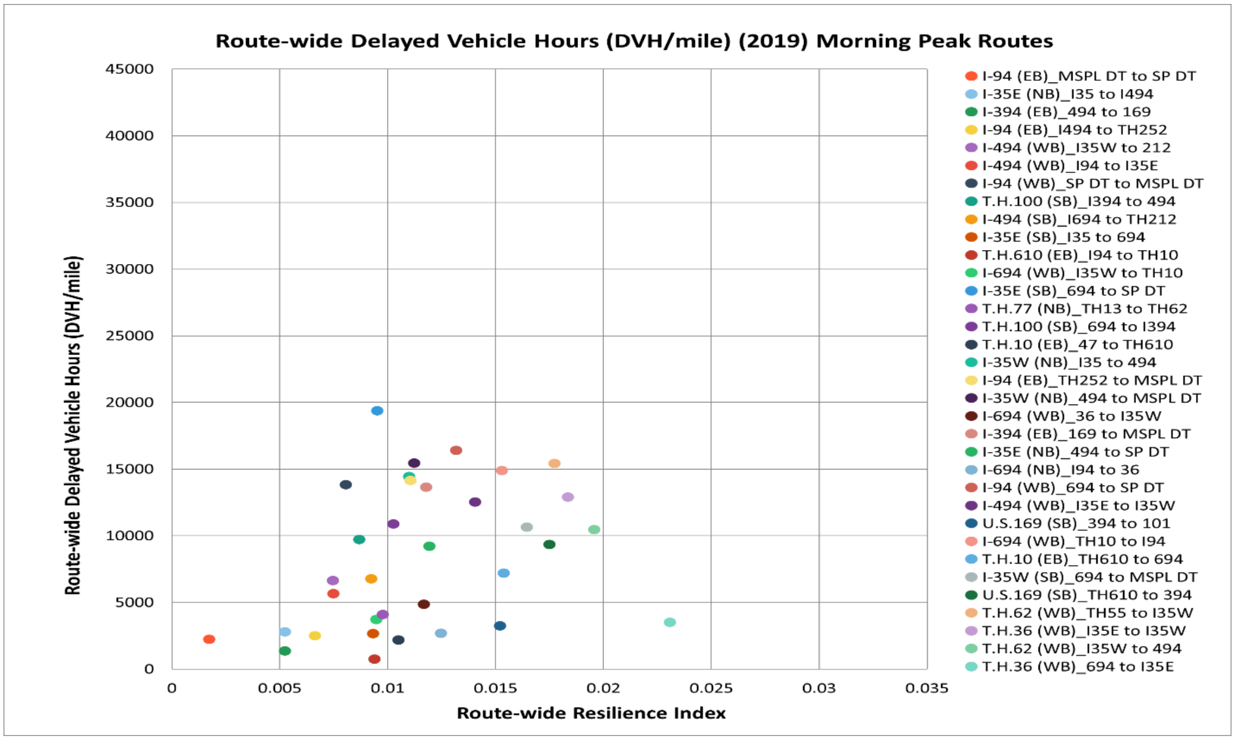


Figure 5.3.9 Route-wide Resilience Index vs DVH/mile (2019, Morning-Peak Routes)

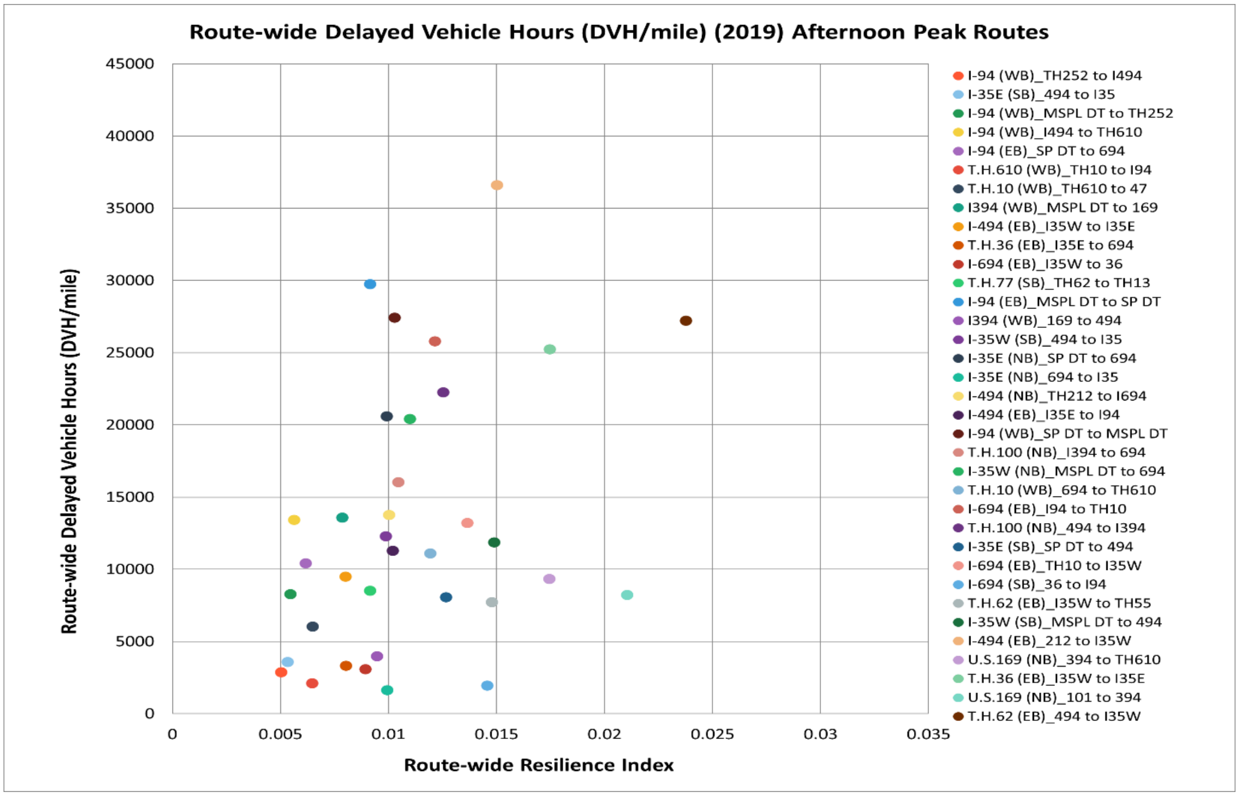


Figure 5.3.10 Route-wide Resilience Index vs DVH/mile (2019, Afternoon-Peak Routes)

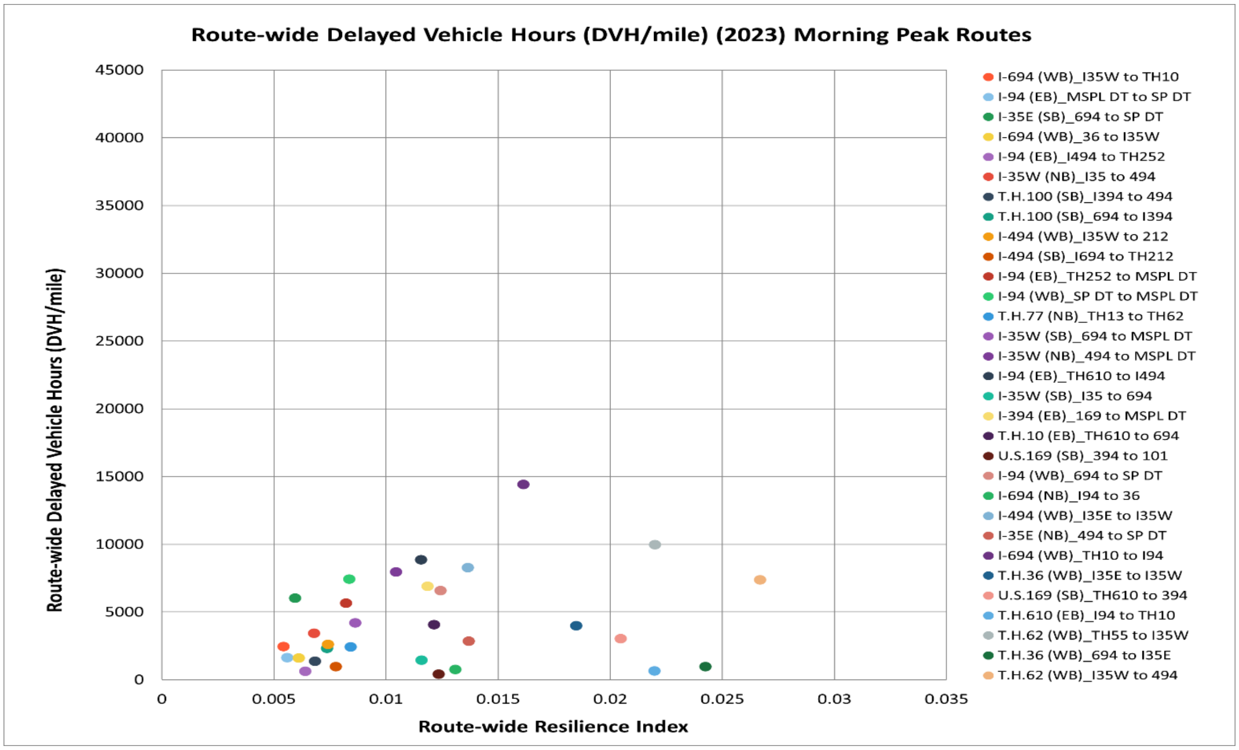


Figure 5.3.11 Route-wide Resilience Index vs DVH/mile (2023, Morning-Peak Routes)

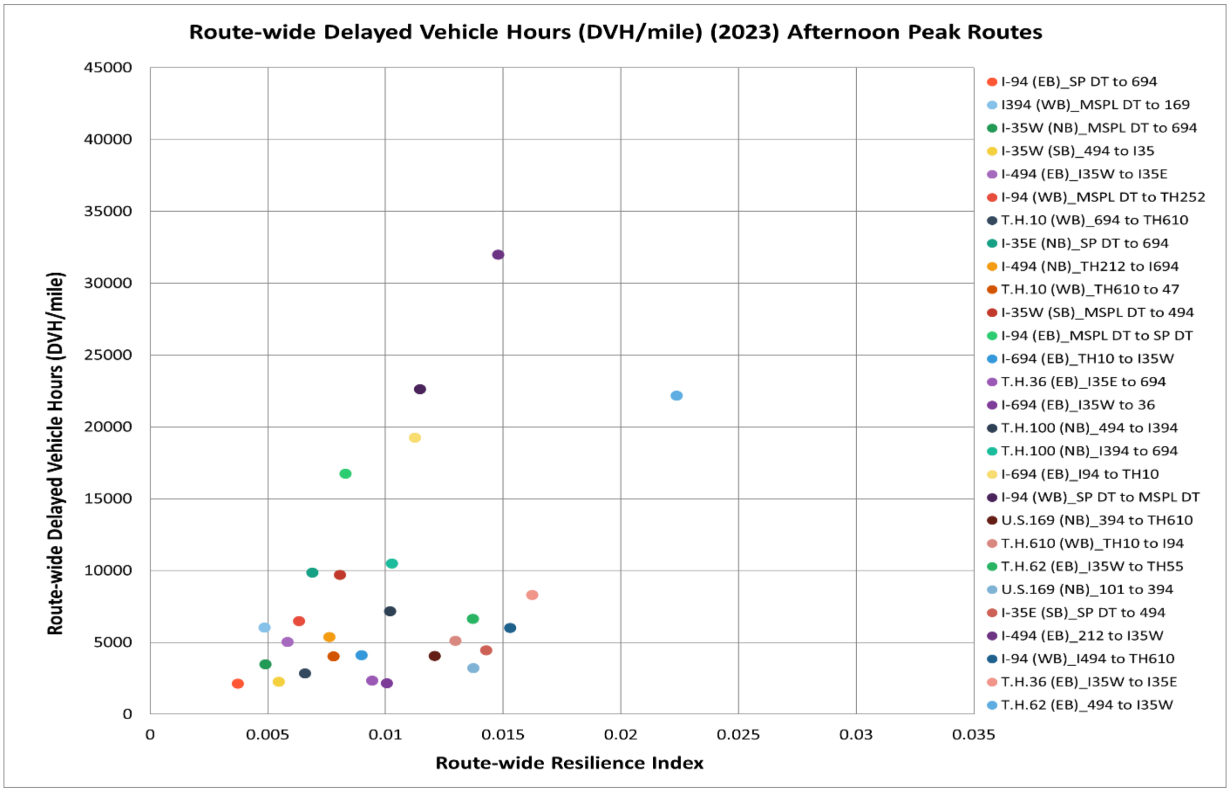


Figure 5.3.12 Route-wide Resilience Index vs DVH/mile (2023, Afternoon-Peak Routes)

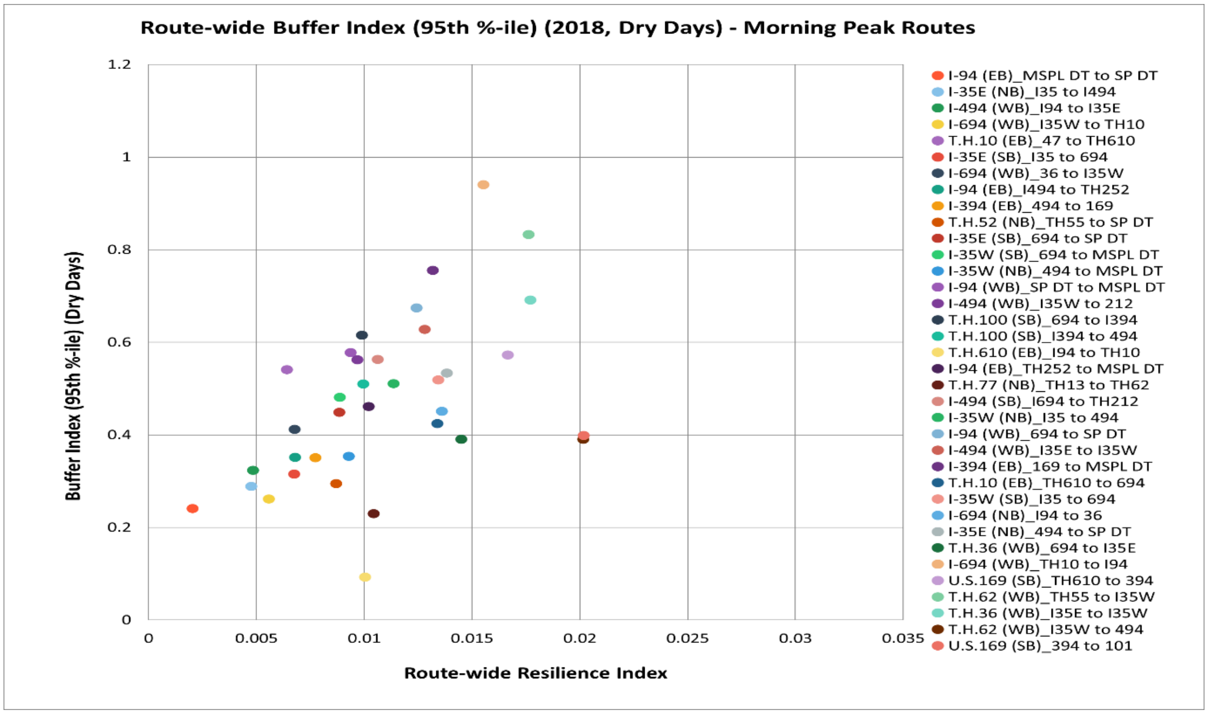


Figure 5.3.13 Route-wide Resilience Index vs Buffer Index (2018, Morning-Peak Routes)

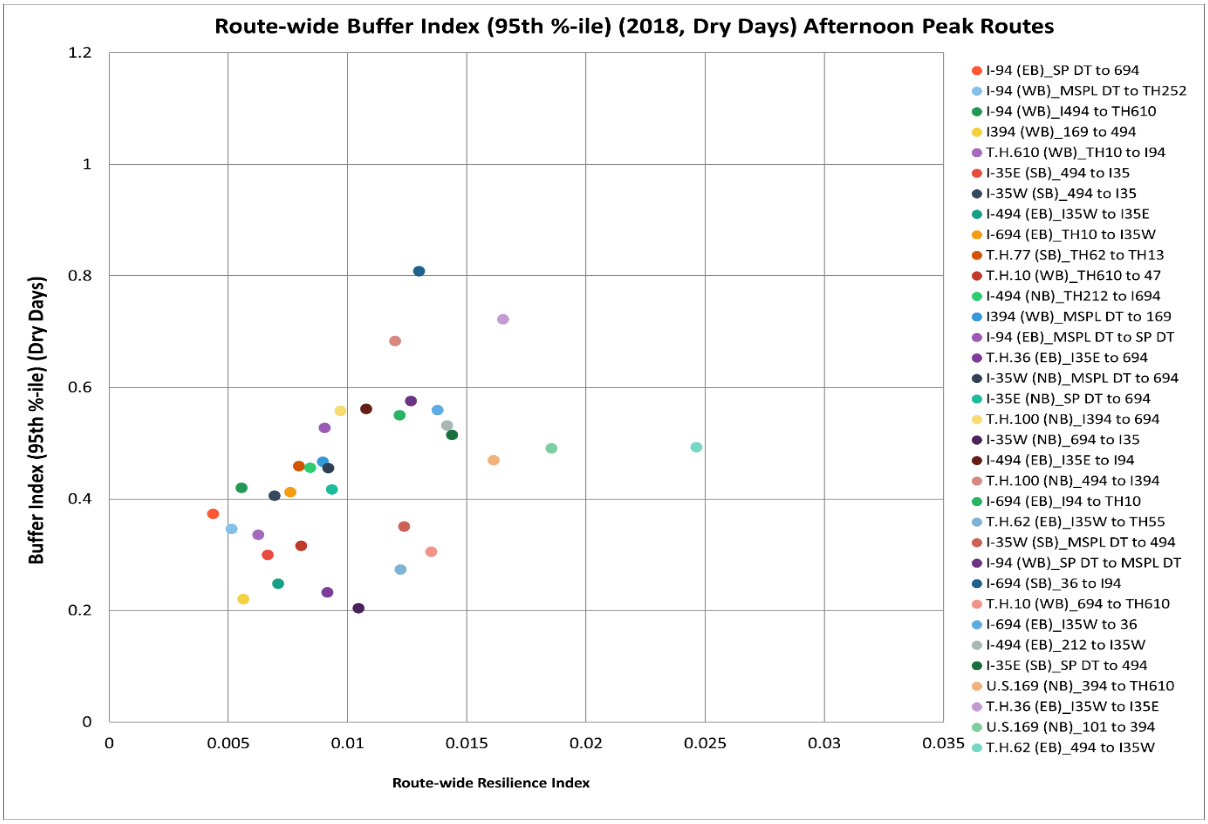


Figure 5.3.14 Route-wide Resilience Index vs Buffer Index (2018, Afternoon-Peak Routes)

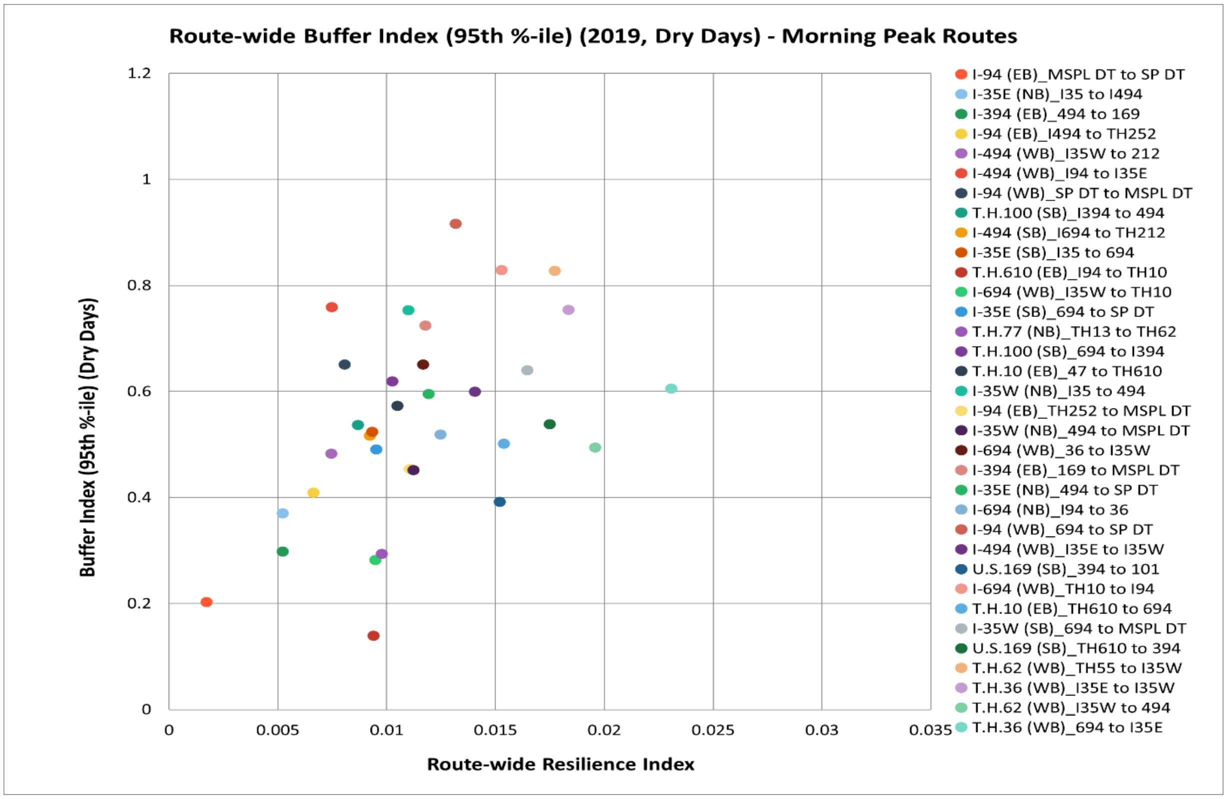


Figure 5.3.15 Route-wide Resilience Index vs Buffer Index (2019, Morning-Peak Routes)

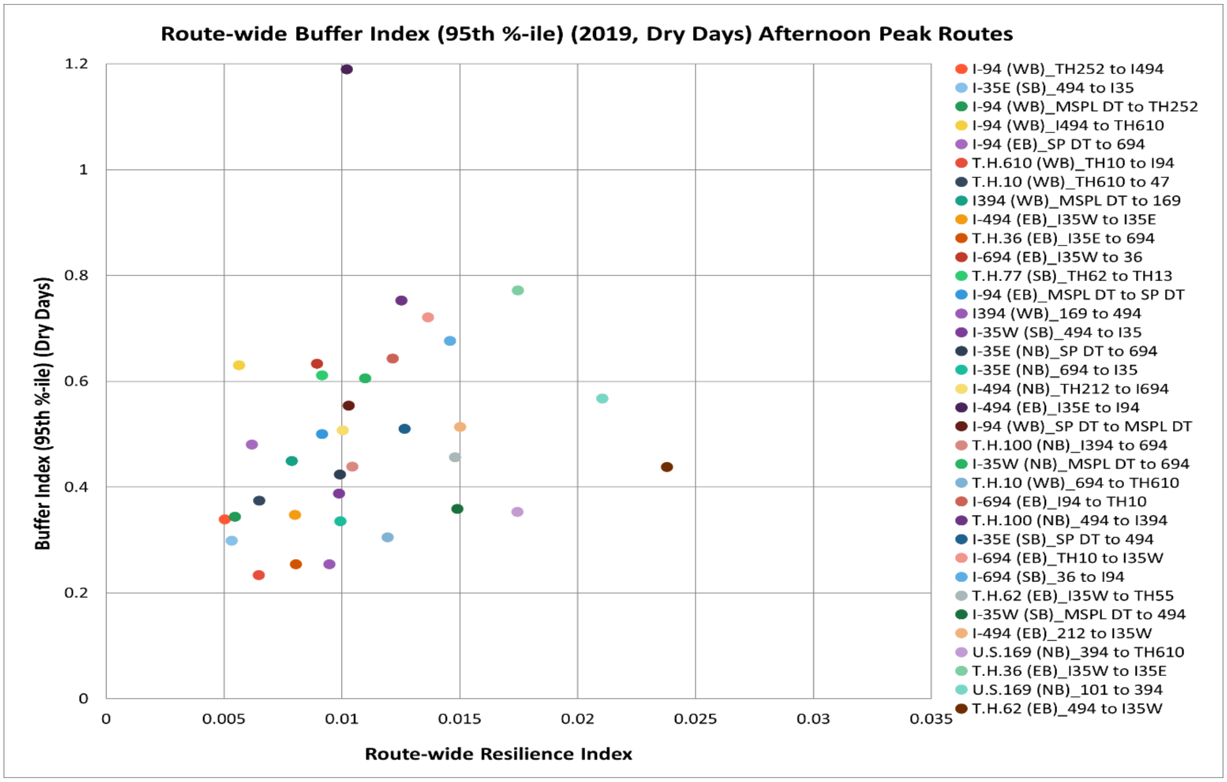


Figure 5.3.16 Route-wide Resilience Index vs Buffer Index (2019, Afternoon-Peak Routes

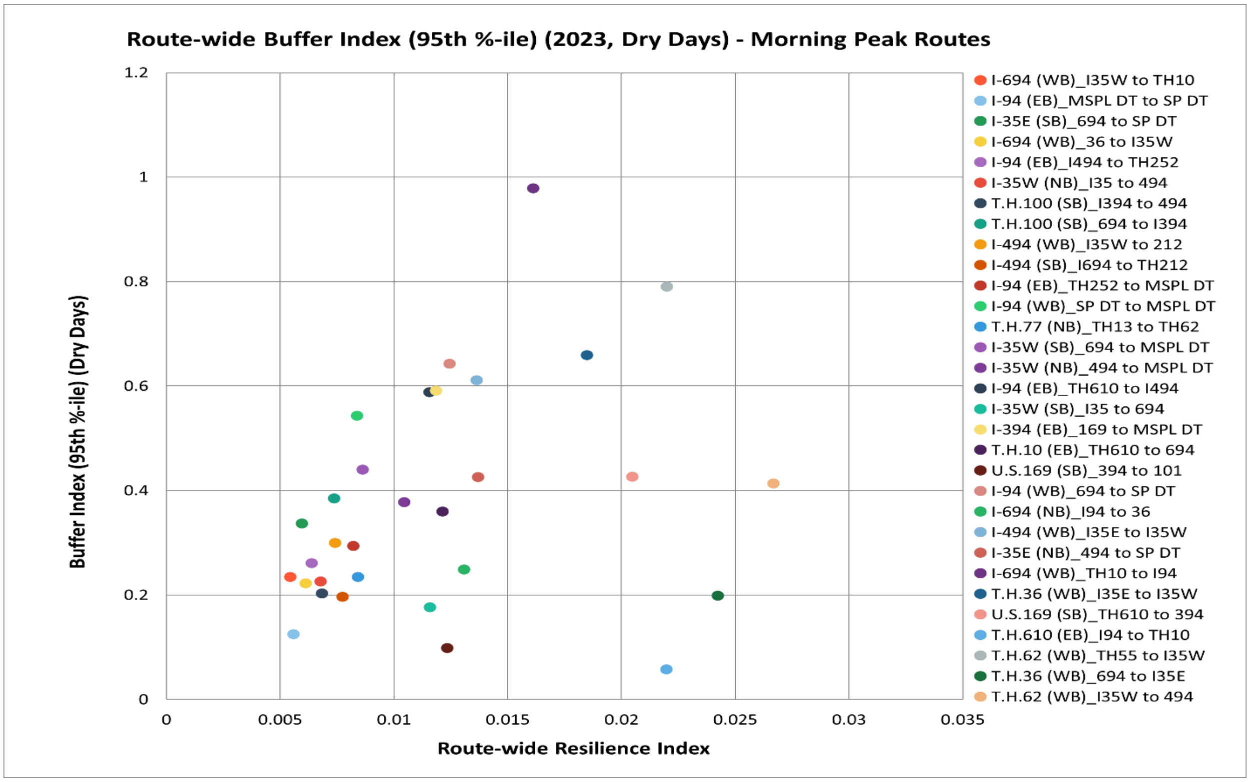


Figure 5.3.17 Route-wide Resilience Index vs Buffer Index (2023, Morning-Peak Routes)

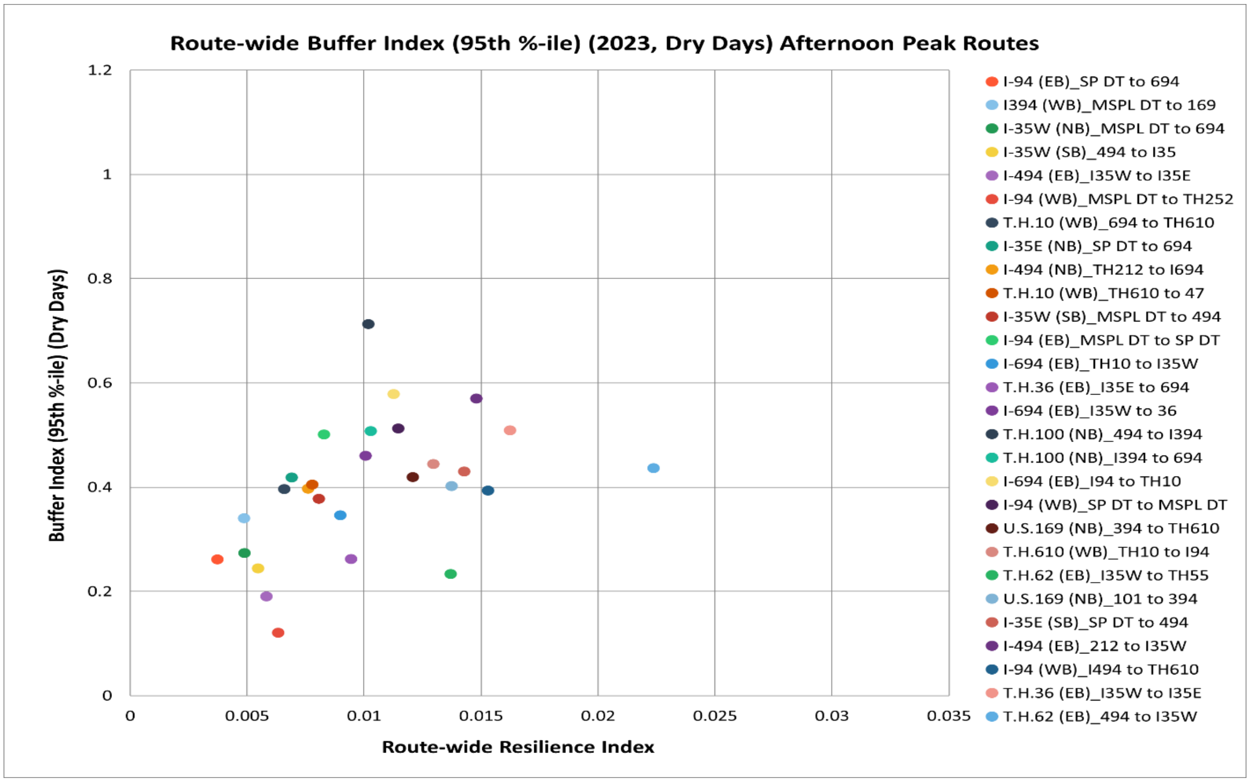


Figure 5.3.18 Route-wide Resilience Index vs Buffer Index (2023, Afternoon-Peak Routes)

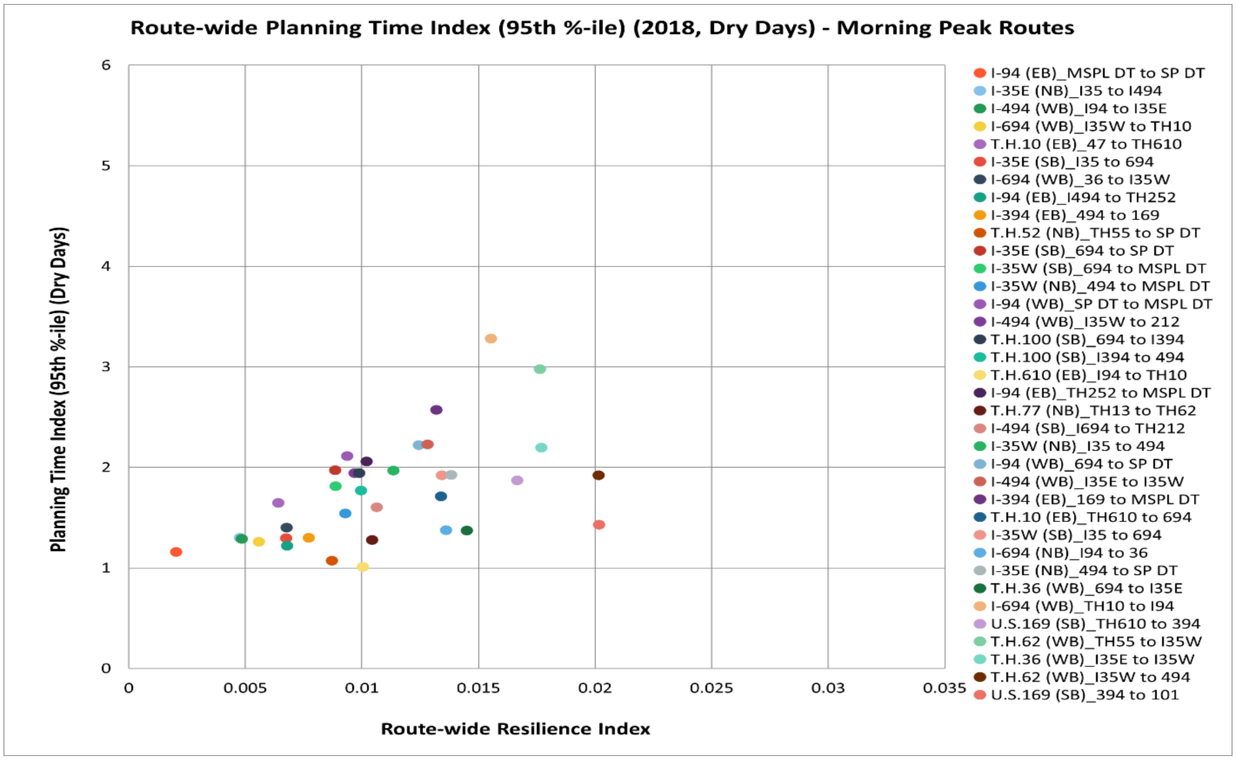


Figure 5.3.19 Route-wide Resilience Index vs Planning Index (2018, Morning-Peak Routes)

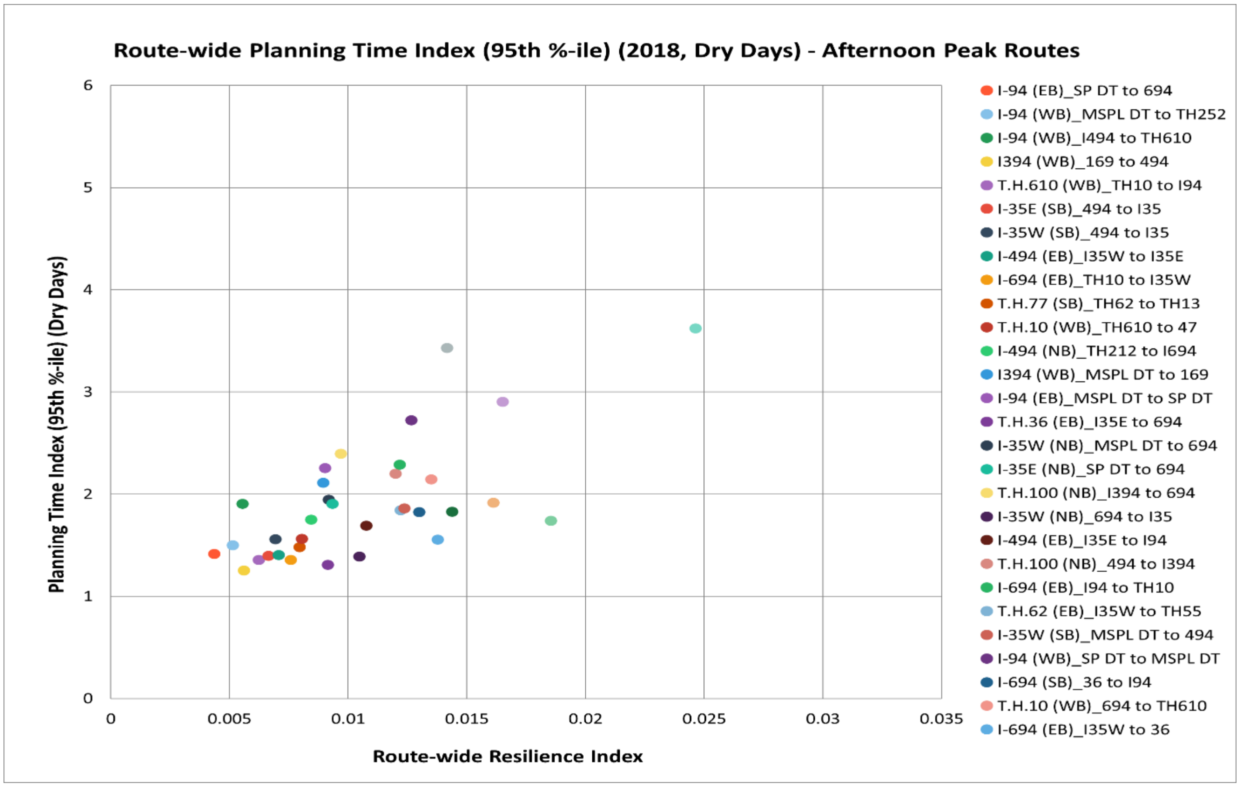


Figure 5.3.20 Route-wide Resilience Index vs Planning Index (2018, Afternoon-Peak Routes)

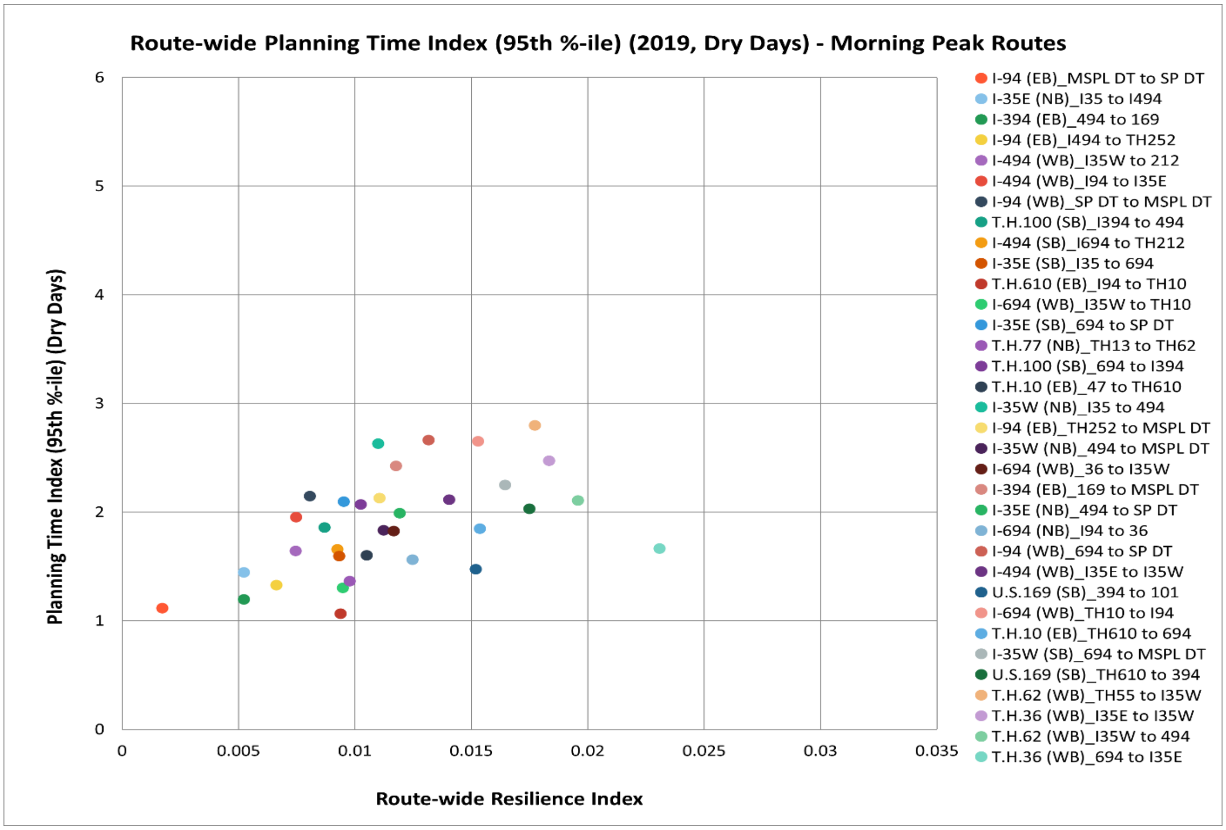


Figure 5.3.21 Route-wide Resilience Index vs Planning Index (2019, Morning-Peak Routes)

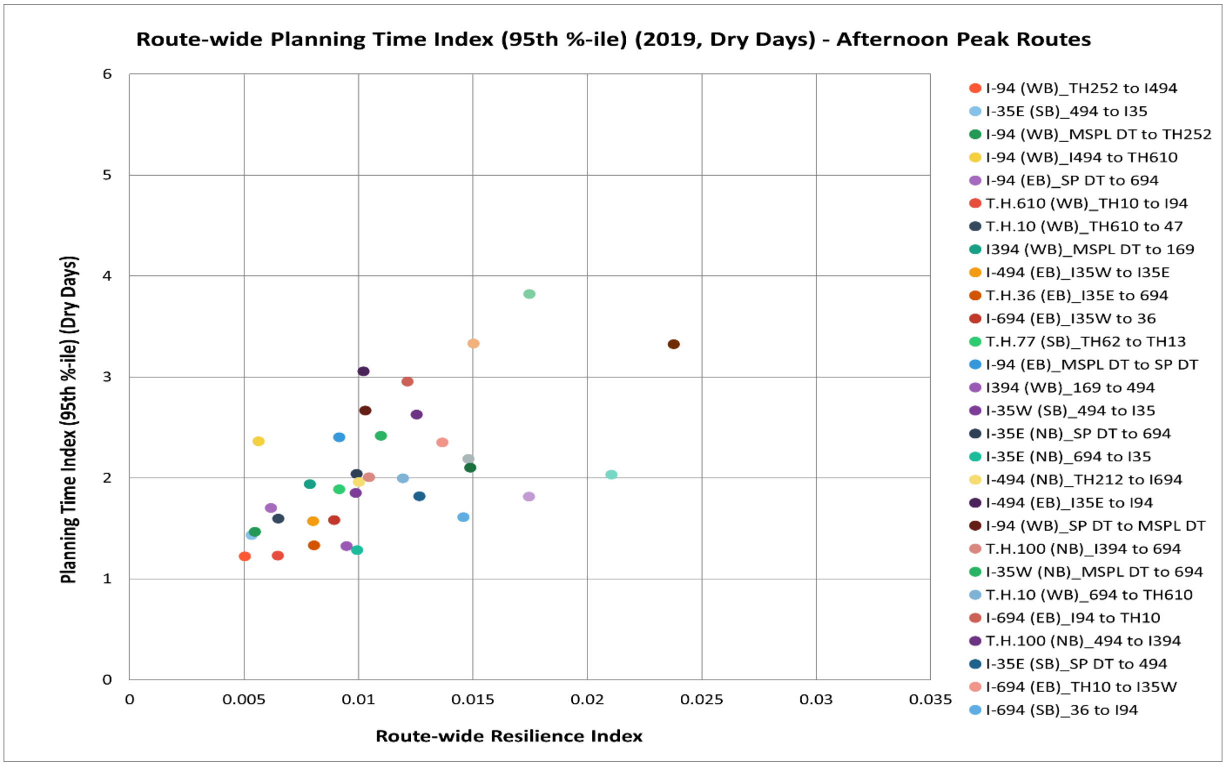


Figure 5.3.22 Route-wide Resilience Index vs Planning Index (2019, Afternoon-Peak Routes)

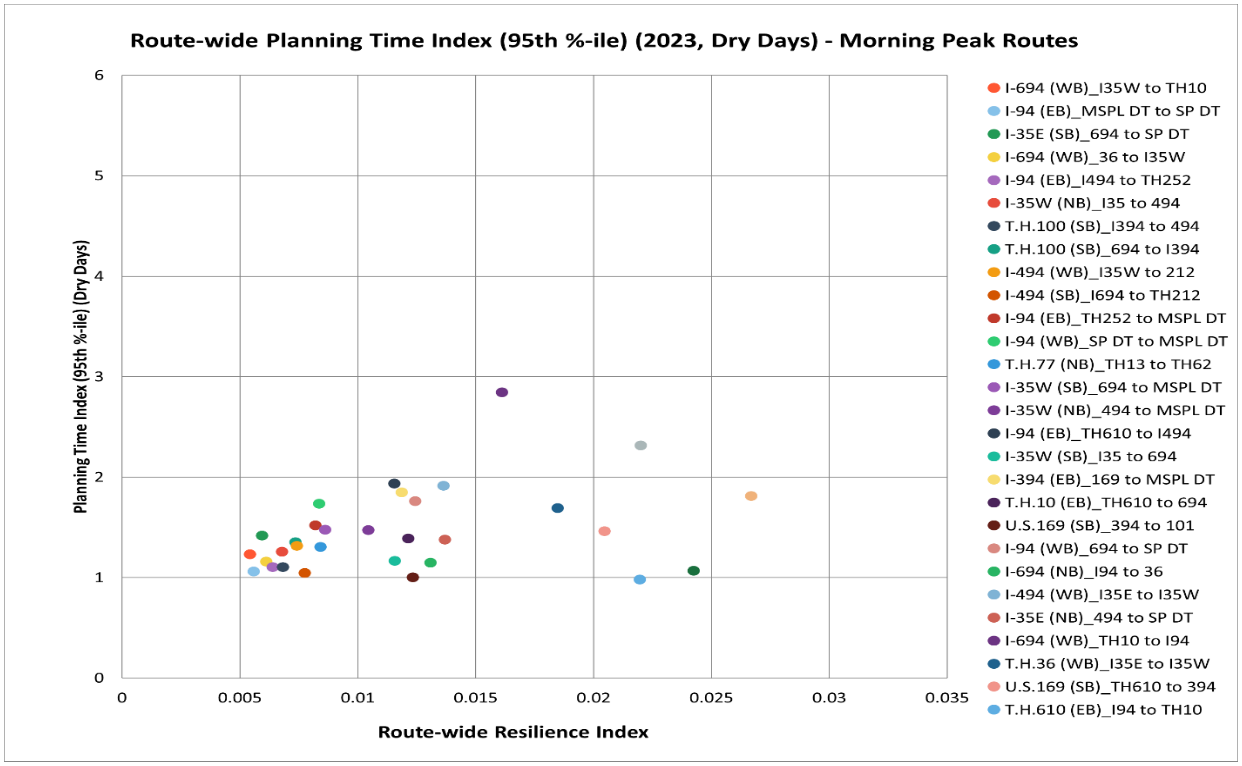


Figure 5.3.23 Route-wide Resilience Index vs Planning Index (2023, Morning-Peak Routes)

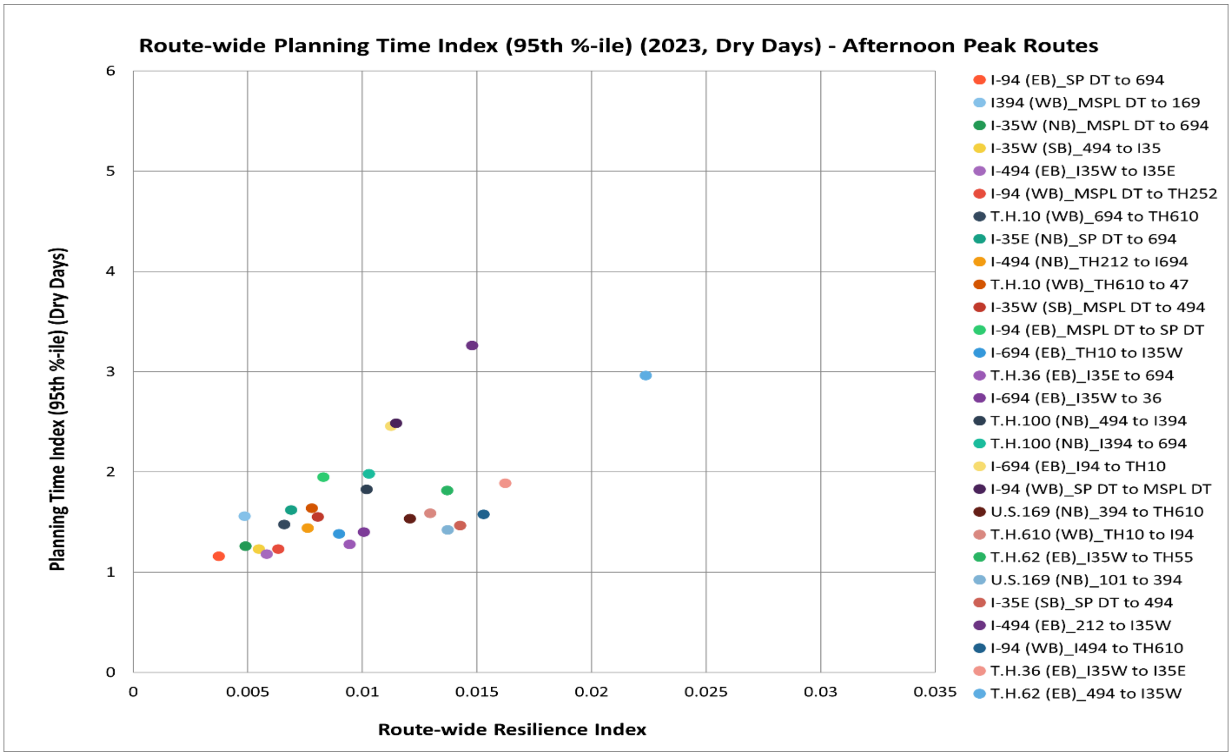


Figure 5.3.24 Route-wide Resilience Index vs Planning Index (2023, Afternoon-Peak Routes)

5.4 Summary

In this chapter, the resilience model enhanced in the previous chapter was applied to estimate the corridor-wide operational resilience indices, CORI, of 74 directional routes using the traffic data from the September-October period in 2018, 2019 and 2023. Based on the estimation results, a group of the directional routes exhibiting consistently low-level of resilience were identified for both morning and afternoon-peak periods. Further, the effects of the geometric configuration on the operational resilience were also analyzed by examining the relationships between the geometric-friction index, G, developed from the previous phase, and the operational resilience of individual routes. The G-CORI plots for the metro freeway corridors resulted in the expected patterns, i.e., the routes with efficient geometric structure in terms of handling through traffic exhibit strong resilience compared with those routes with high levels of geometric friction. Finally, the effects of the operational resilience on the traffic-flow measures and travel-time reliability at individual directional corridors were also analyzed in this chapter. The analysis results indicate that the routes with strong resilience also have better productivity and reliability, e.g., higher VMT/mile with less variability in travel times, than those routes with low levels of resilience. The findings from this chapter could provide the basis for future improvements of freeway corridors in terms of geometric design and operational strategies.

Chapter 6: CONCLUSIONS – RESEARCH BENEFITS/IMPLEMENTATION/FUTURE STUDY NEEDS

This report summarized the major results from the current study, whose main goal was to assess the travel-time reliability and the operational resilience of the Twin Cities' freeway corridors. First, the various types of traffic and non-traffic data required for TeTRES, the Travel-time Reliability Estimation System, developed in previous studies, were collected from September 2020 to December 2023 and processed to populate the TeTRES database, which was used to estimate the travel-time TTR measures of the individual freeway corridors from January 2018 to December 2023. Furthermore, the prototype resilience model, developed from the previous phase, was enhanced with an expanded data set reflecting different weather conditions from the metro freeway network. Using the enhanced resilience model, the operational-resilience indices of individual freeway corridors were estimated and a group of the directional corridors with low levels of resilience were identified. Furthermore, the analysis of the relationships between geometric configuration and operational resilience resulted in the expected patterns, i.e., the routes with efficient geometric structure for through traffic exhibited strong resilience compared to those routes with high levels of geometric friction. It was also found that the routes with strong resilience had higher VMT/mile with less variability of travel times, i.e., smaller values of buffer and planning indices, than the routes with low levels of resilience. The above findings could provide specific directions for future improvements of freeway corridors in terms of geometric design and operational strategies.

RESEARCH BENEFITS

Decrease Engineering/Administrative Costs**:** The updated TeTRES database populated with the new set of historical data, including various types of traffic/non-traffic data, such as weather, incident, work zone, winter-road conditions and special events, as well as the monthly/yearly estimates of the travel-time reliability and traffic-flow measures that resulted from this study for a set of the predefined routes can substantially reduce the time and effort of MnDOT staff in collecting, processing data and analyzing these measures.

Enhance Effectiveness of Operations and Maintenance: The results from this study, i.e., the travel-time reliability under different operating conditions, such as incident type and weather, can be directly applicable to MnDOT staff in identifying the major sources of recurring/non-recurring congestion at a corridor level. This can lead to the development of corridor-specific operation and maintenance strategies. Furthermore, the resilience estimates for individual corridors can be applied in prioritizing corridors for operational improvements. Such capability to develop prioritized, corridor-specific improvement plans can substantially improve the efficiency and effectiveness of the MnDOT operational and maintenance strategies for the metro freeway network.

***Environmental Aspects*:** The prioritized, corridor-specific improvements in operations and maintenance can contribute to mitigating traffic congestion in the metro freeway network, resulting in reductions in excess energy consumption and emissions due to smoother traffic flow and less queueing.

***Safety*:** The assessment of the travel-time reliability at corridor levels under different operating conditions can lead to accurate understanding of the main sources of congestion and travel-time variations. Such an understanding, with the resilience-based prioritization of corridors, can directly lead to proactively improving the operational efficiency and safety of each corridor, thus, reducing the incident-related delays and queueing, which could further increase the risk of secondary crashes.

***Reduce Risk*:** The reliability trends and resilience measures can be directly applicable in prioritizing metro freeway corridors for short/long-term improvements, and therefore, can reduce the risk of inefficient allocation of the operational resources for the metro network. Further, it can be pointed out that travel-time variability represents an important source of risk to both passengers and freight traffic. Improving corridor-wide travel-time reliability and resilience could substantially reduce the risks faced by various users.

***Other – Sustainability*:** A reliable and resilient freeway network, which reduces the frequency and severity of degraded performance, can improve the environmental and economic sustainability of the Twin Cities, Minnesota, by reducing the external costs of emissions from fuel consumption as well as time and money expenditure of the public.

IMPLEMENTATION STEPS

To facilitate the realization of the benefits from this study, the following steps will be taken in cooperation with the relevant offices in MnDOT:

- Technical workshops will be conducted for the relevant MnDOT staff regarding the main results from this study and potential applications.
- All the TeTRES files including the updated database will be provided to MnDOT as needed.
- Technical assistance to each MnDOT office will be provided in estimating and analyzing the travel-time reliability and resilience measures for office-specific applications, e.g., before/after performance analysis and corridor prioritization for short/long-term planning.

FUTURE STUDY NEEDS

Future research needs identified from this study are as follows:

- Continuous collection of data and assessment of travel-time reliability of the freeway corridors in the metro network.

- Enhancement of the geometry-friction model with the explicit incorporation of the connectivity and accessibility of a given route to adjacent corridors.
- Study on the potential effects of heavy-vehicle flows on the corridor-wide operational resilience, since the operational characteristics of heavy vehicles, i.e., acceleration and deceleration, could significantly affect the congestion formulation and recovery patterns of a given route.

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1. E. Kwon & C. Park. (2018). *Development of Travel-Time Reliability Measurement System* (MN/RC 2018-28, Final Report). St. Paul, MN: Minnesota Department of Transportation
2. E. Kwon, C. Jurrens, C. Wright, & A. Mahmud. (2022). *Estimation of Metro Freeway System Reliability and Resilience* (MN 2022-01, Final Report). St. Paul, MN: Minnesota Department of Transportation.
3. E. Kwon & C. Park. (2012). *Development of Freeway Operational Strategies with IRIS-in-Loop Simulation* (MN/RC 2012-04, Final Report). St. Paul, MN: Minnesota Department of Transportation.

APPENDIX A: Monthly and Yearly Estimates of Travel-Time Reliability and Traffic-Flow Measures for Individual Directional Corridors in the Metro Freeway Network (1/2018 – 12/2023)

TABLE OF CONTENTS

A.1 Configuration of Freeway Corridors for Travel-Time Reliability/Traffic-Flow MOE Estimation

Figure A.1.1 shows the metro-freeway network consisting with the individual corridors, whose travel-time reliability (TTR) and traffic-flow measures are estimated with TeTRES for each directional route. The TTR measures of each route are based on the travel times calculated every 5-minute interval during non-holiday weekdays, i.e., Tuesdays, Wednesdays, Thursdays. In addition, a set of the commonly used traffic-flow measures were also estimated and presented for each route. The specific measures and operating conditions used in this analysis are as follows:

Travel-time Reliability (TTR) Measures

Buffer Index (BI, 95th %ile) = (95th %ile Travel Time – Average Travel Time)/(Average Travel Time)

Planning Index (PI, 95th %ile) = 95th %ile Travel Time / Free-Flow Travel Time

Travel Rate (TR, 95th %ile, minutes/mile) = 95th %ile Travel Time / Route Length

Operating Conditions

Weather: All, Dry, Rain, Snow

Incident: All, No-Incident (N), Property Damage Only (PD), Severe/Fatal (INJ, FA)

Work Zone: All, No-WZ (N), Light Impact-WZ (L), Medium-Heavy Effect WZ (M, H)

Special Event: No-Event, Small (< 20,000 attendees), Medium-Large (> 20,000 attendees) events

Peak Periods*: Morning: 6:00 – 9:00 a.m. Afternoon: 3:30 – 6:30 p.m.*

Traffic-Flow Measures*:*

VMT (Vehicle-Miles Traveled), VHT (Vehicle-Hours Traveled), DVH (Delayed Vehicle-Hours)

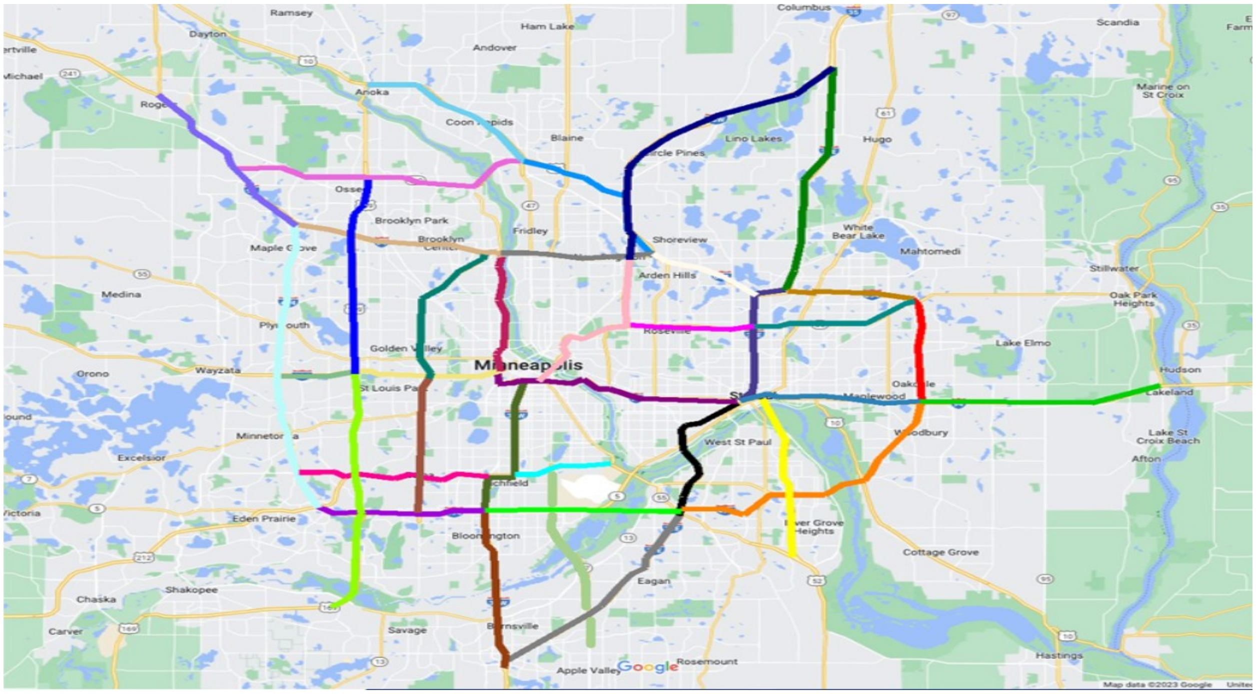


Figure A.1.1 Configuration of Freeway Corridors (36 Corridors, 74 Peak-Directional Routes)

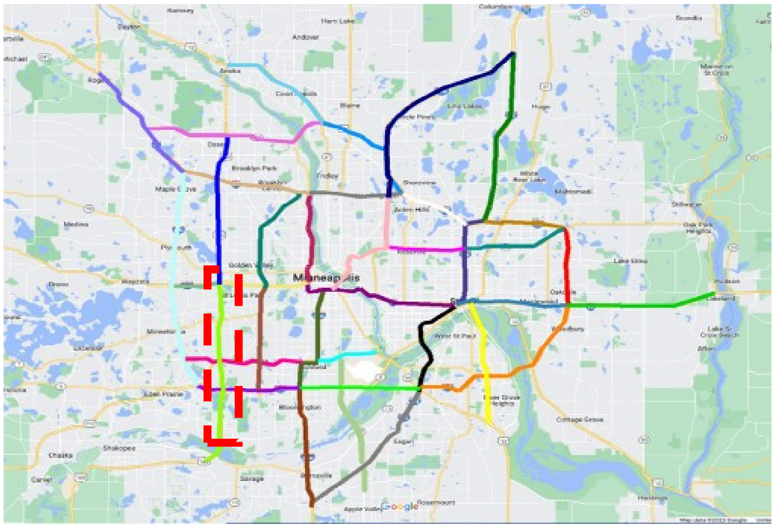
Table A.1.1 Start/End Stations of Each Directional Route

L2_Corridor	L2_Description	L2_Start	L2_End	Length(Miles)
I-35E (NB)	i35 - 494	S870	S826	10.9
I-35E (NB)	494 - Saint Pol DT	S826	S619	7.6
I-35E (NB)	Saint Pol DT - 694	S619	S1447	5.8
I-35E (NB)	694 - i35	S1447	S1504	14
I-35E (SB)	Saint Pol DT - 494	S644	S858	7.5
I-35E (SB)	494 - i35	S858	S905	11
I-35E (SB)	i35 - 694	S1531	S1464	13.5
I-35E (SB)	694 - Saint Pol DT	S1464	S644	6
I-35W (NB)	i35 - 494	S911	S43	8.4
I-35W (NB)	494 - Mineapolis DT	S43	S566	8.9
I-35W (NB)	Mineapolis DT - 694	S566	S659	9.2
I-35W (NB)	694 - i35	S659	S1561	14.7
I-35W (SB)	Mineapolis DT - 494	S585	S13	8.4
I-35W (SB)	494 - i35	S13	S915	9
I-35W (SB)	i35 - 694	S1567	S686	14.8
I-35W (SB)	694 - Mineapolis DT	S686	S585	9.1
I-394 (EB)	494 - 169	S269	S274	2.7
I-394 (EB)	169 - Mineapolis DT	S274	S290	5.5
I394 (WB)	Mineapolis DT - 169	S289	S340	5.6
I394 (WB)	169 - 494	S340	S346	3.3
I-494 (EB)	212 - I35w	S474	S120	6.2
I-494 (EB)	i35w-i35e	S120	S863	7.8
I-494 (EB)	i35e-i94	S863	S1026	12.4
I-494 (NB)	TH212 - I694	S485	S730	14.4
I-494 (SB)	I694 - TH212	S209	S473	15.5
I-494 (WB)	i35e-i35w	S864	S119	7.8
I-494 (WB)	i35w-212	S119	S483	5.9
I-494 (WB)	i94-i35e	S1029	S864	12.4
I-694 (EB)	i94 - TH10	S145	S1074	5.4
I-694 (EB)	TH10 - I35w	S1074	S1452	4.7
I-694 (EB)	I35w - 36	S1452	S1397	5.7
I-694 (SB)	36 - i94	S1398	S1028	5.3
I-694 (NB)	I94 - 36	S1027	S1418	4.9
I-694 (WB)	36 - i35w	S1419	S1459	6.5
I-694 (WB)	I35w - TH10	S1461	S1089	3.8
I-694 (WB)	TH10 - I94	S1089	S144	5.5
I-94 (EB)	TH610 - I494	S1115	S211	9.1
I-94 (EB)	Saint Pol DT - 694	S499	S2151	7.3
I-94 (EB)	694 - 95	S2151	S1358	9.2
I-94 (EB)	I494 - TH252	S211	S170	8
I-94 (EB)	TH252 - Mineapolis DT	S170	S110	8.1
I-94 (EB)	Mineapolis DT - Saint Pol DT	S110	S499	8.4
I-94 (WB)	I494 - TH610	S208	S1112	8.4
I-94 (WB)	Saint Pol DT - Mineapolis DT	S500	S1943	8.3
I-94 (WB)	95 - 694	S1359	S1062	9
I-94 (WB)	694 - Saint Pol DT	S1062	S500	7.5
I-94 (WB)	Mineapolis DT - TH252	S76	S159	8
I-94 (WB)	TH252 - I494	S159	S216	7.1
T.H.10 (EB)	47 - TH610	S940	S954	7.5
T.H.10 (EB)	TH610 - 694	S954	S1825	7.3
T.H.10 (WB)	694 - TH610	S1820	S978	7.7
T.H.10 (WB)	TH610 - 47	S978	S992	7.6
T.H.100 (NB)	494 - I394	S375	S391	7.6
T.H.100 (NB)	I394 - 694	S391	S1627	6.9
T.H.100 (SB)	694 - I394	S1615	S405	6.8
T.H.100 (SB)	I394 - 494	S405	S421	7.7
T.H.36 (EB)	I35w - I35e	S587	S599	5.2
T.H.36 (EB)	I35e - 694	S600	S1427	6.6
T.H.36 (WB)	I35e - I35w	S609	S618	4.4
T.H.36 (WB)	694 - I35e	S1425	S608	11.2
T.H.52 (NB)	TH55 to Saint Paul Downtown	S1166	S1178	8.2
T.H.52 (SB)	Saint Paul Downtown to TH55	S1151	S1163	8.4
T.H.610 (EB)	I94 to TH10	S1954	S966	8.2
T.H.610 (WB)	TH10 to I94	S996	S1961	8.4
T.H.62 (EB)	494 - I35w	S301	S69	6.9
T.H.62 (EB)	I35w - 55	S69	S1135	4.8
T.H.62 (WB)	I35w - 494	S127	S369	6.7
T.H.62 (WB)	55 - I35w	S330	S127	4.2
U.S.169 (NB)	101 - 394	S1617	S441	16
U.S.169 (NB)	394 - TH610	S441	S1799	11.1
U.S.169 (SB)	TH610 - 394	S1795	S448	10.9
U.S.169 (SB)	394 - 101	S448	S1626	16.2
T.H.77 (NB)	TH13 to TH62	S799	S531	6.1
T.H.77 (SB)	TH62 to TH13	S534	S814	8.2

A.2 Monthly and Yearly Trends of TT-Reliability and Traffic-Flow Measures for Individual Corridors

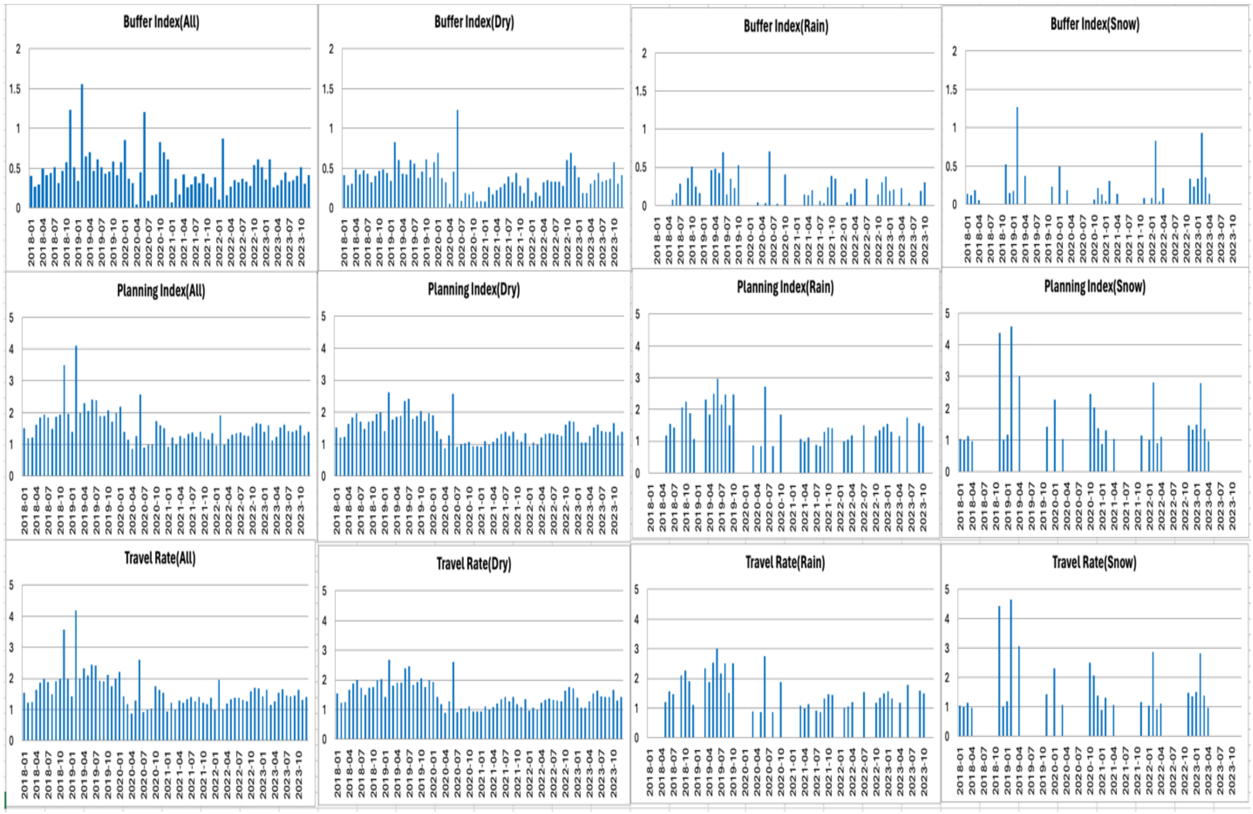
1) US-169 Corridor A (TH 101 < -- > I-394)

i) US-169 Corridor A- NB Route TH 101 to I-394 for Afternoon Peak Period

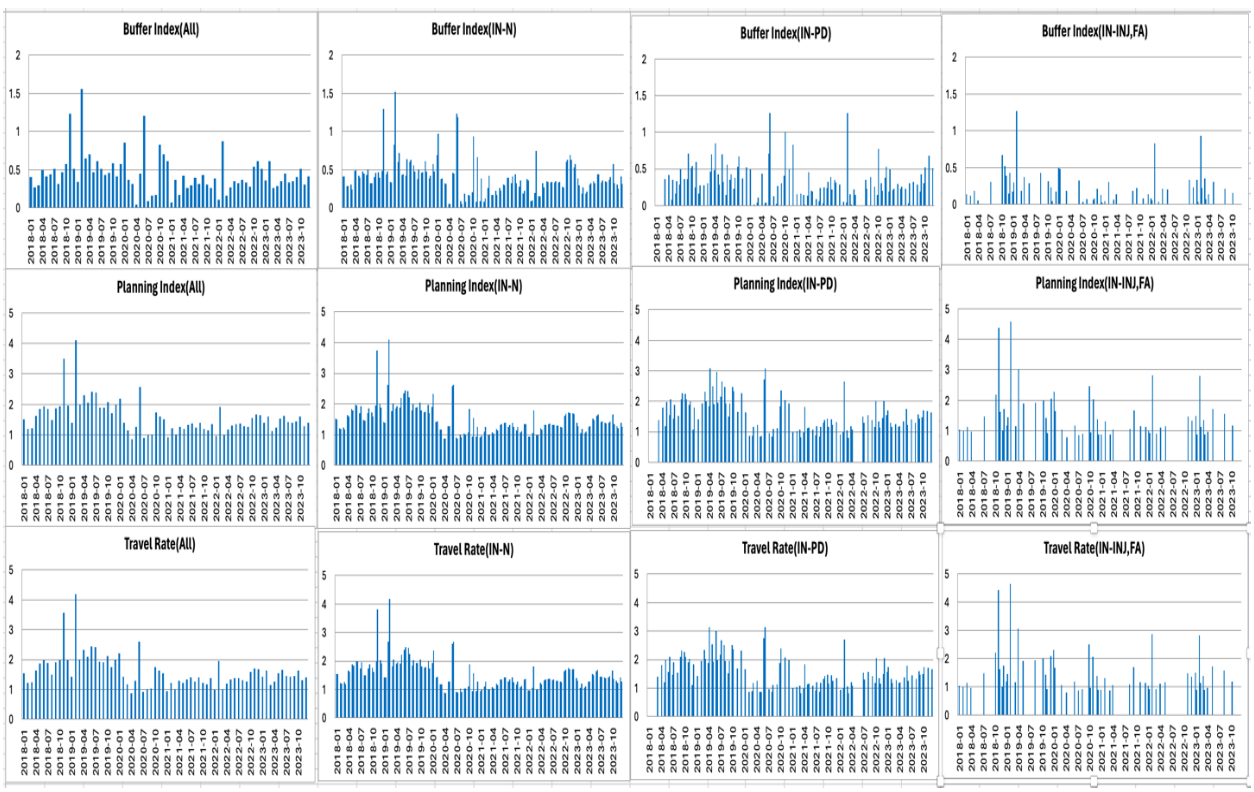


Location of 169 NB Route

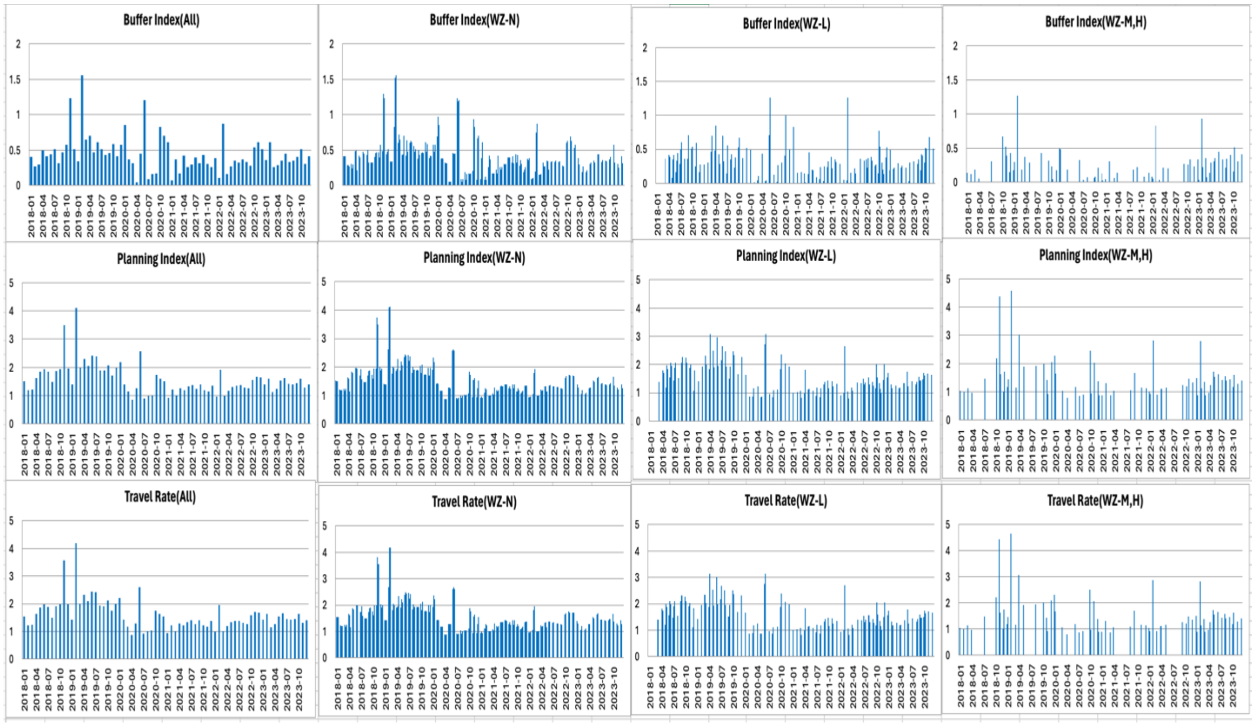
Effects of Weather conditions on Travel-Time Reliability



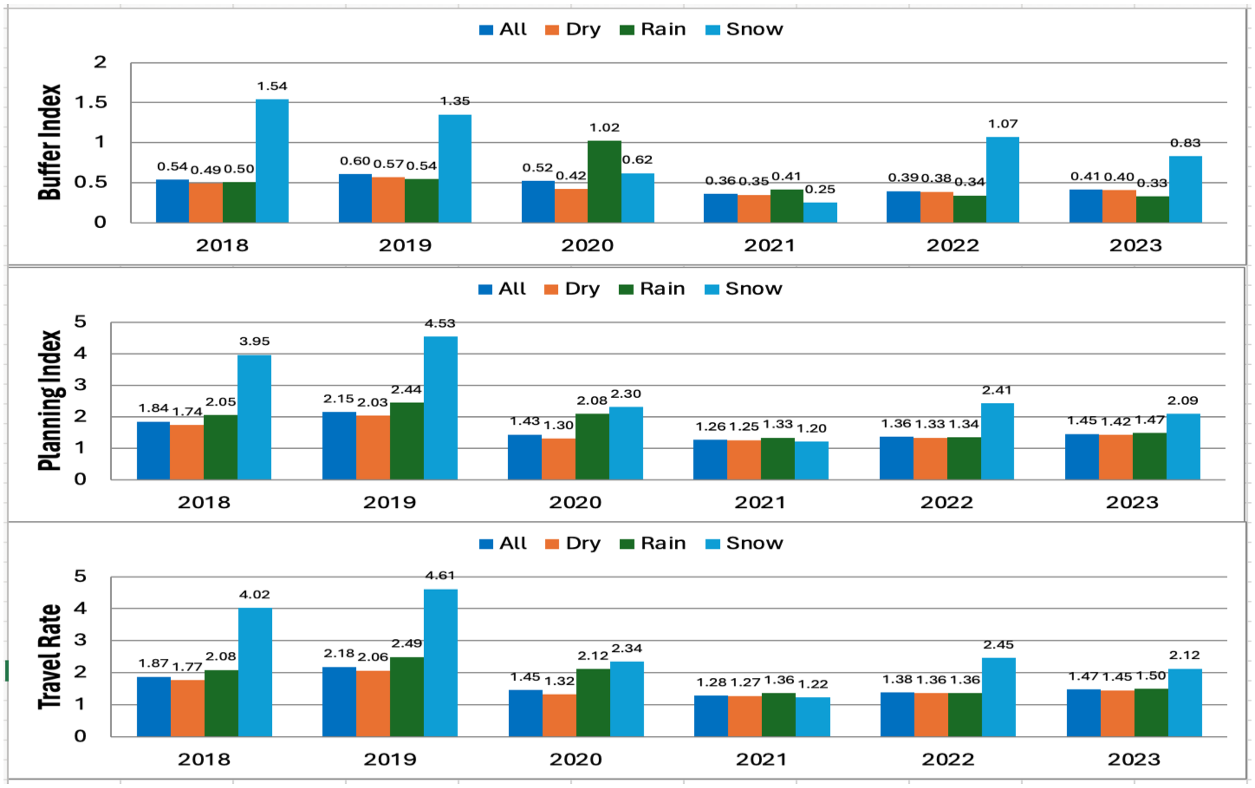
Effects of Incidents



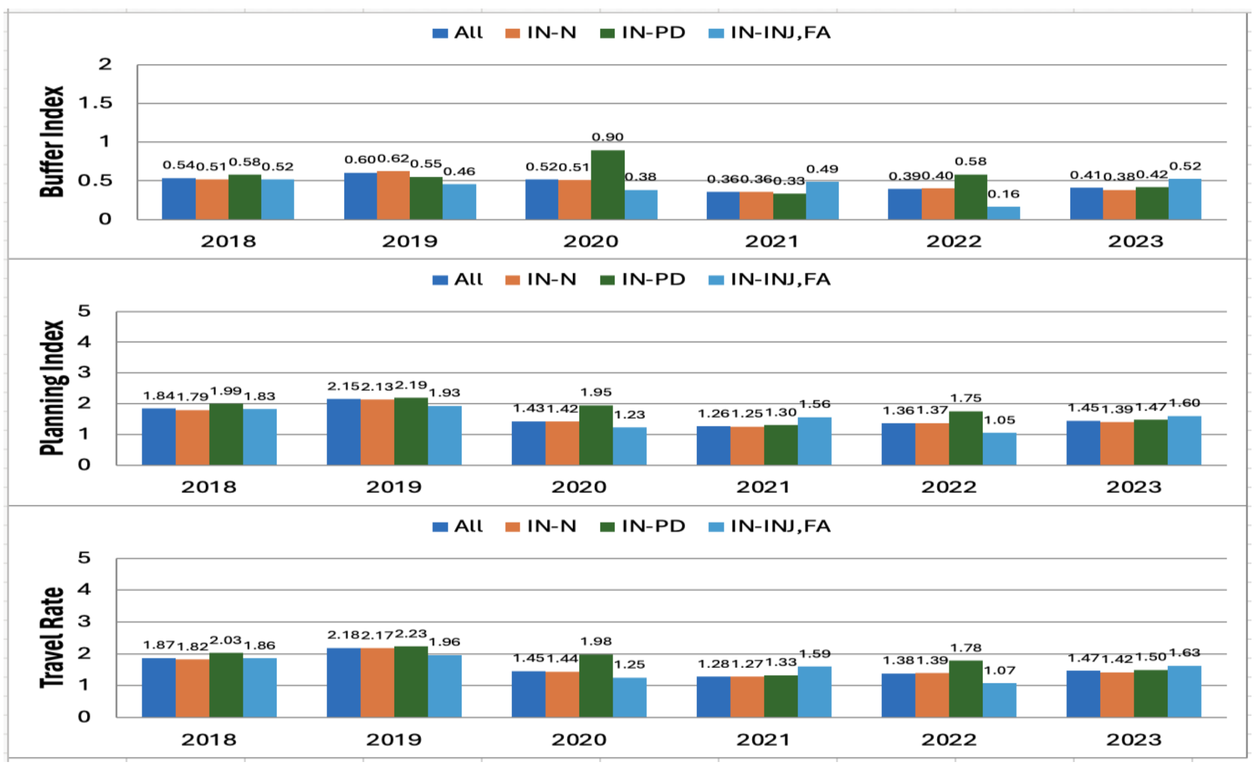
Effects of Work Zones



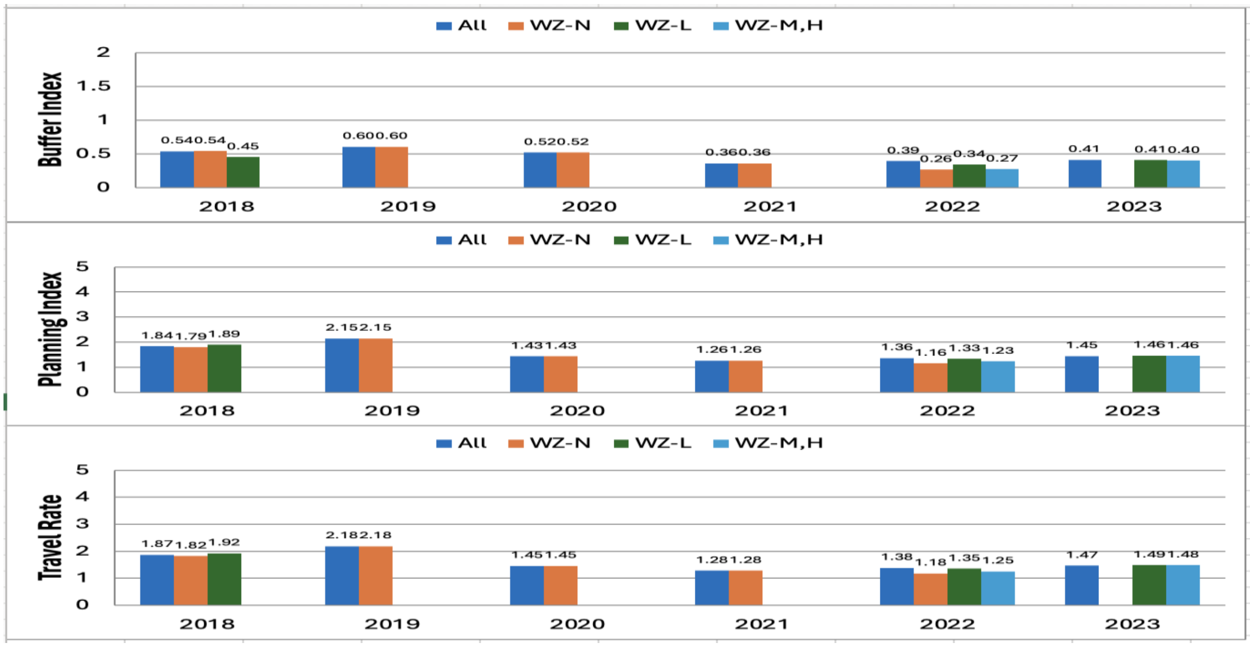
Yearly Variations of TTR - ***Weather Effects***



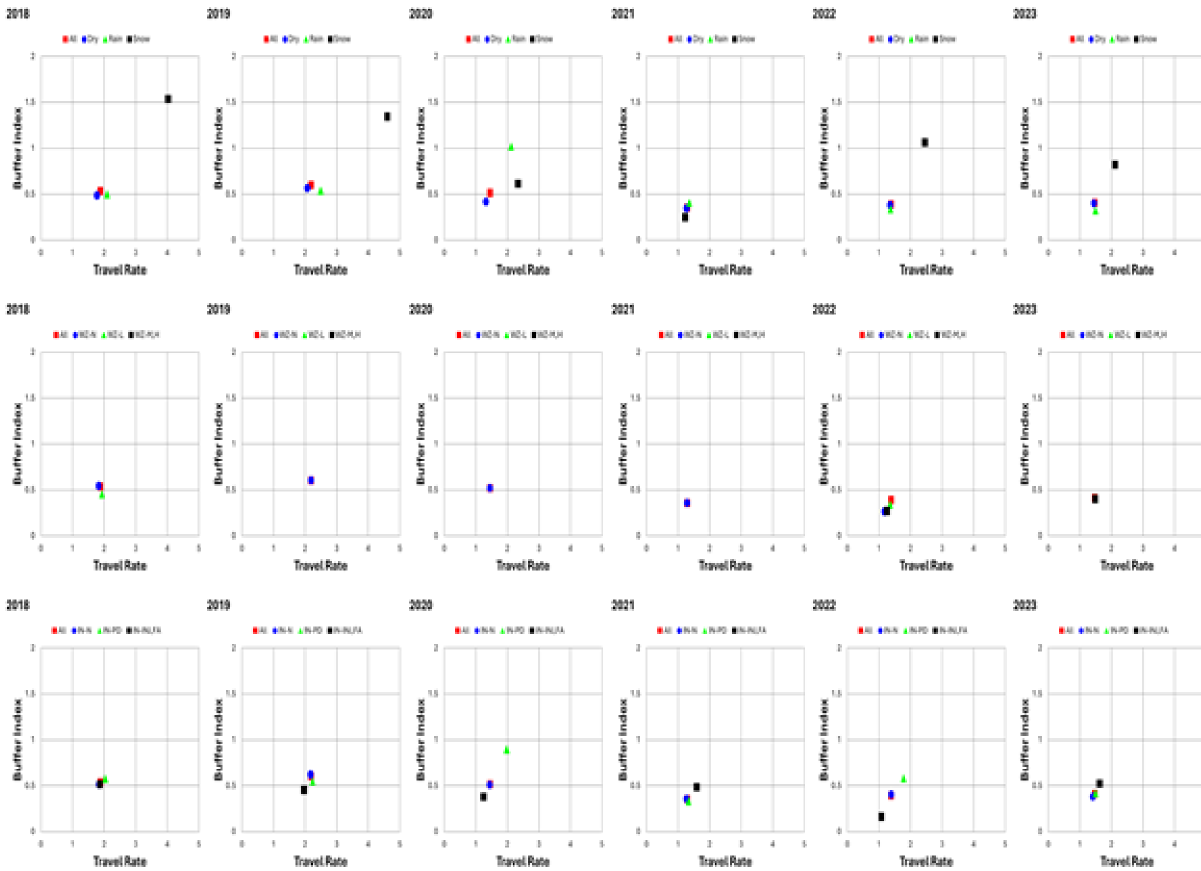
Incident Effects



Work-Zone Effects



Yearly Variations of Buffer Index - Travel Rate Relationships

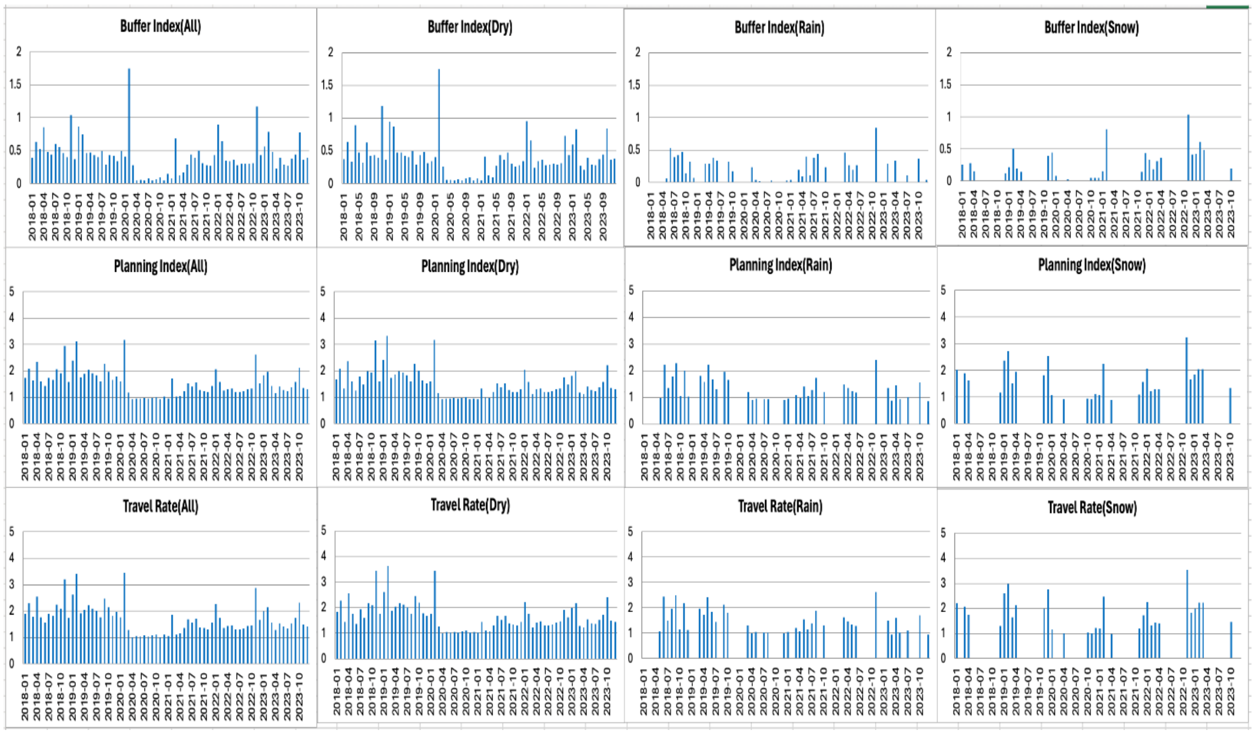


Variations of Traffic-Flow Measures

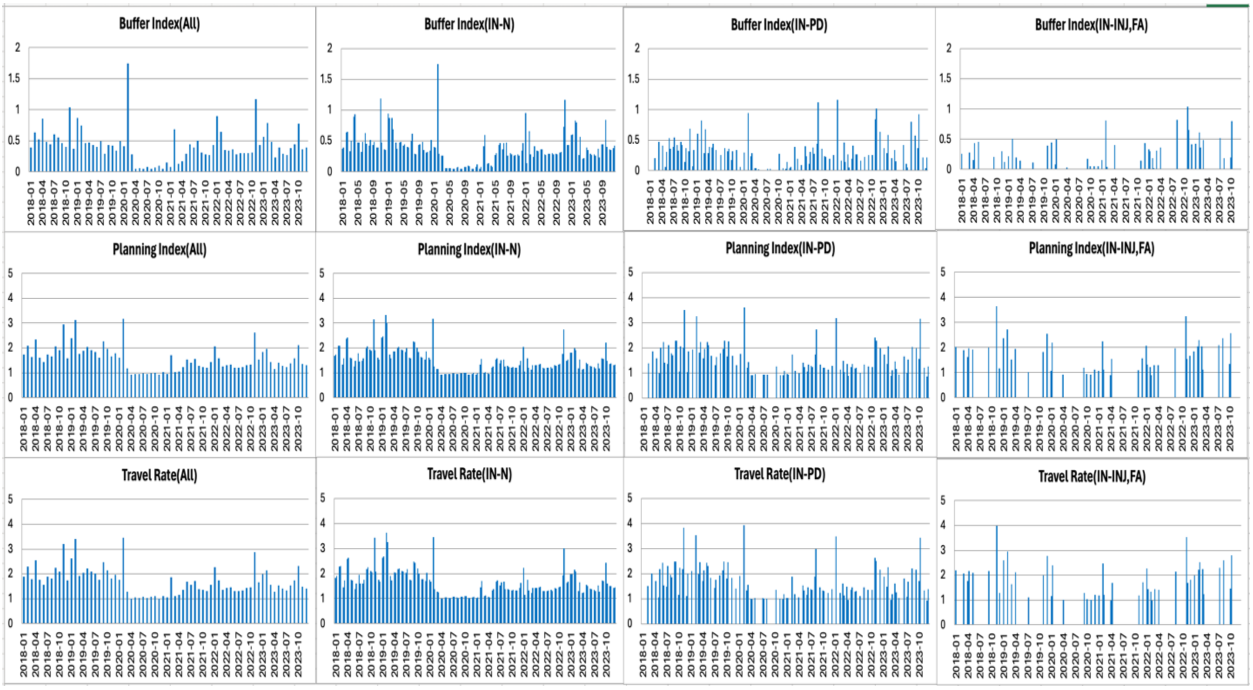

VMT(All)
VHT(All)
DVH(All)
VMT (All)
VHT (All)
DVH (All)
2018
2019
2020
2021
2022
2023

ii) US-169 Corridor A - SB Route I-394 to TH 101 for Moring-Peak Period

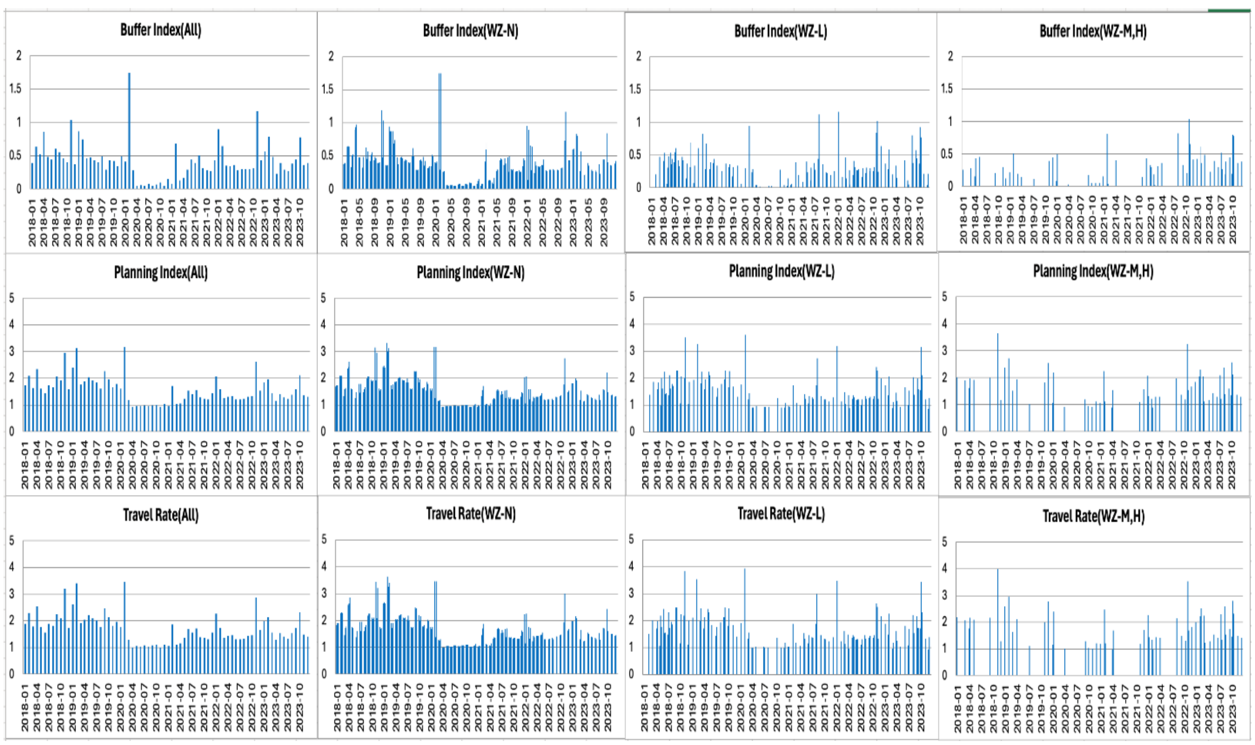
Effects of Weather conditions on Travel-Time Reliability



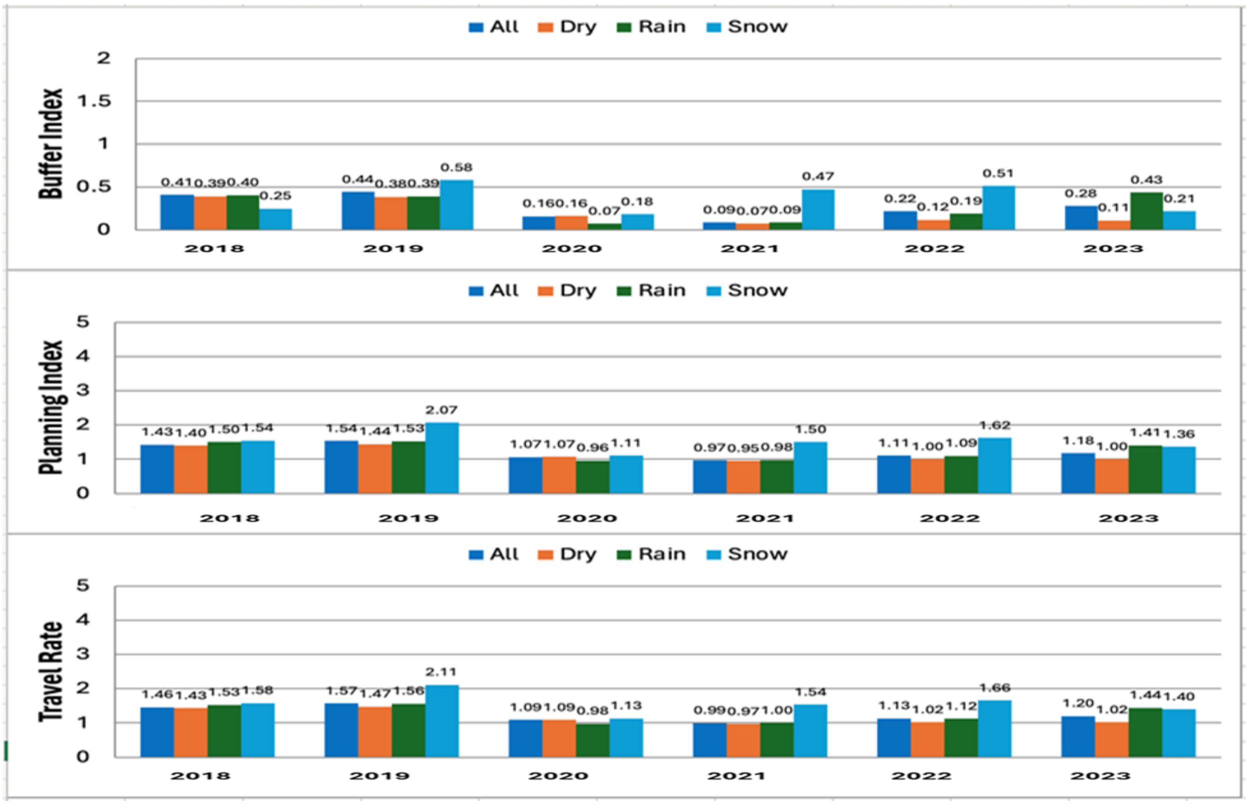
Effects of Incidents



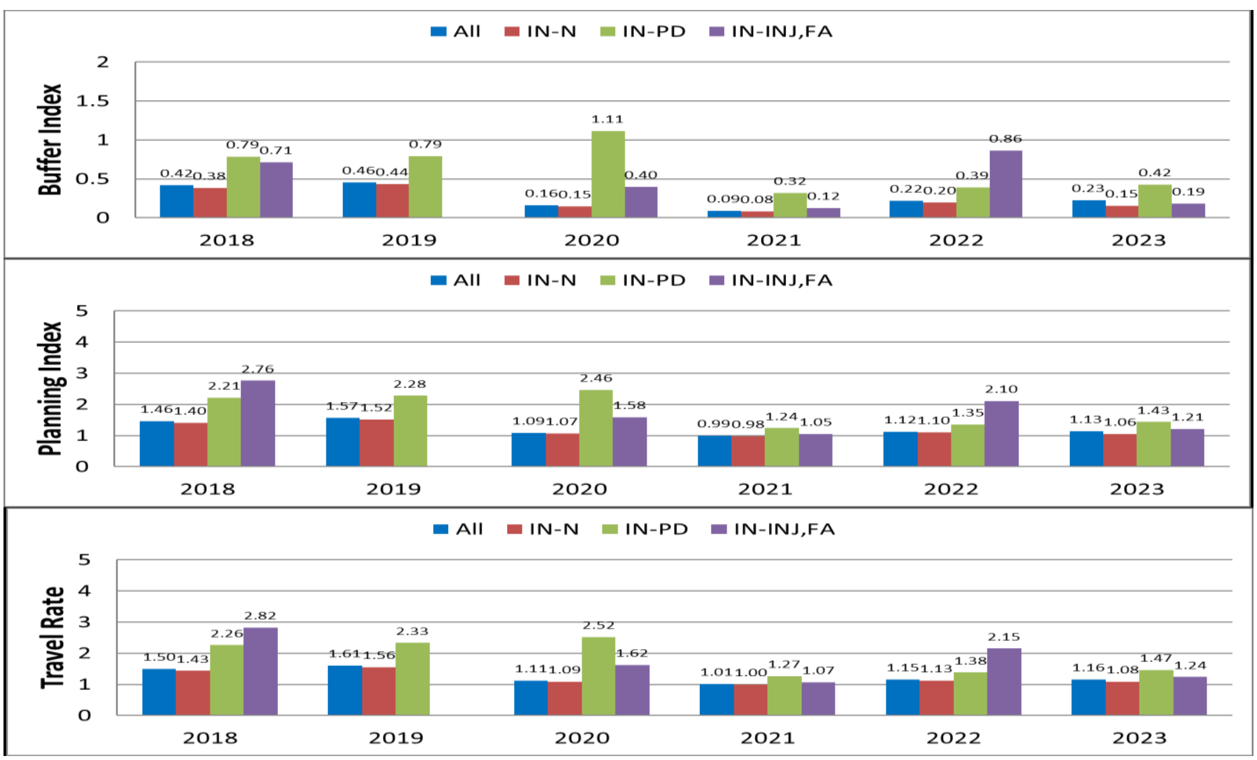
Effects of Work Zones



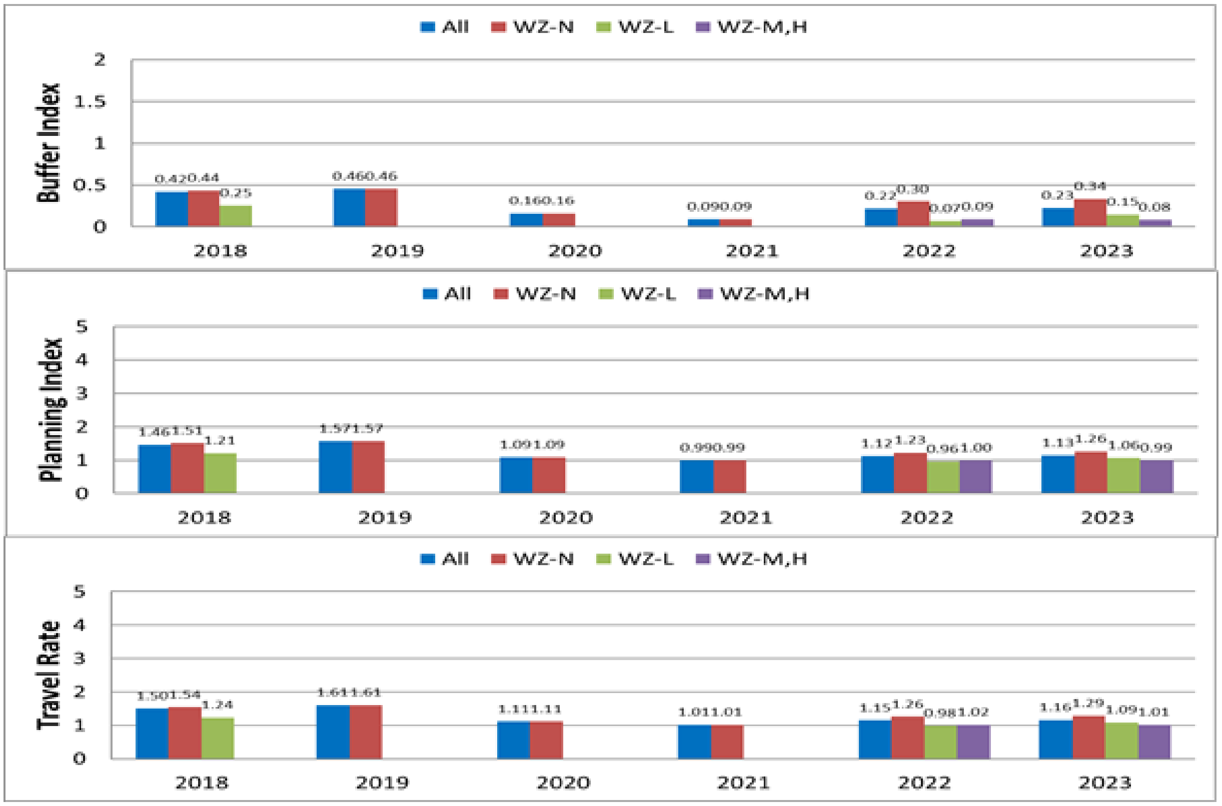
Yearly Variations - *Weather Effects*



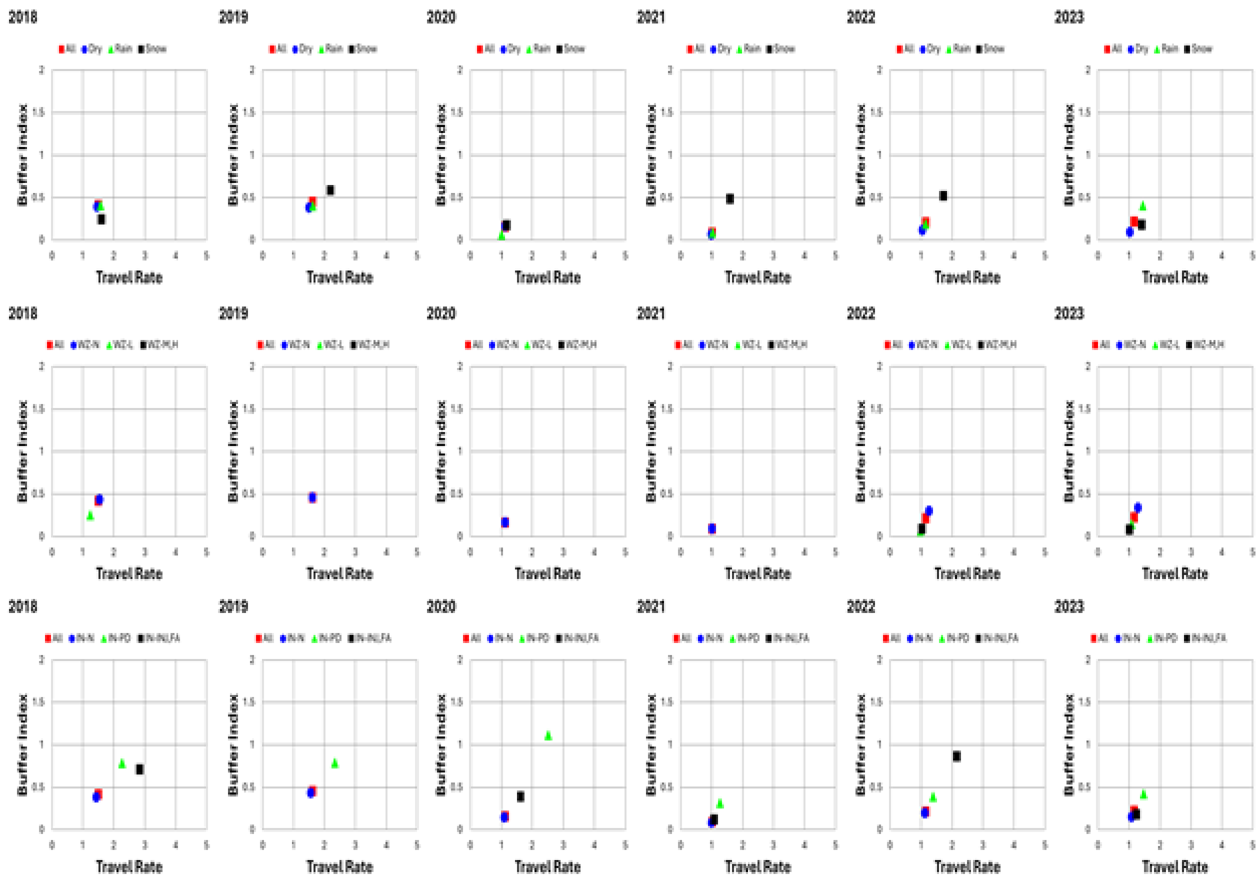
Incident Effects



Work-Zone Effects



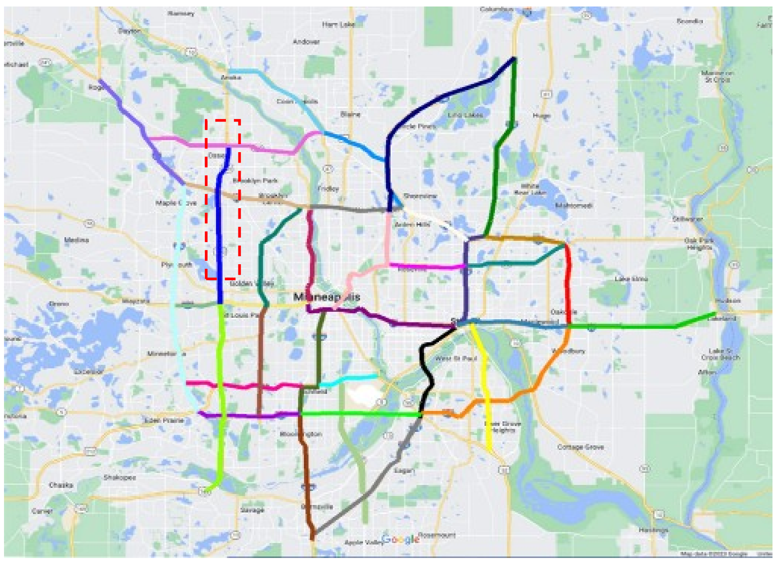
Yearly Variations of Buffer Index - Travel Rate Relationships



Variations of Traffic-Flow Measures

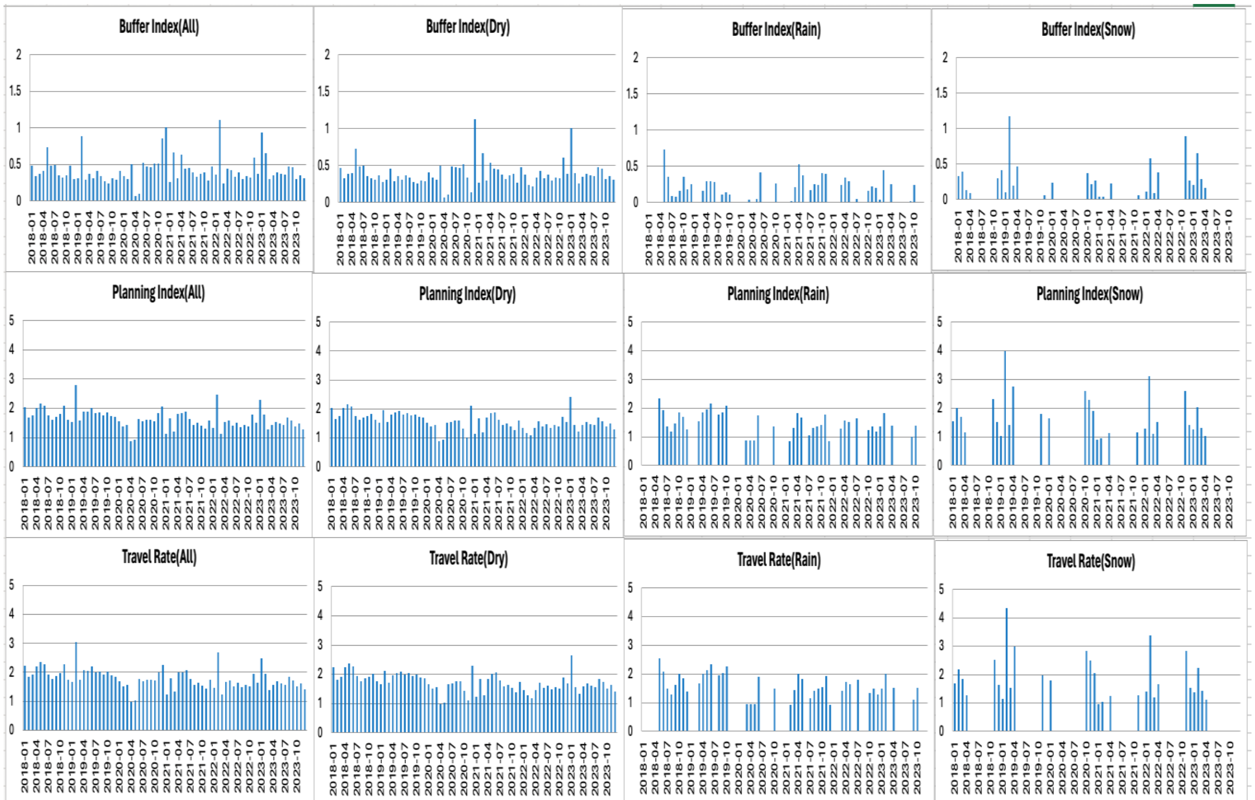
2) US-169 Corridor B (I394 < -- > TH610)

i) US-169 Corridor B – NB I394 to TH610 for Afternoon Peak Periods

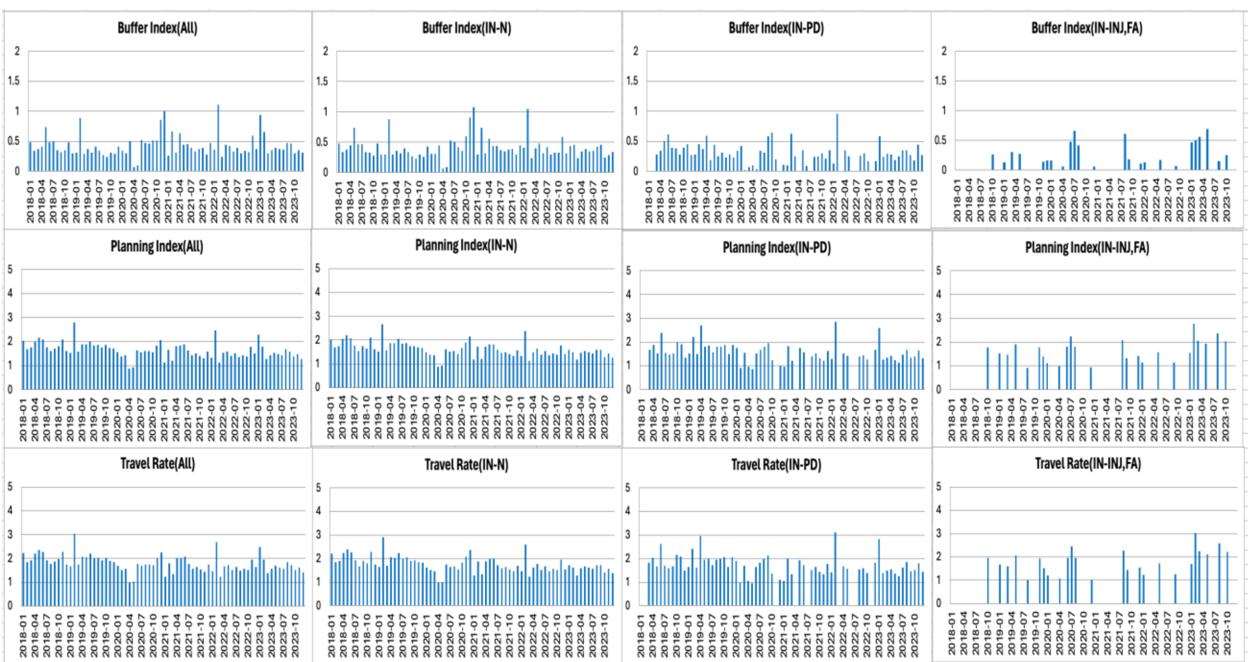


Location of 169 NB Route

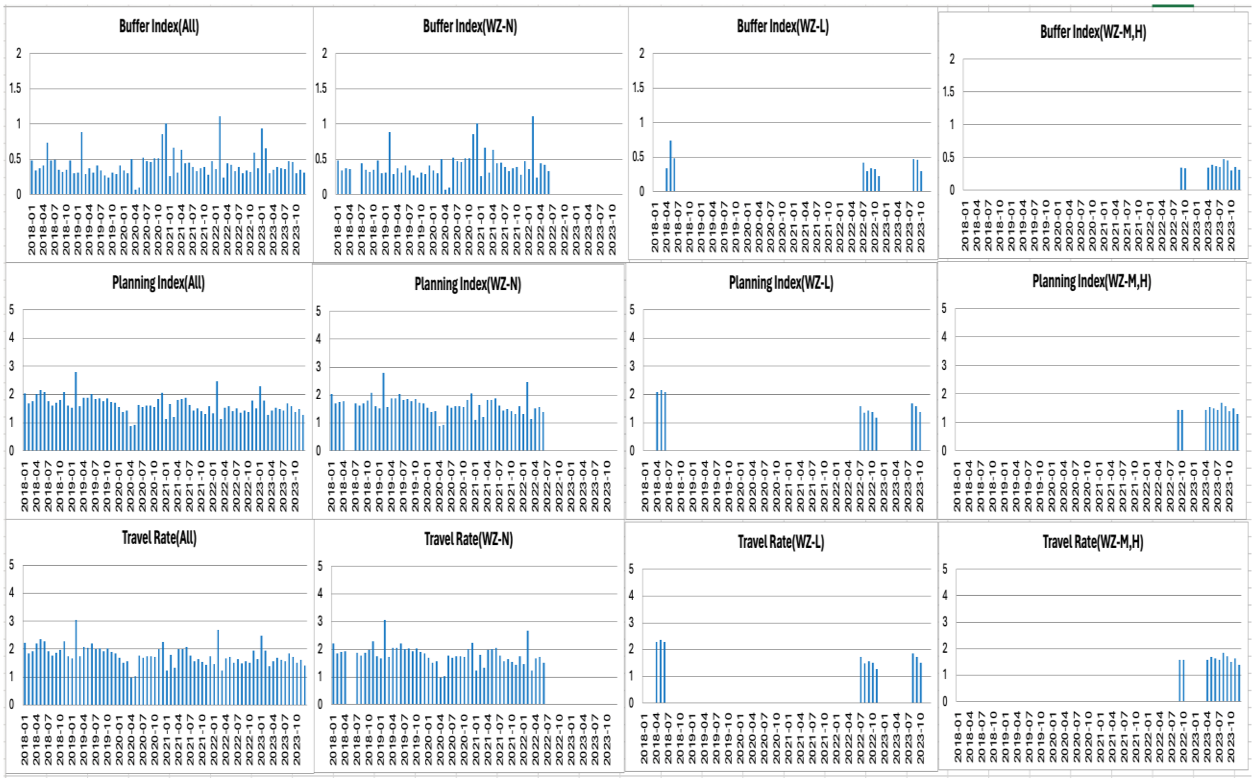
Effects of Weather conditions on Travel-Time Reliability



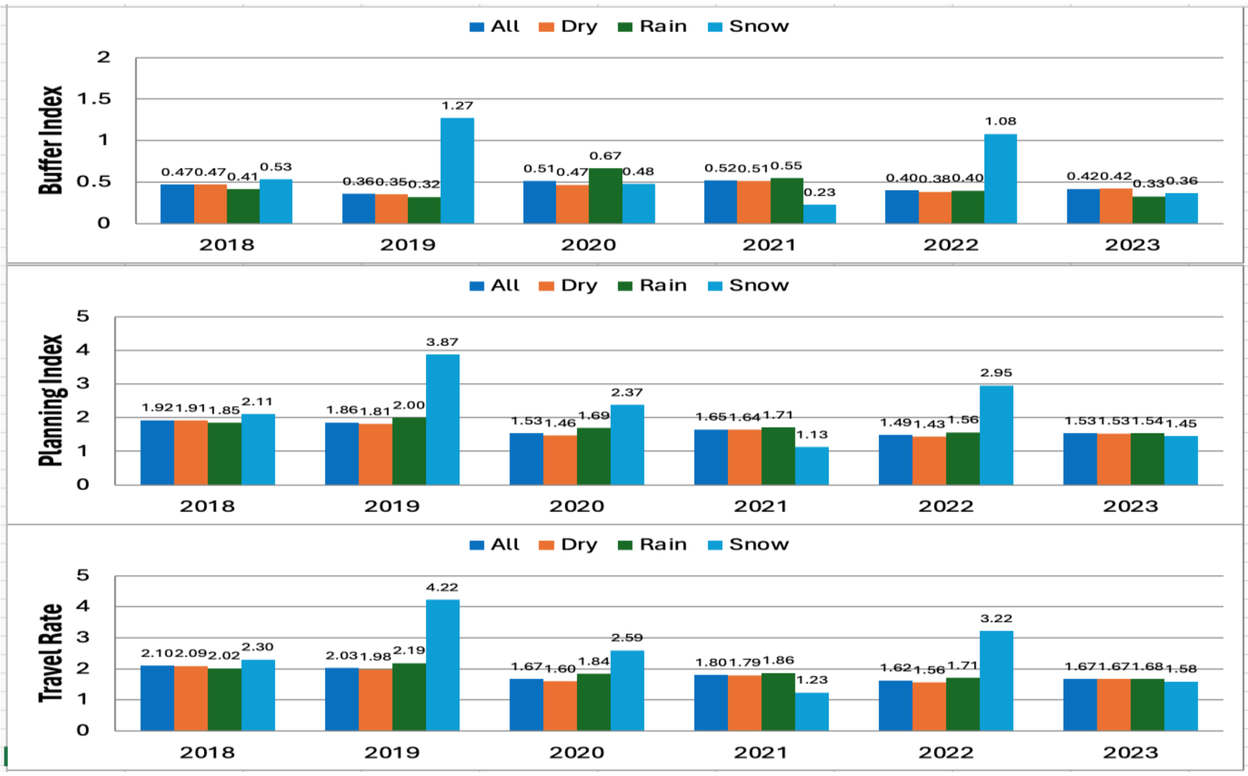
Effects of Incidents



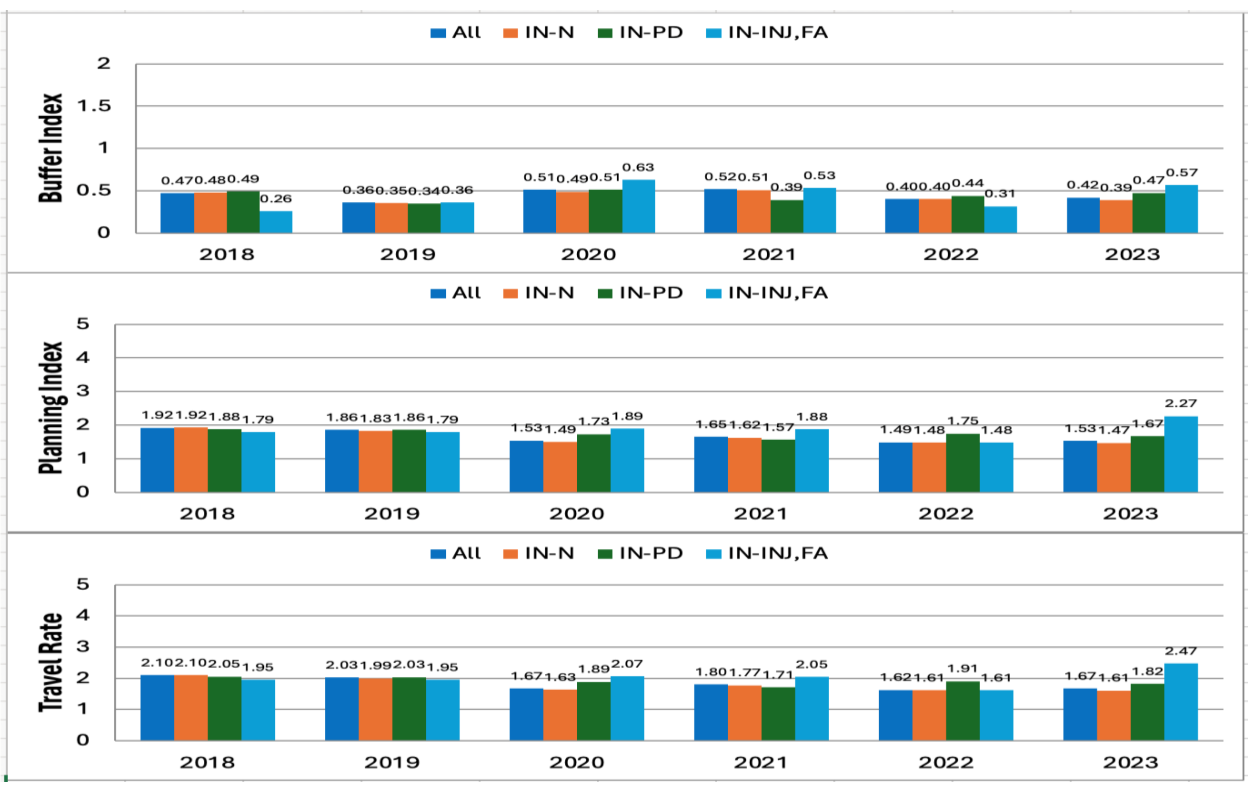
Effects of Work Zones



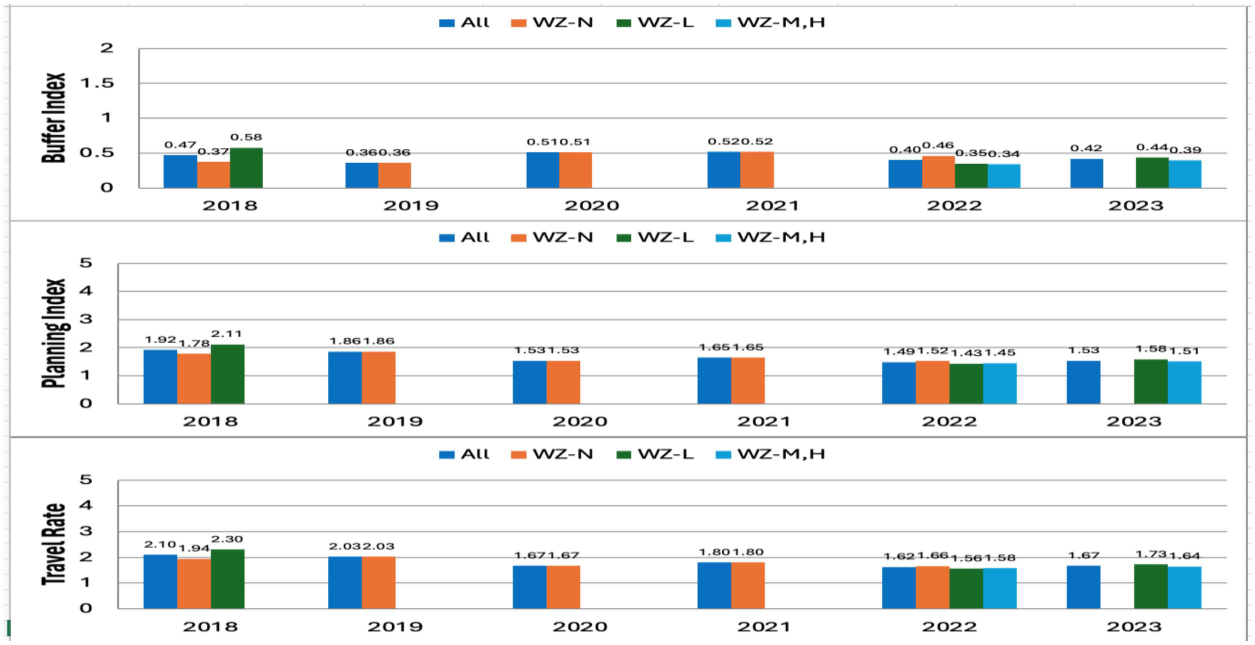
Yearly Variations of TTR - *Weather Effects*



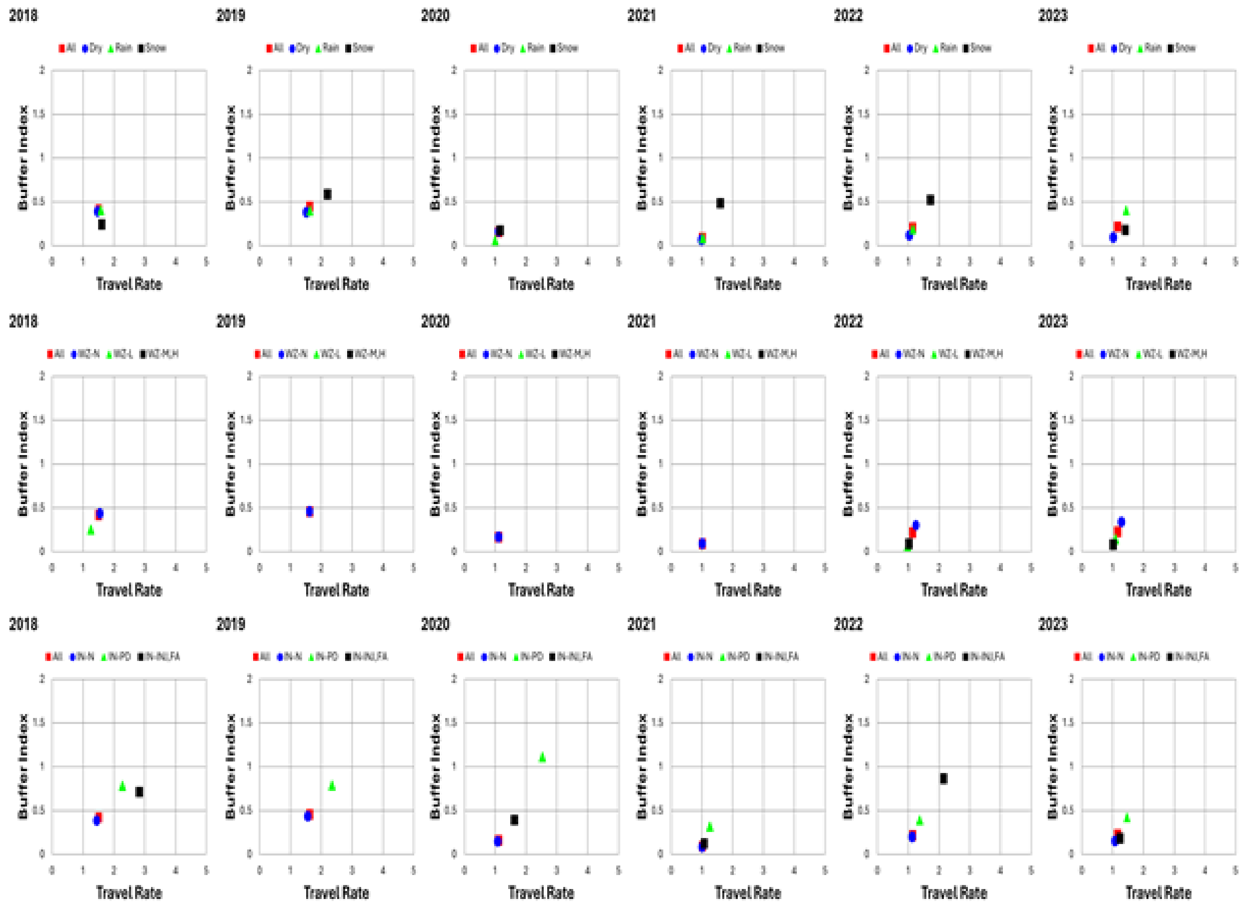
Incident Effects



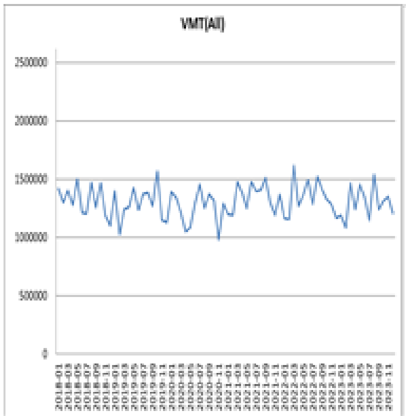
Work-Zone Effects

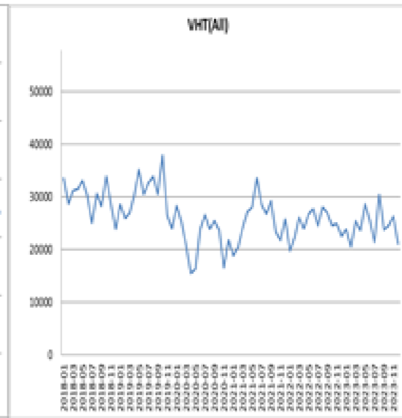


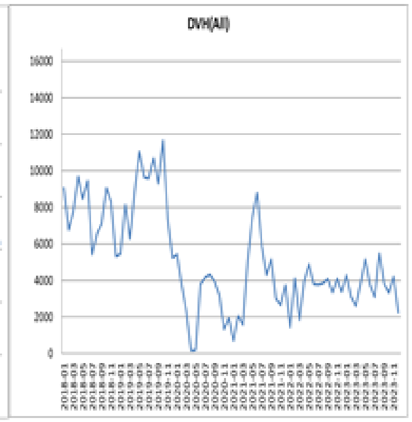
Yearly Variations of Buffer Index - Travel Rate Relationships

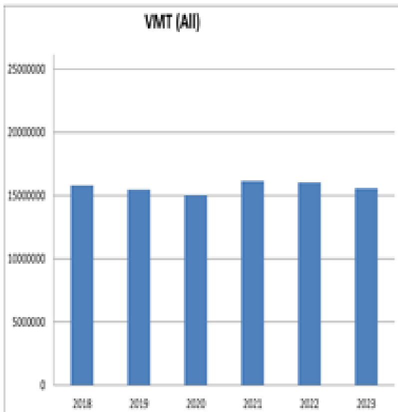


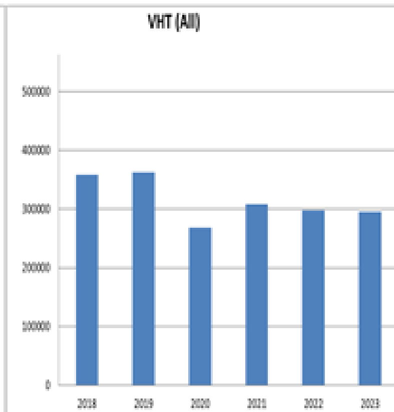
Variations of Traffic-Flow Measures

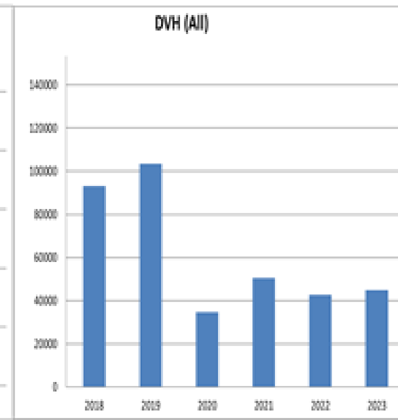

VMT(All)
2500000
2000000
1500000
1000000
500000
0


VHT(All)
50000
40000
30000
20000
10000
0


DVH(All)
16000
14000
12000
10000
8000
6000
4000
2000
0

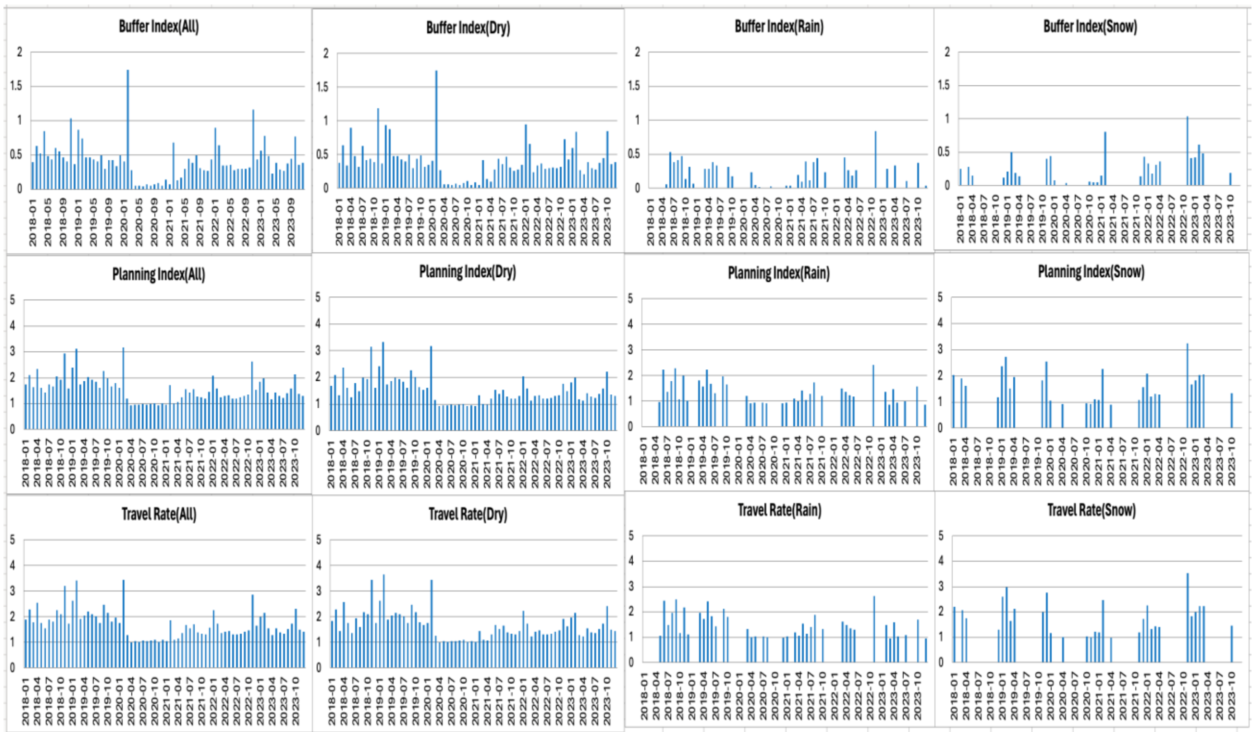

VMT (All)
25000000
20000000
15000000
10000000
5000000
0
2018
2019
2020
2021
2022
2023


VHT (All)
500000
400000
300000
200000
100000
0
2018
2019
2020
2021
2022
2023

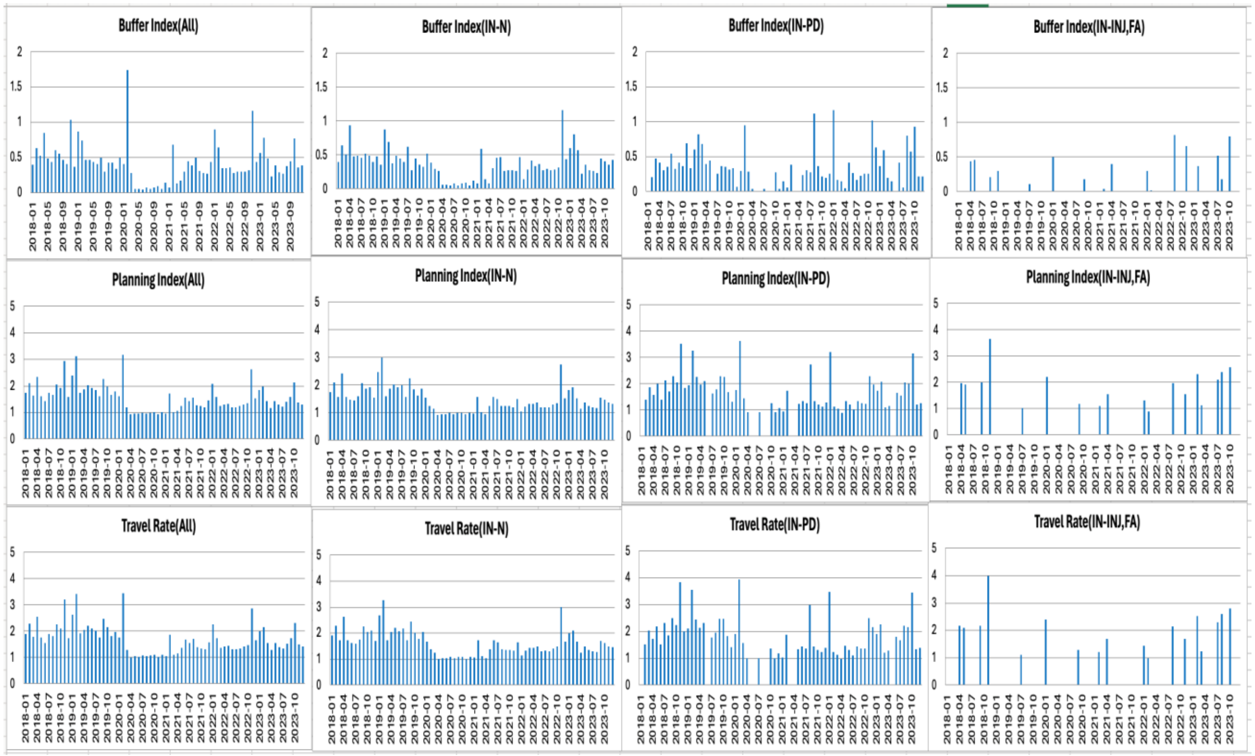

DVH (All)
140000
120000
100000
80000
60000
40000
20000
0
2018
2019
2020
2021
2022
2023

ii) US-169 Corridor B – SB TH610 to I394 for Morning Peak Periods

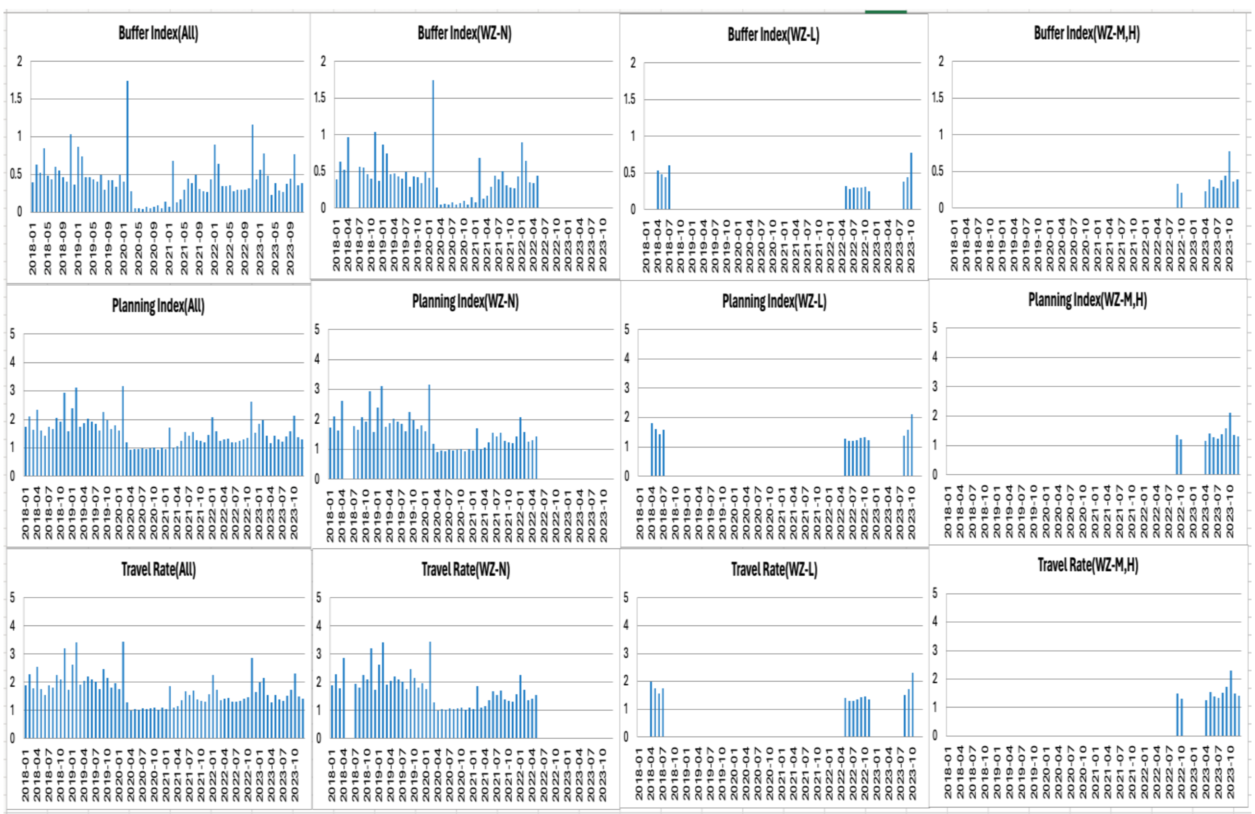
Effects of Weather conditions on Travel-Time Reliability



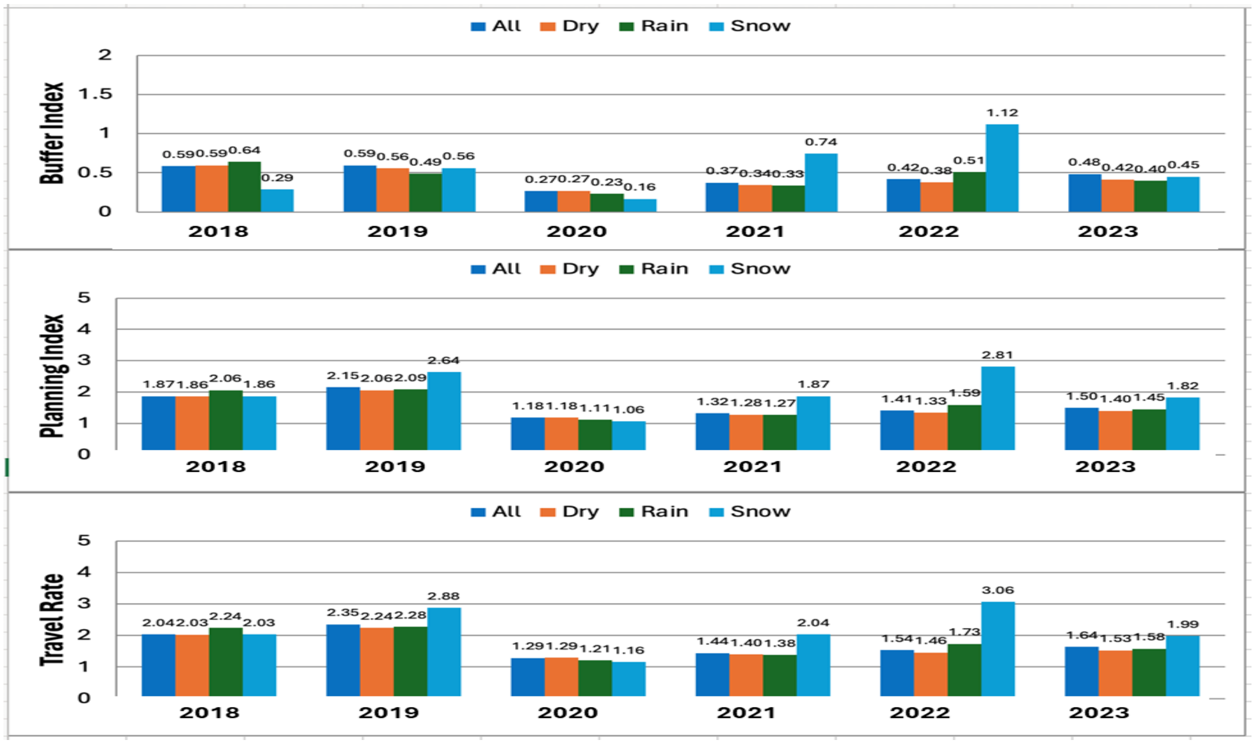
Effects of Incidents



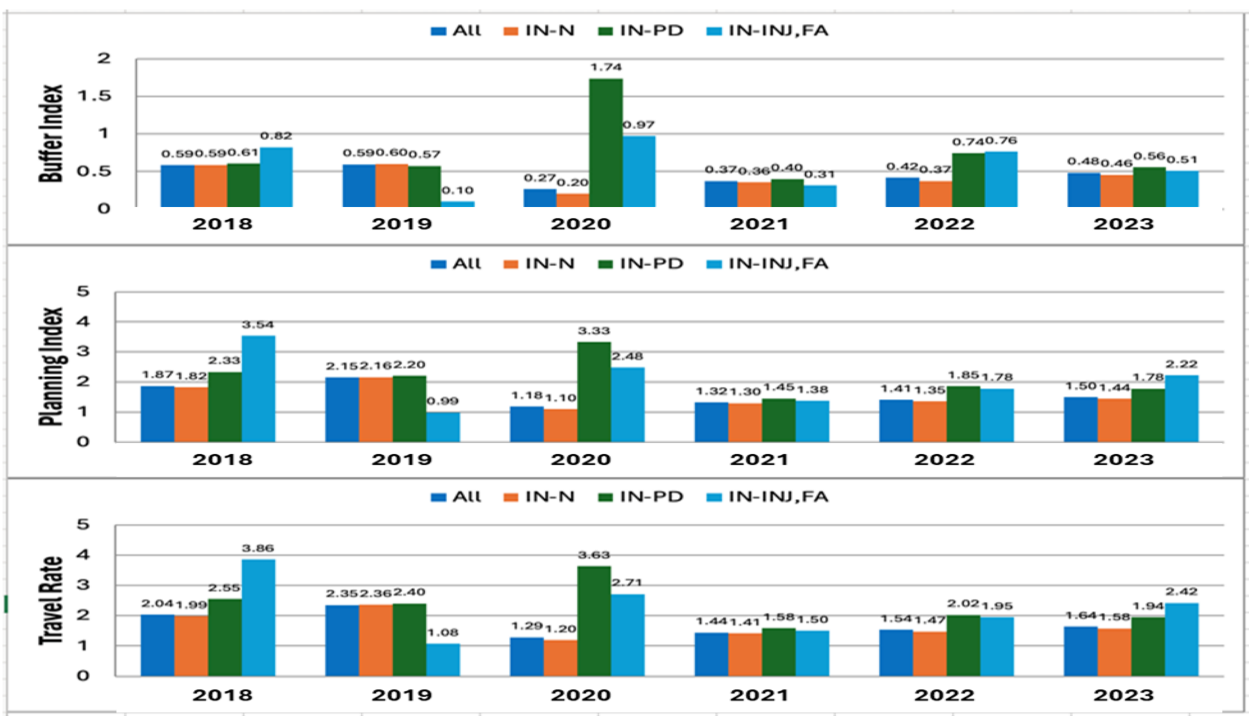
Effects of Work Zones



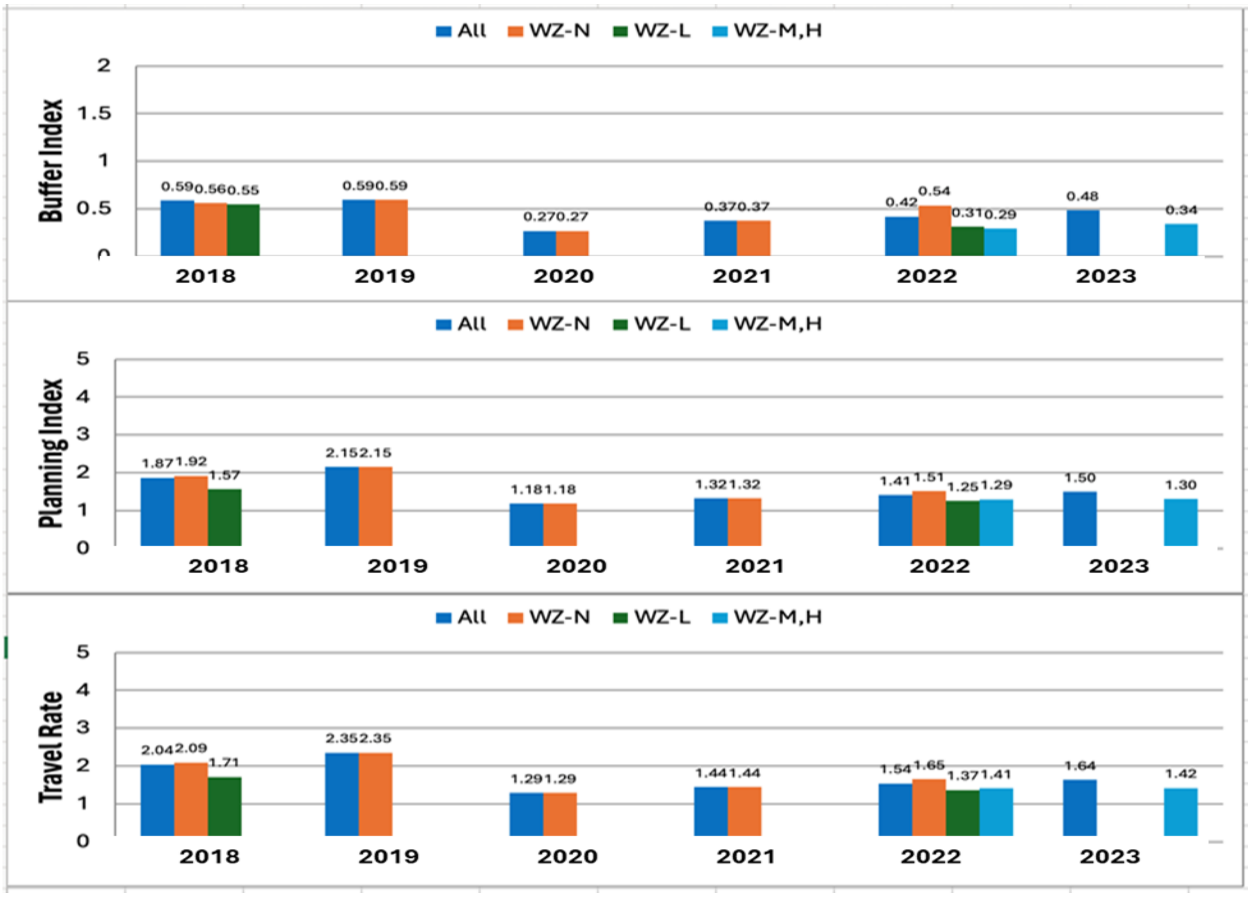
Yearly Variations - *Weather Effects*



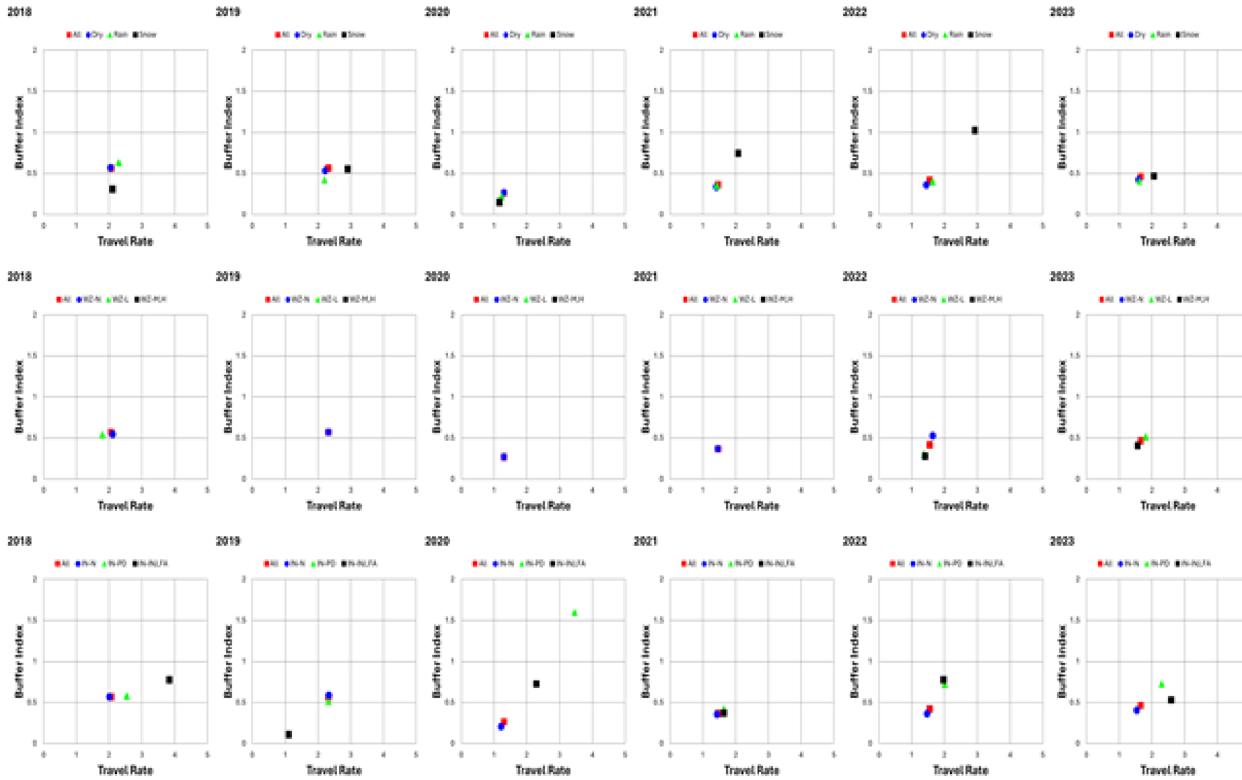
Incident Effects



Work-Zone Effects

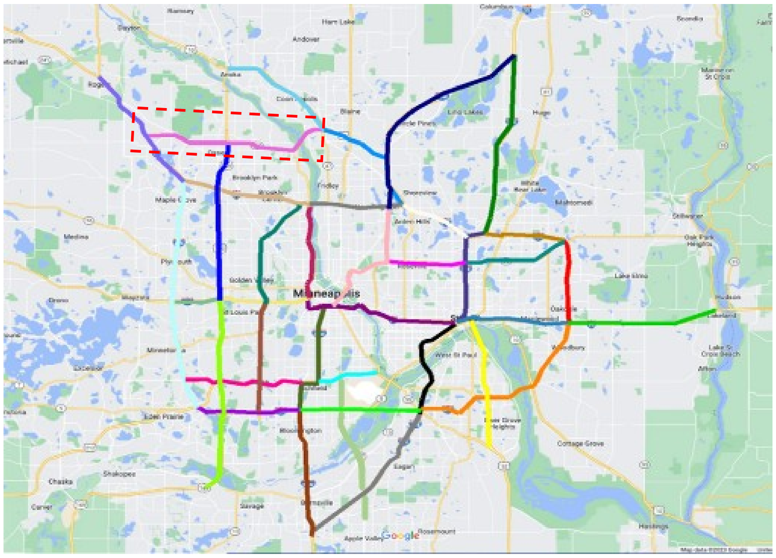


Yearly Variations of Buffer Index - Travel Rate Relationships



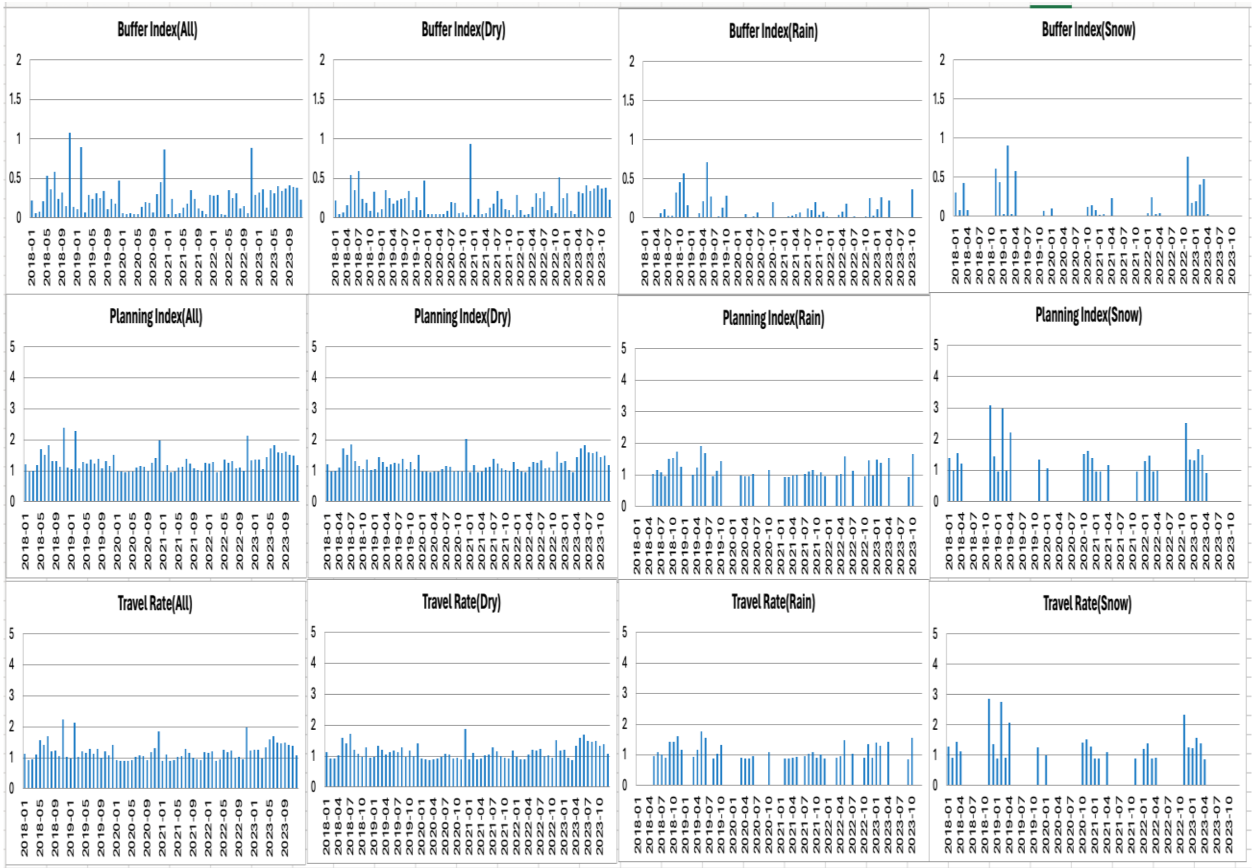
Variations of Traffic-Flow Measures

3) TH-610 Corridor (I94 < -- > TH10)

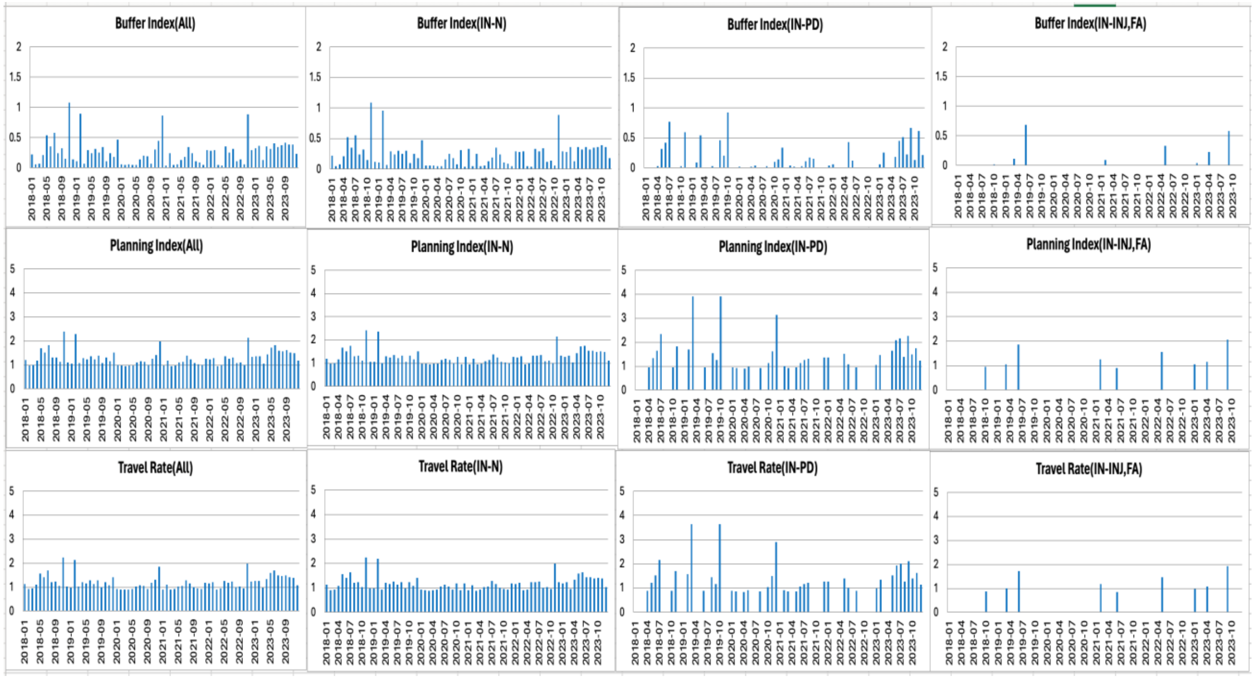


i) TH-610 WB Corridor WB TH10 – I94 for Afternoon Peak Period

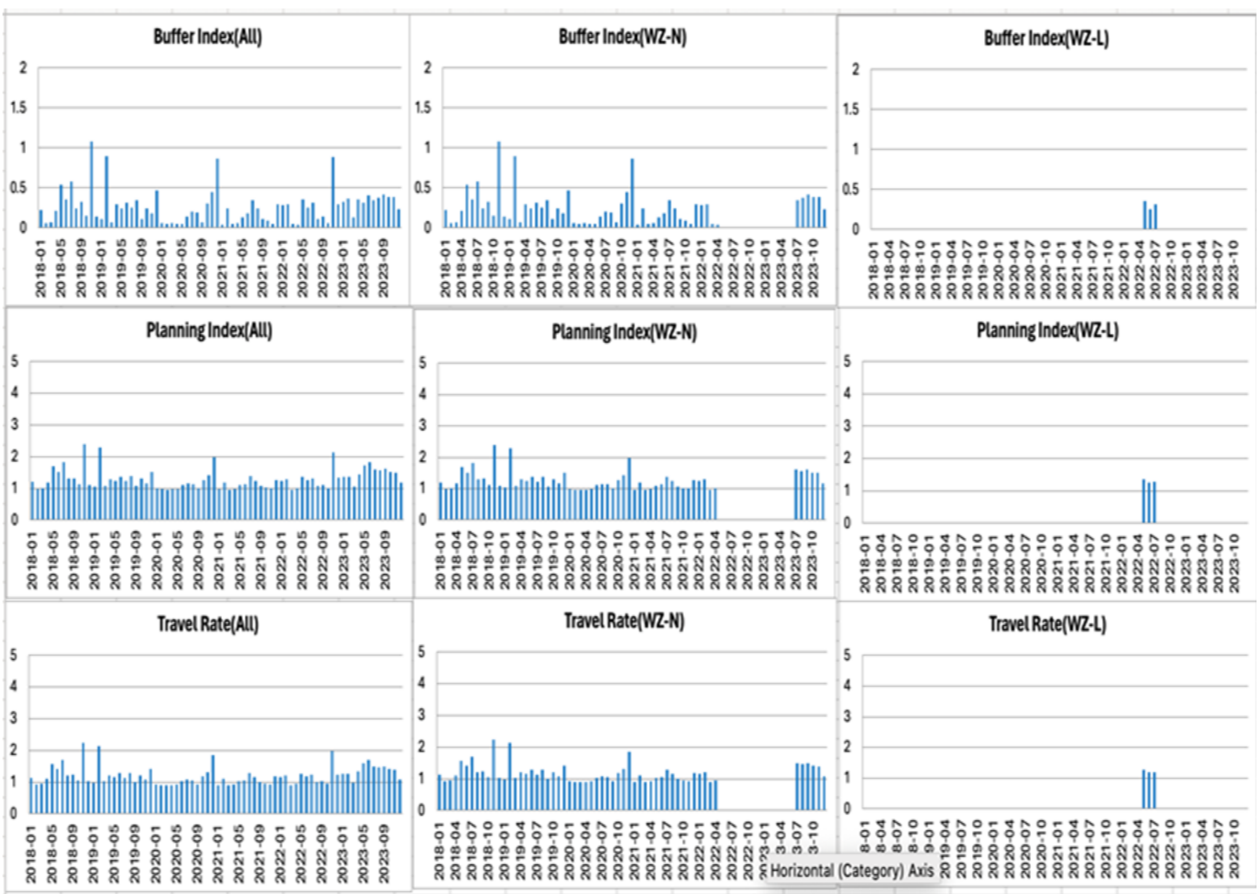
Effects of Weather conditions on Travel-Time Reliability



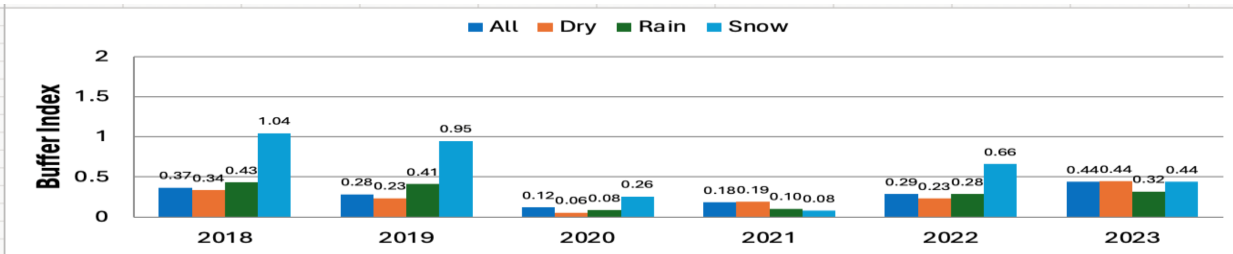
Effects of Incidents

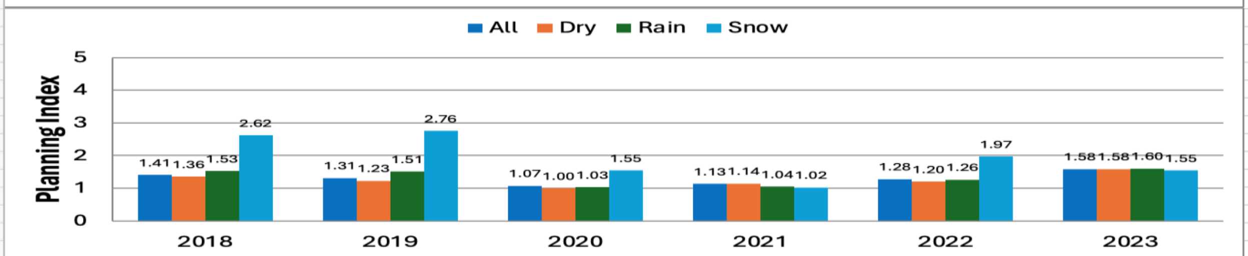


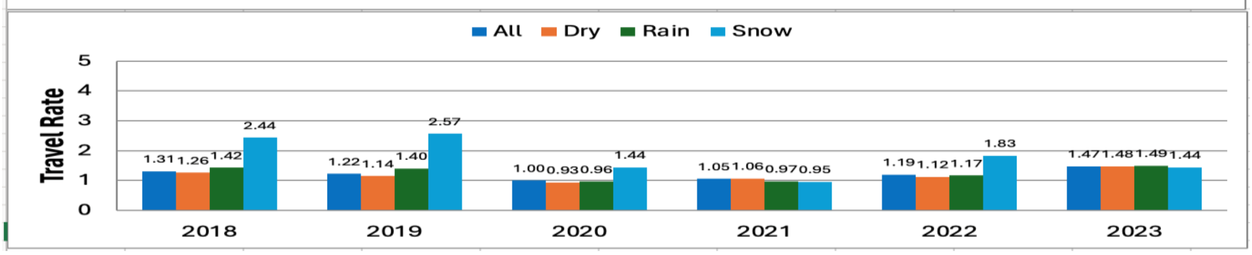
Effects of Work Zones



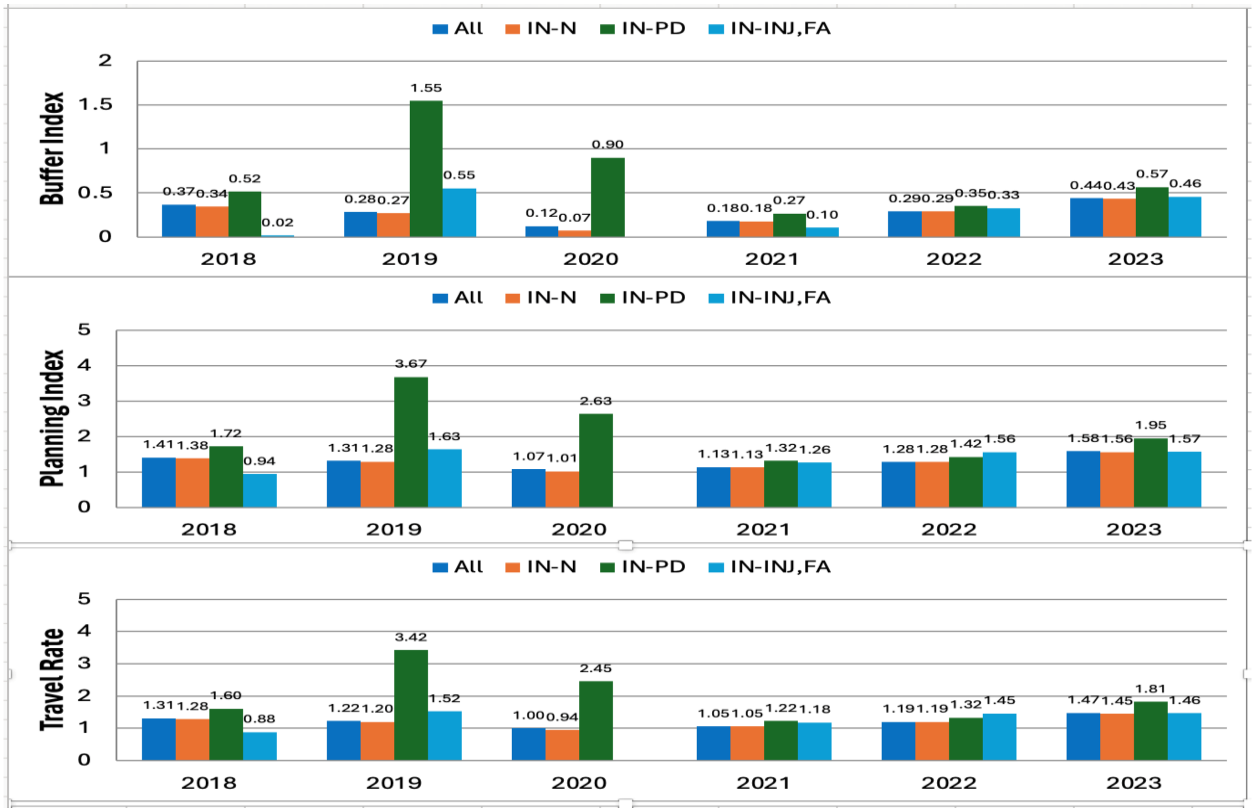
Yearly Variations - *Weather Effects*



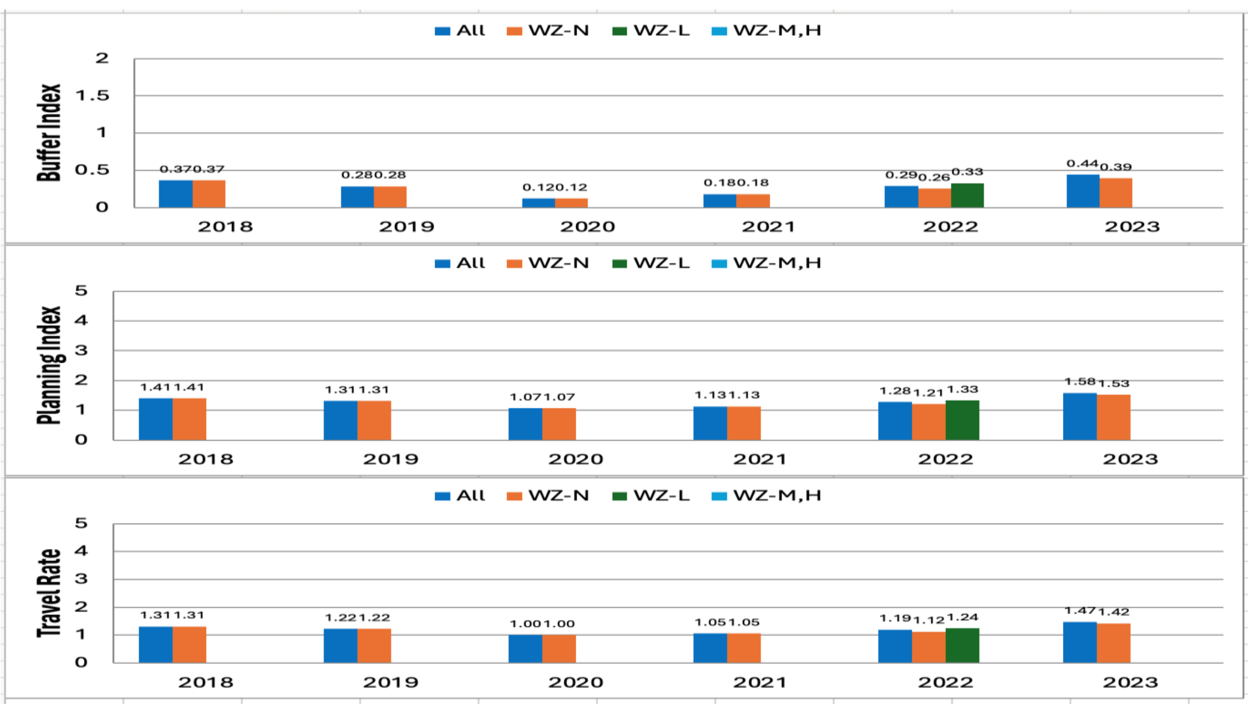




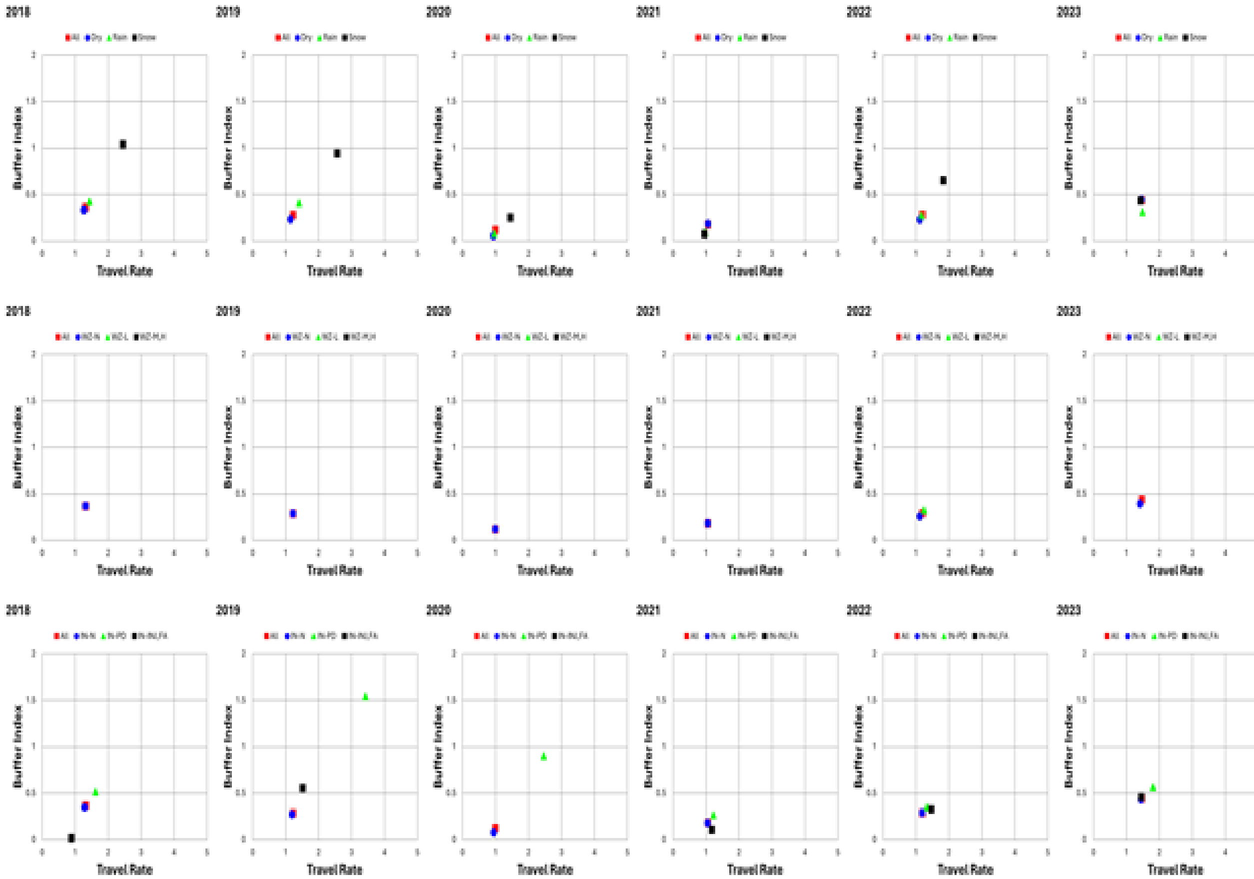
Incident Effects



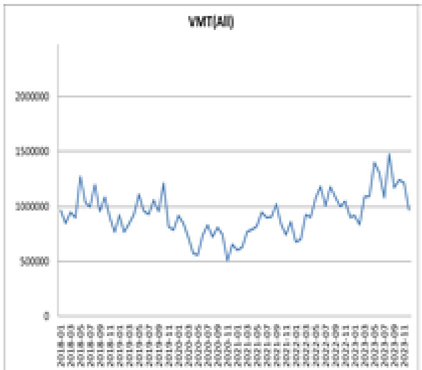
Work-Zone Effects

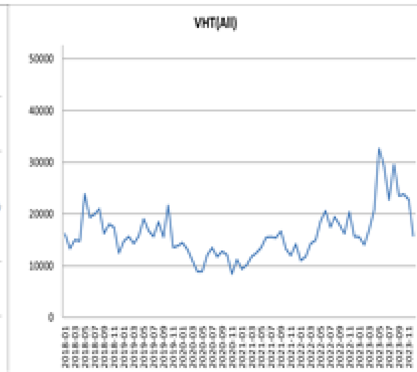


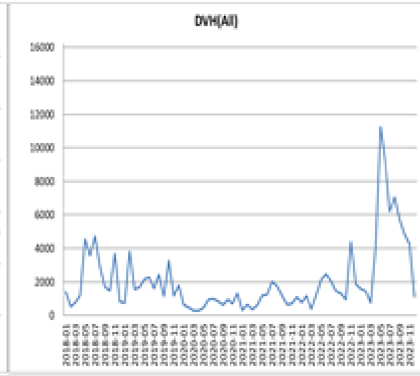
Yearly Variations of Buffer Index - Travel Rate Relationships

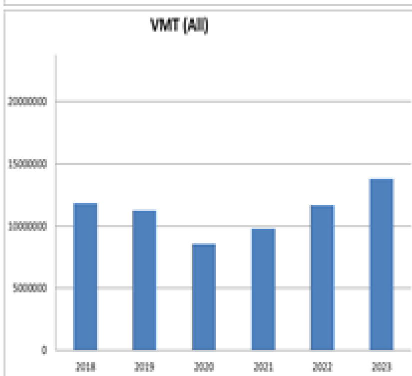


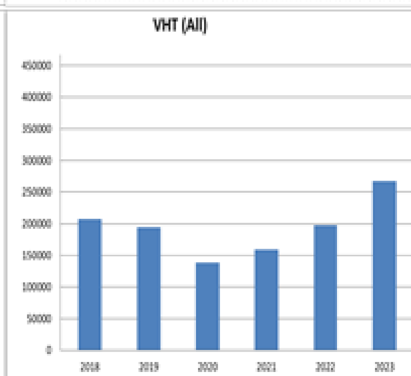
Variations of Traffic-Flow Measures

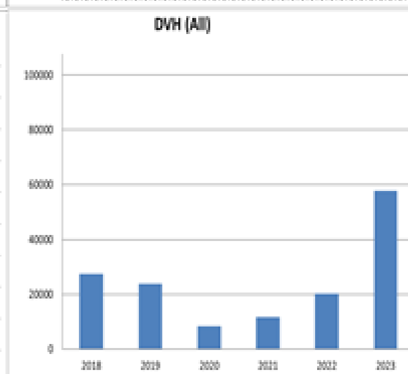

VMT(All)


VHT(All)


DVH(All)

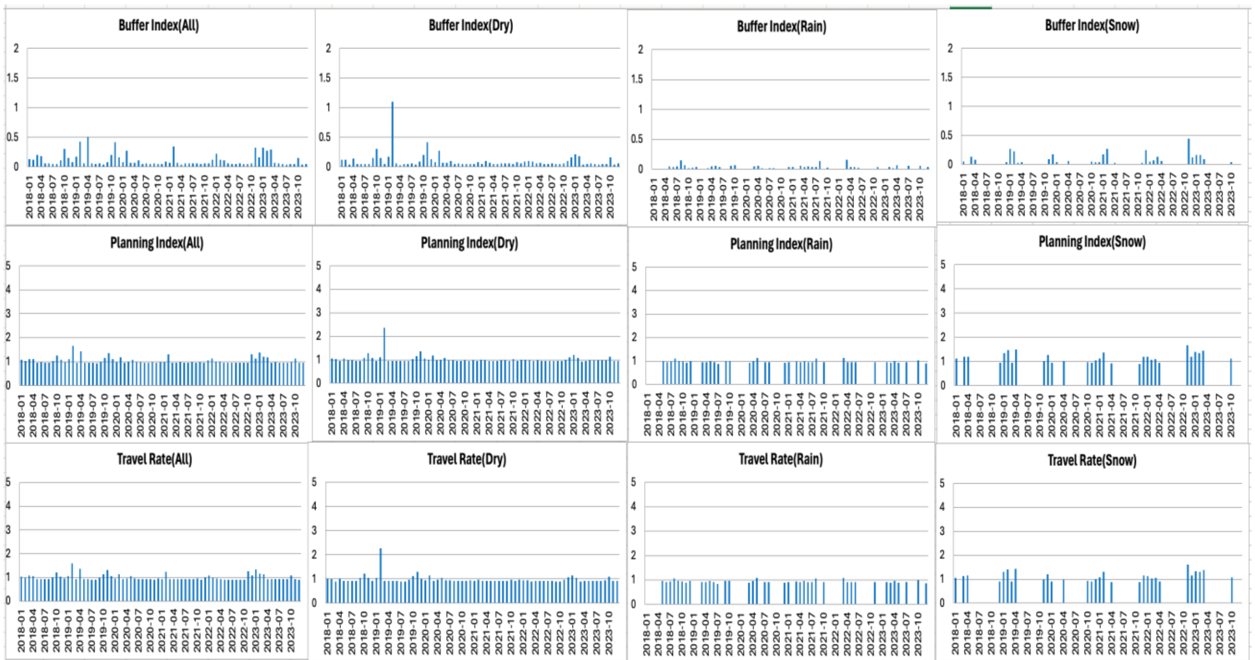

VMT (All)
2018
2019
2020
2021
2022
2023


VHT (All)
2018
2019
2020
2021
2022
2023

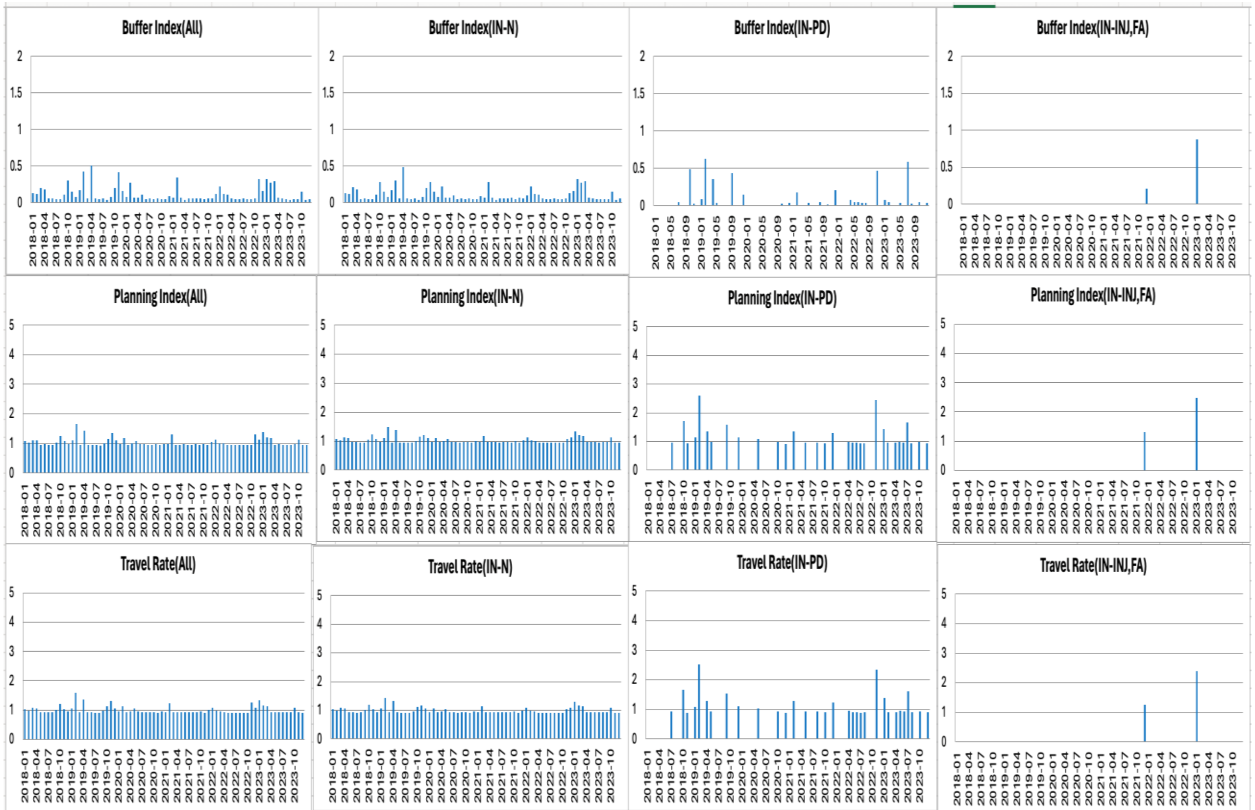

DVH (All)
2018
2019
2020
2021
2022
2023

ii) TH-610 EB Corridor – EB I94 to TH10 for Morning Peak Periods

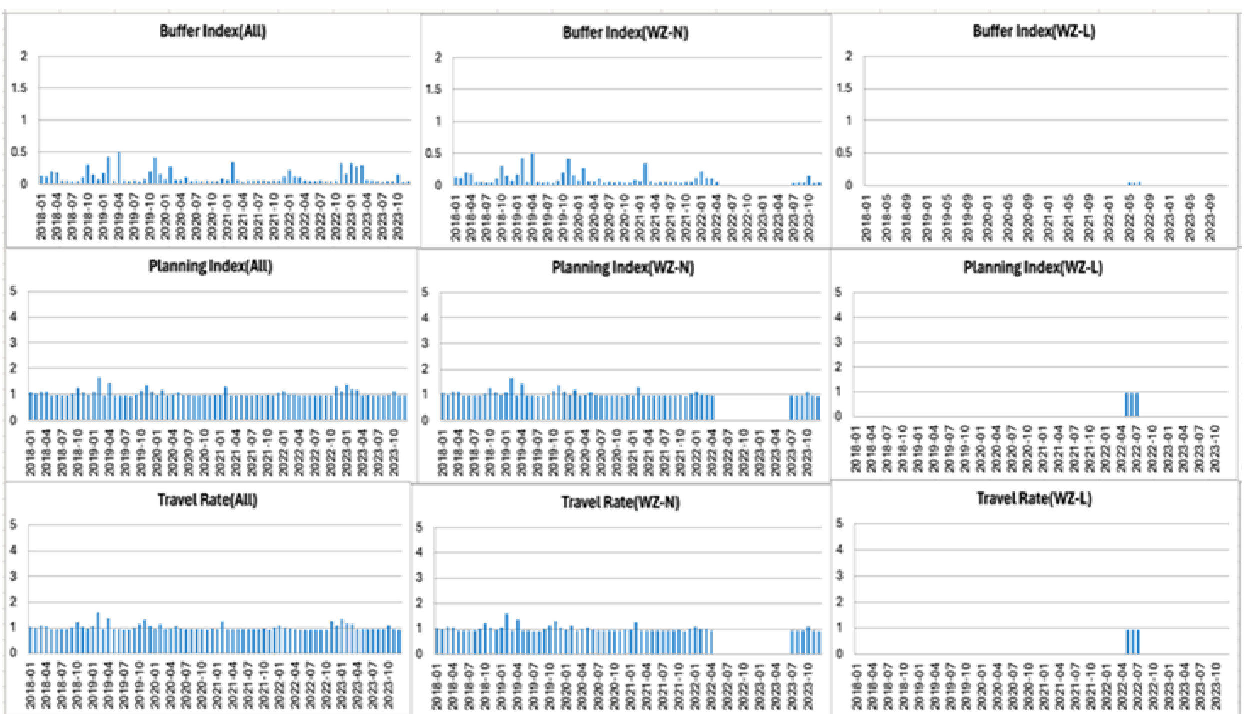
Effects of Weather conditions on Travel-Time Reliability



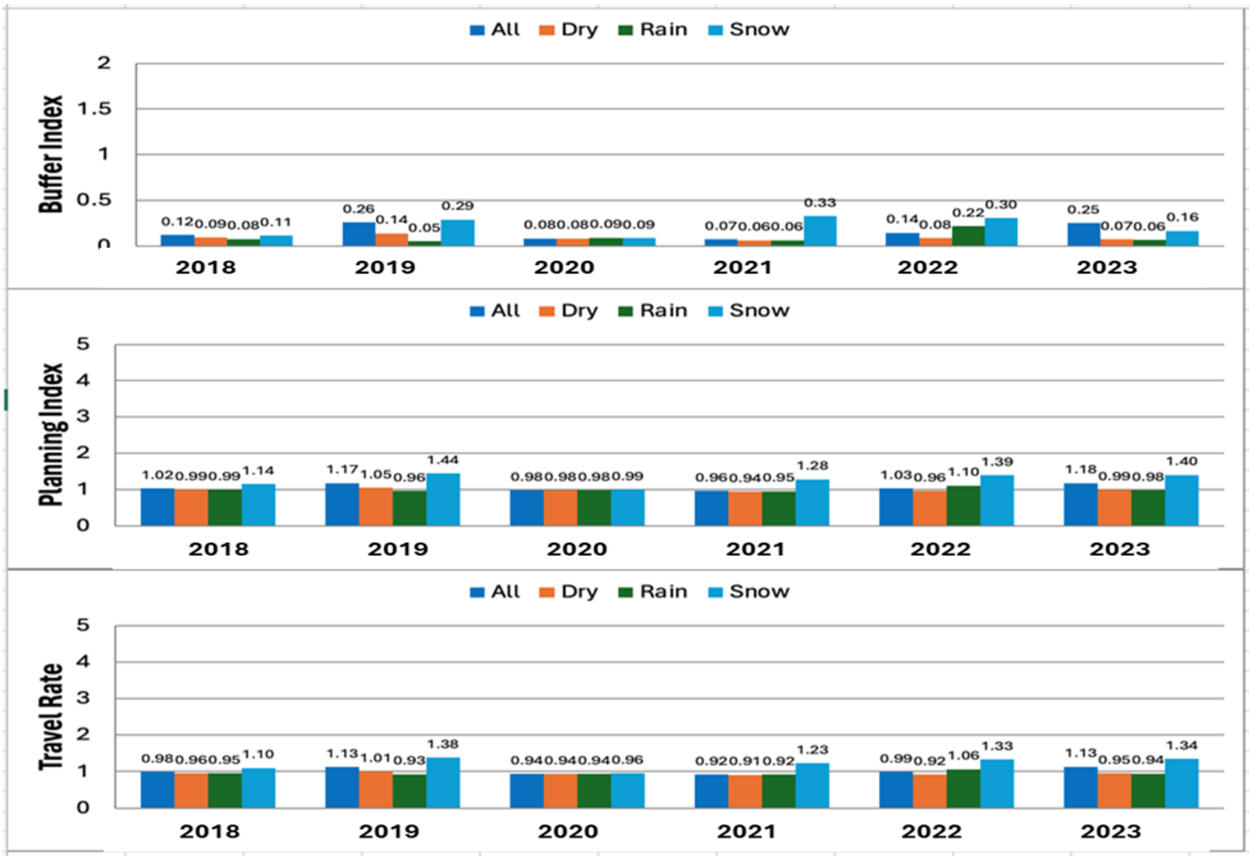
Effects of Incidents



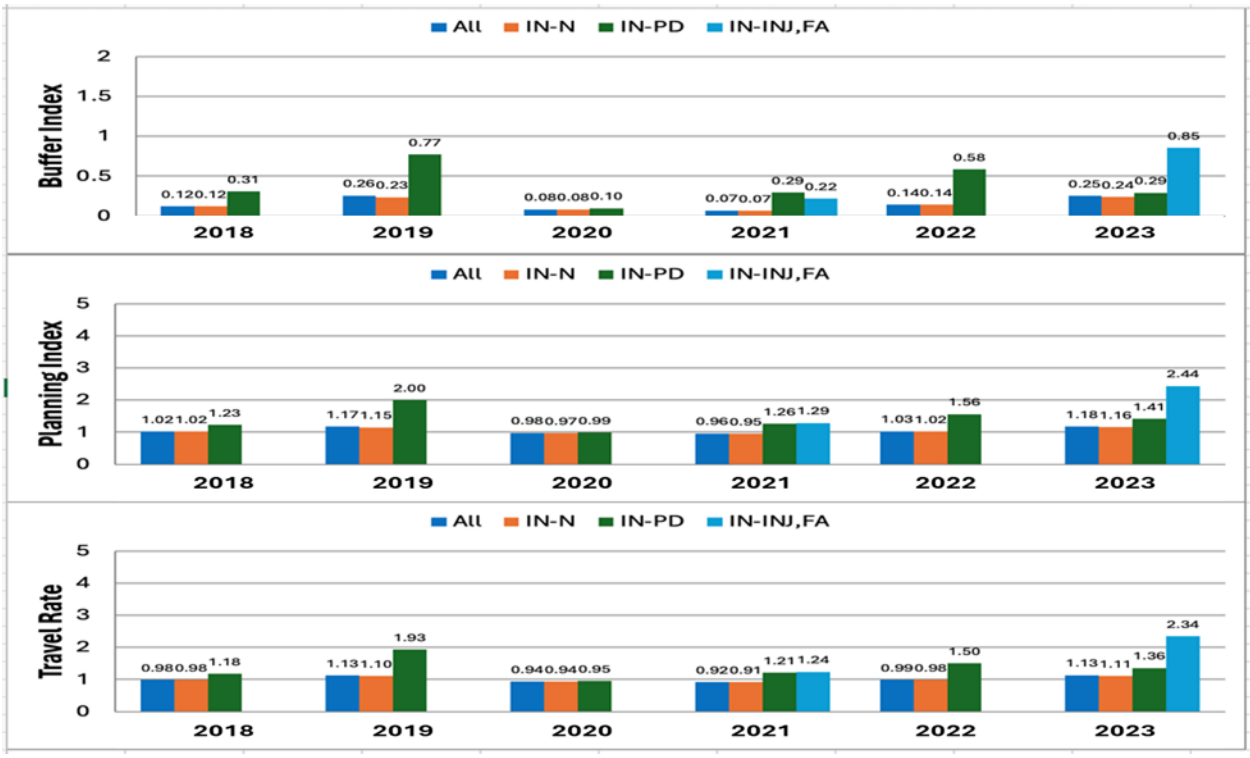
Effects of Work Zones



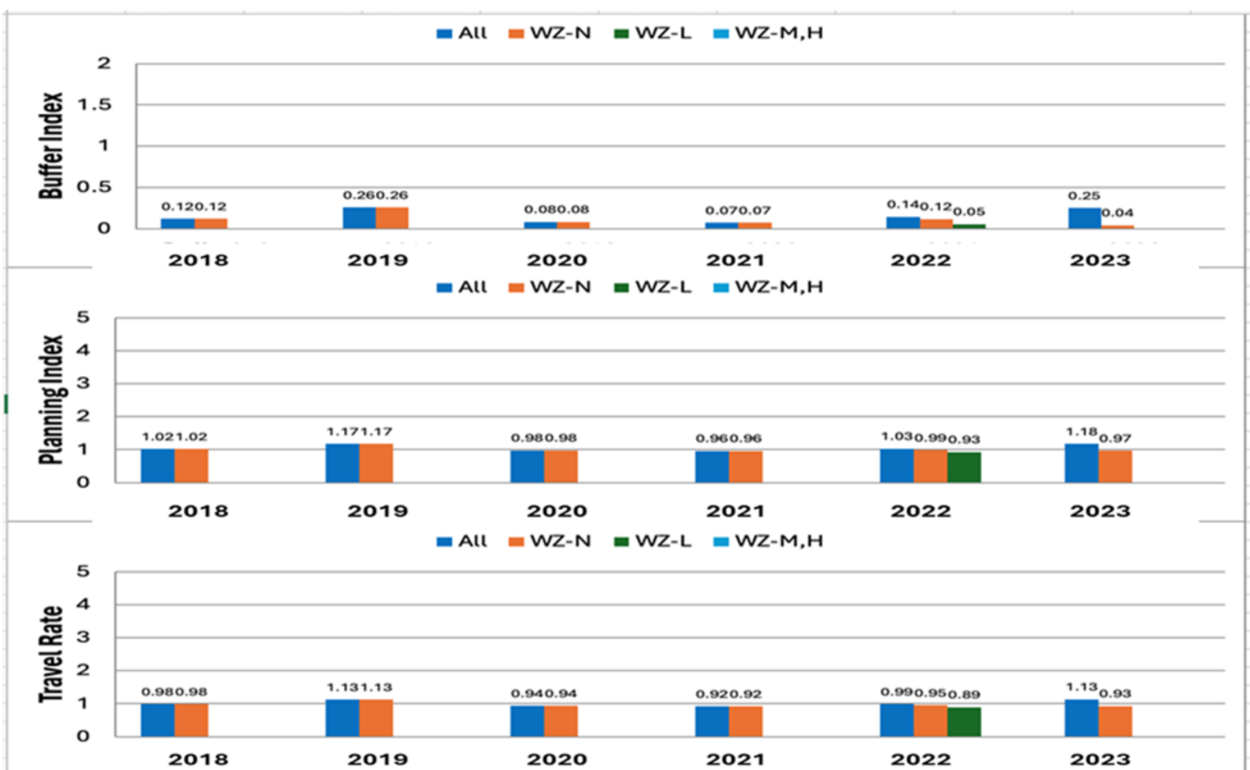
Yearly Variations - *Weather Effects*



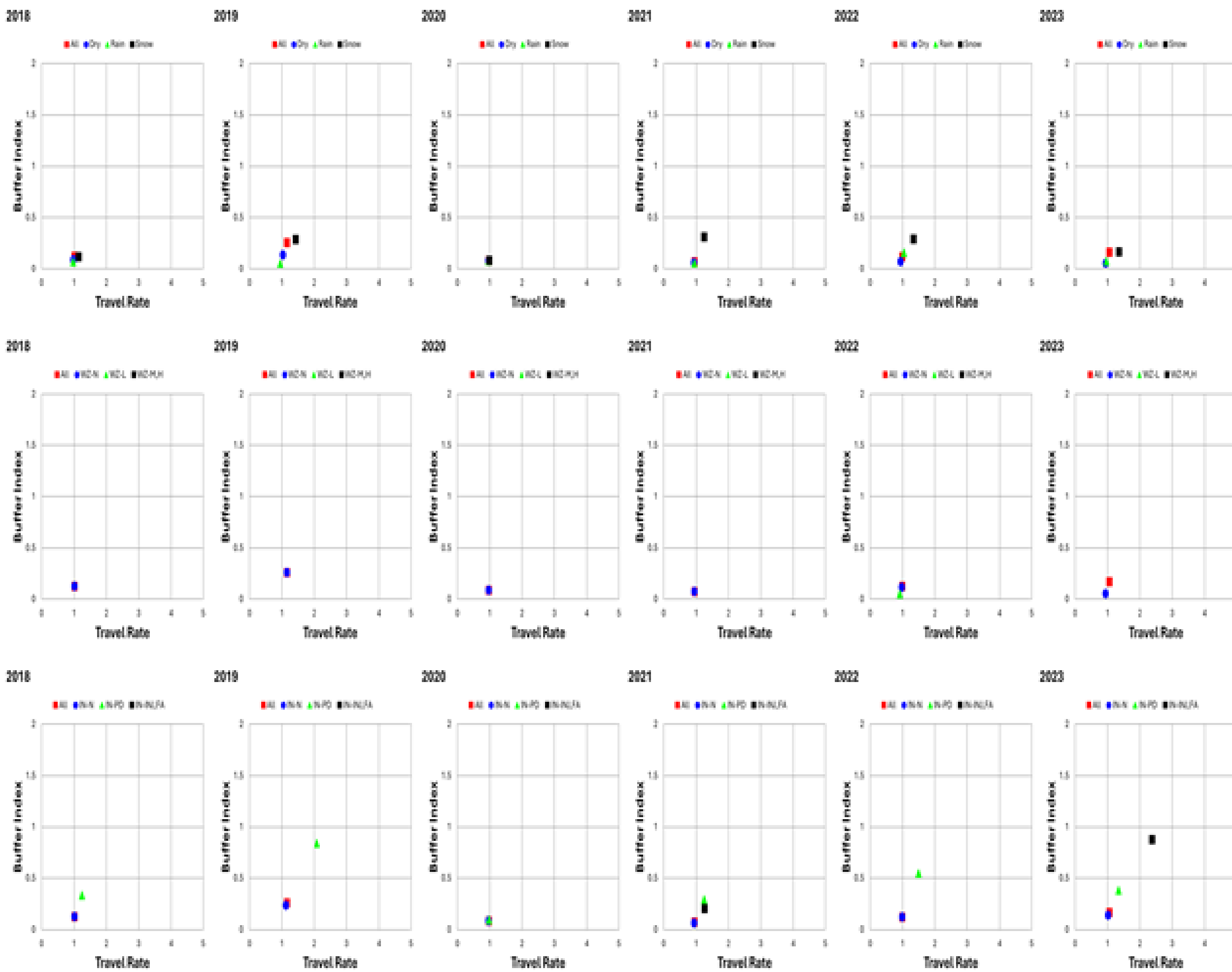
Incident Effects



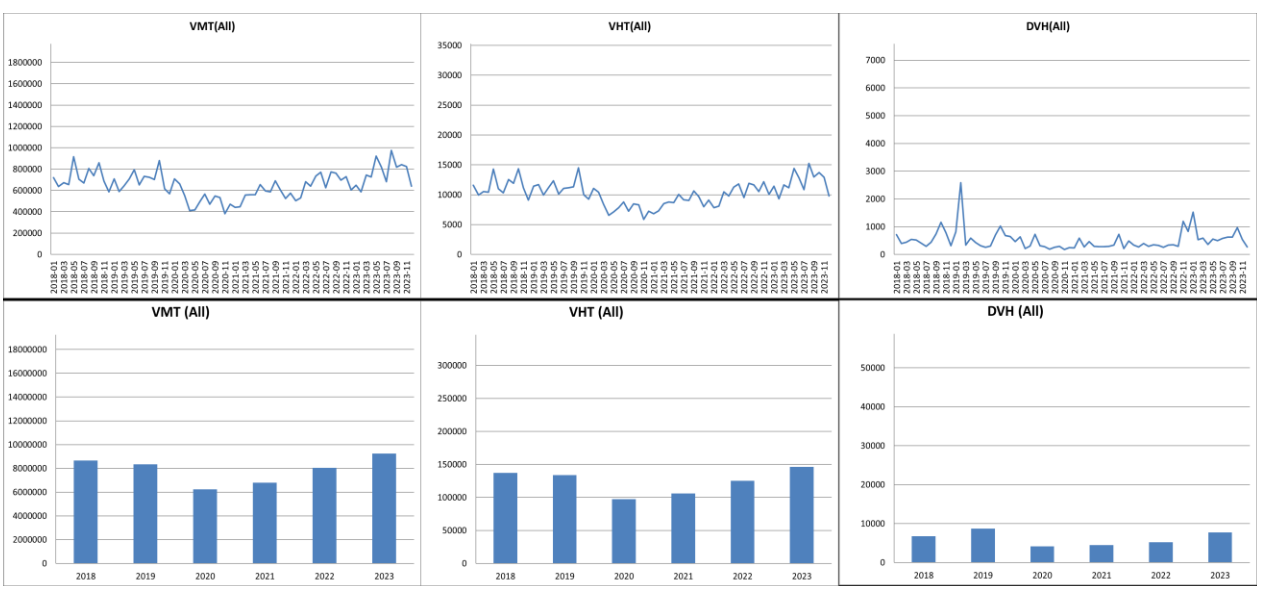
Work-Zone Effects



Yearly Variations of Buffer Index - Travel Rate Relationships

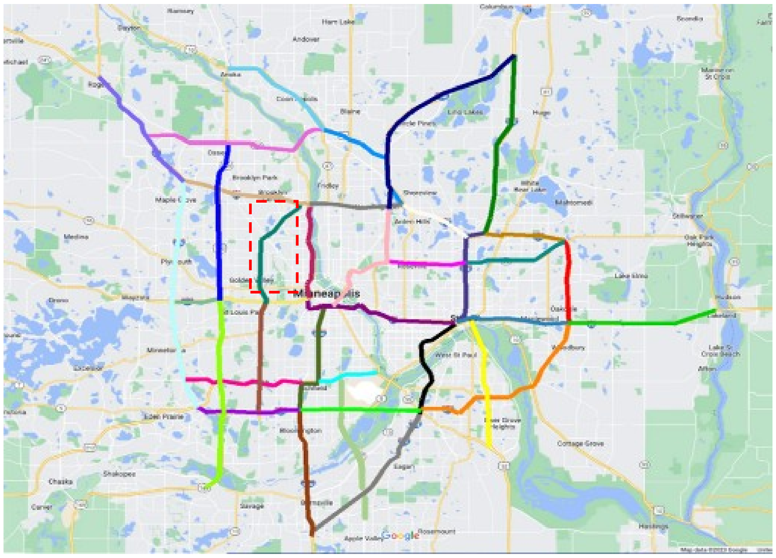


Variations of Traffic-Flow Measures

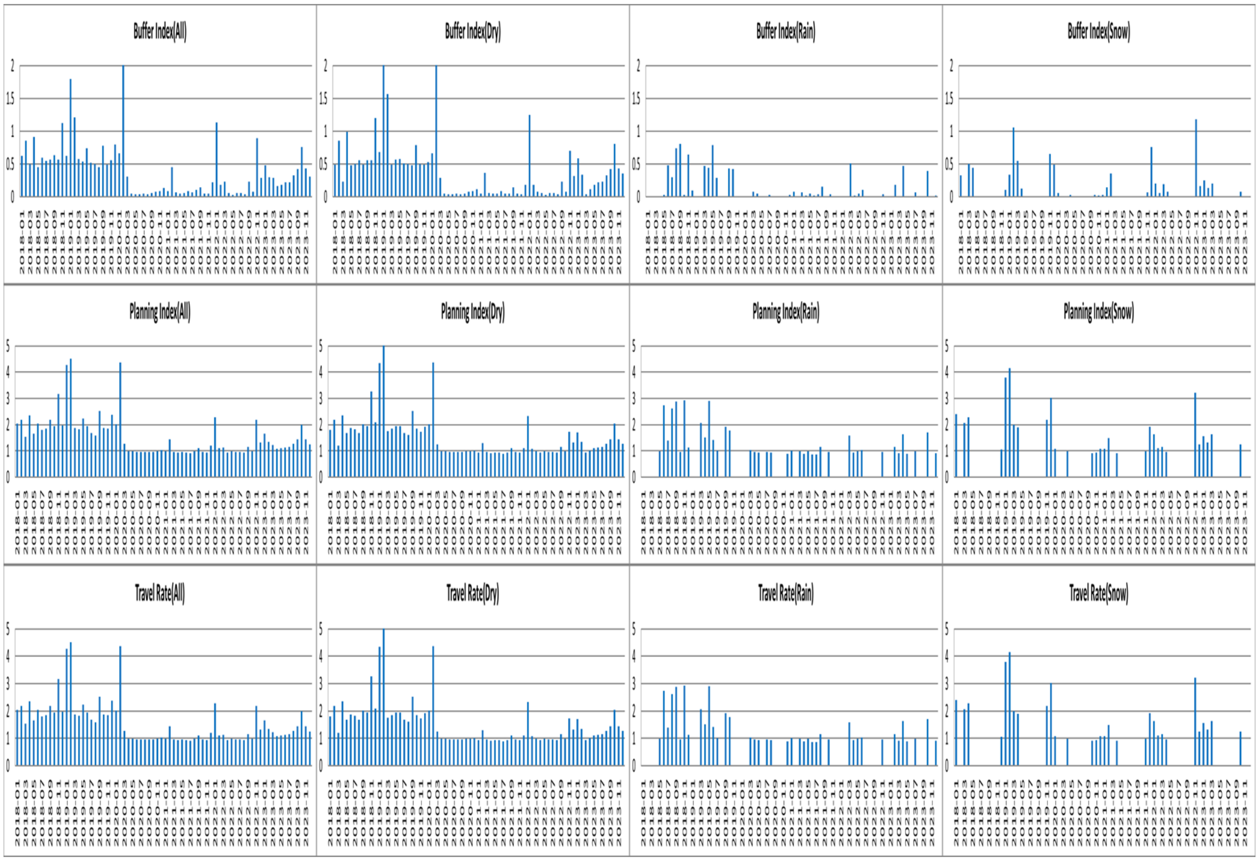


4) TH-100 Corridor A (I694 < -- > I394)

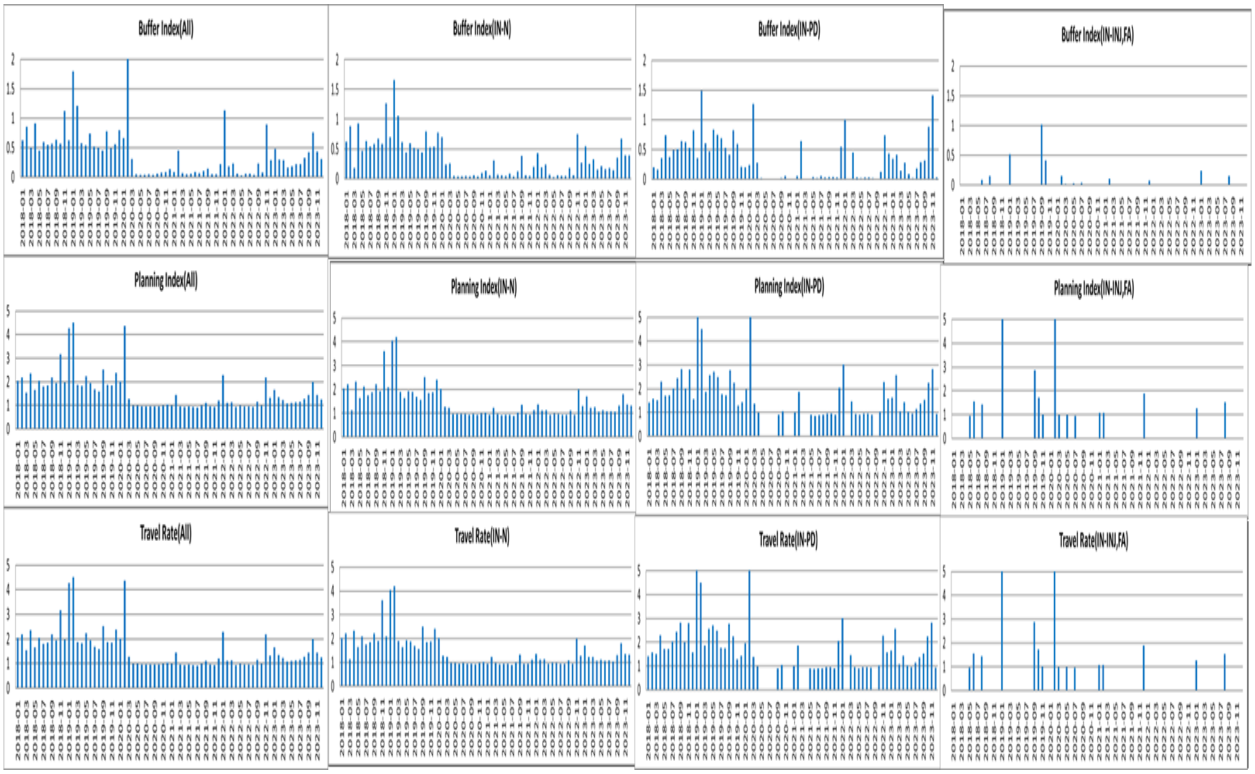
i) TH-100 Corridor A - SB I694 to I394 for Morning Peak Periods



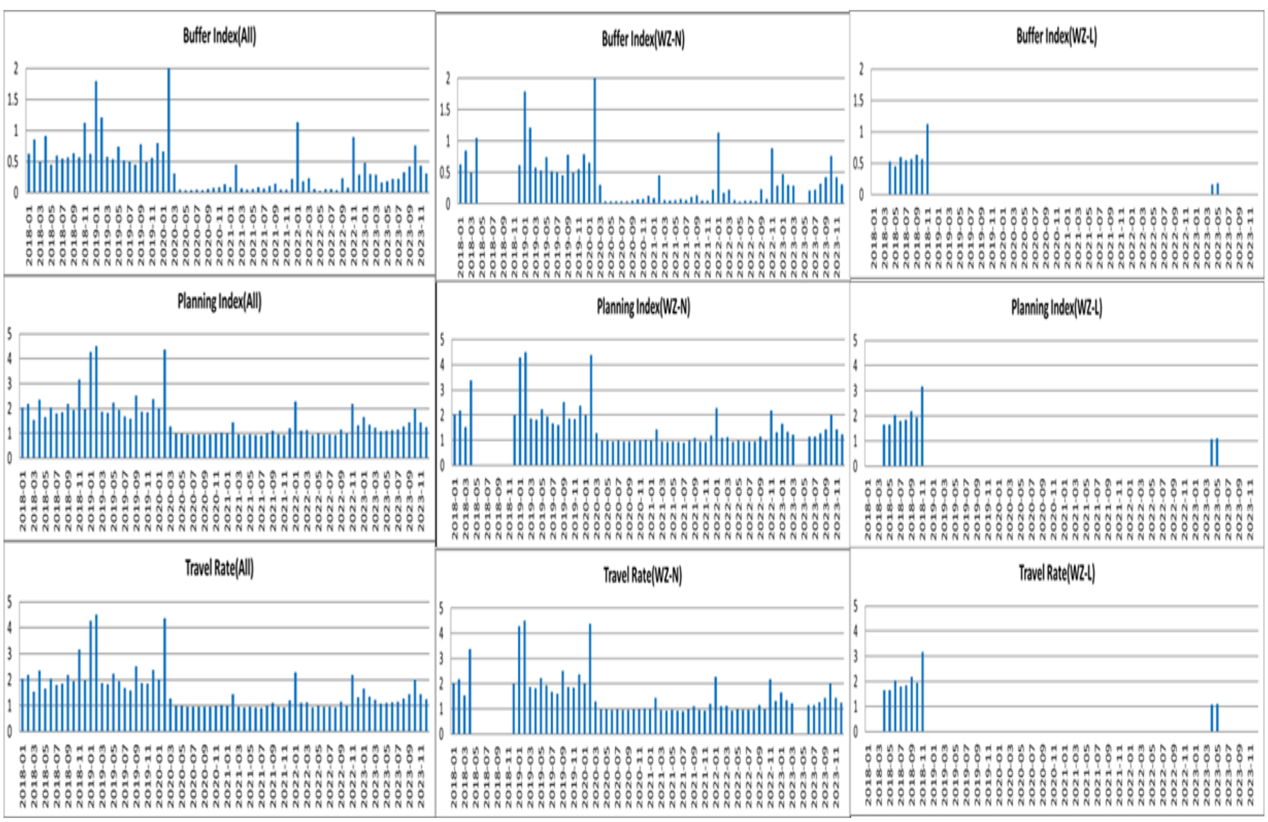
Effects of Weather conditions on Travel-Time Reliability



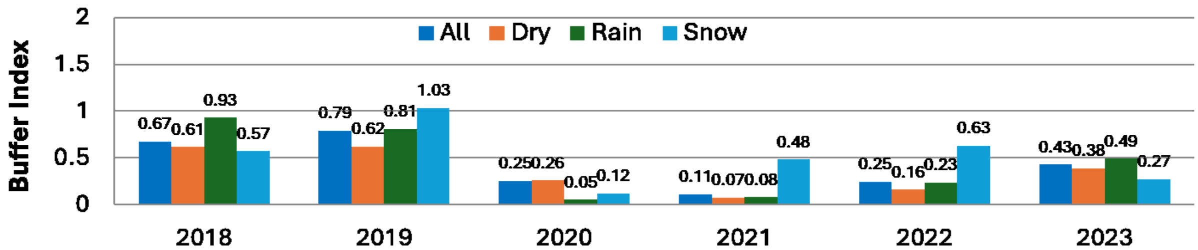
Effects of Incidents

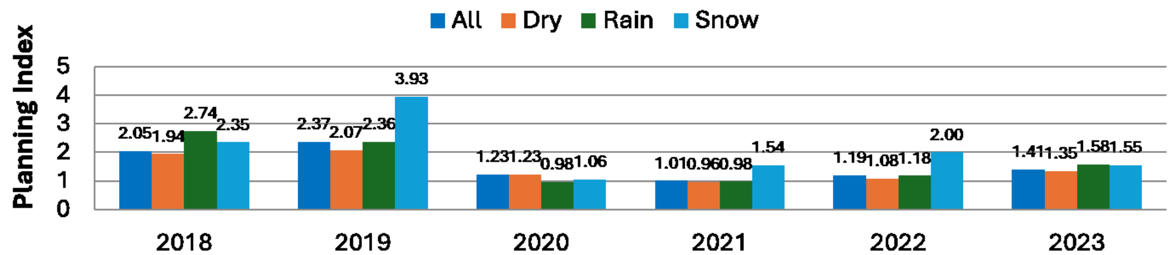


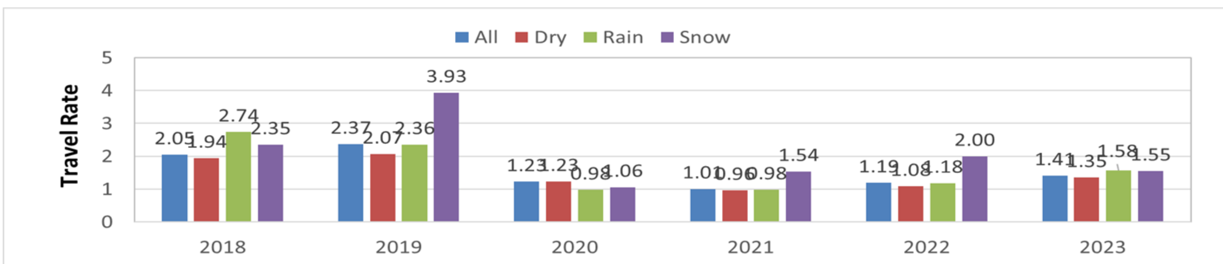
Effects of Work Zones



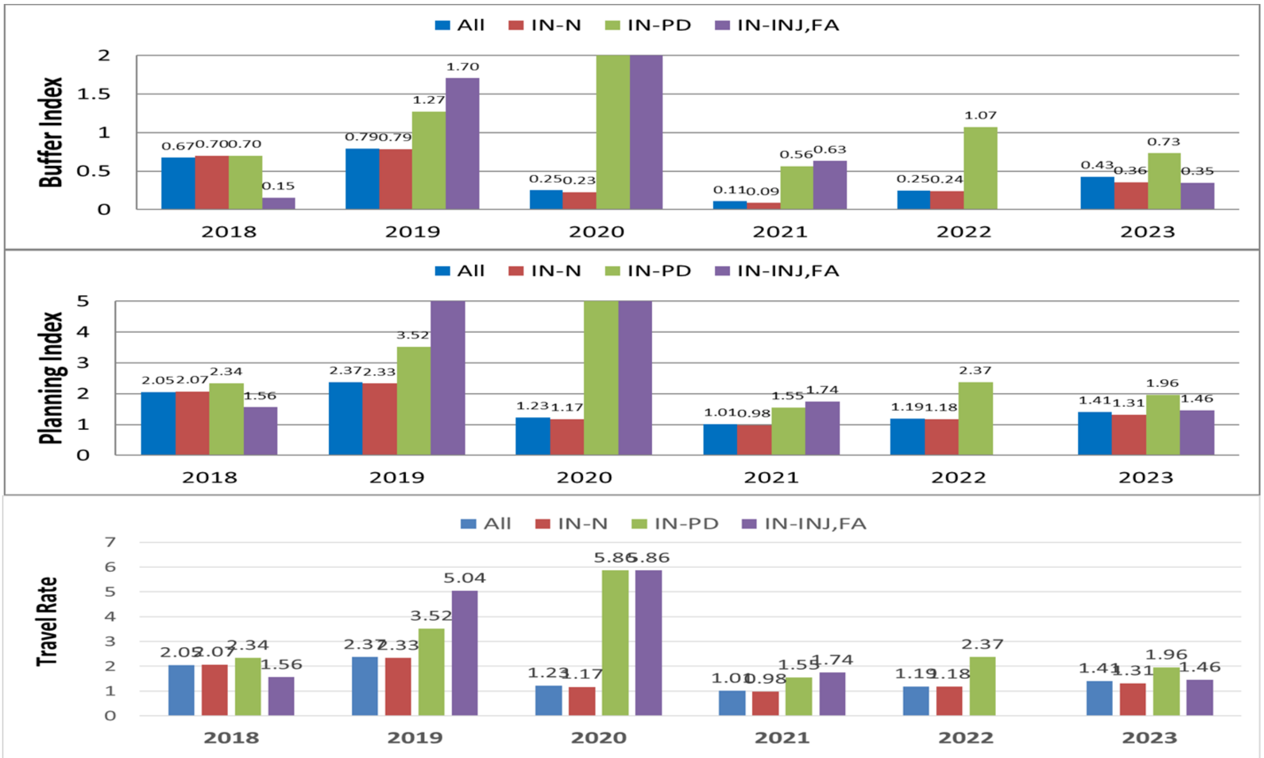
Yearly Variations - *Weather Effects*





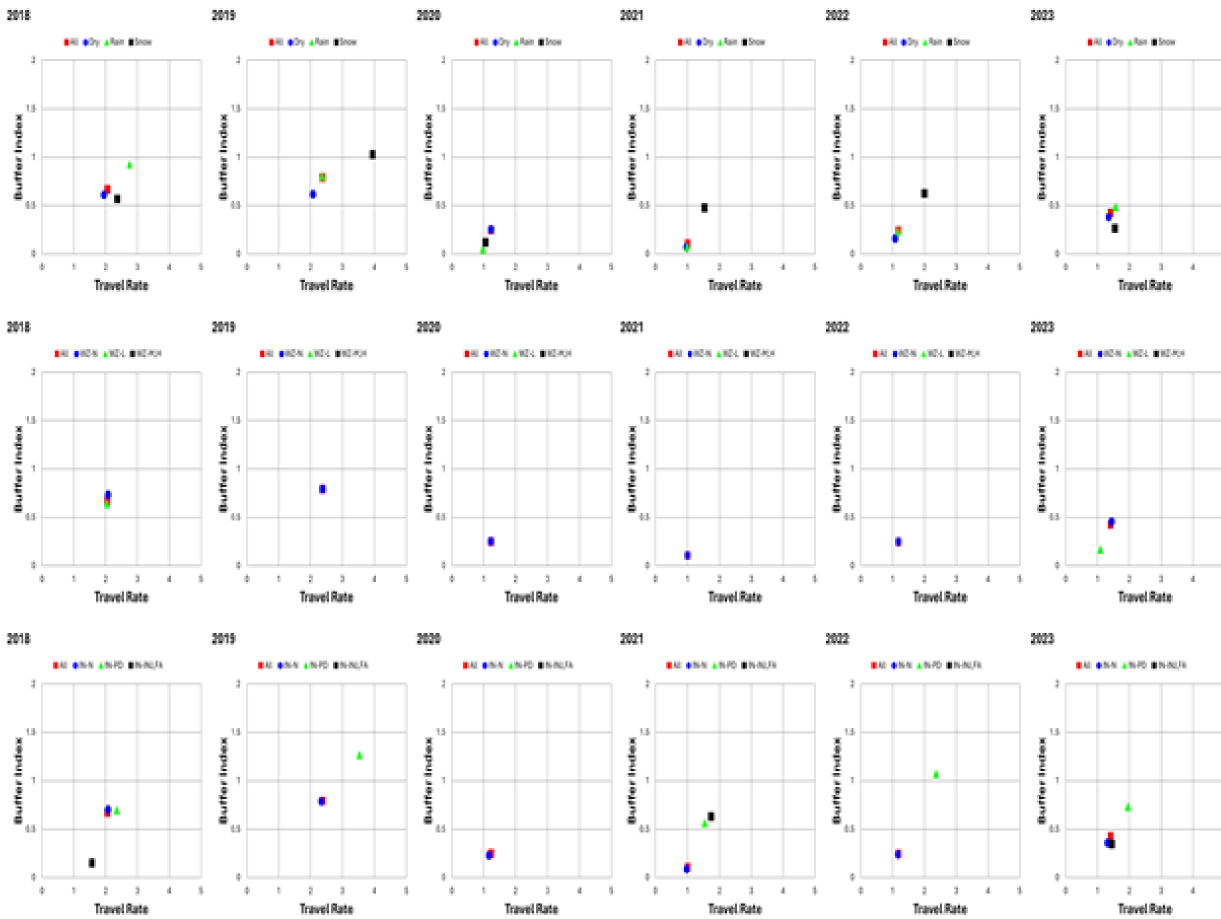


Incident Effects



Work-Zone Effects

Yearly Variations of Buffer Index - Travel Rate Relationships

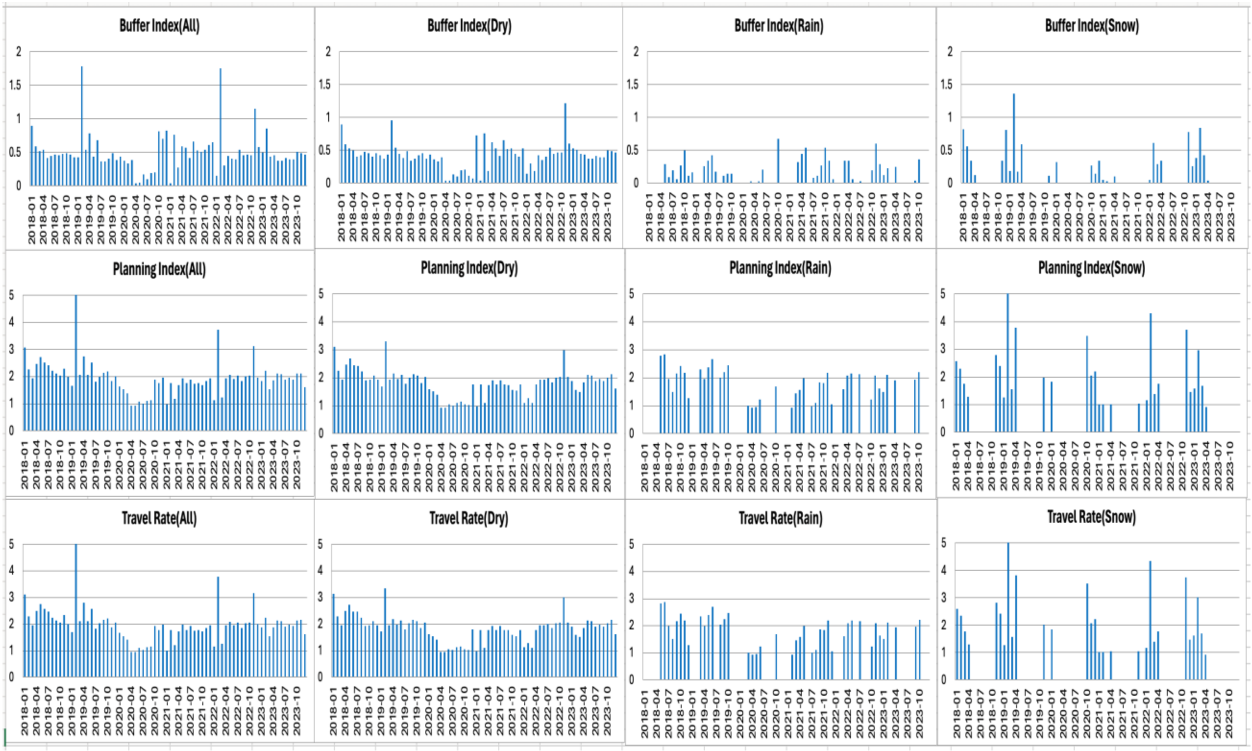


Variations of Traffic-Flow Measures

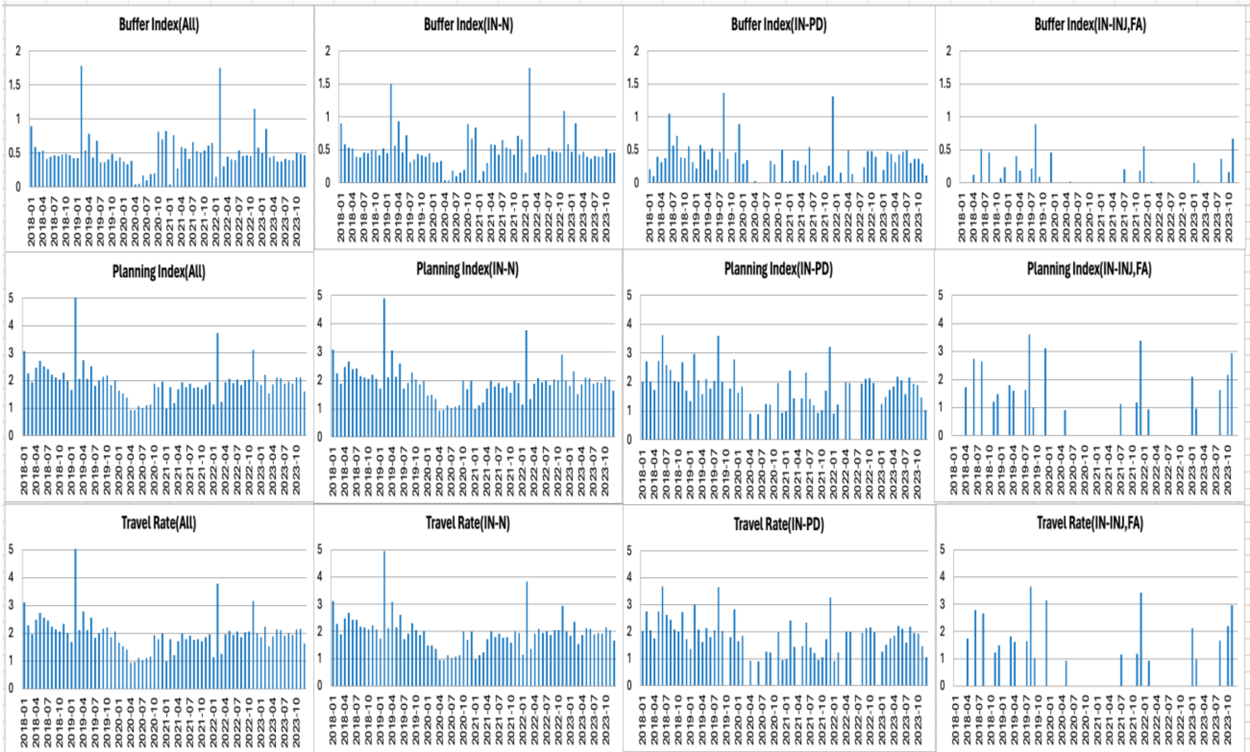

VMT(All)
VHT(All)
DVH(All)
VMT (All)
VHT (All)
DVH (All)

ii) TH-100 NB Corridor A- NB I394 to 694 for Afternoon Peak Periods

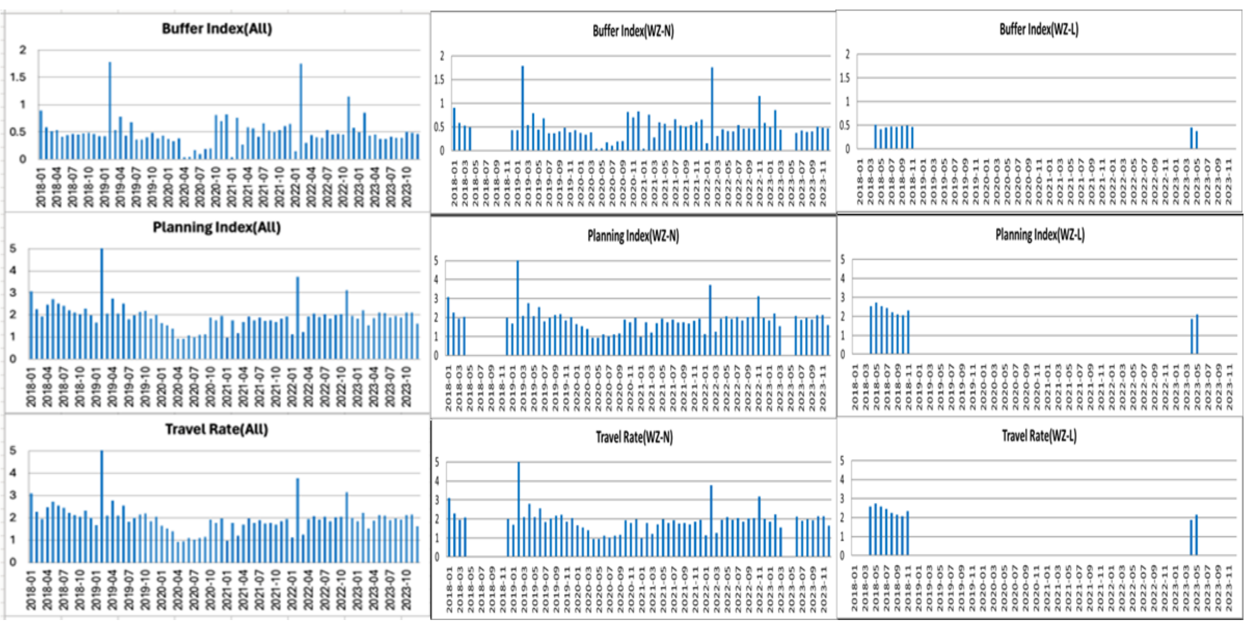
Effects of Weather conditions on Travel-Time Reliability



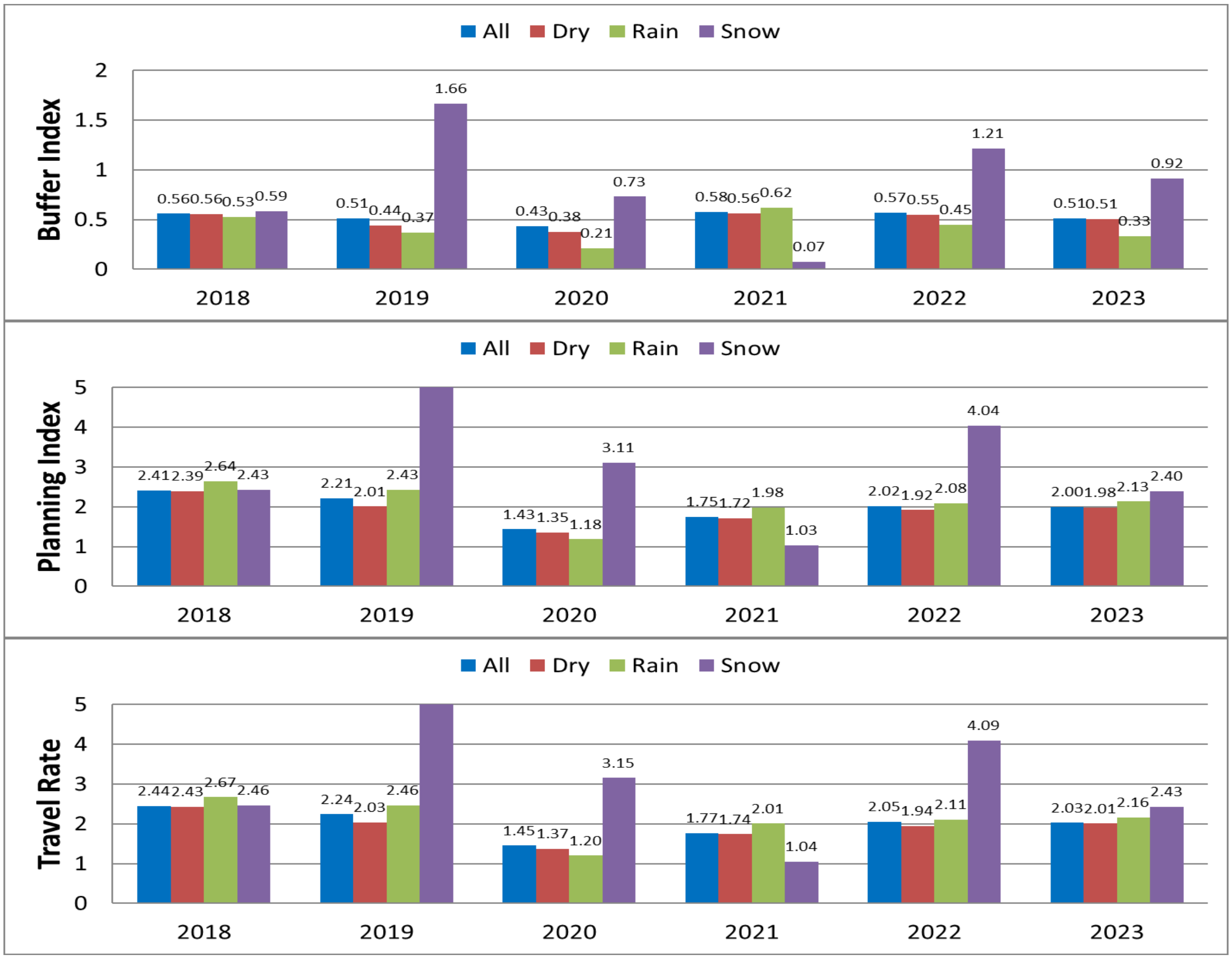
Effects of Incidents



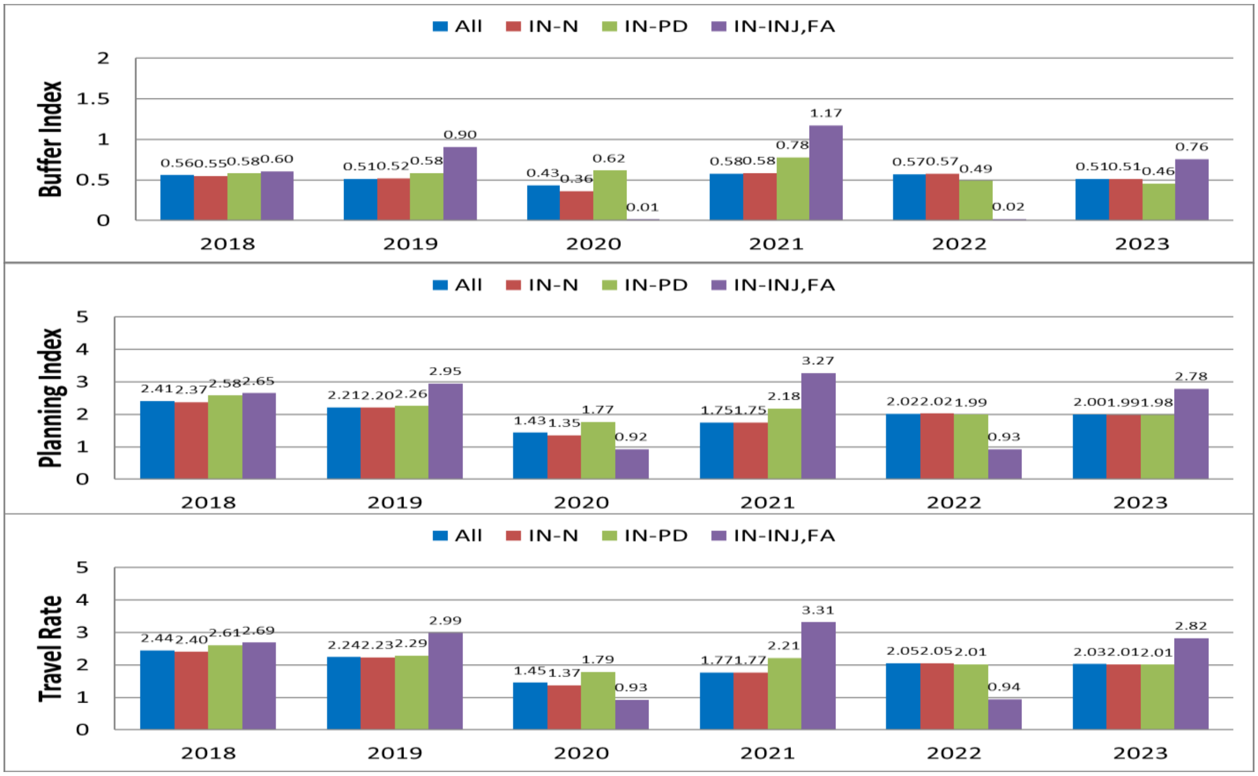
Effects of Work Zones



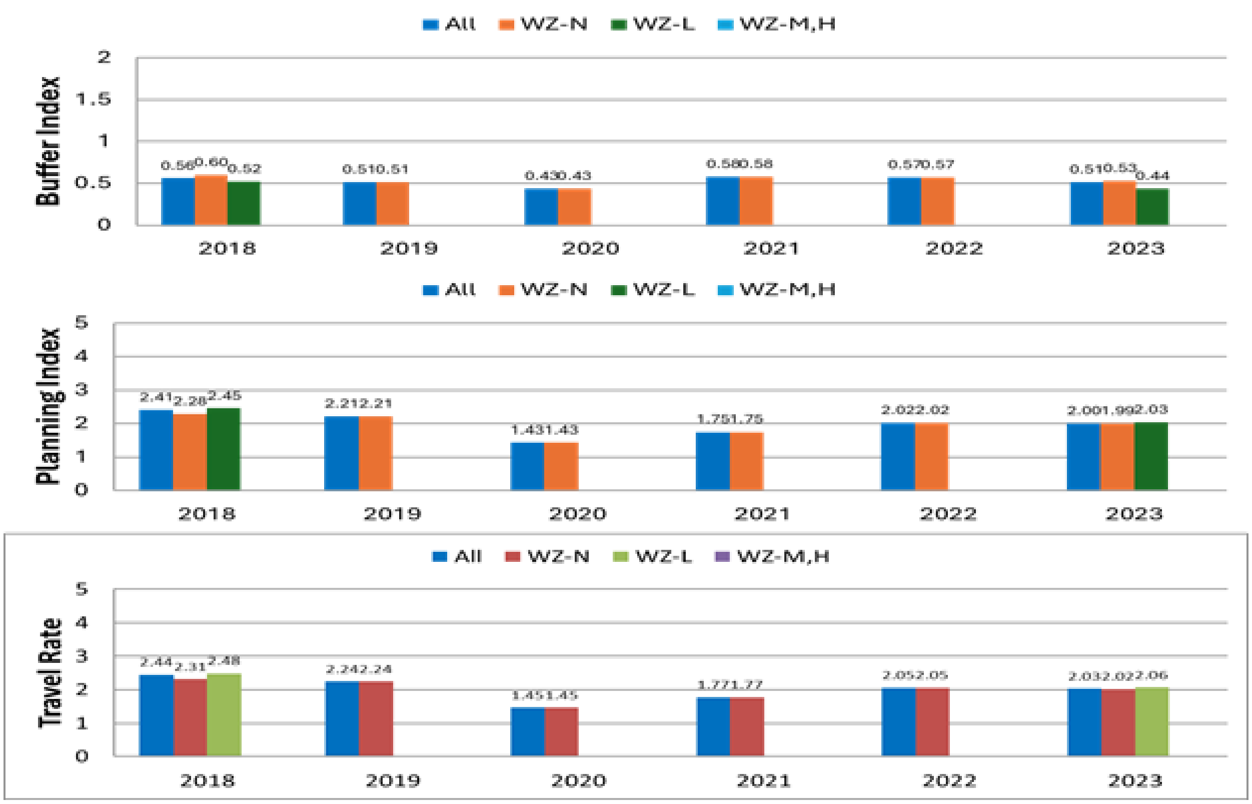
Yearly Variations - *Weather Effects*



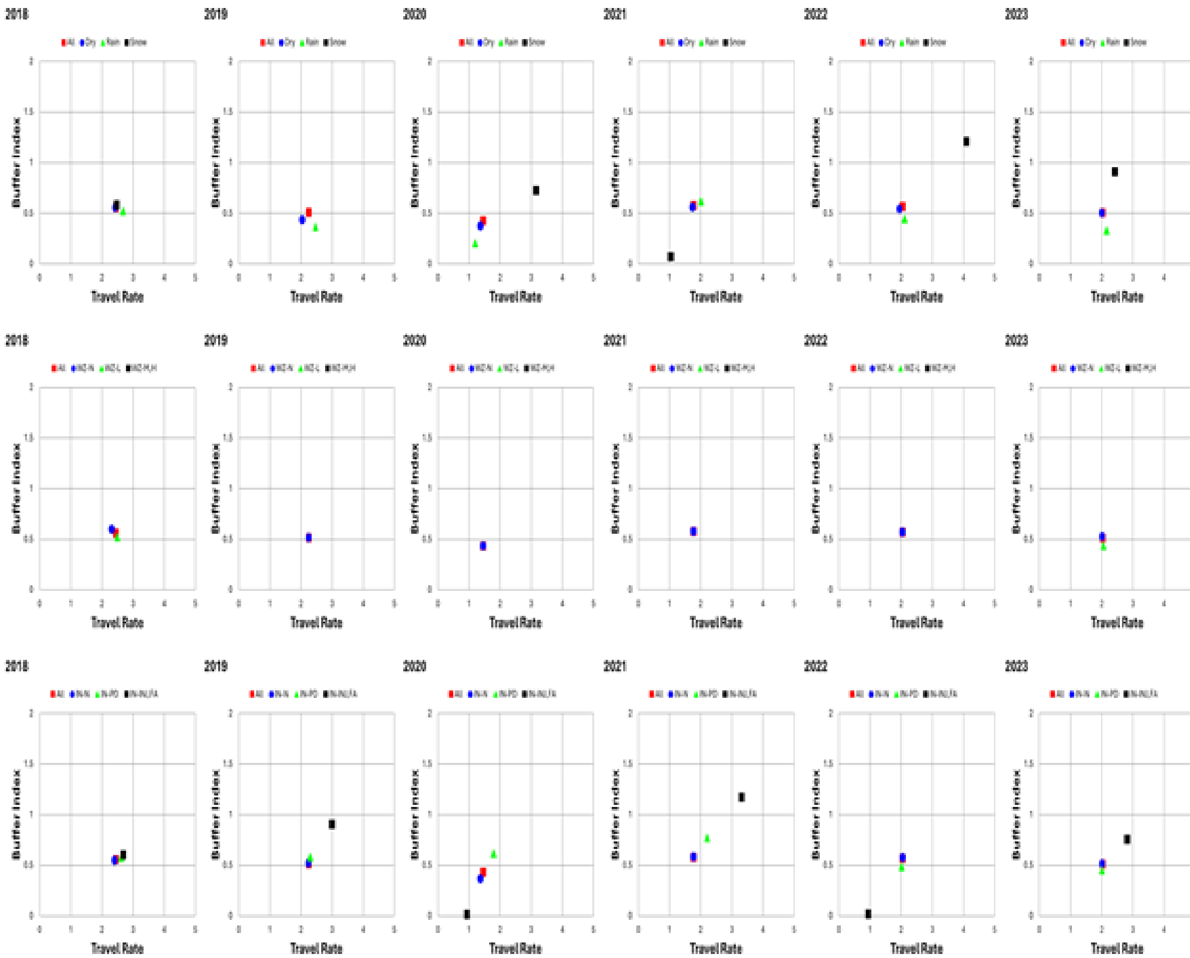
Incident Effects



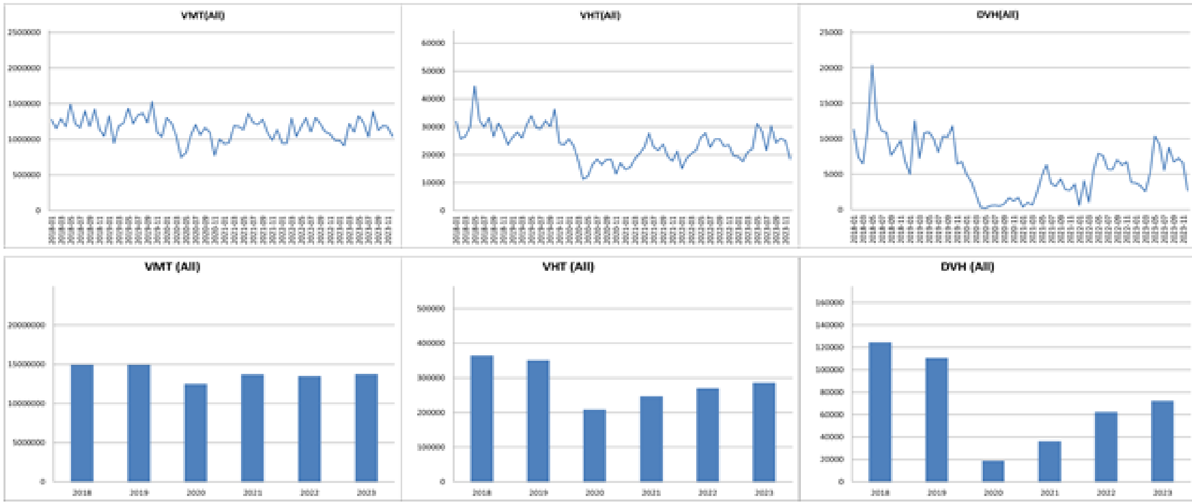
Work-Zone Effects



Yearly Variations of Buffer Index - Travel Rate Relationships

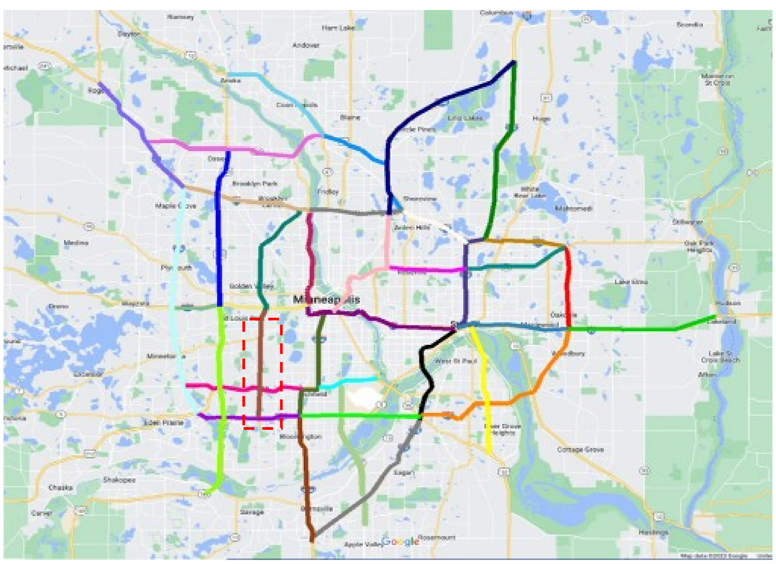


Variations of Traffic-Flow Measures

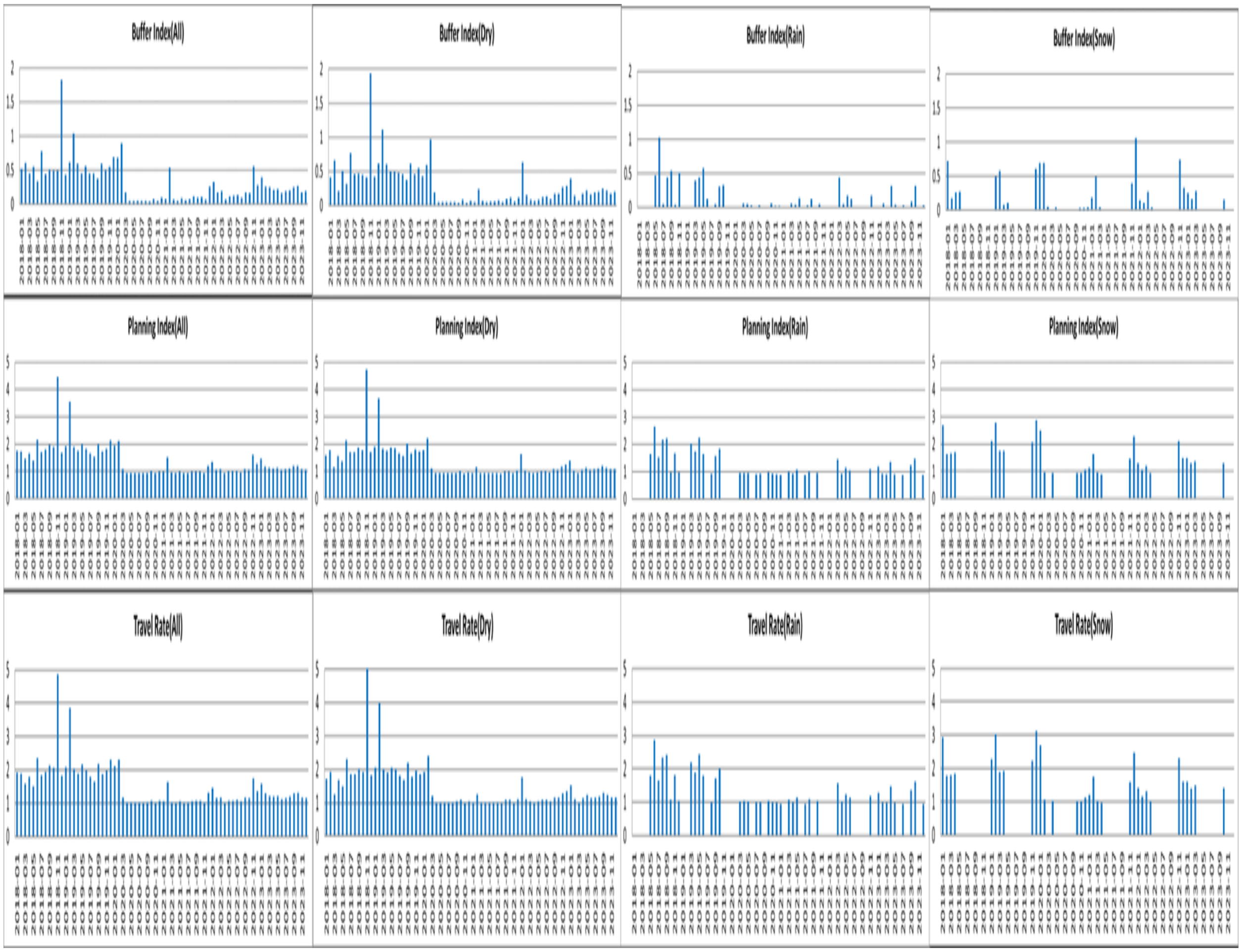


5) TH-100 Corridor B (I394 < -- > I494)

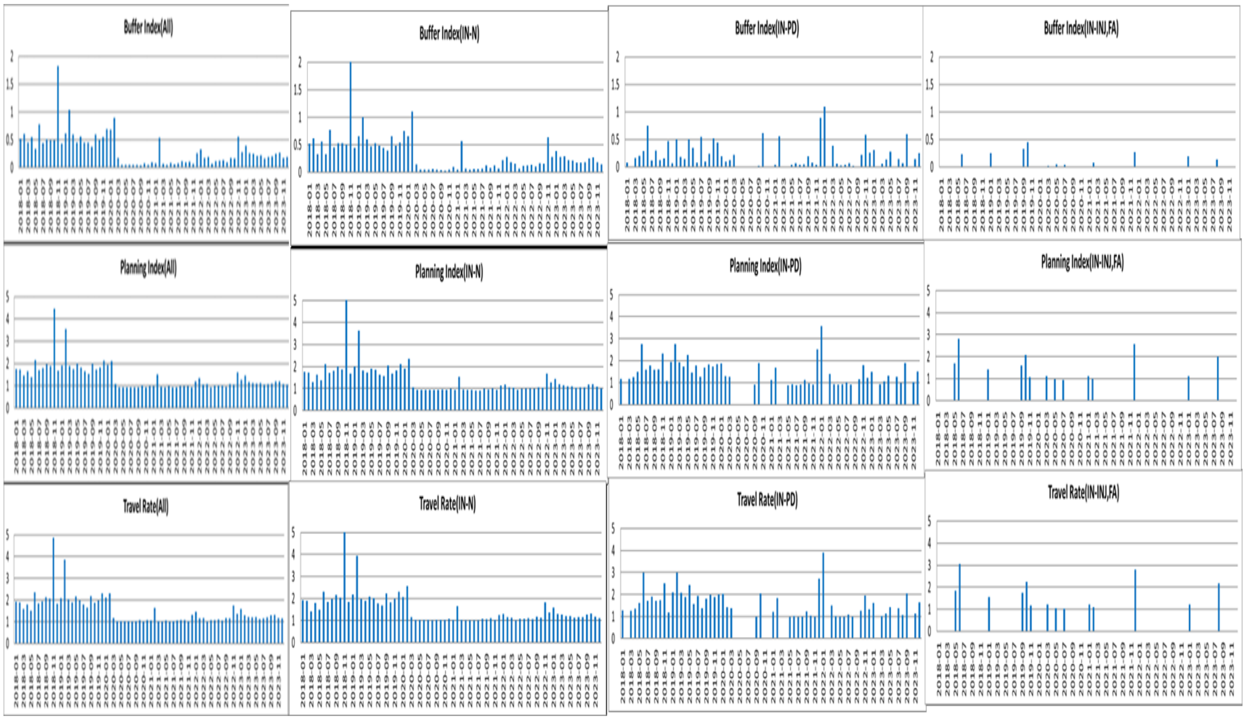
i) TH-100 Corridor B -SB I394 to I494 for Morning Peak Periods



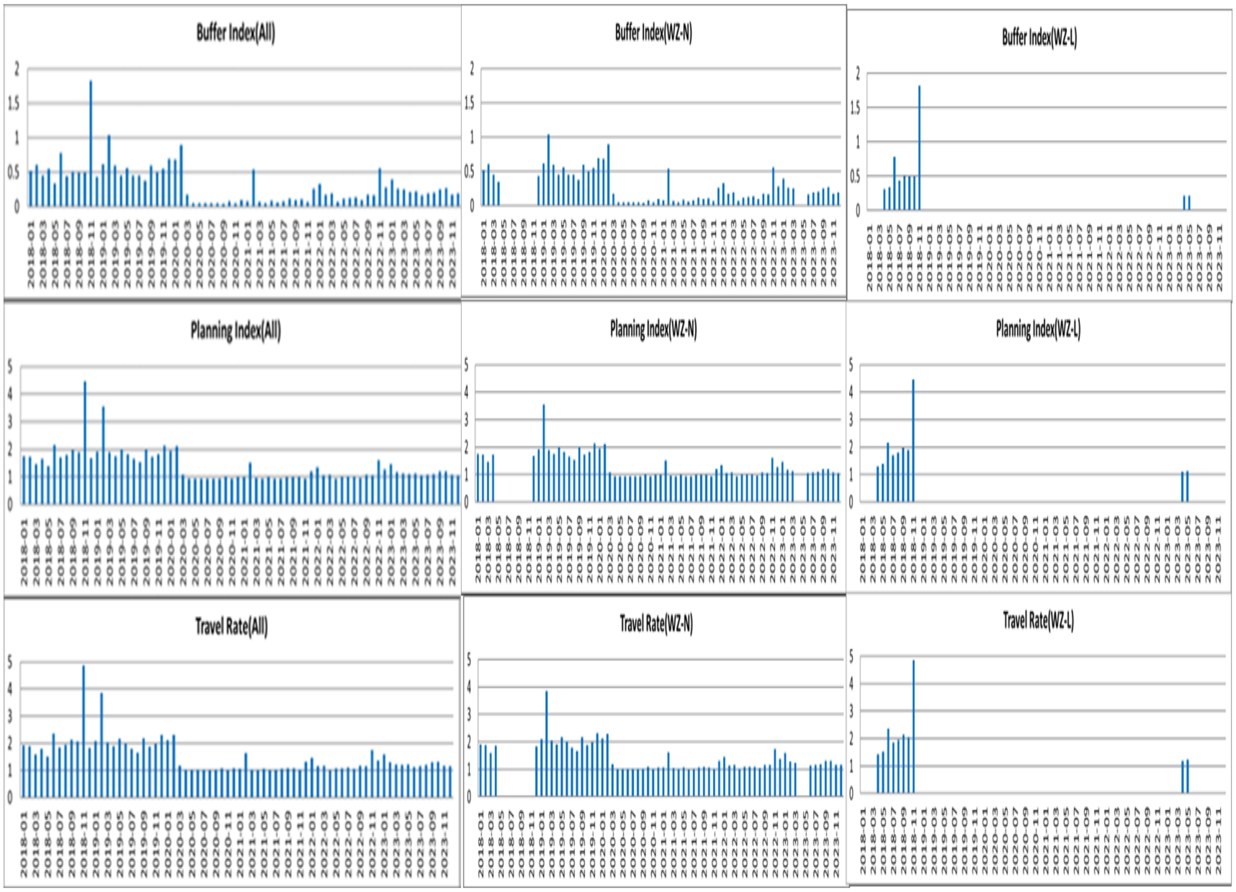
Effects of Weather conditions on Travel-Time Reliability


Buffer Index(All)
Buffer Index(Dry)
Buffer Index(Rain)
Buffer Index(Snow)
Planning Index(All)
Planning Index(Dry)
Planning Index(Rain)
Planning Index(Snow)
Travel Rate(All)
Travel Rate(Dry)
Travel Rate(Rain)
Travel Rate(Snow)

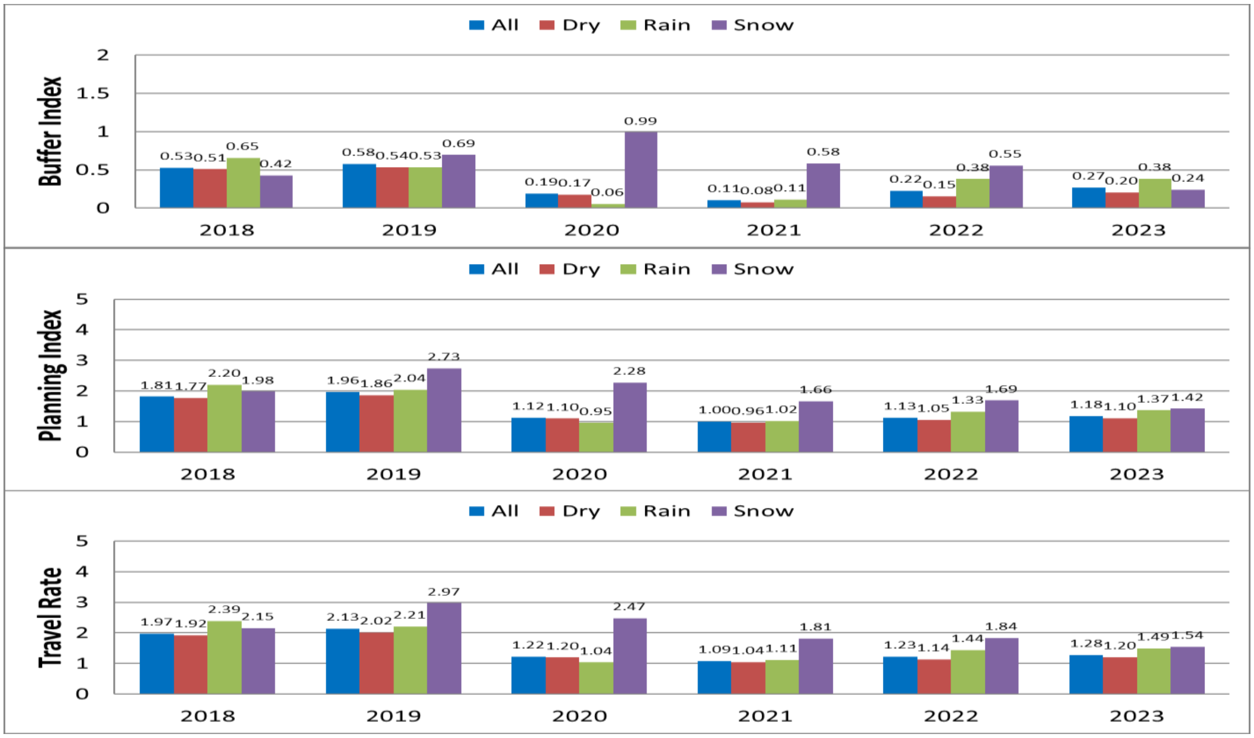
Effects of Incidents



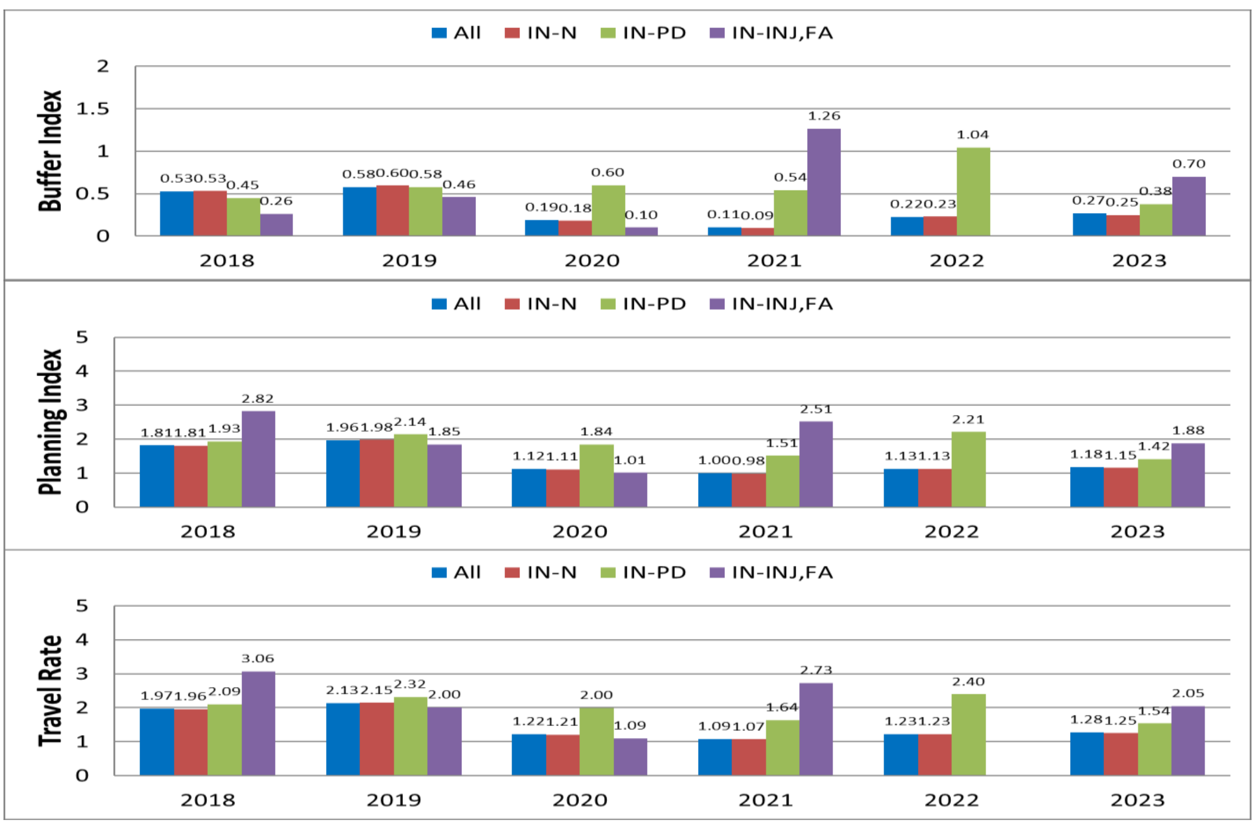
Effects of Work Zones



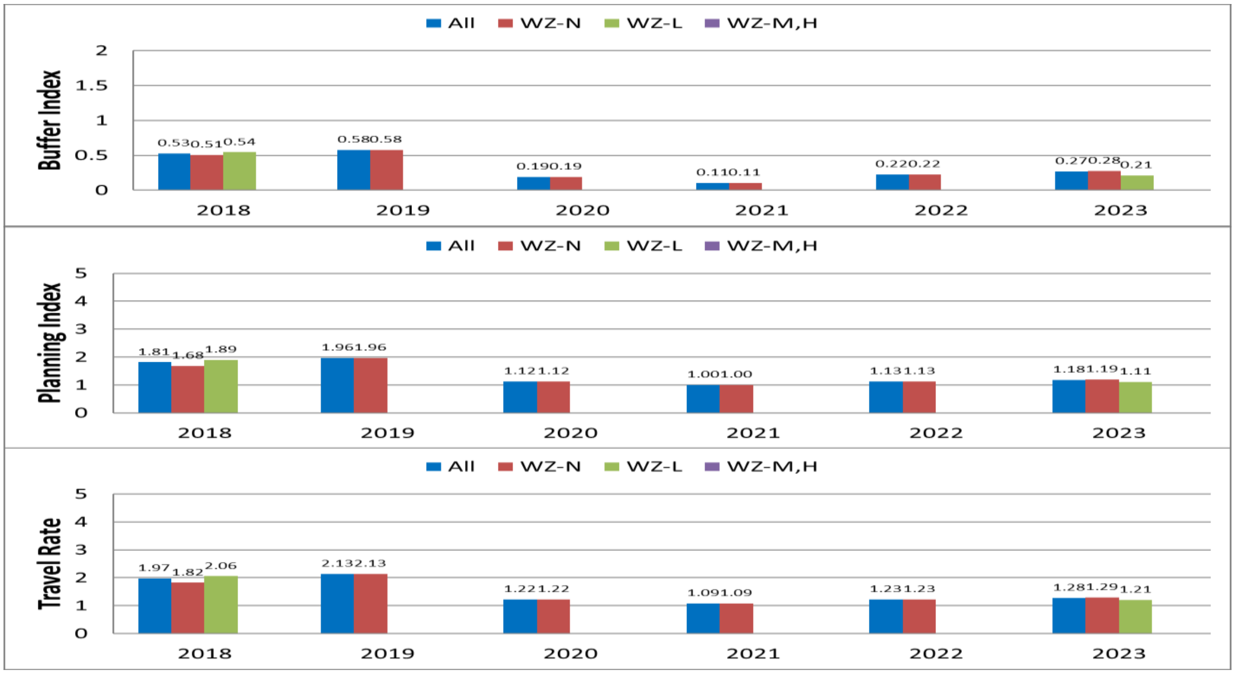
Yearly Variations - *Weather Effects*



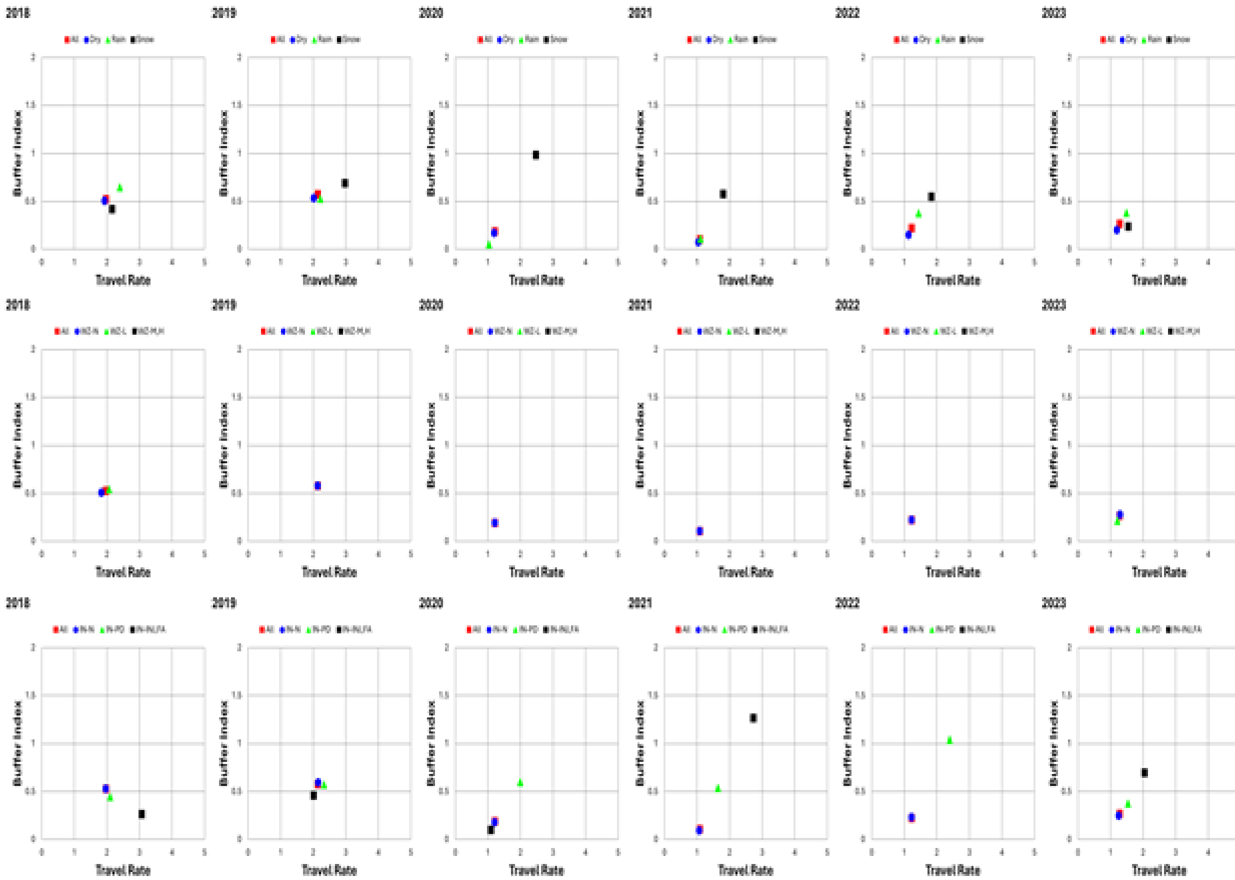
Incident Effects



Work-Zone Effects



Yearly Variations of Buffer Index - Travel Rate Relationships

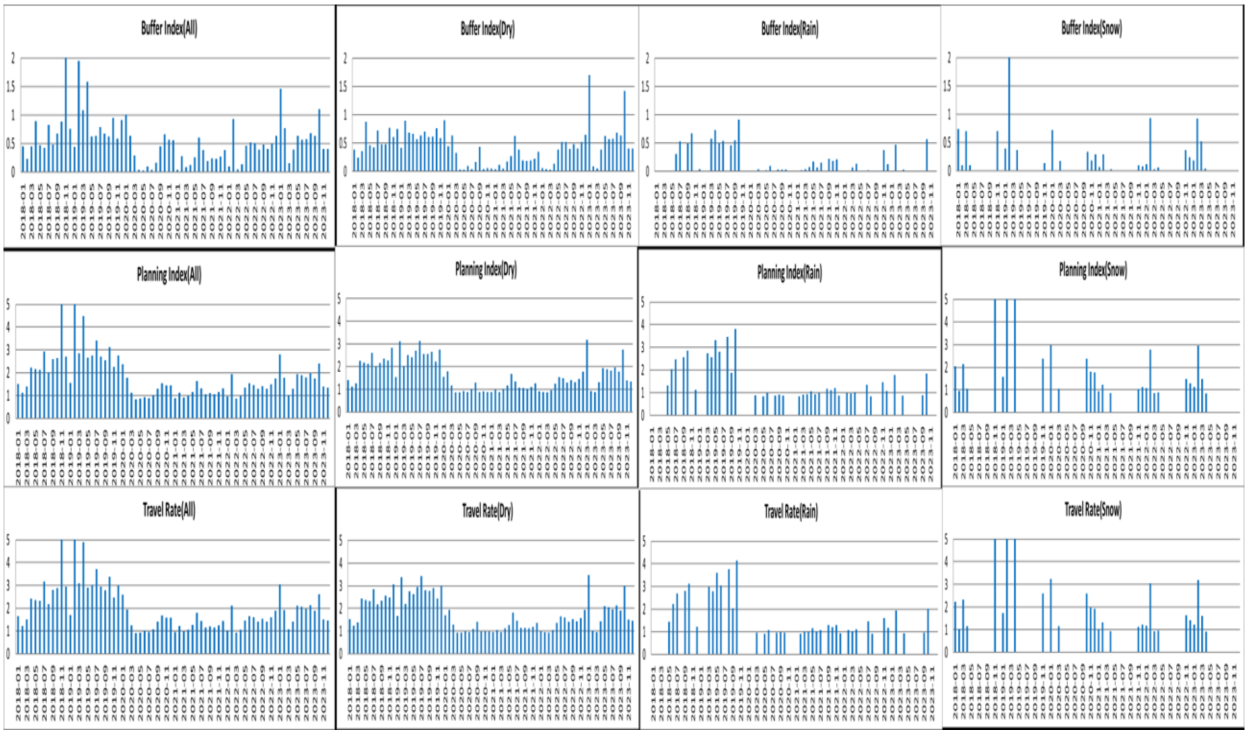


Variations of Traffic-Flow Measures

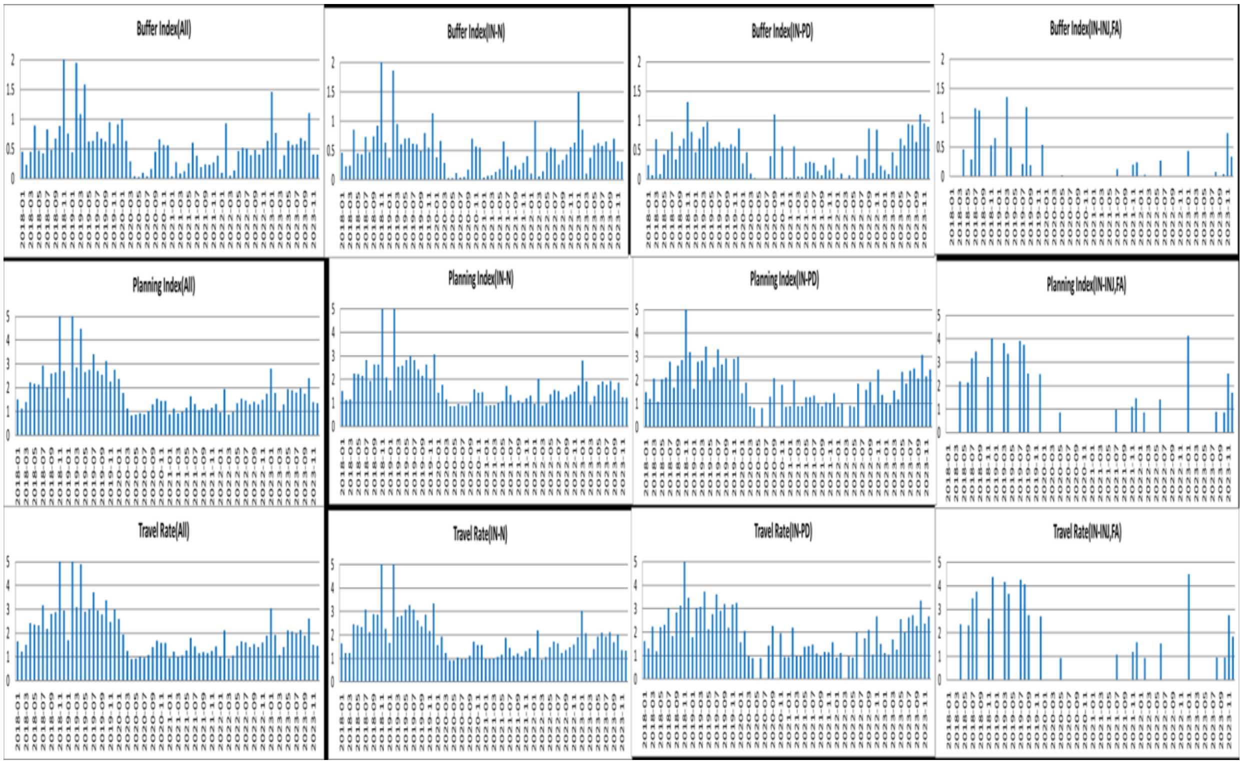

VMT(All)
2500000
2000000
1500000
1000000
500000
0
VHT(All)
50000
40000
30000
20000
10000
0
DVH(All)
16000
14000
12000
10000
8000
6000
4000
2000
0
VMT (All)
25000000
20000000
15000000
10000000
5000000
0
2018
2019
2020
2021
2022
2023
VHT (All)
500000
400000
300000
200000
100000
0
2018
2019
2020
2021
2022
2023
DVH (All)
120000
100000
80000
60000
40000
20000
0
2018
2019
2020
2021
2022
2023

ii) TH-100 Corridor B - NB 494 to I394 for Afternoon Peak Periods

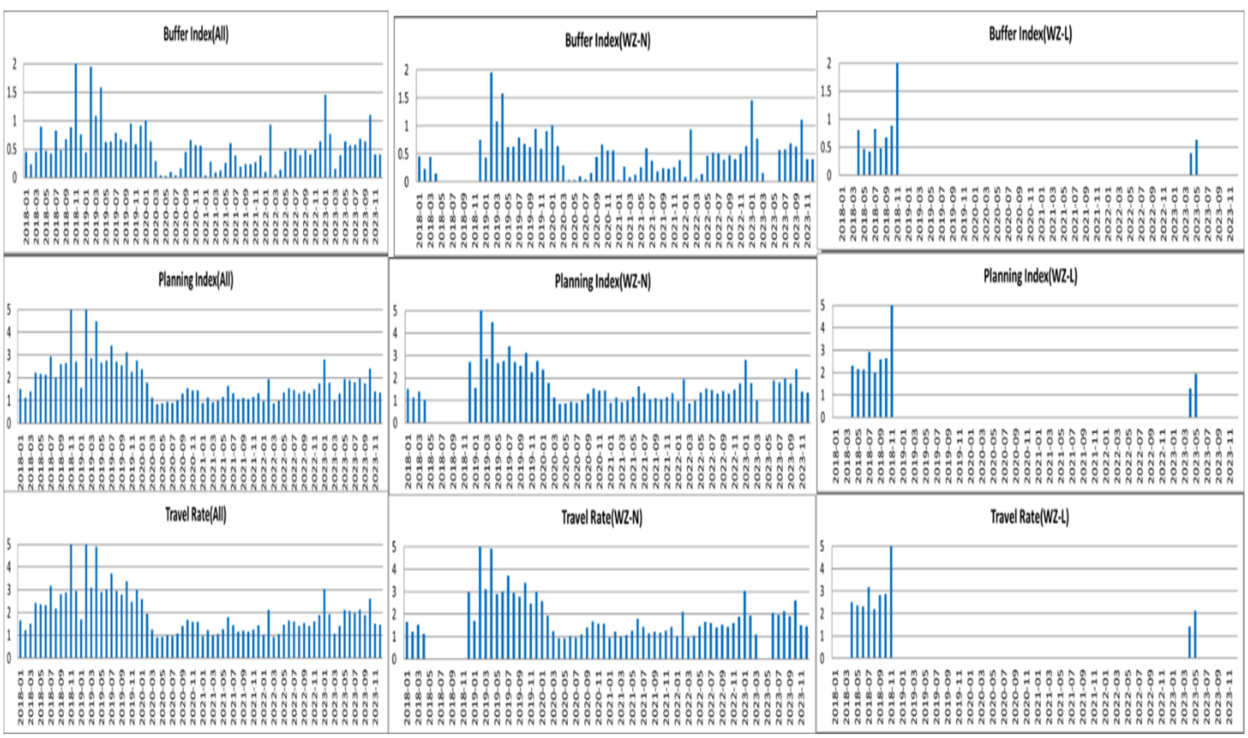
Effects of Weather conditions on Travel-Time Reliability



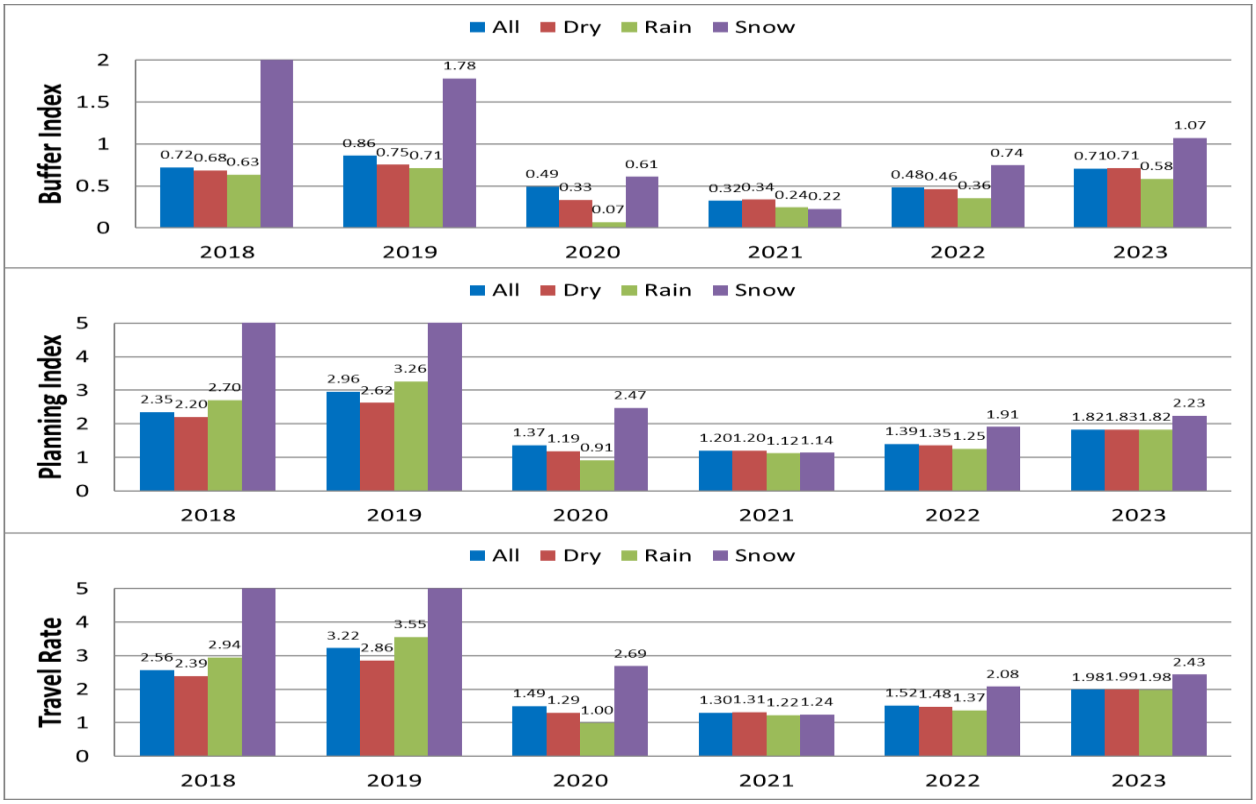
Effects of Incidents



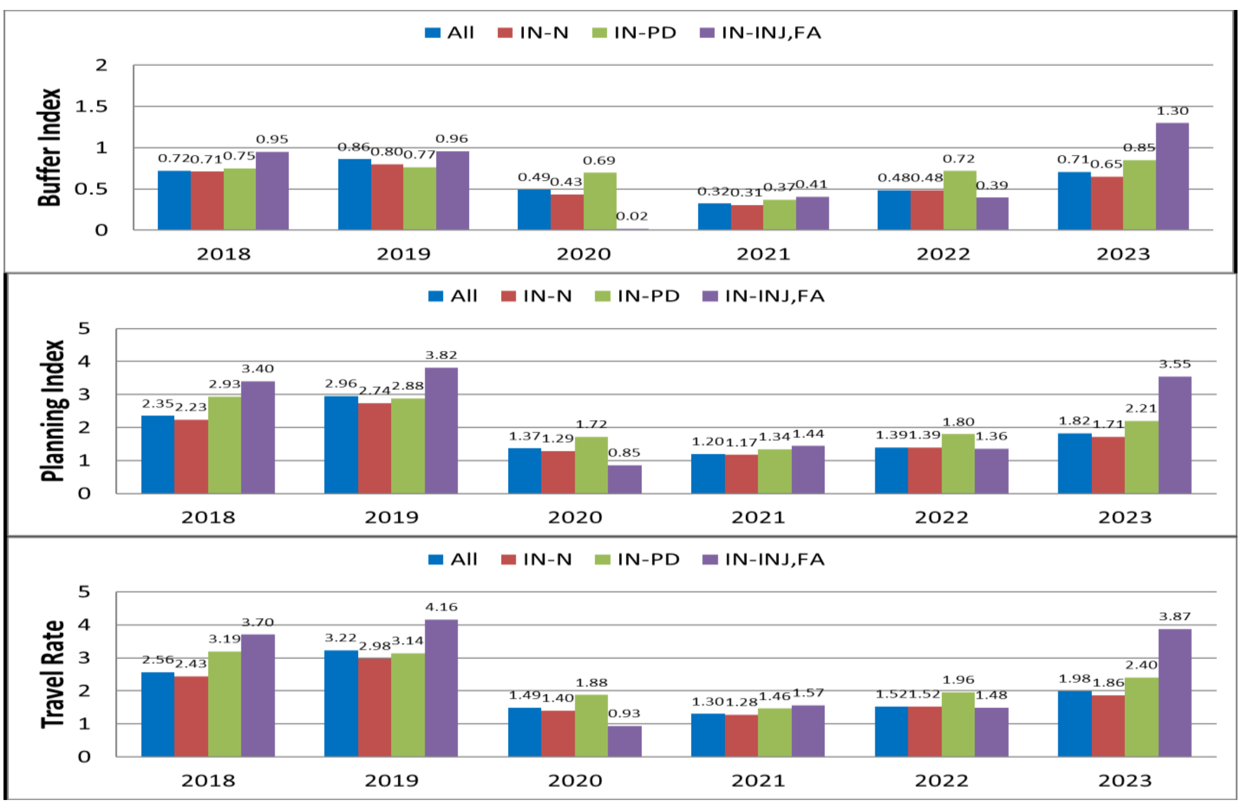
Effects of Work Zones



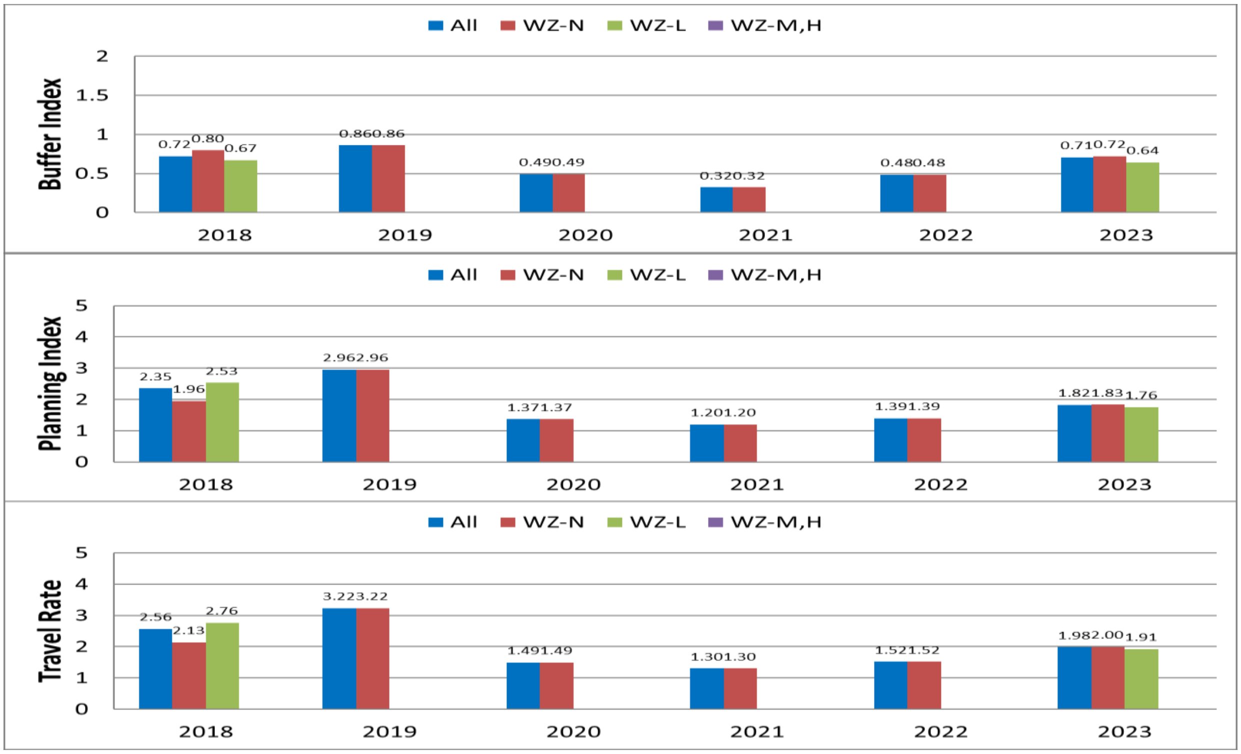
Yearly Variations - *Weather Effects*



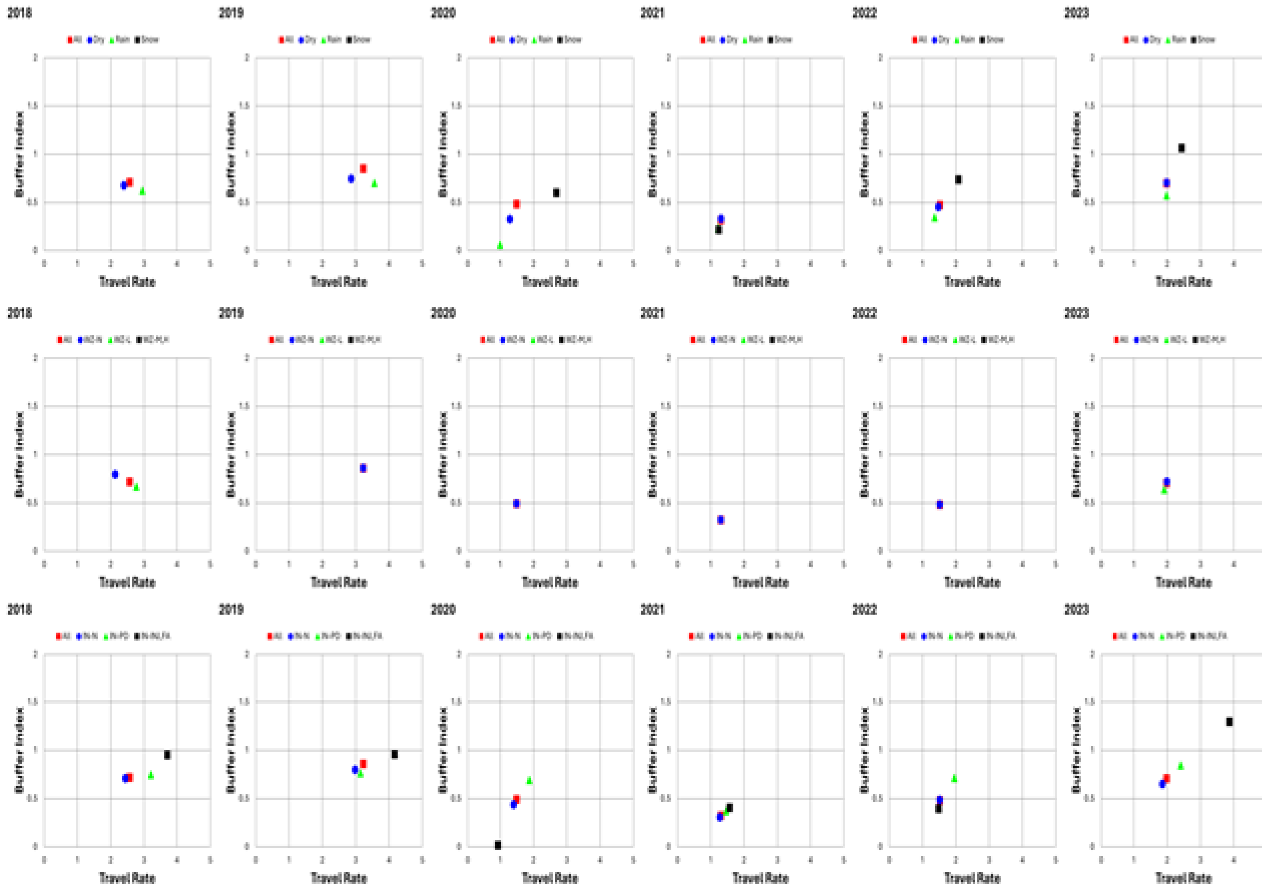
Incident Effects



Work-Zone Effects

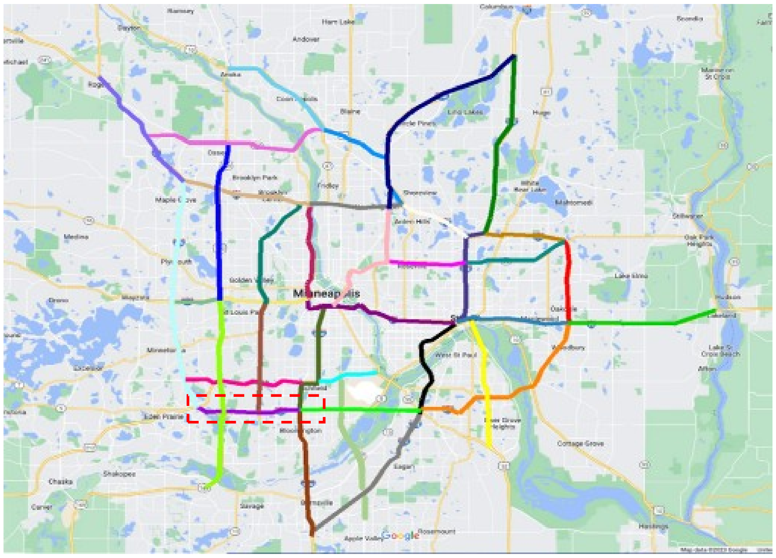


Yearly Variations of Buffer Index - Travel Rate Relationships



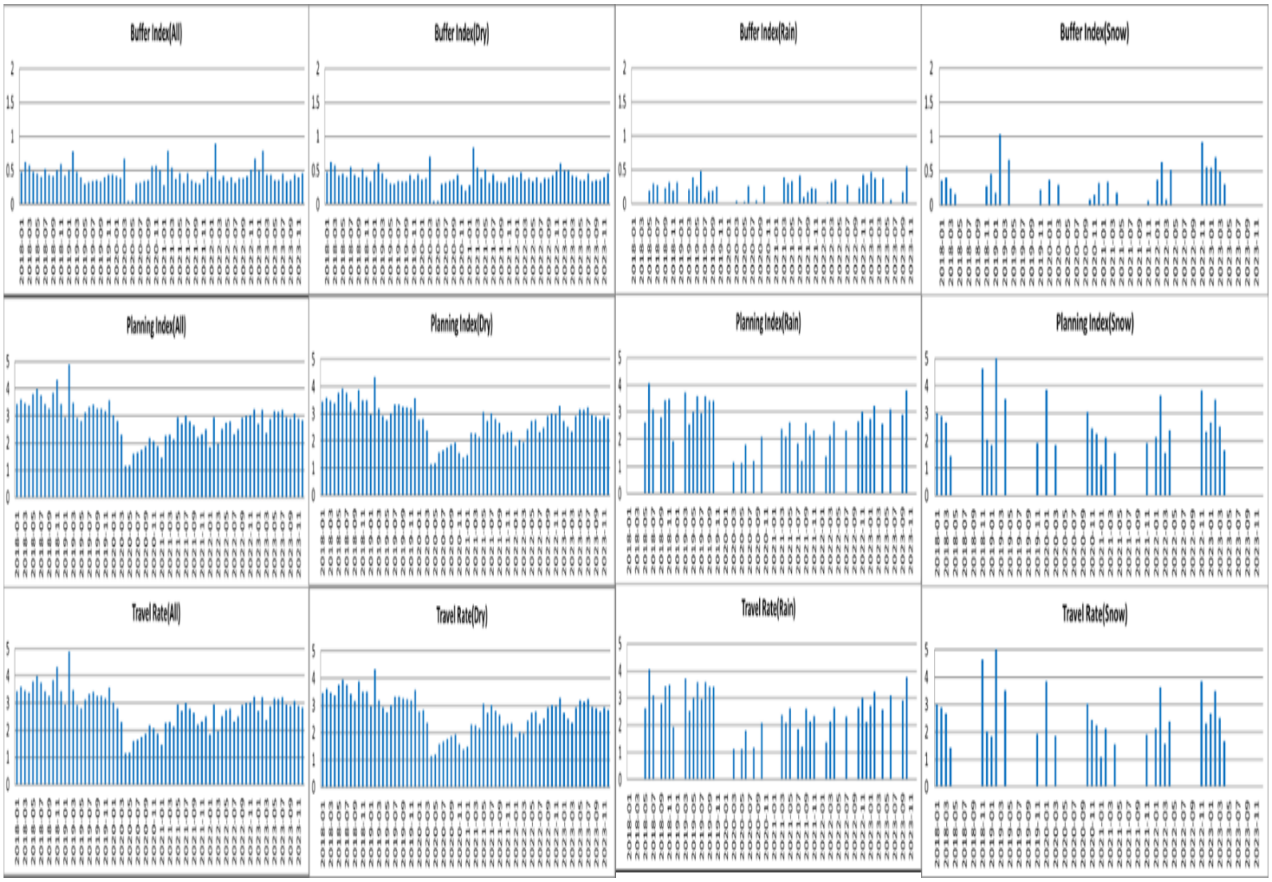
Variations of Traffic-Flow Measures

6) TH-62 Corridor A (I494 <--> I35W)

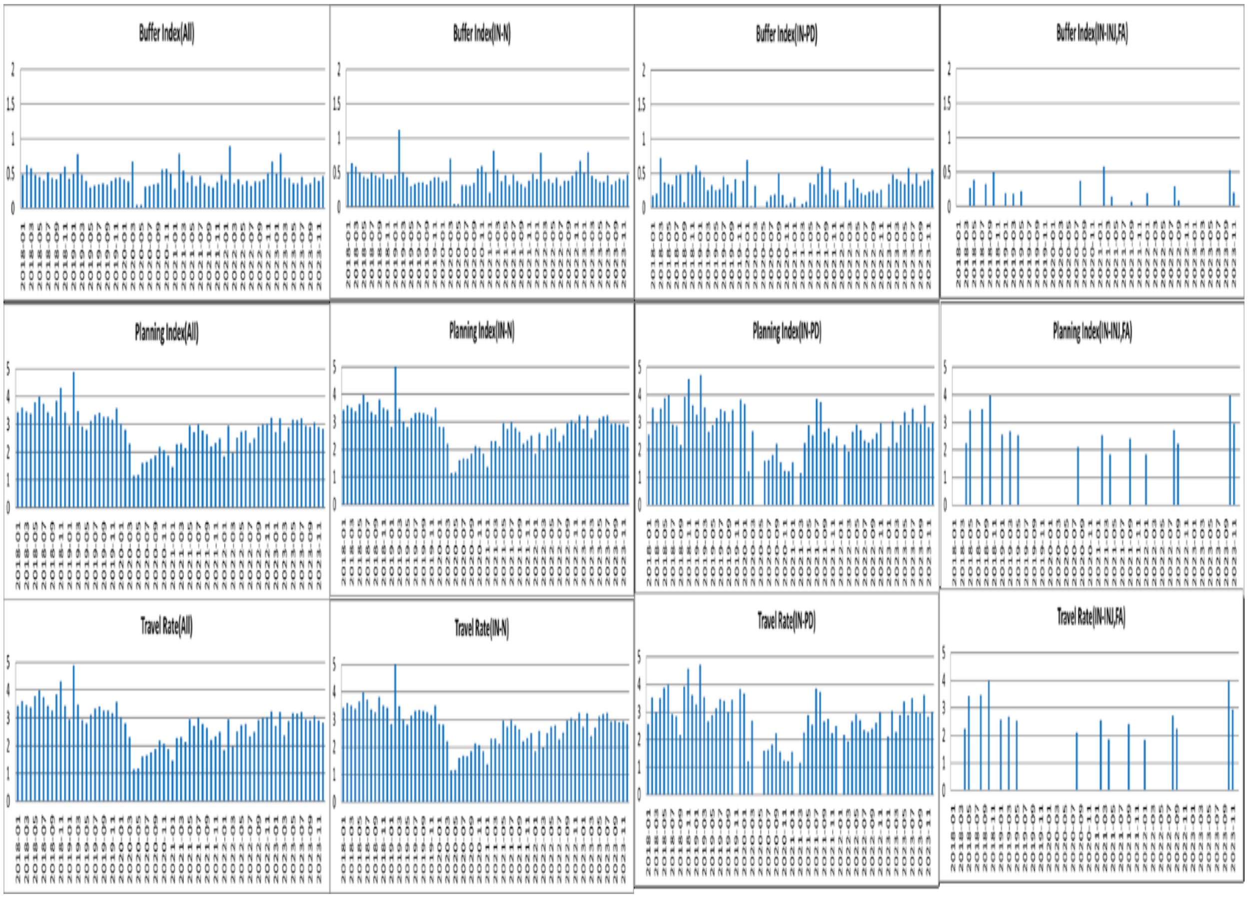


i) TH-62 Corridor A EB – I494 to I35W for Afternoon Peak Periods

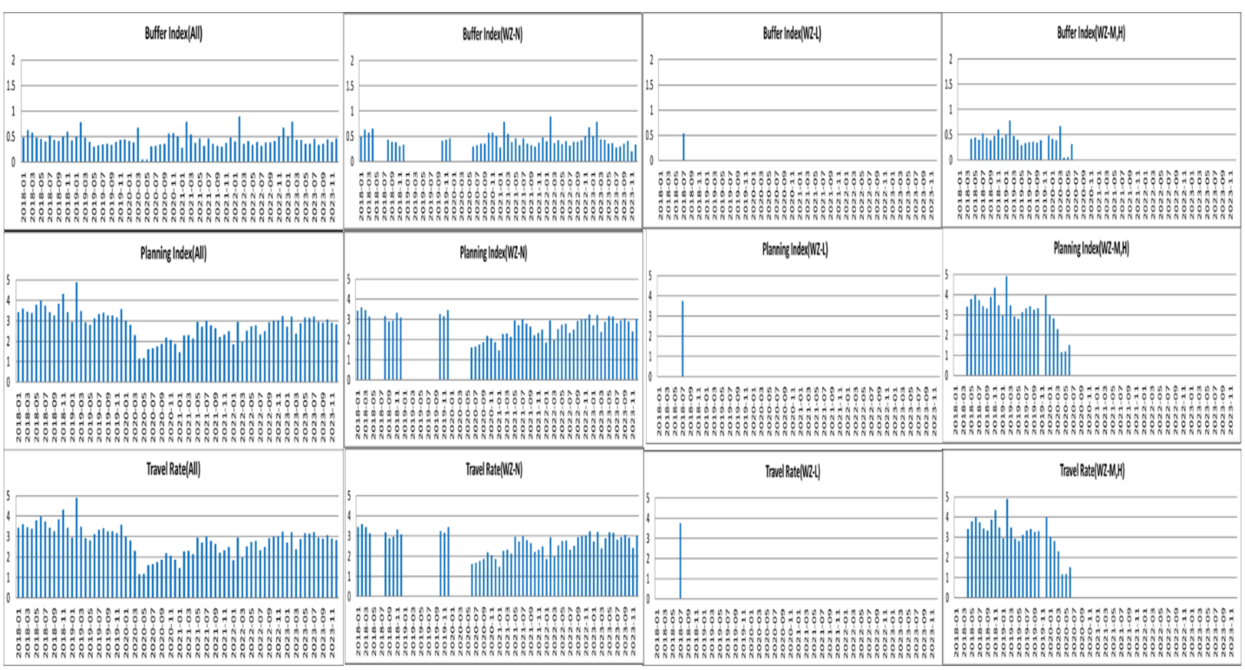
Effects of Weather conditions on Travel-Time Reliability



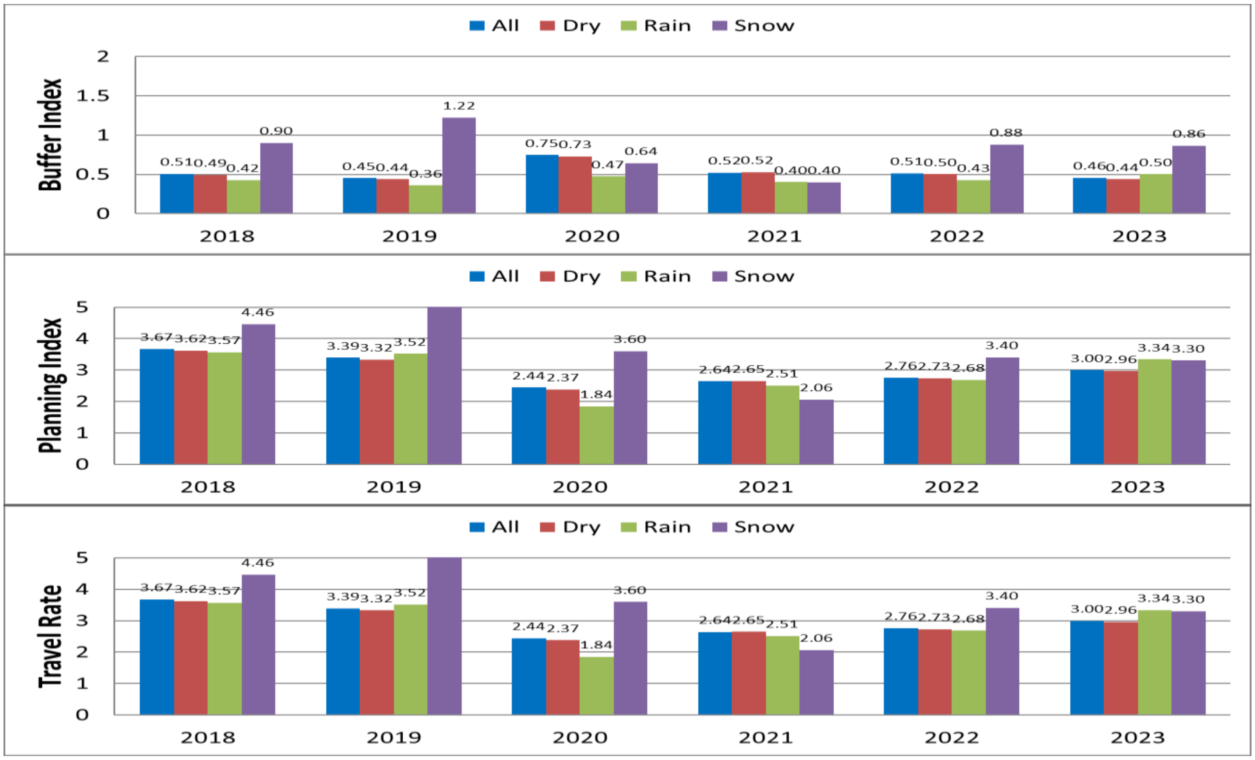
Effects of Incidents



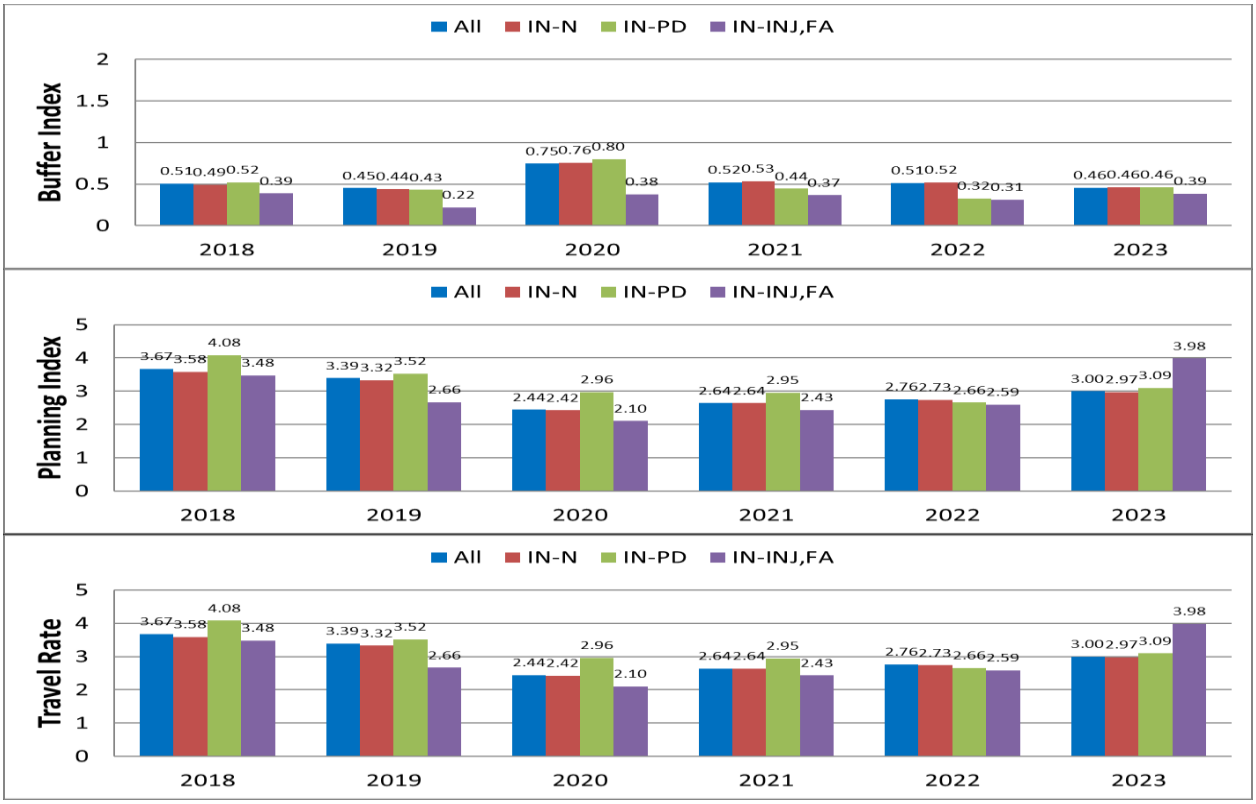
Effects of Work Zones



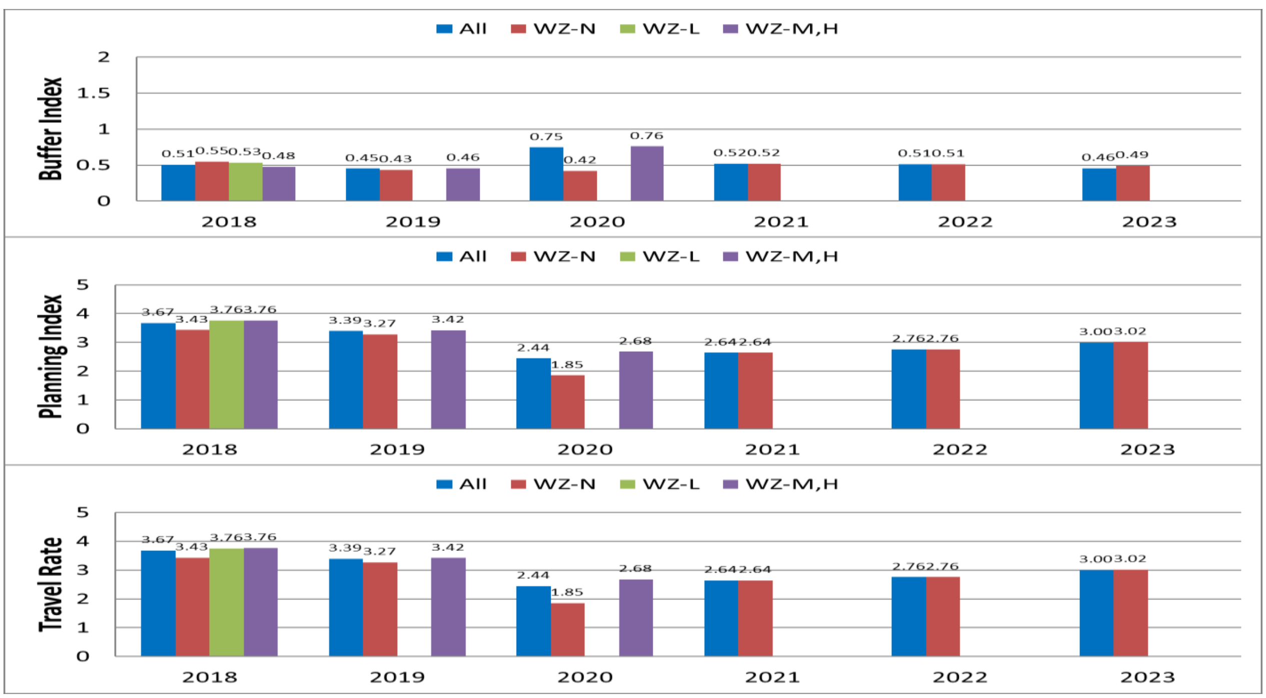
Yearly Variations - *Weather Effects*



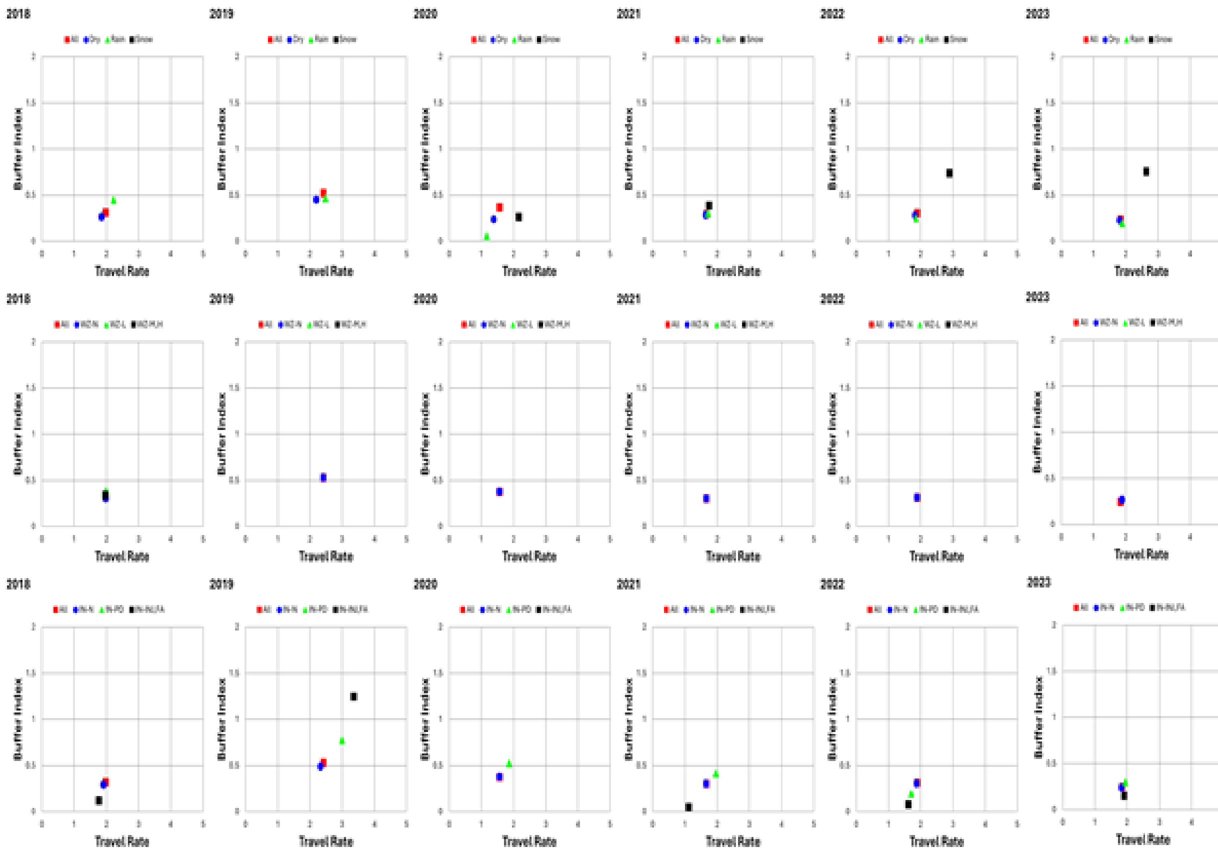
Incident Effects



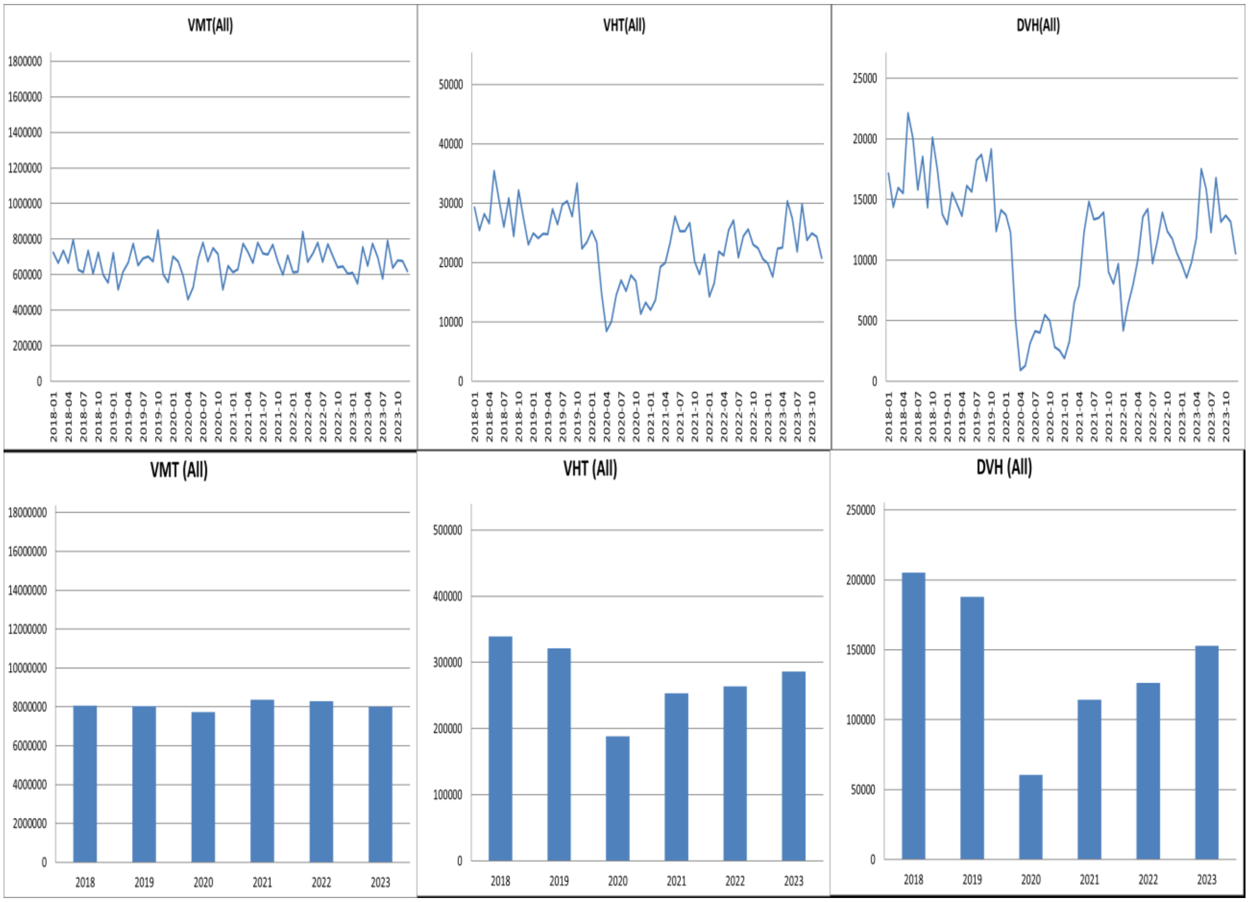
Work-Zone Effects



Yearly Variations of Buffer Index - Travel Rate Relationships

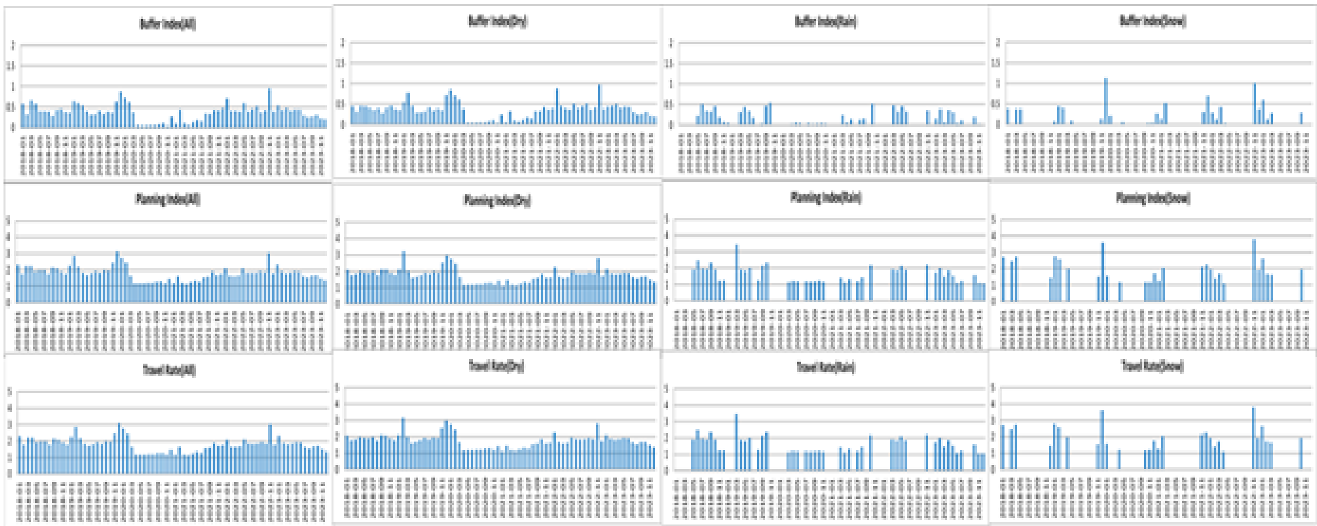


Variations of Traffic-Flow Measures

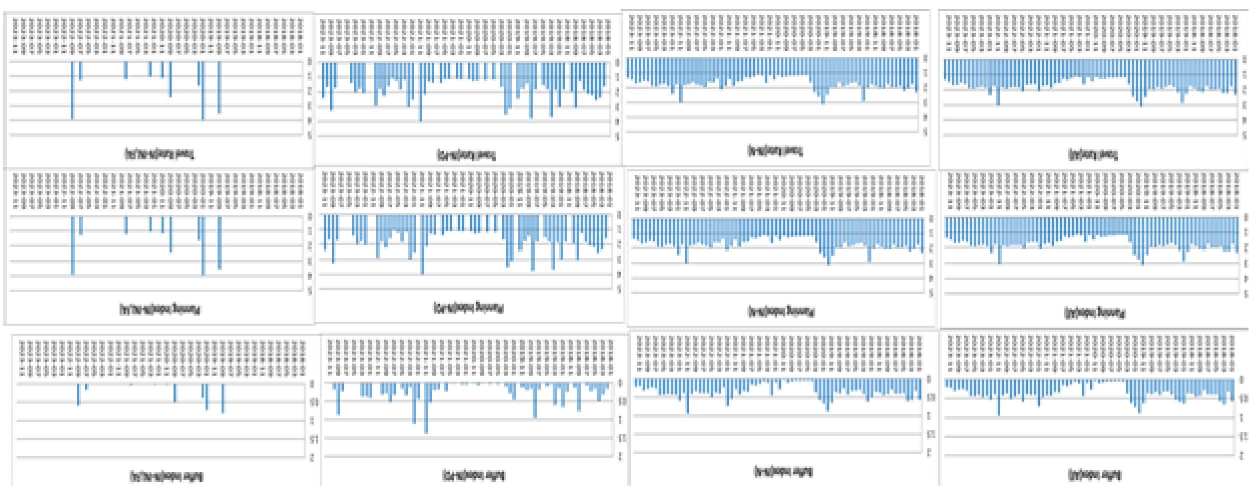

VMT(All)
VHT(All)
DVH(All)
VMT (All)
VHT (All)
DVH (All)
2018
2019
2020
2021
2022
2023

ii) TH-62 Corridor A- WB I35W to 494 for Morning Peak Periods

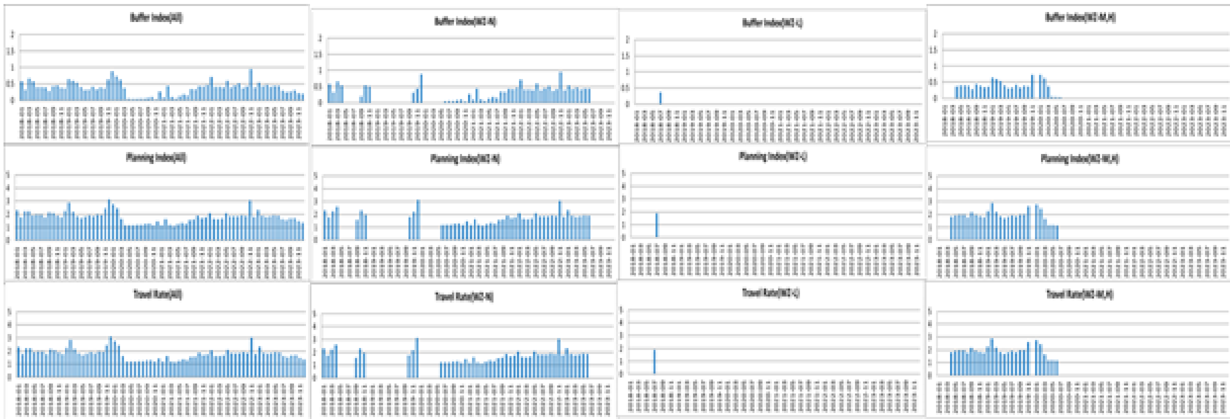
Effects of Weather conditions on Travel-Time Reliability



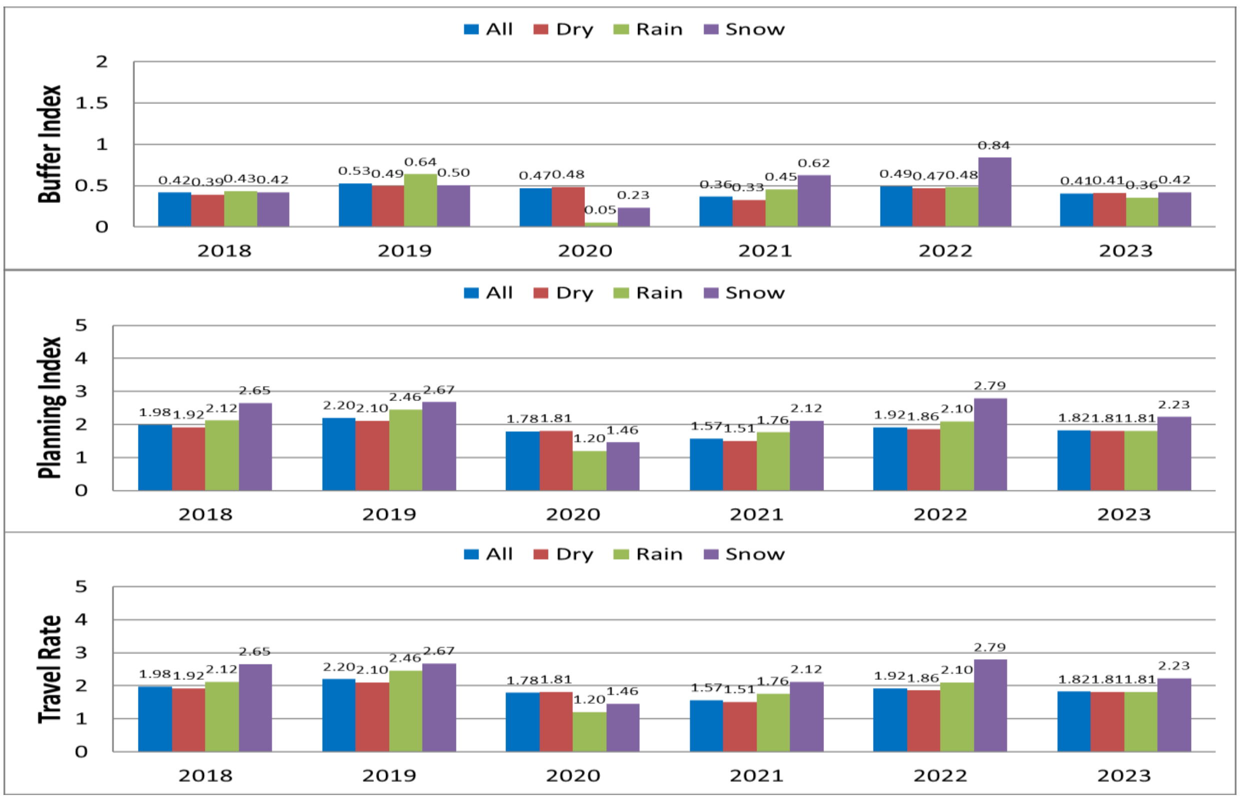
Effects of Incidents



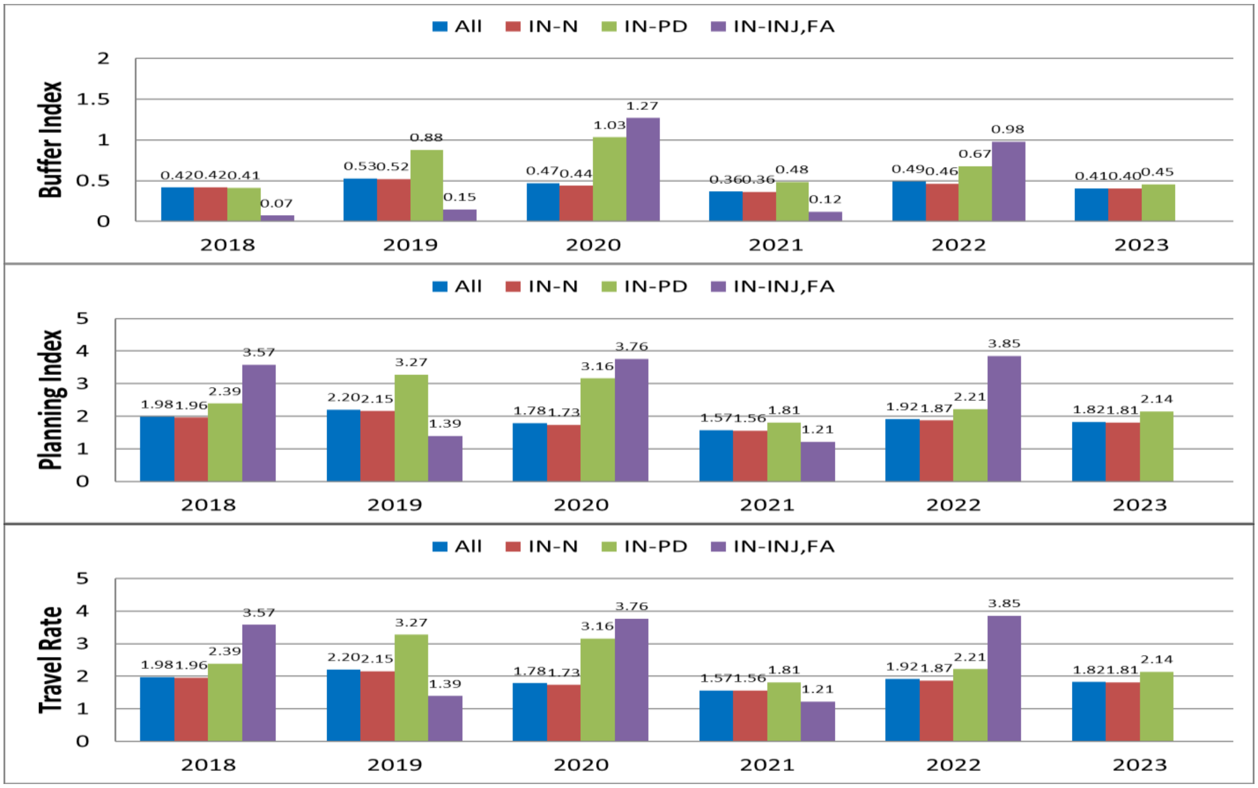
Effects of Work Zones



Yearly Variations - *Weather Effects*

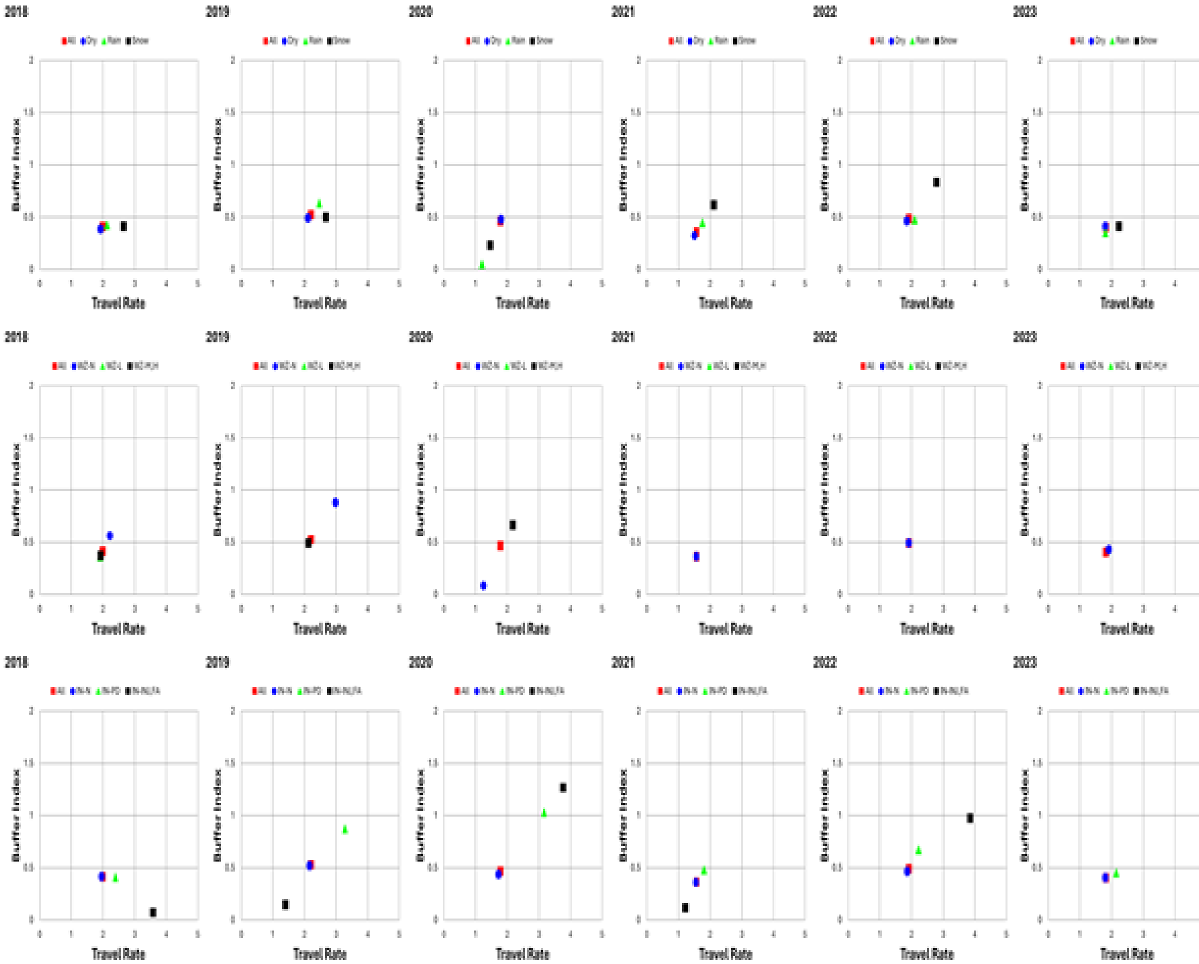


Incident Effects



Work-Zone Effects

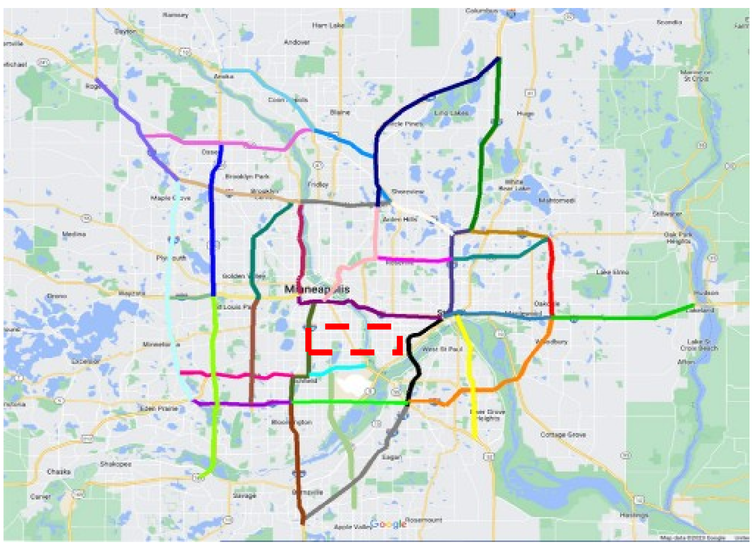
Yearly Variations of Buffer Index - Travel Rate Relationships



Variations of Traffic-Flow Measures

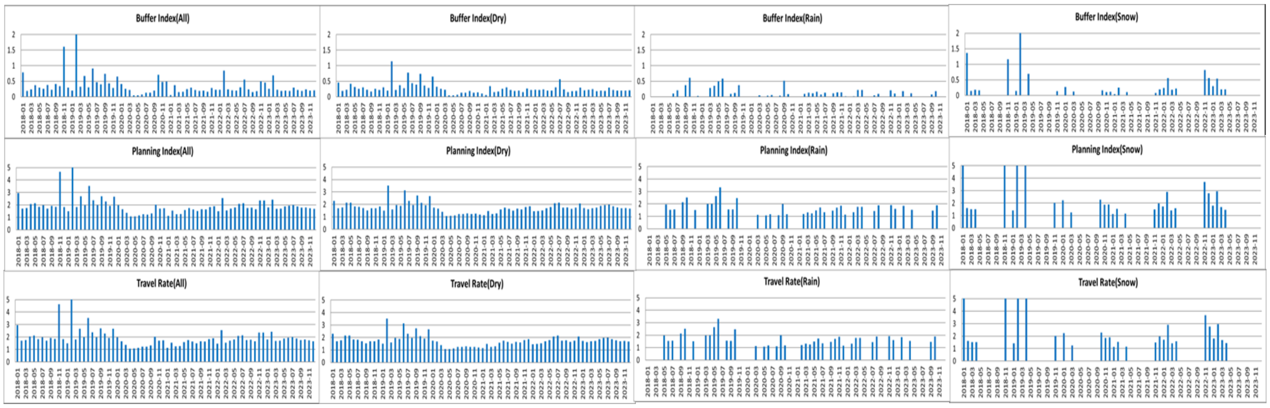

VMT(All)
VHT(All)
DVH(All)
VMT (All)
VHT (All)
DVH (All)
2018
2019
2020
2021
2022
2023

7) TH-62 Corridor B (I35W < -- >TH55)

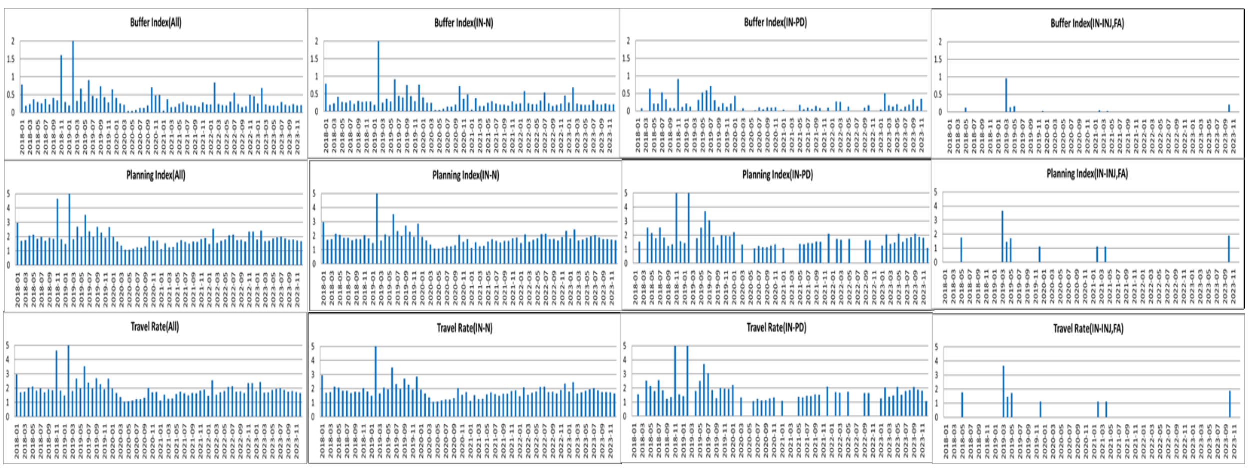


i) TH-62 Corridor B – EB I35W to TH55 for Afternoon Peak Periods

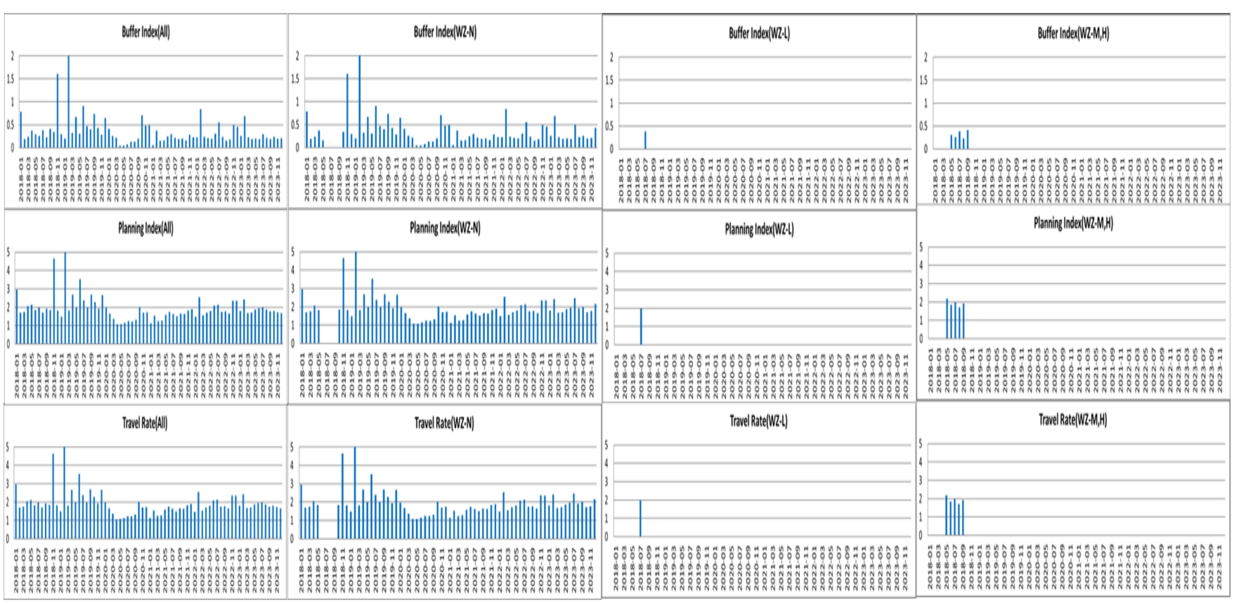
Effects of Weather conditions on Travel-Time Reliability



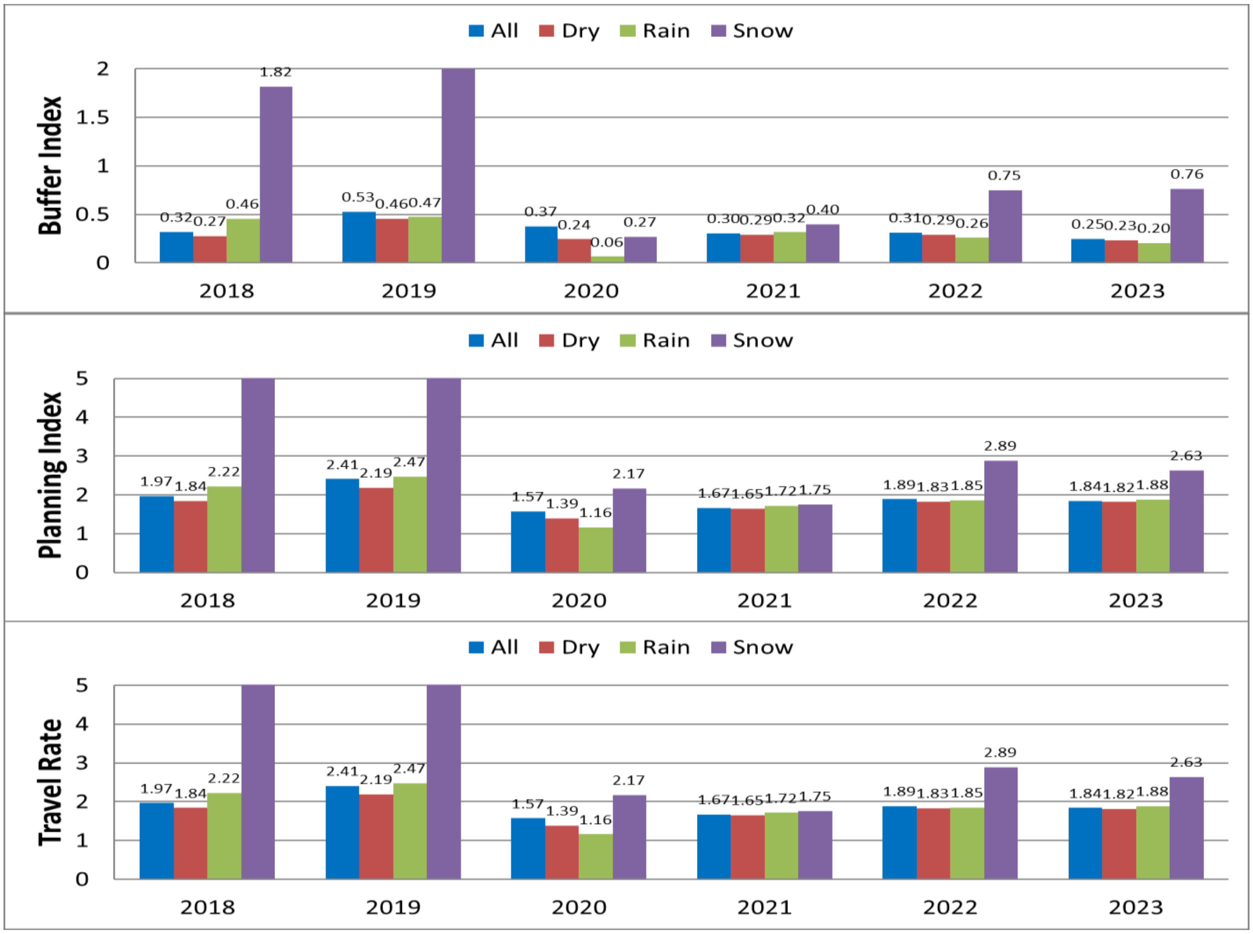
Effects of Incidents



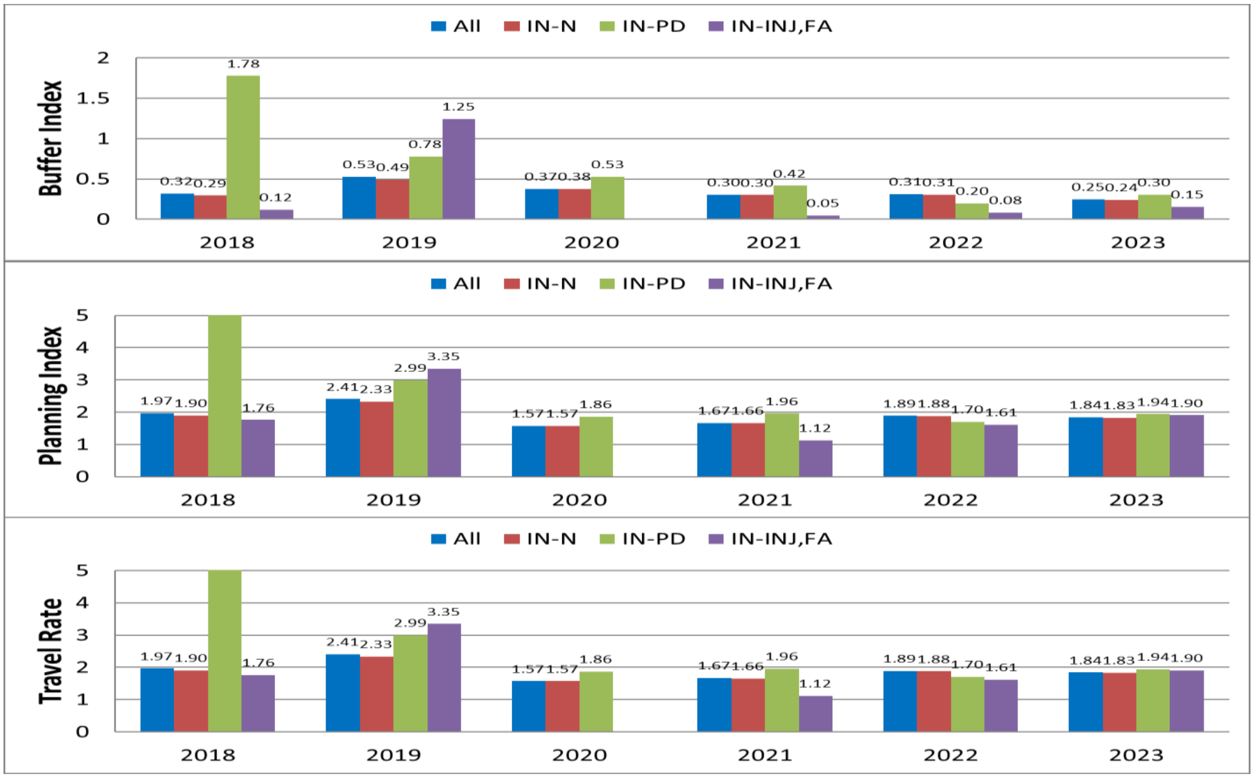
Effects of Work Zones



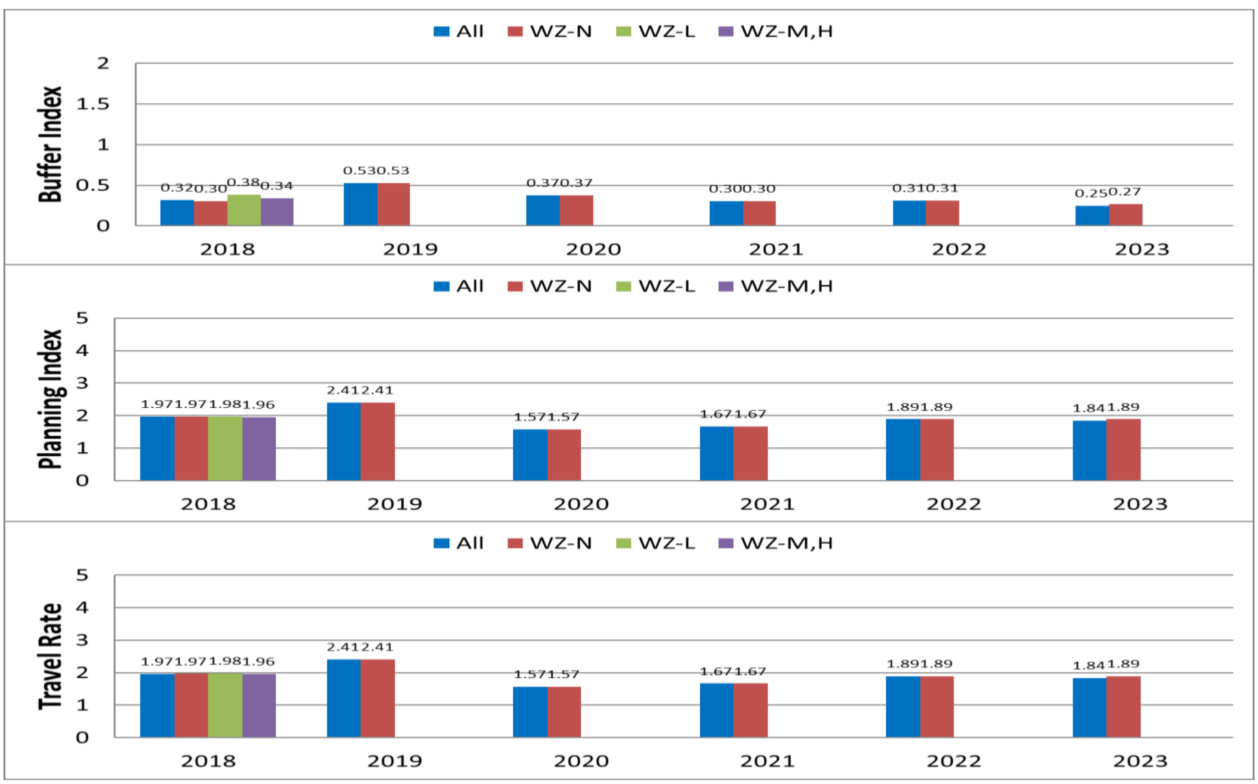
Yearly Variations - *Weather Effects*



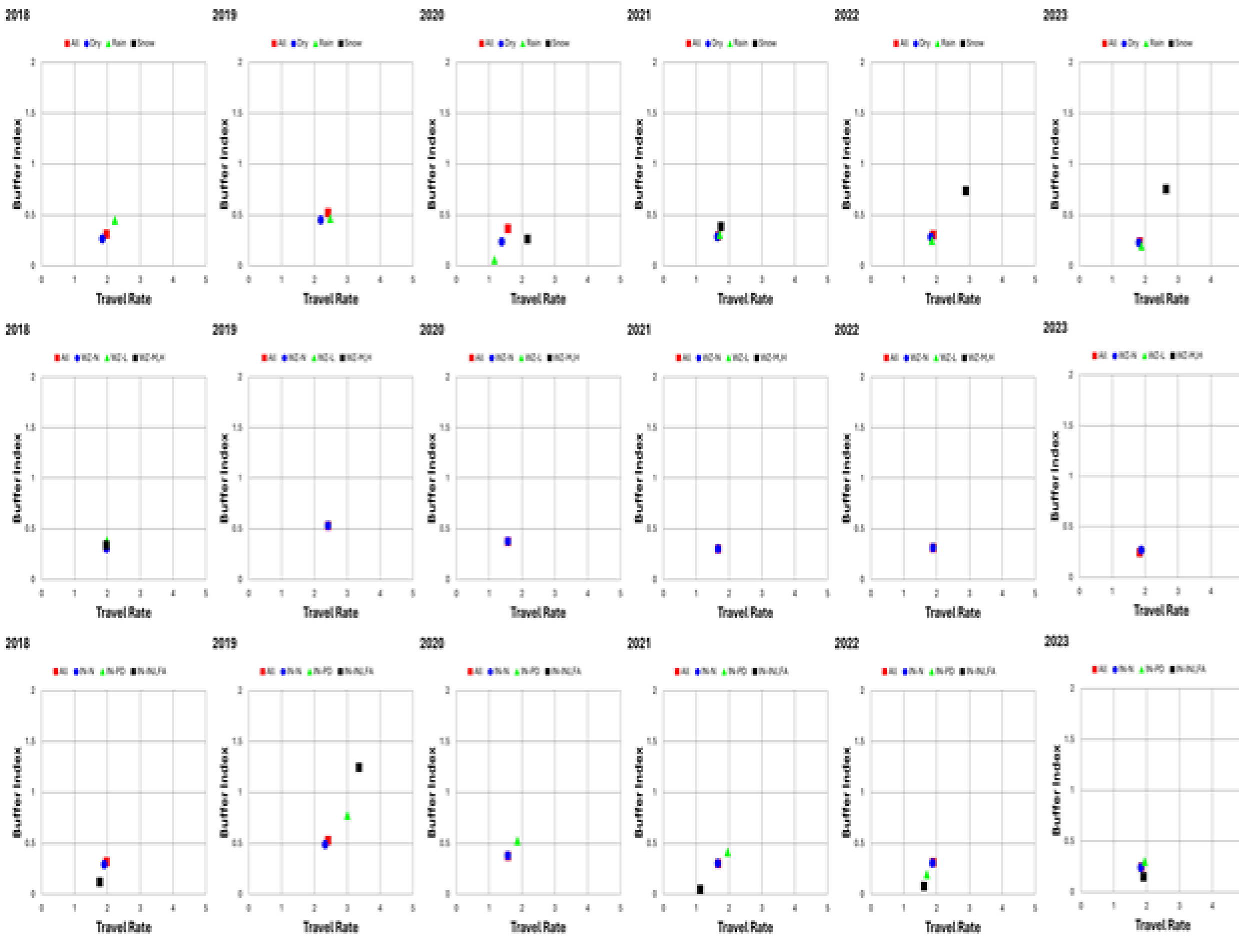
Incident Effects



Work-Zone Effects



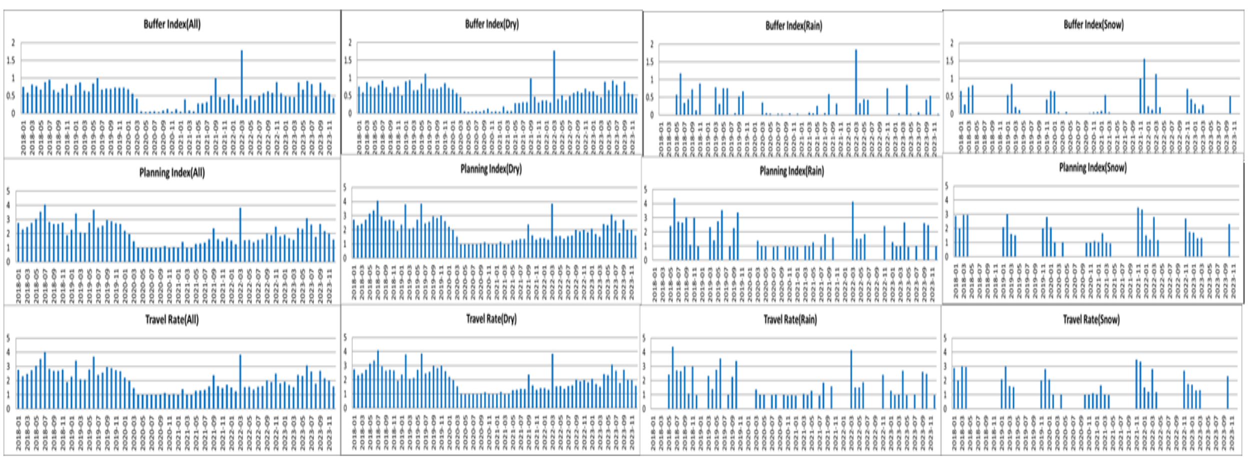
Yearly Variations of Buffer Index - Travel Rate Relationships



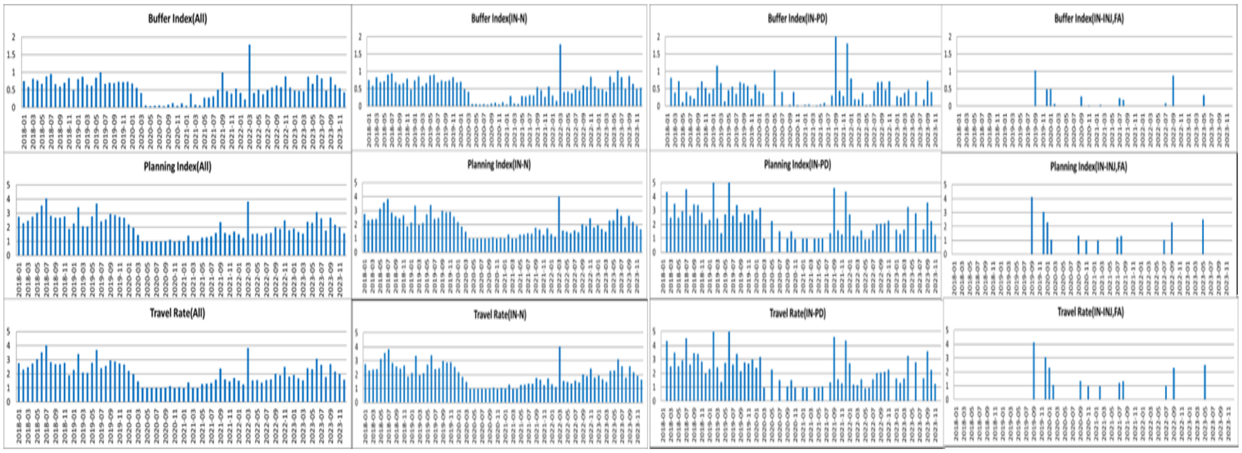
Variations of Traffic-Flow Measures

ii) TH-62 Corridor B - WB TH55 to I35W for Morning Peak Periods

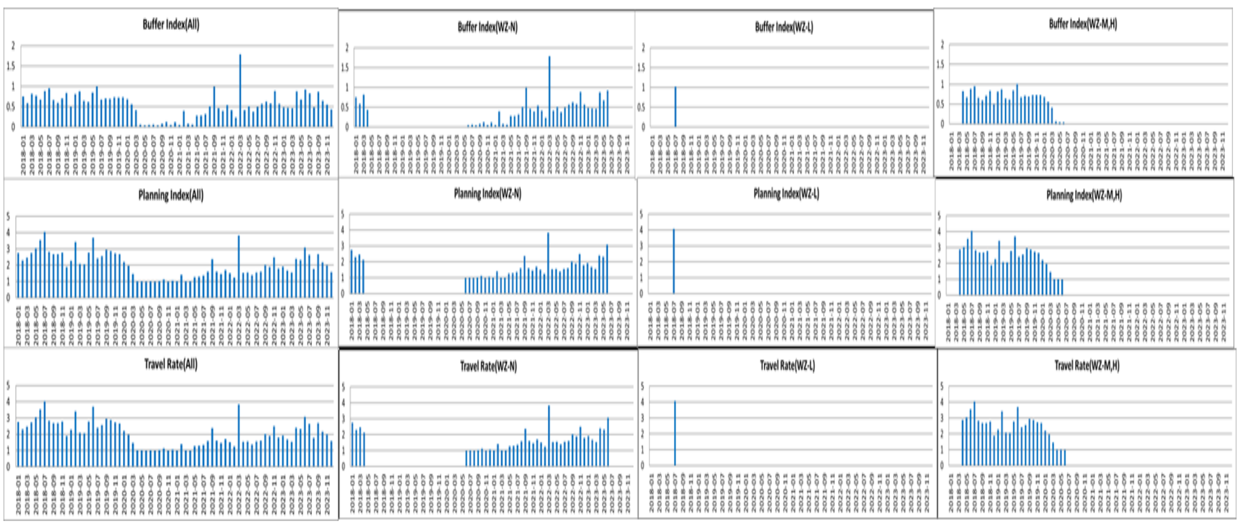
Effects of Weather conditions on Travel-Time Reliability



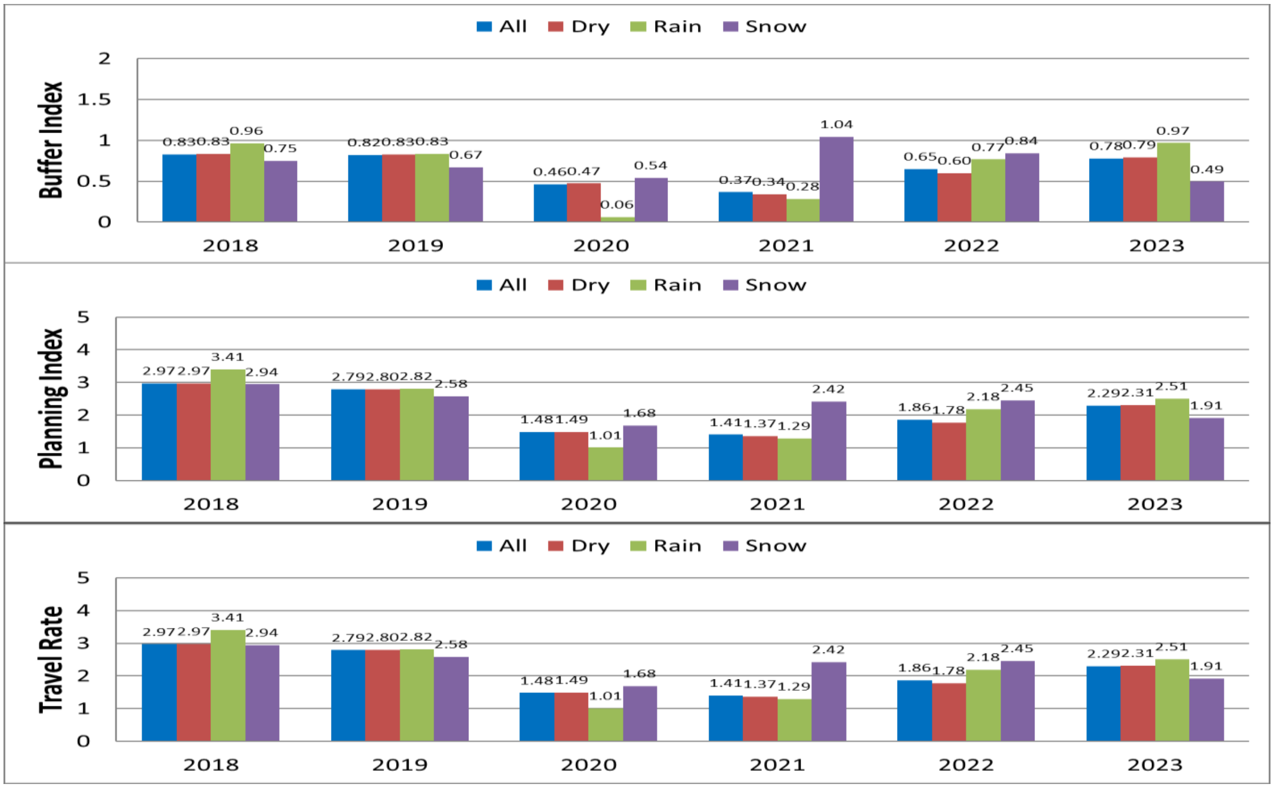
Effects of Incidents



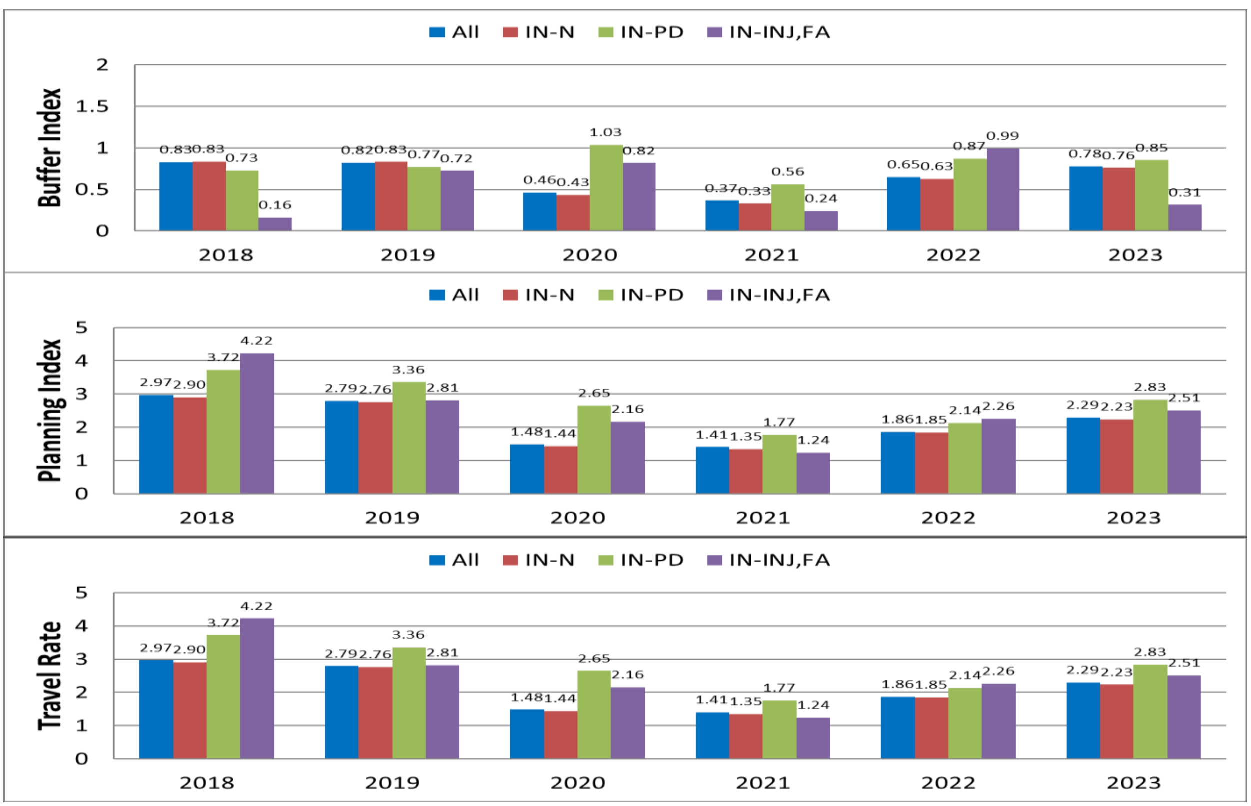
Effects of Work Zones



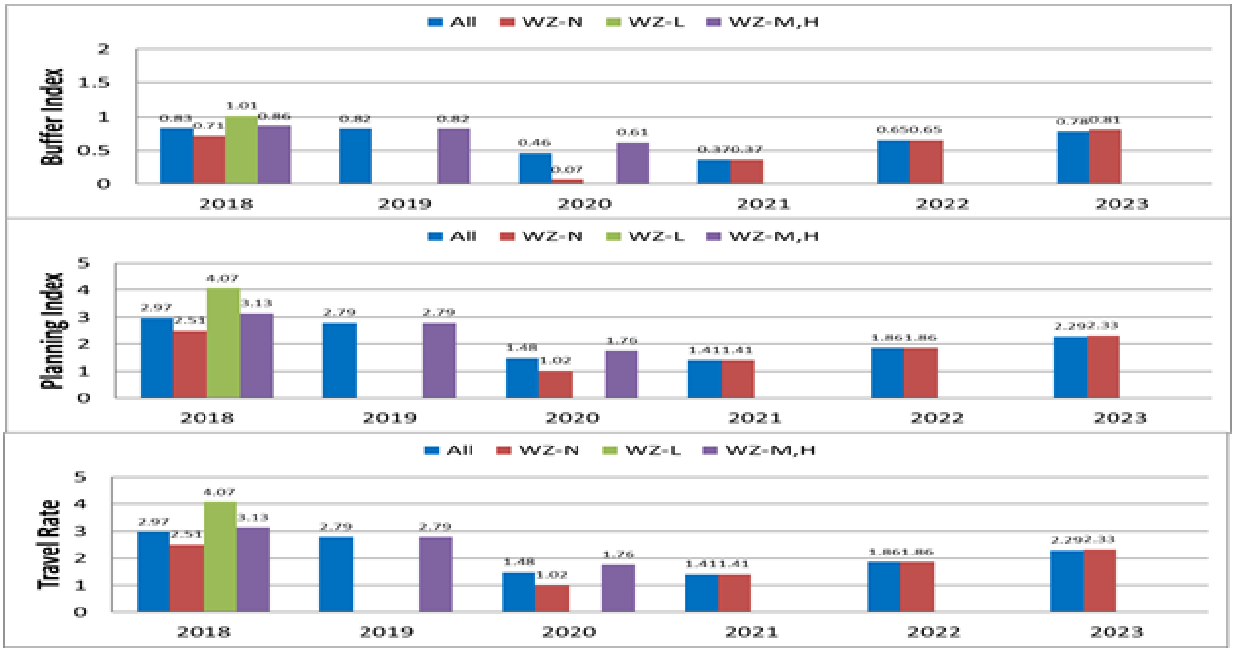
Yearly Variations - *Weather Effects*



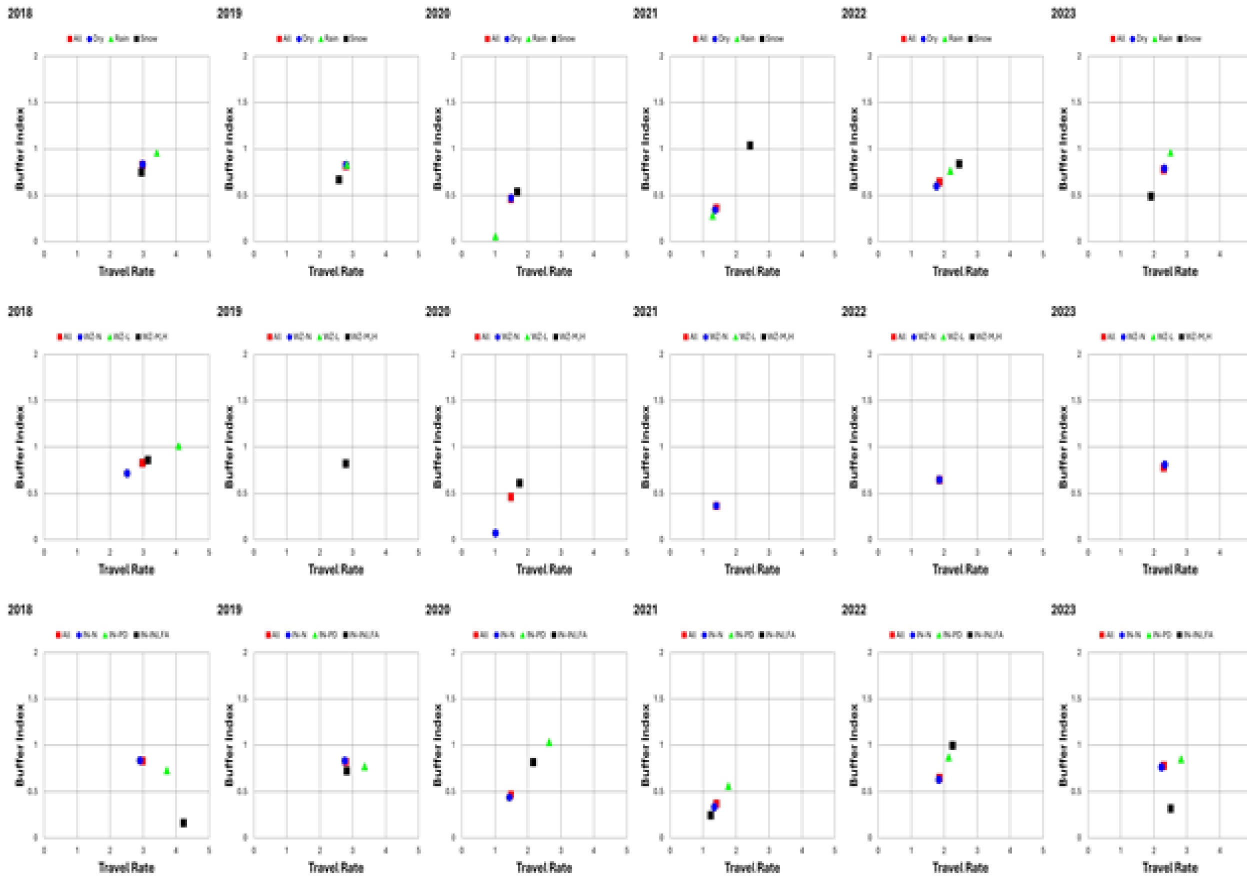
Incident Effects



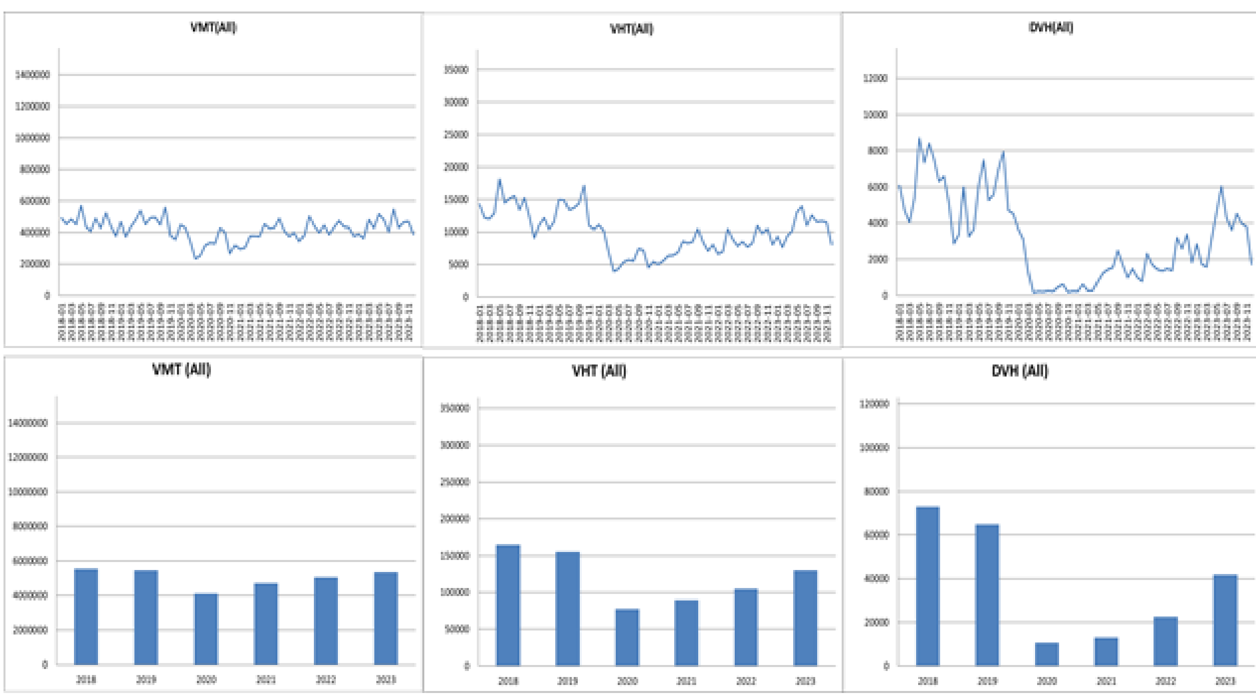
Work-Zone Effects



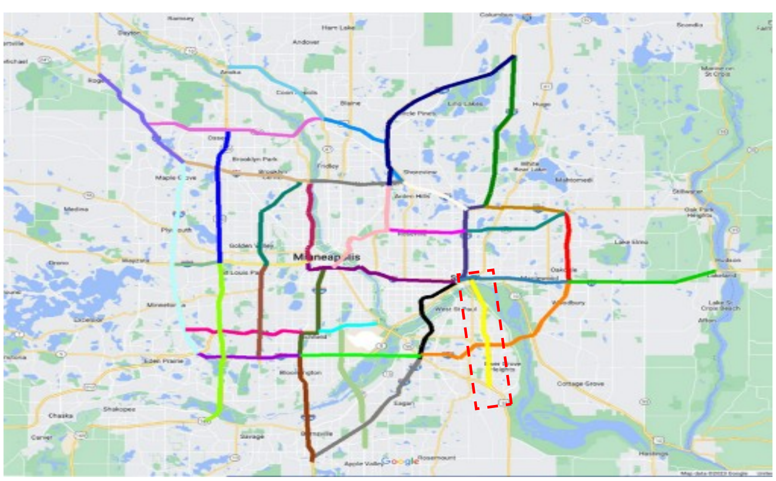
Yearly Variations of Buffer Index - Travel Rate Relationships



Variations of Traffic-Flow Measures

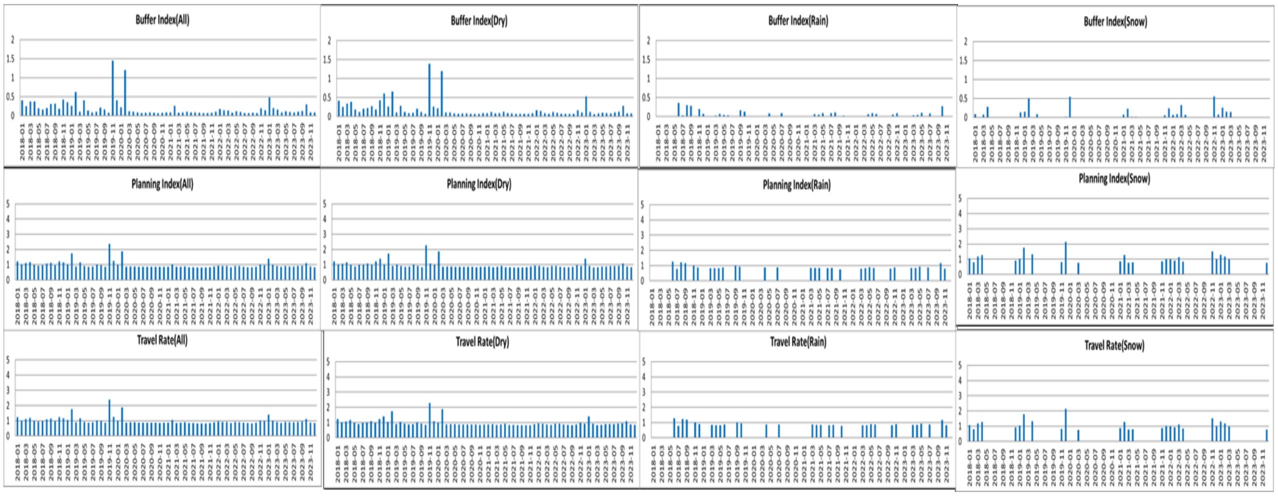


8) TH-52 (TH55 < -- > STPL)

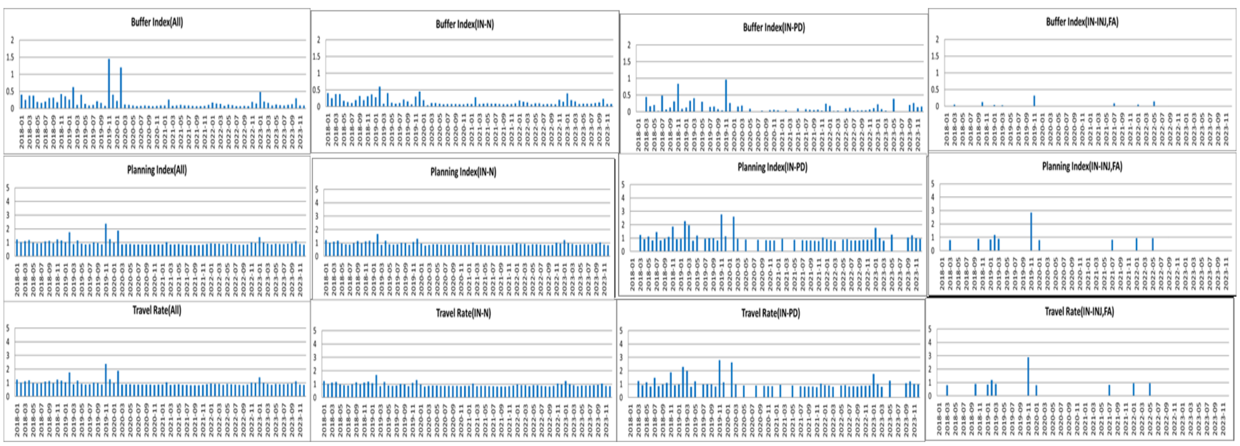


i) TH-52 NB TH55 to STPL for Morning Peak Periods

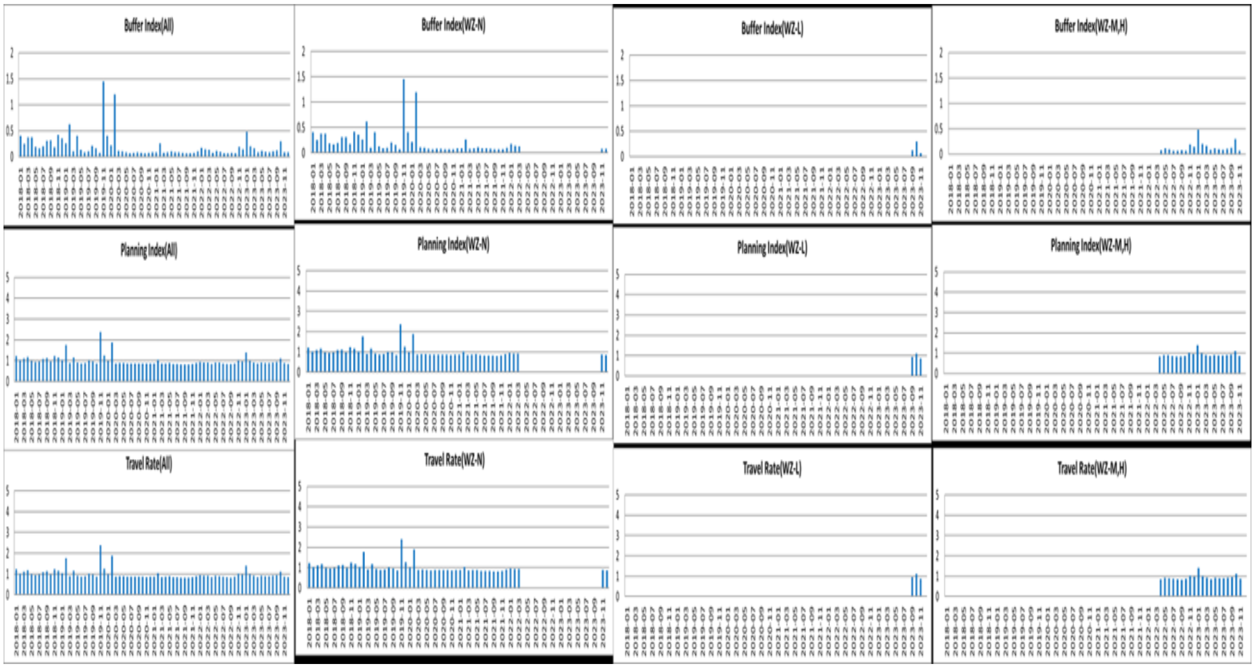
Effects of Weather conditions on Travel-Time Reliability



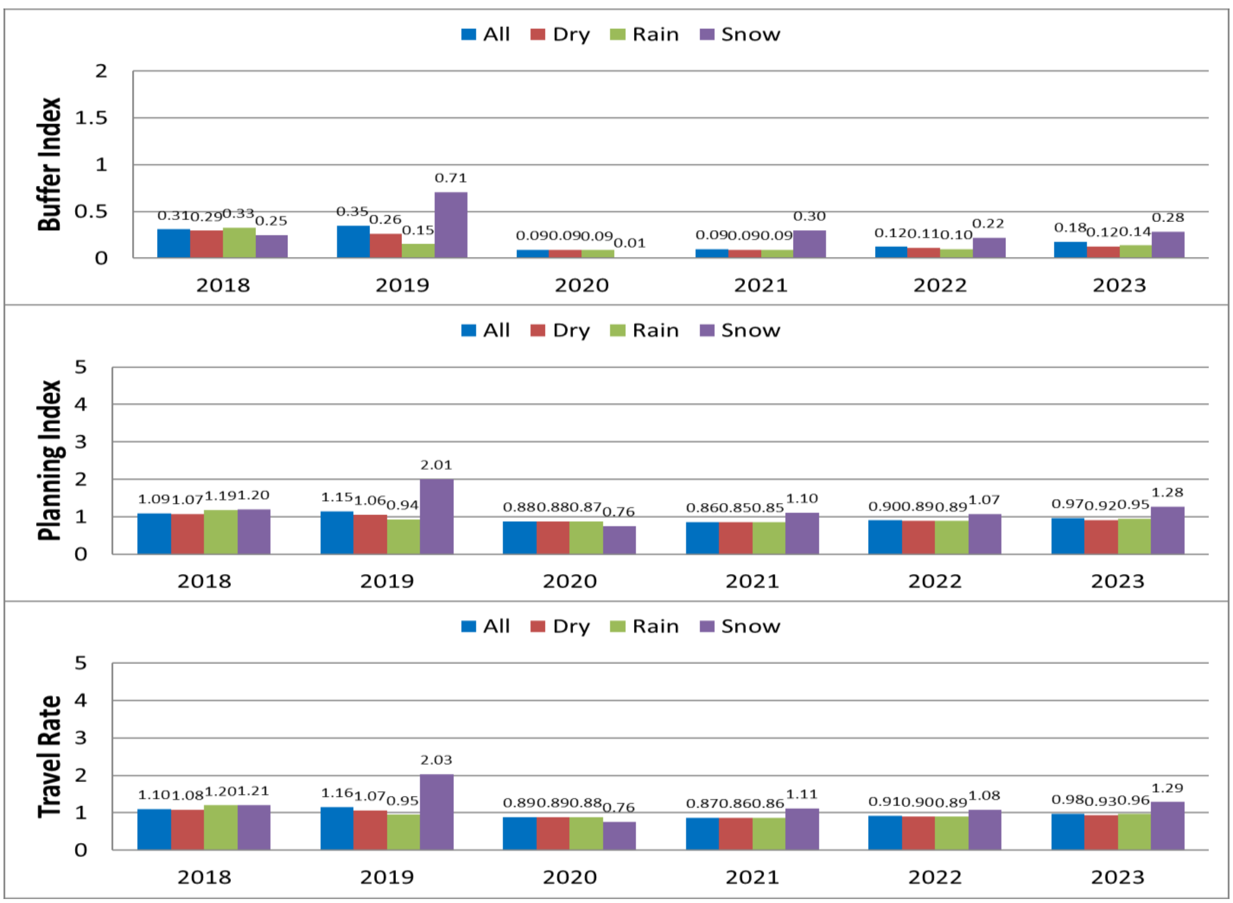
Effects of Incidents



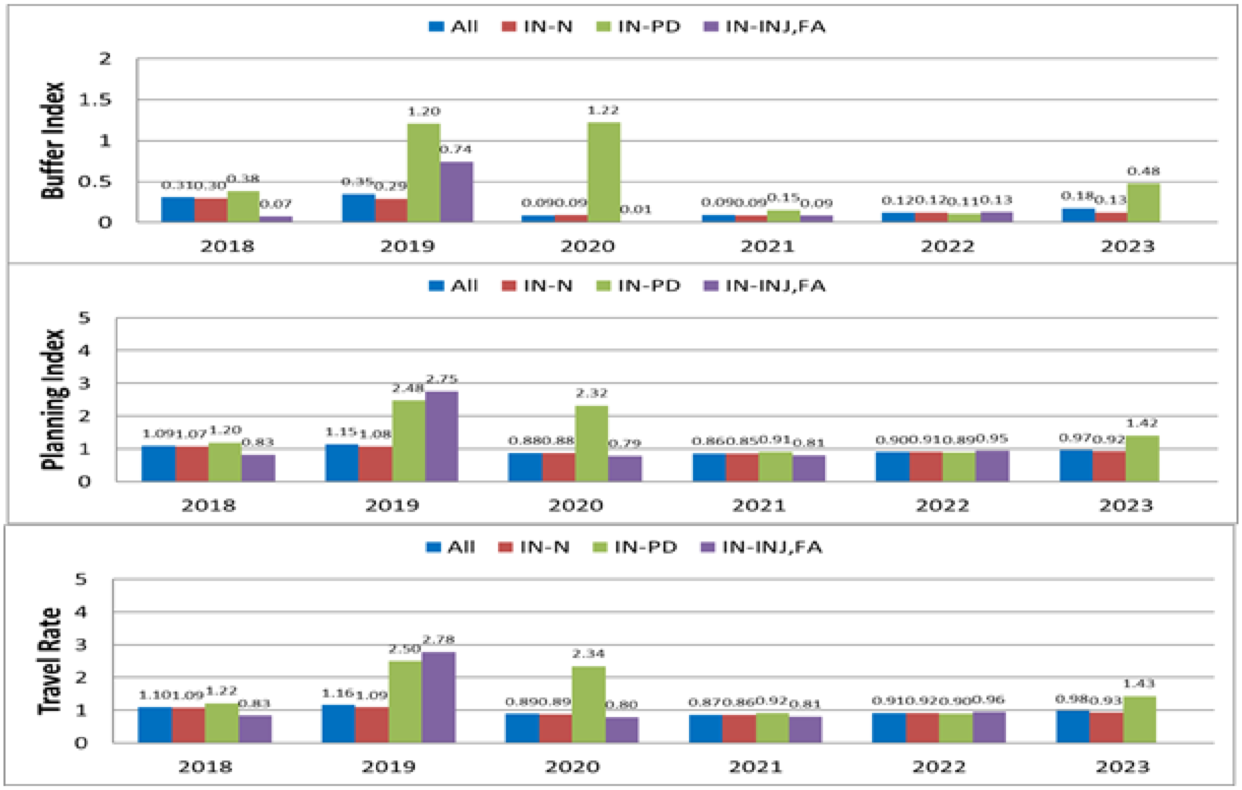
Effects of Work Zones



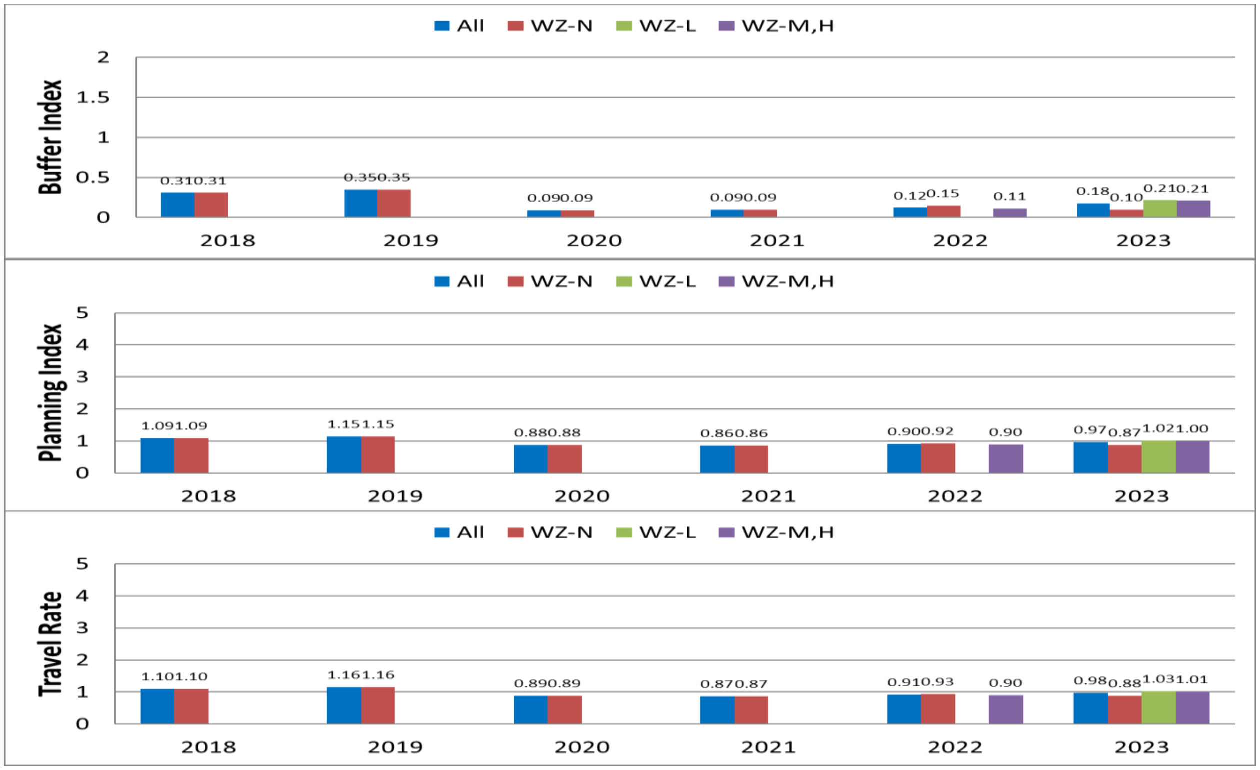
Yearly Variations - *Weather Effects*



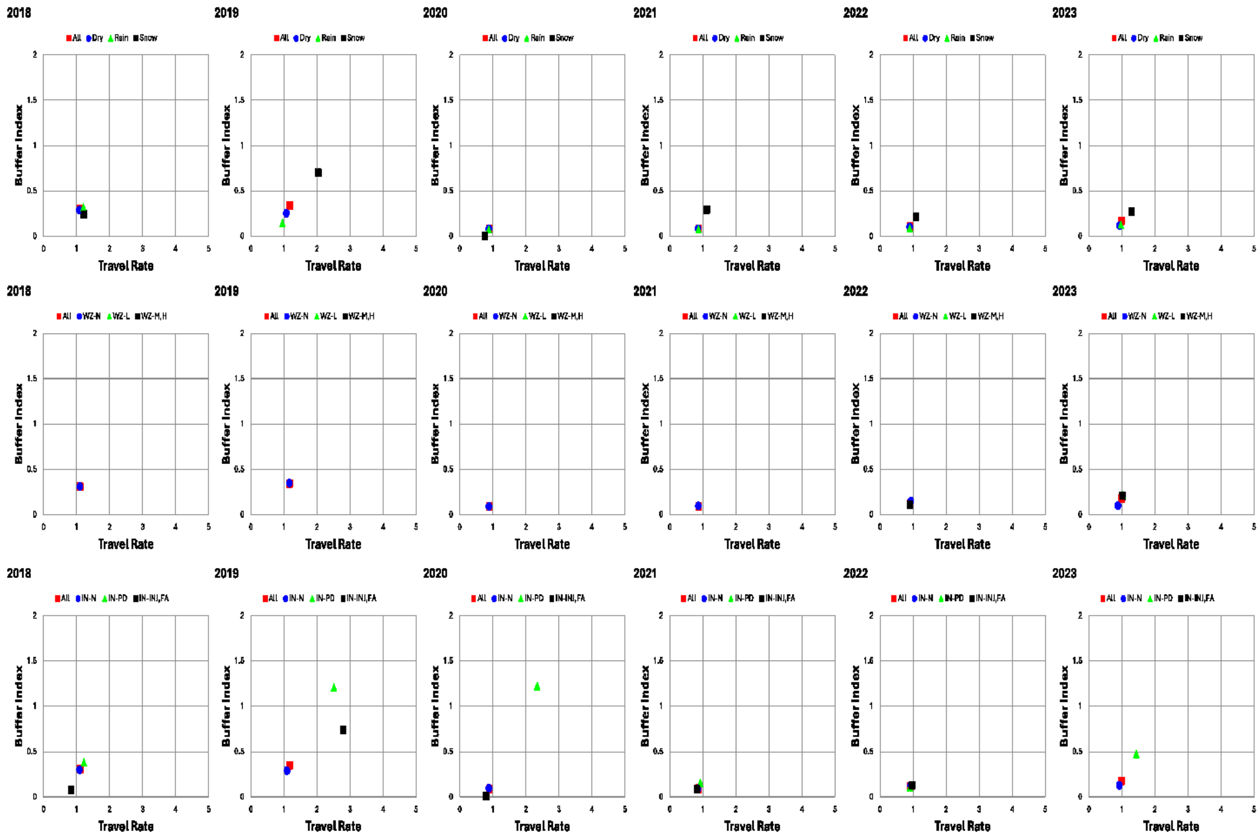
Incident Effects



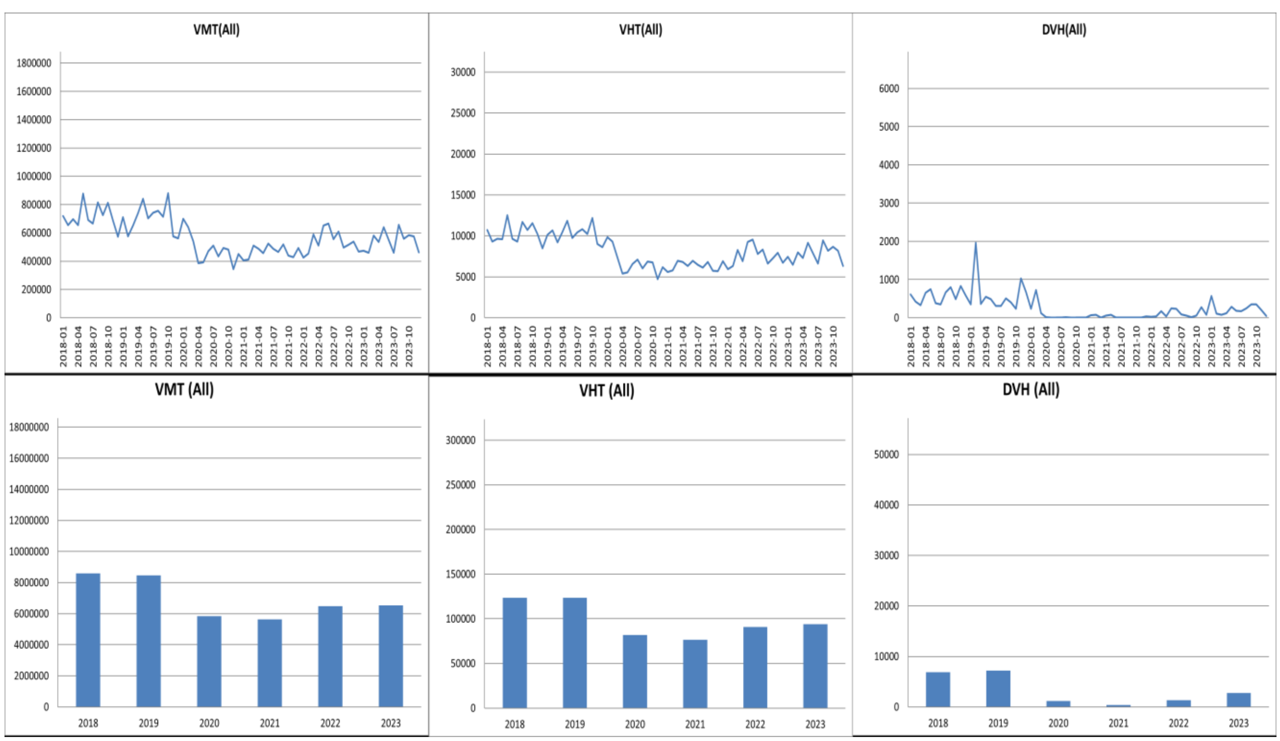
Work-Zone Effects



Yearly Variations of Buffer Index - Travel Rate Relationships

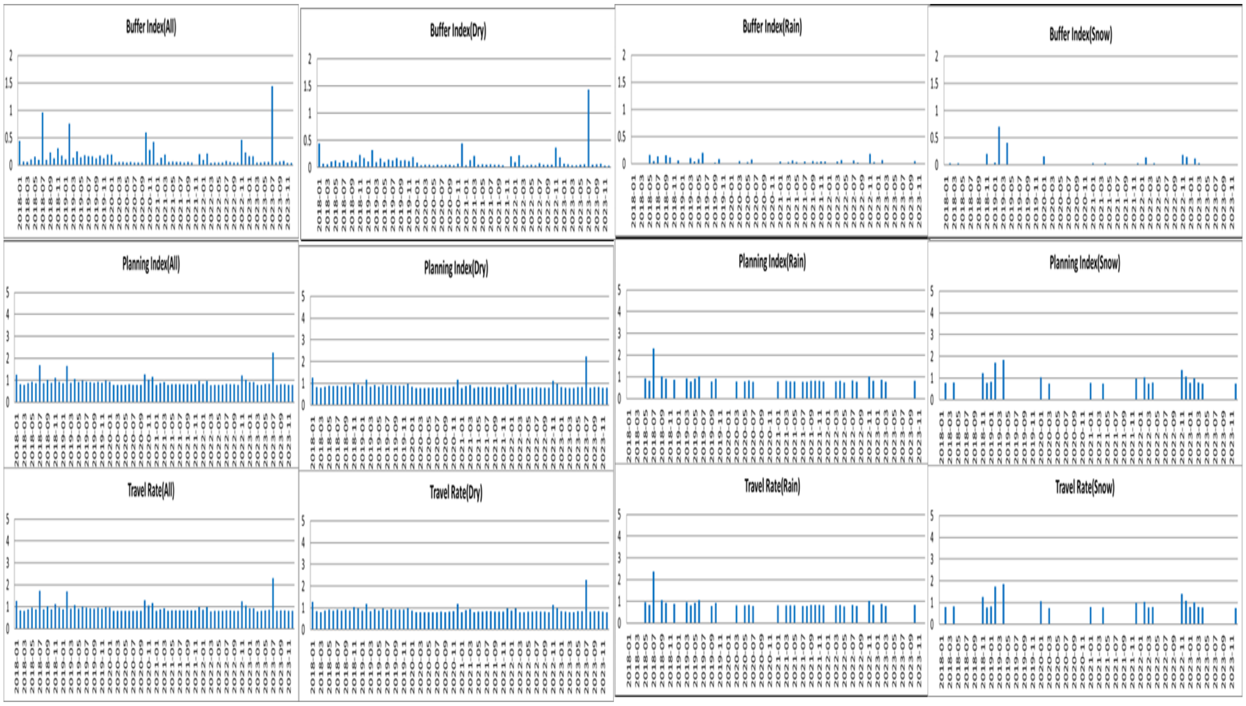


Variations of Traffic-Flow Measures

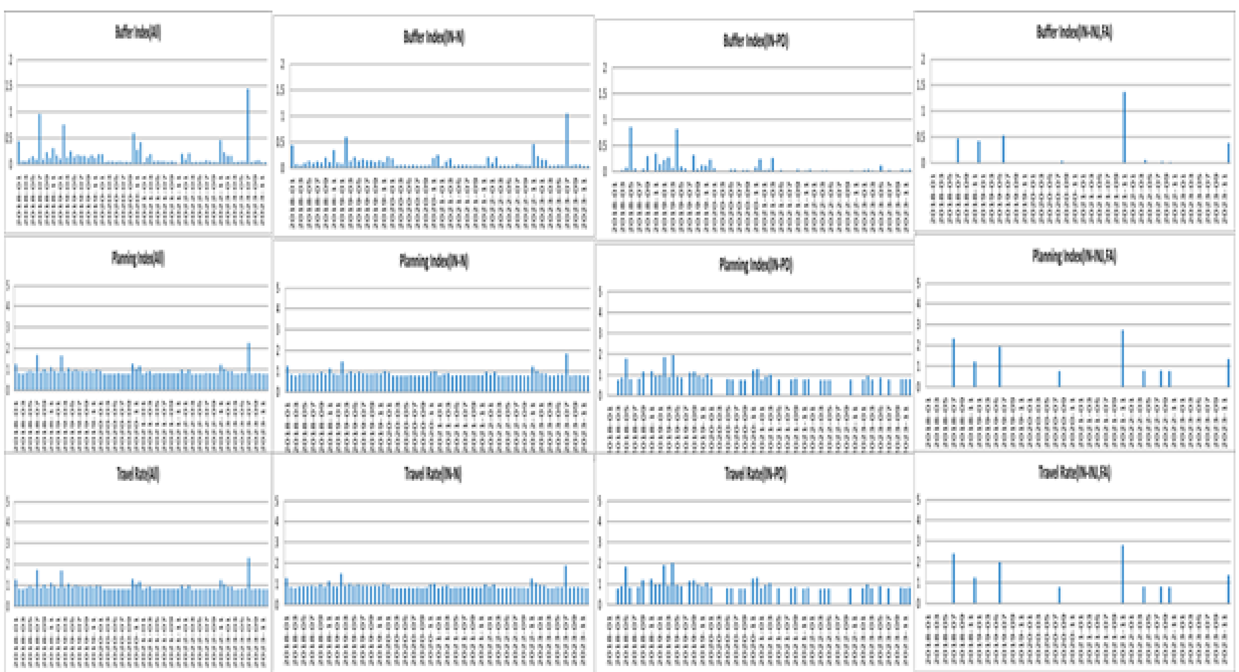


ii) TH-52 SB – STPL to TH55 for Afternoon Peak Periods

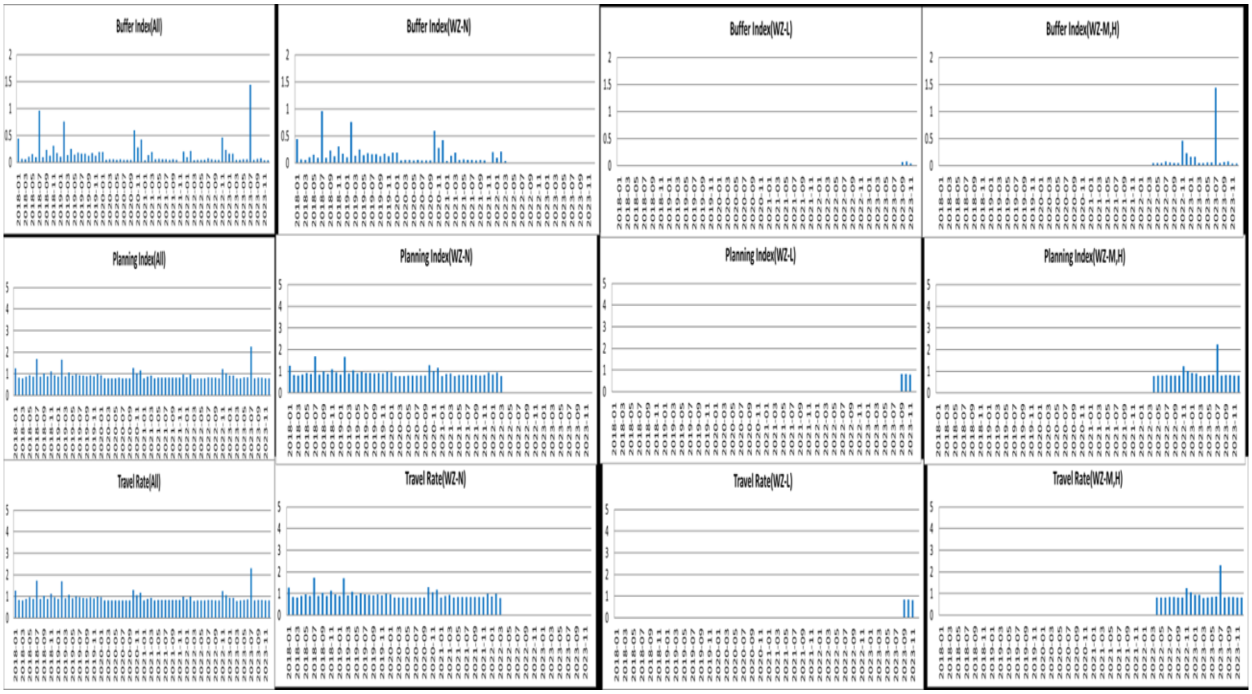
Effects of Weather conditions on Travel-Time Reliability



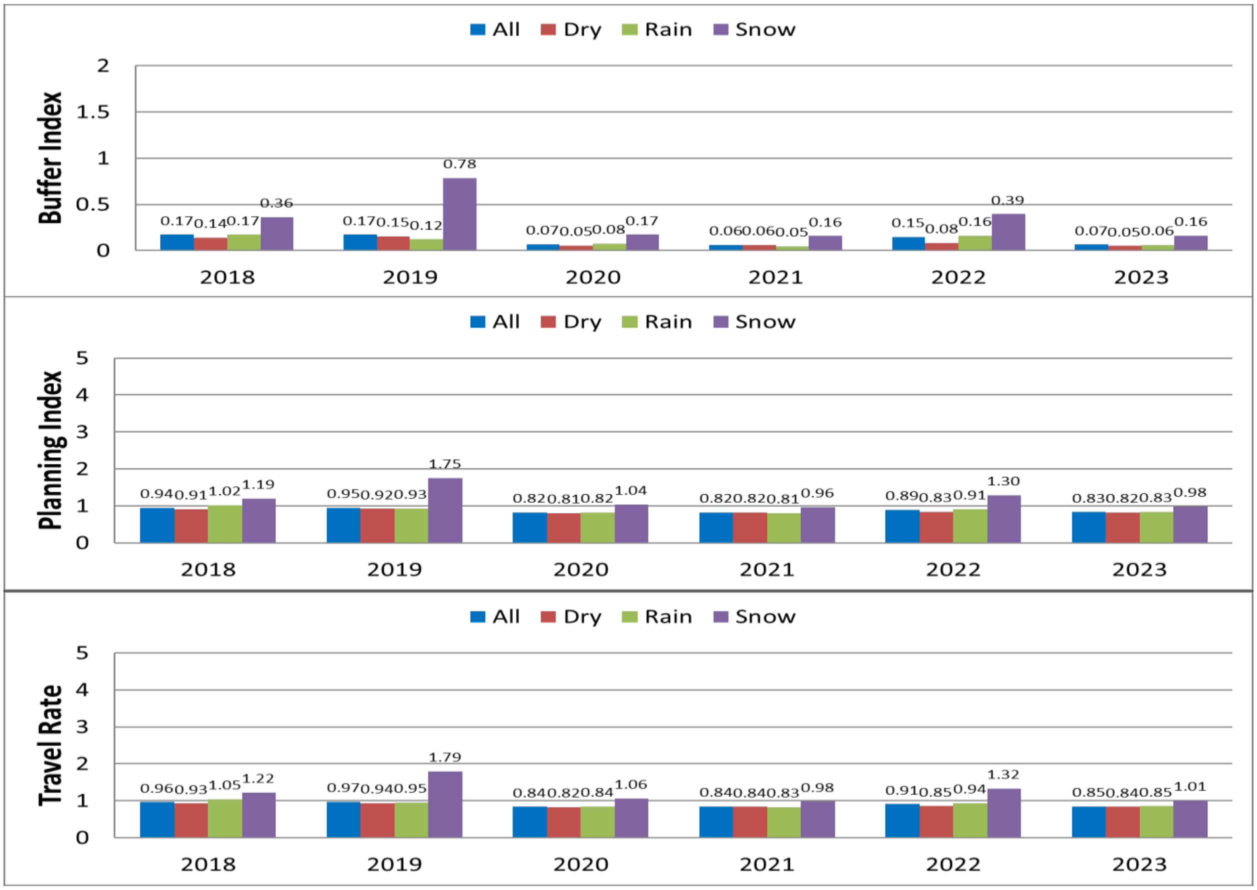
Effects of Incidents



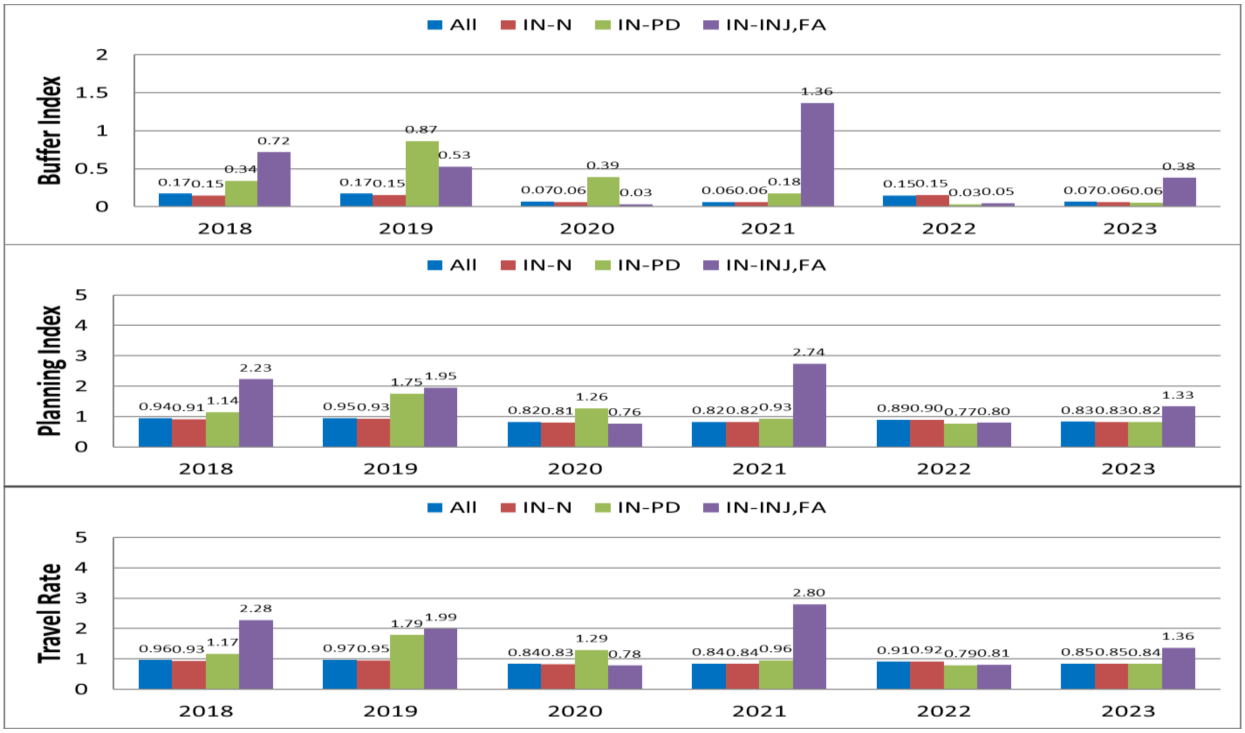
Effects of Work Zones



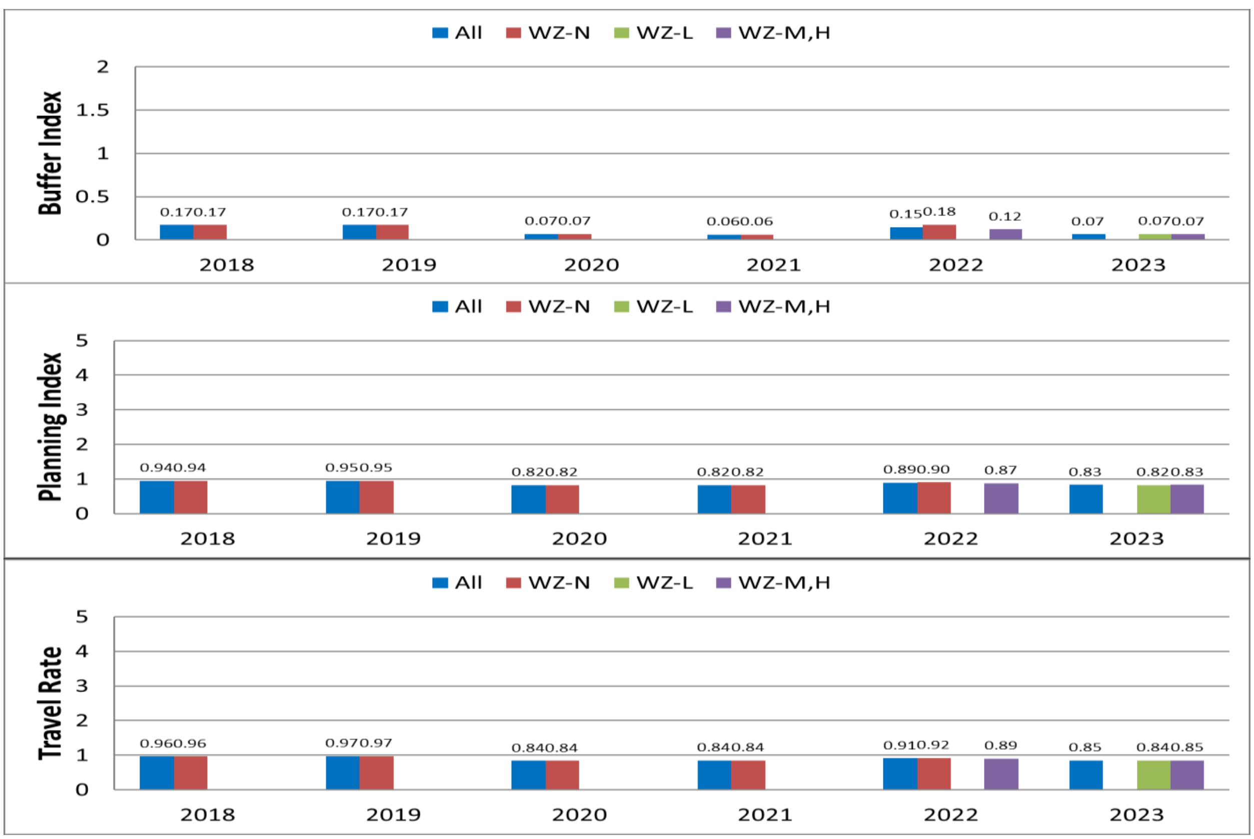
Yearly Variations - ***Weather Effects***



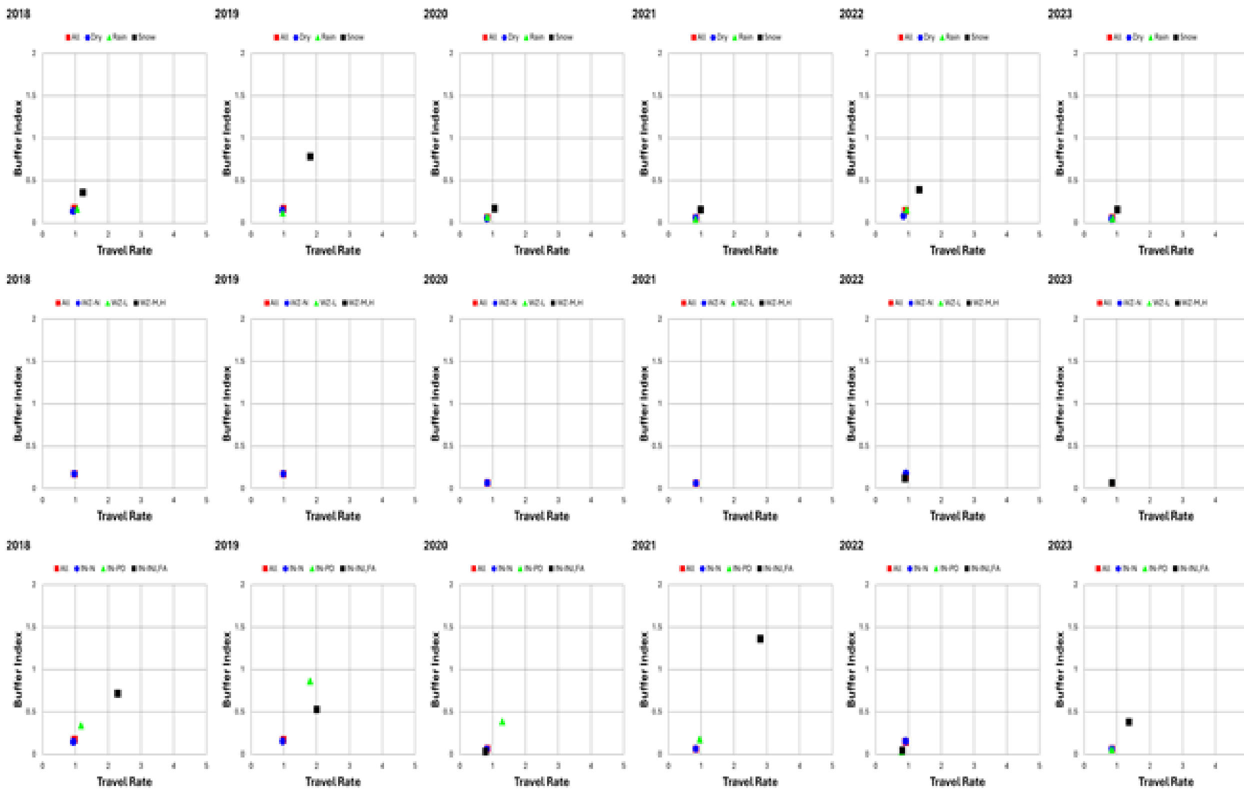
Incident Effects



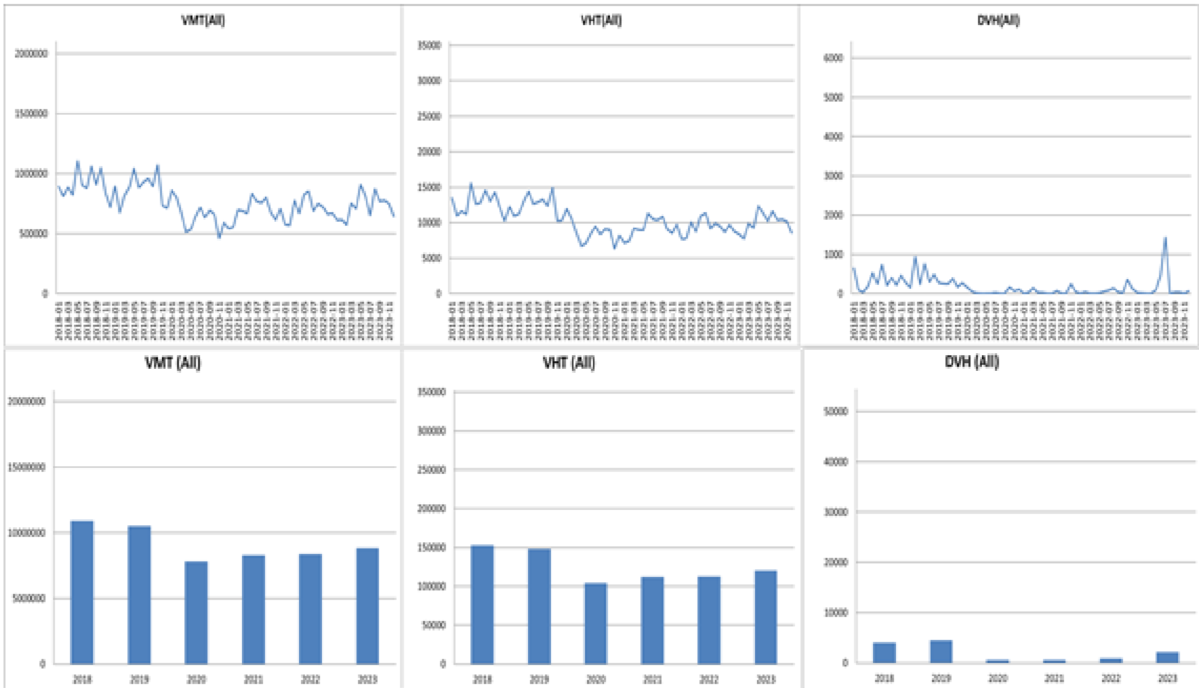
Work-Zone Effects



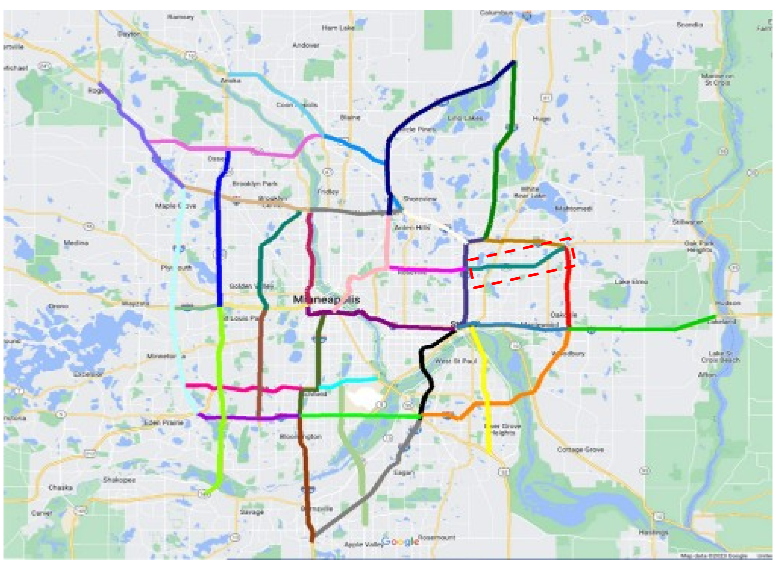
Yearly Variations of Buffer Index - Travel Rate Relationships



Variations of Traffic-Flow Measures

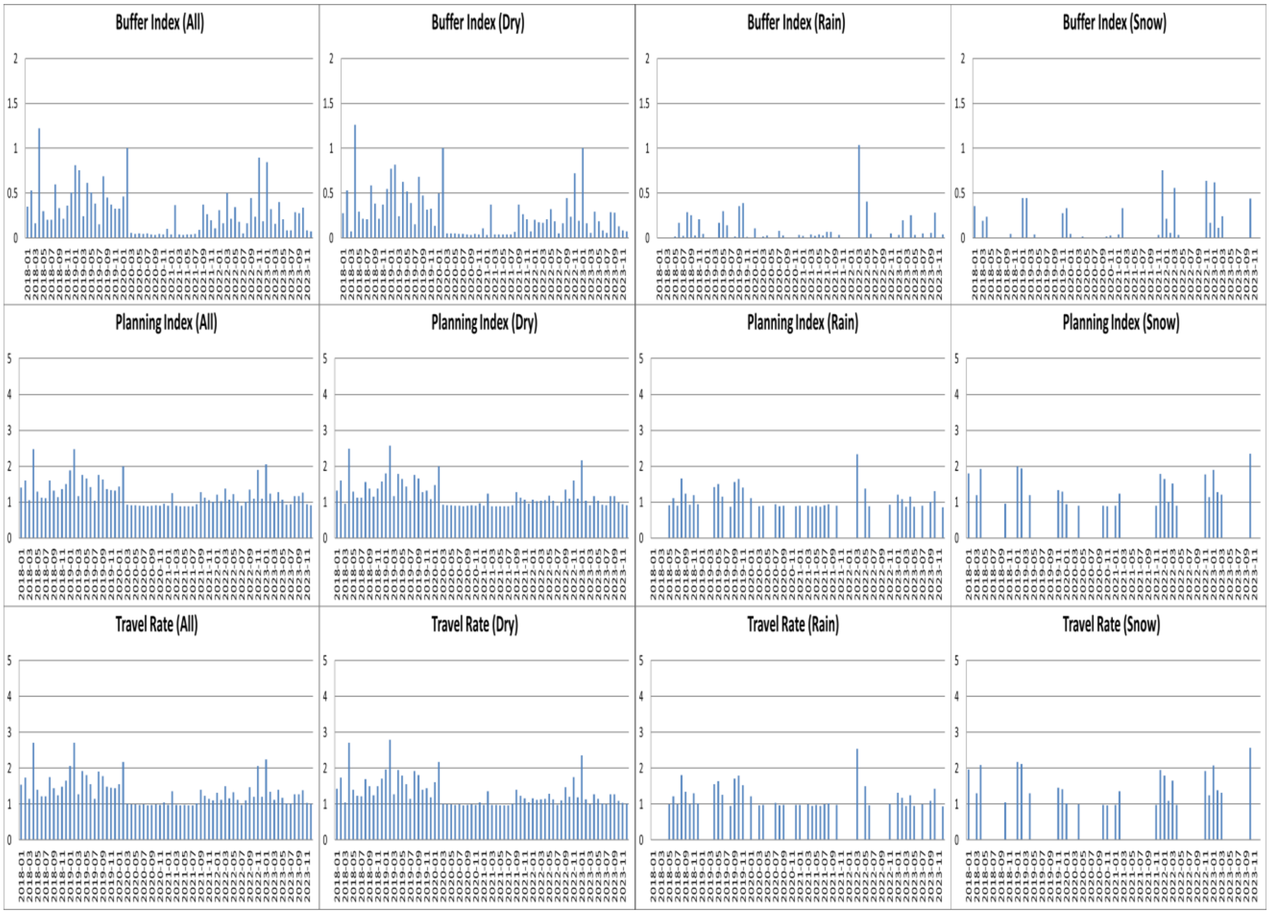


9) TH-36 Corridor A (I694 < -- > I35E)

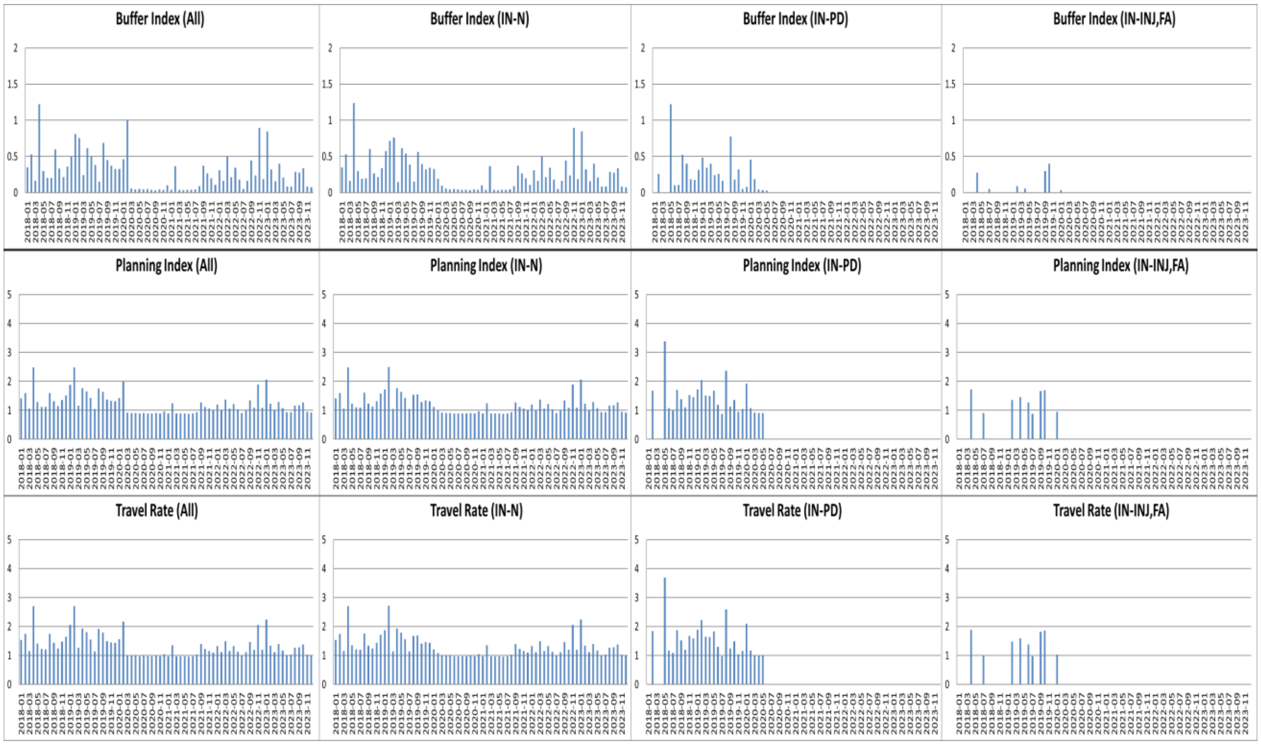


i) TH-36 Corridor A- WB I694 to I35E for Morning Peak Periods

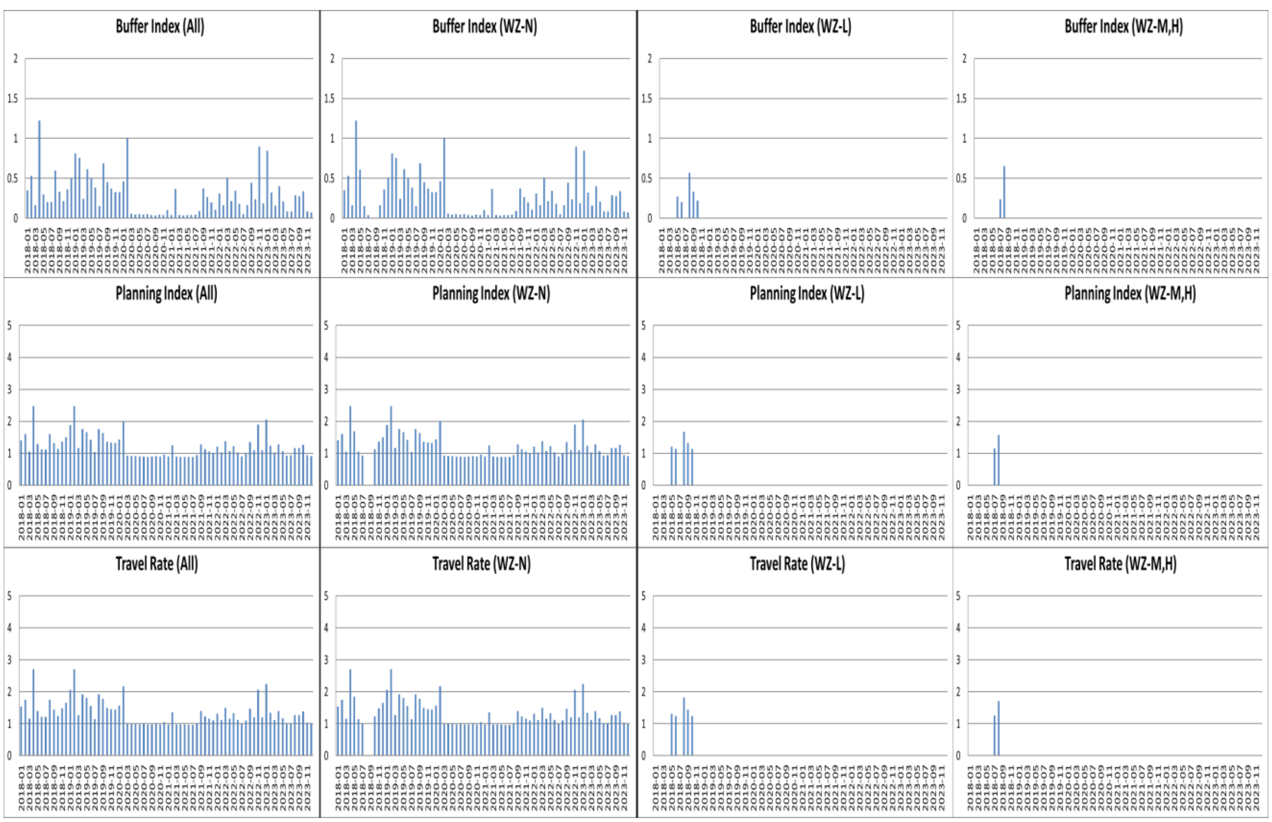
Effects of Weather conditions on Travel-Time Reliability



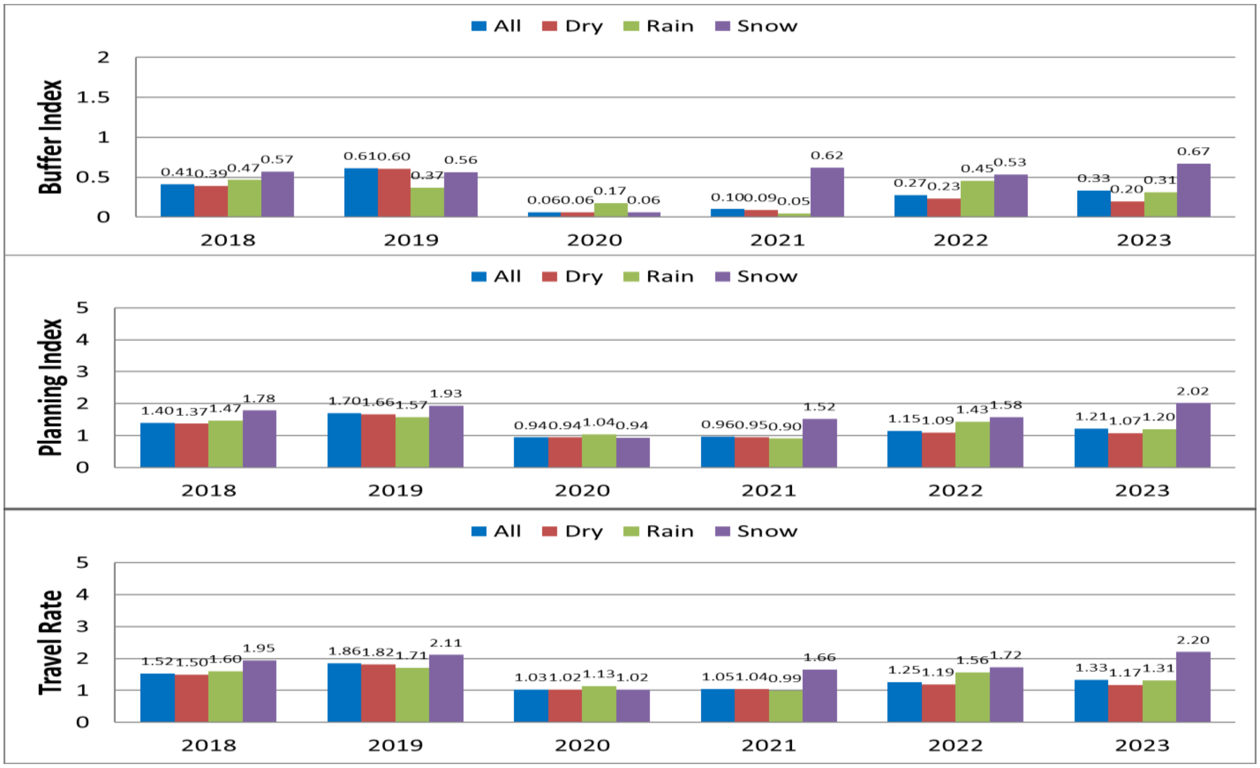
Effects of Incidents



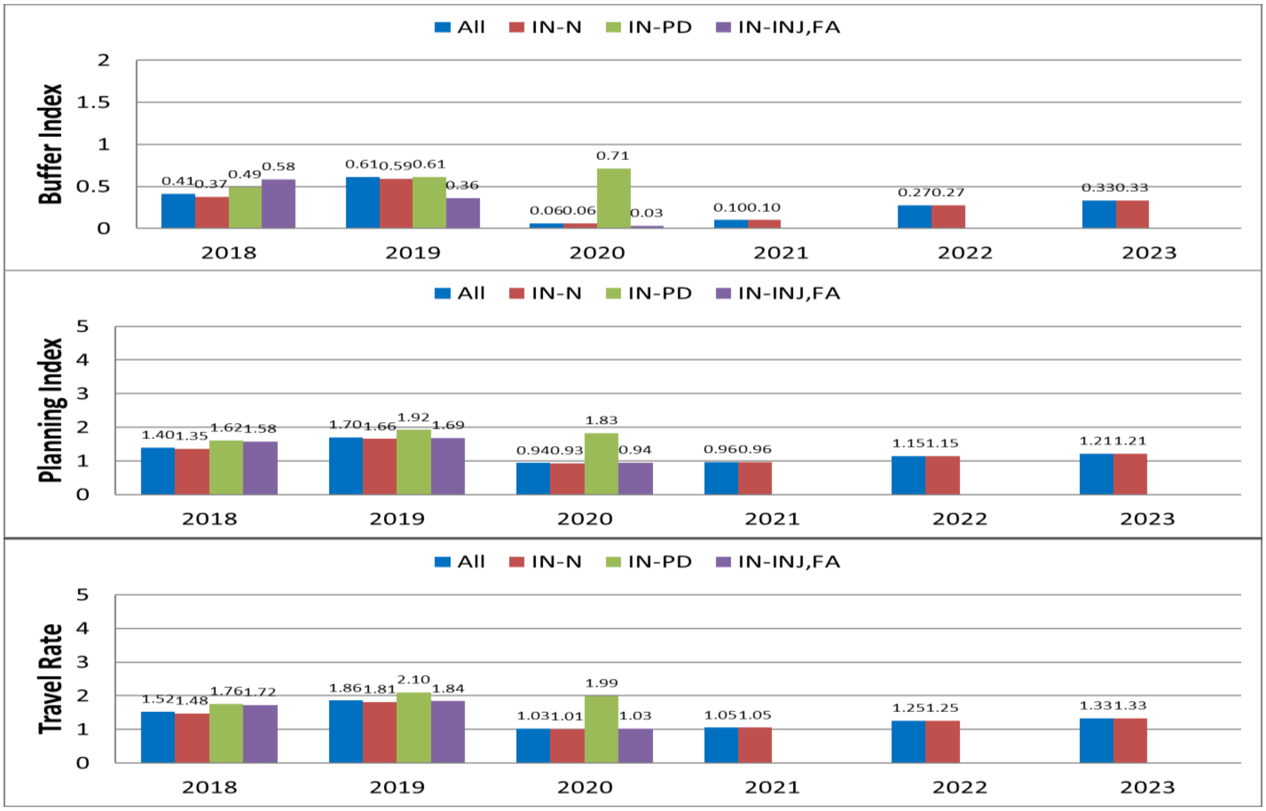
Effects of Work Zones



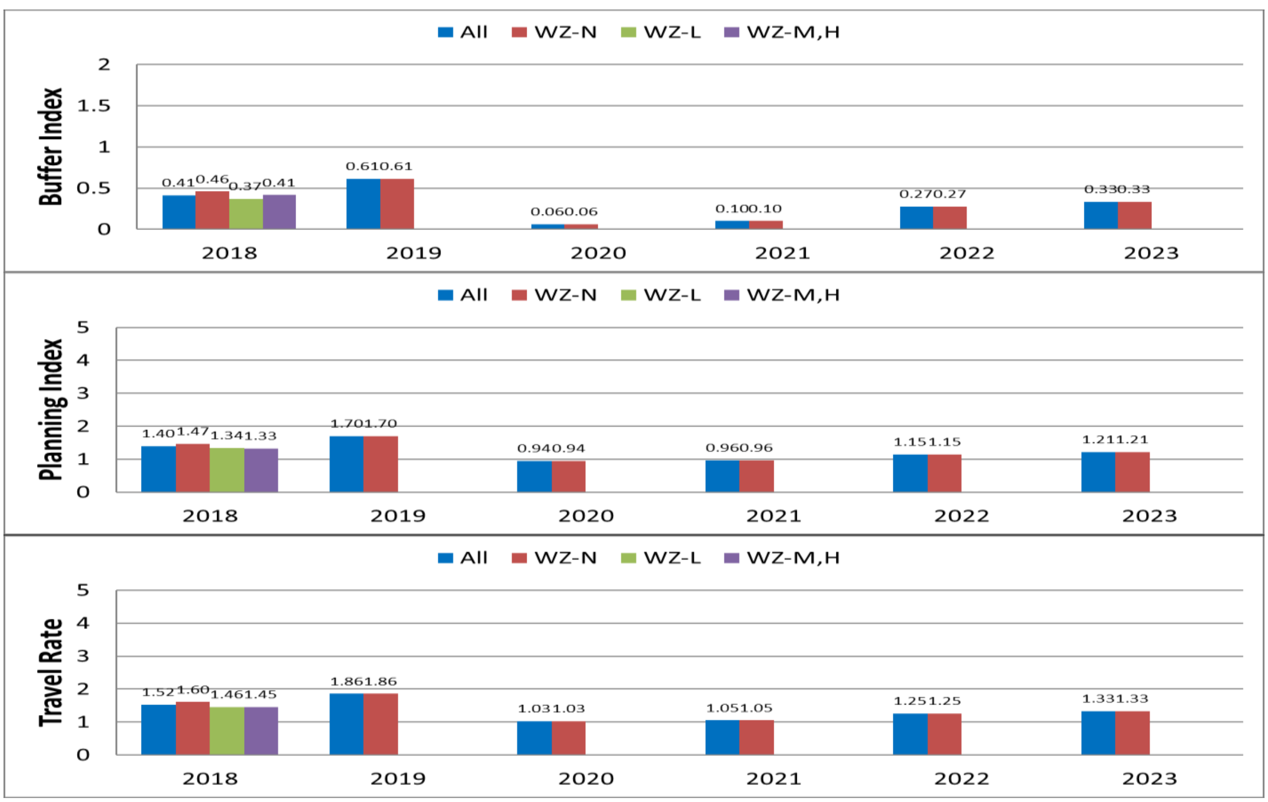
Yearly Variations - *Weather Effects*



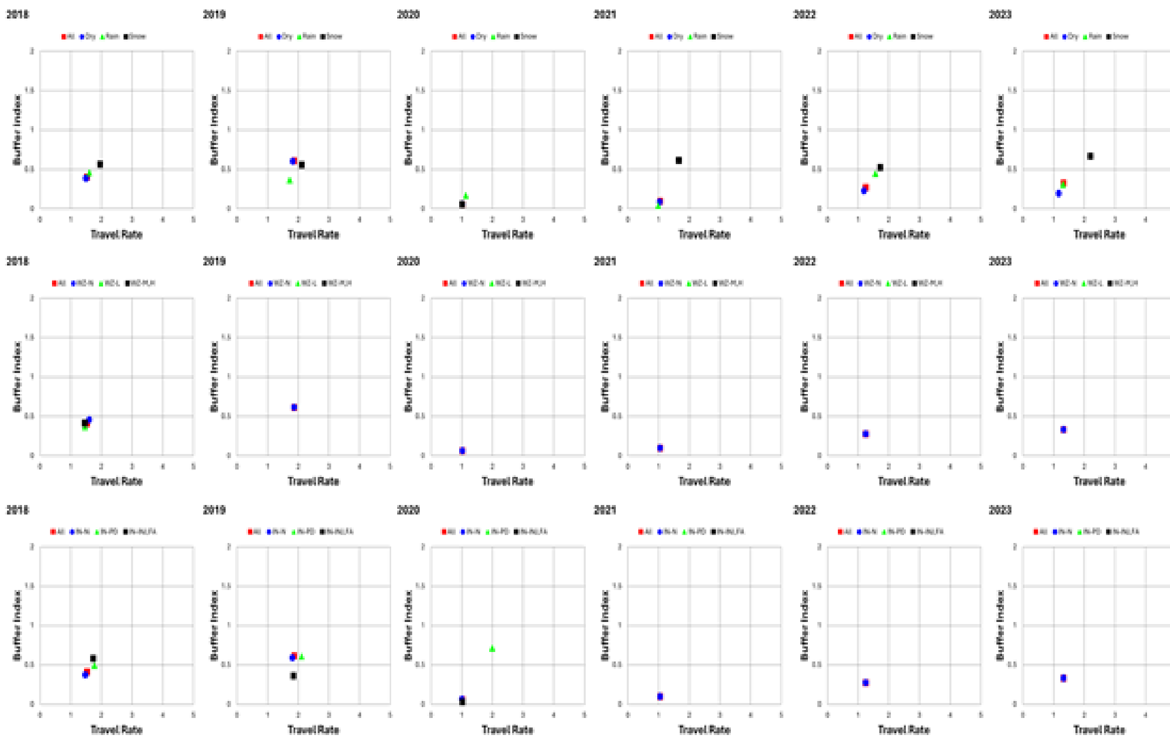
Incident Effects



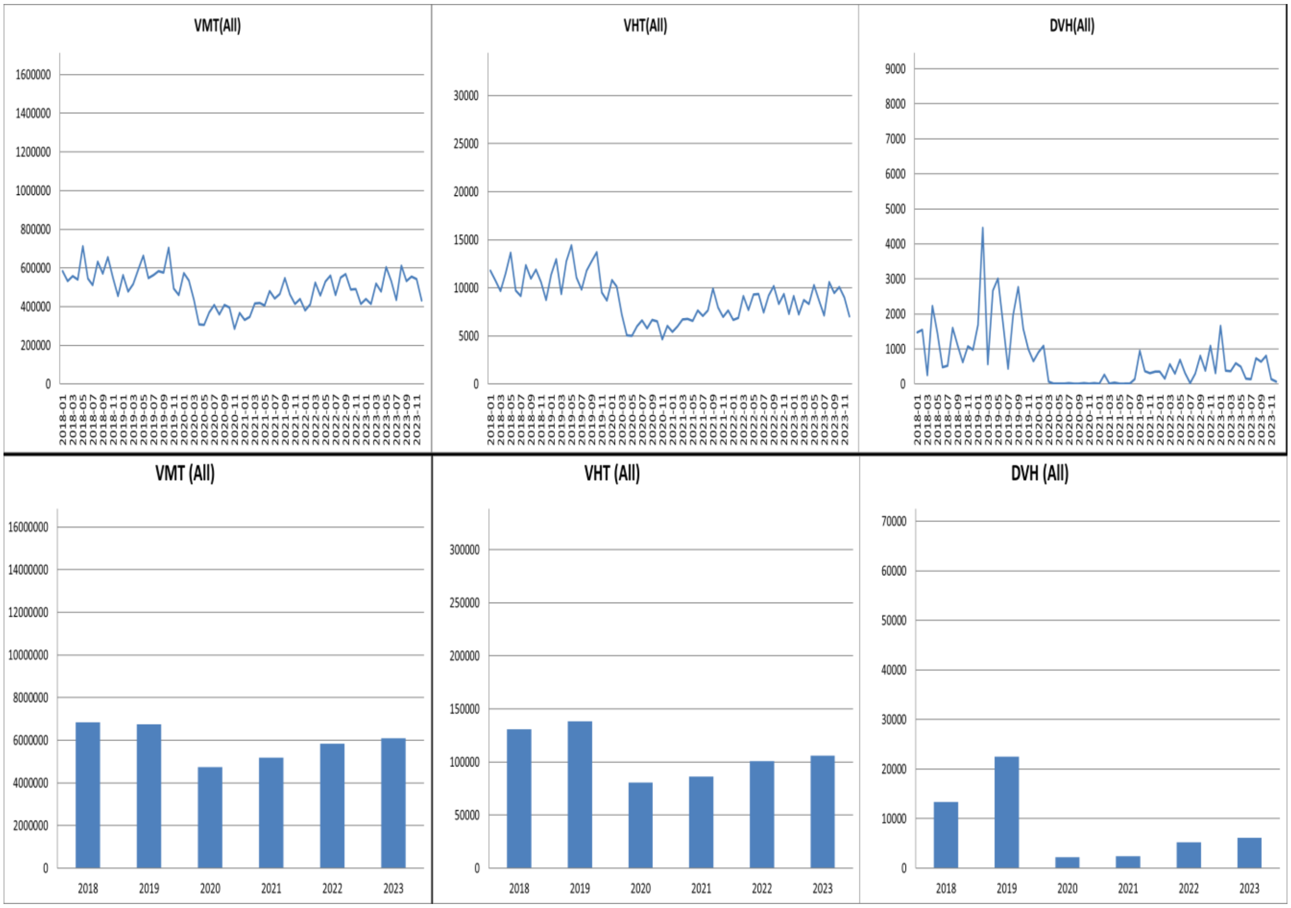
Work-Zone Effects



Yearly Variations of Buffer Index - Travel Rate Relationships

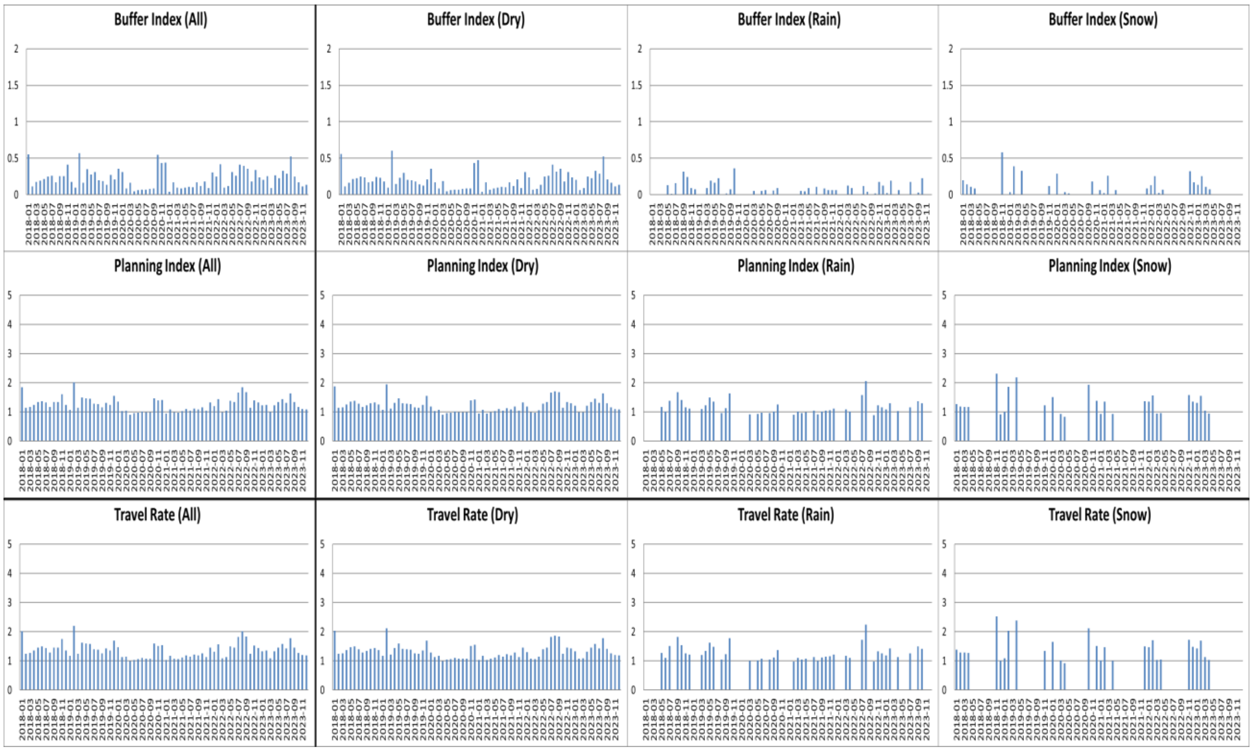


Variations of Traffic-Flow Measures

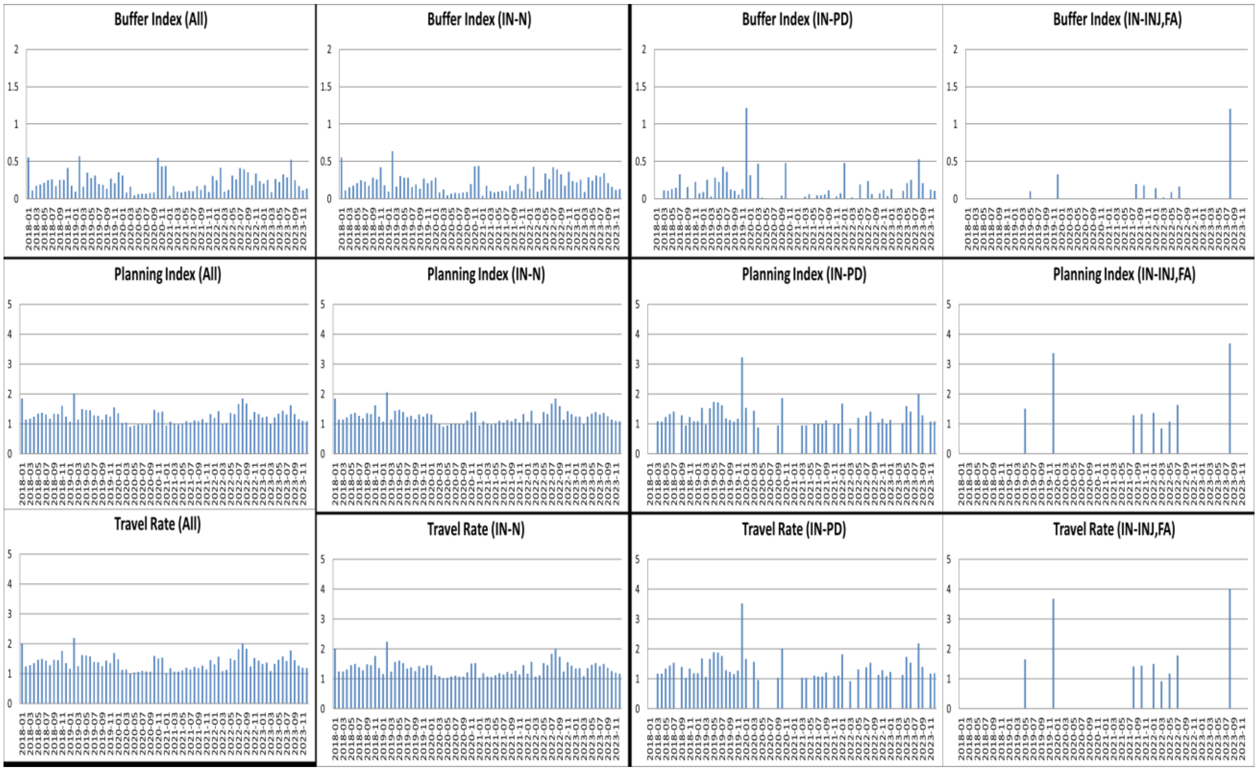

VMT(All)
VHT(All)
DVH(All)
VMT (All)
VHT (All)
DVH (All)
2018
2019
2020
2021
2022
2023

ii) TH-36 Corridor A - EB I35E to 694 for Afternoon Peak Periods

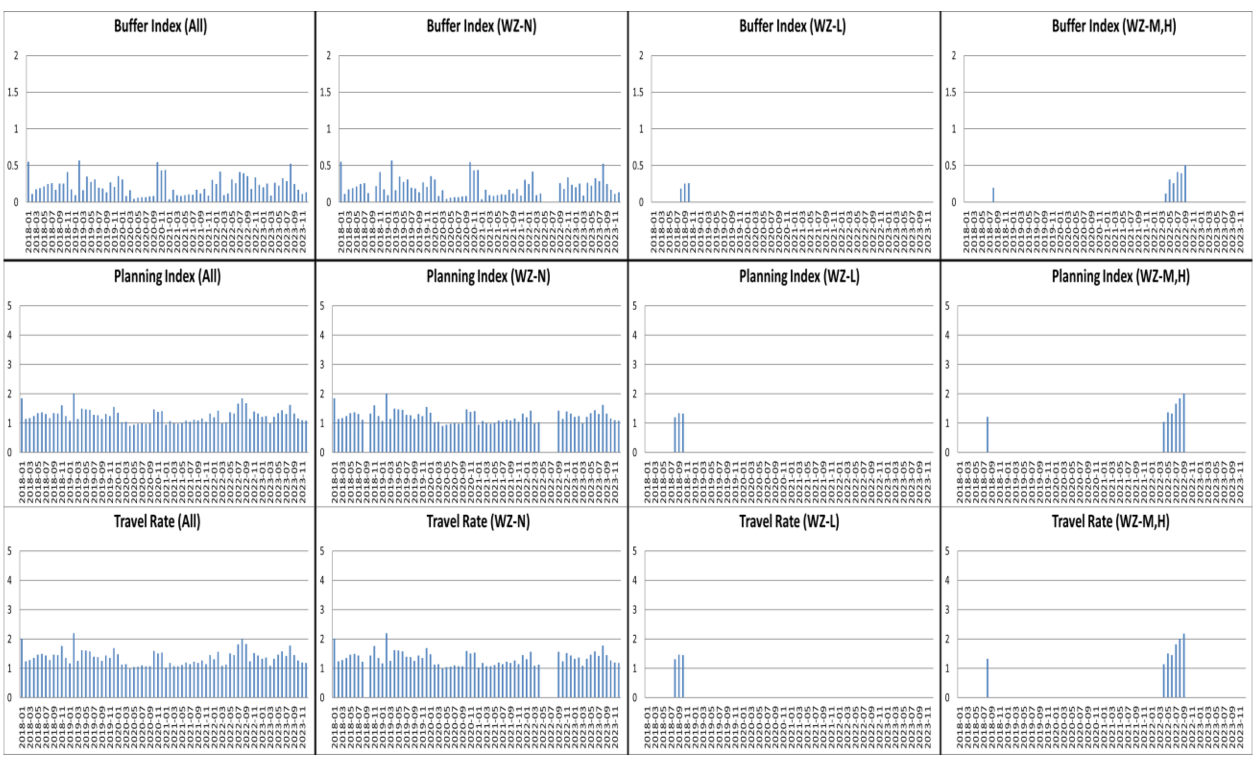
Effects of Weather conditions on Travel-Time Reliability



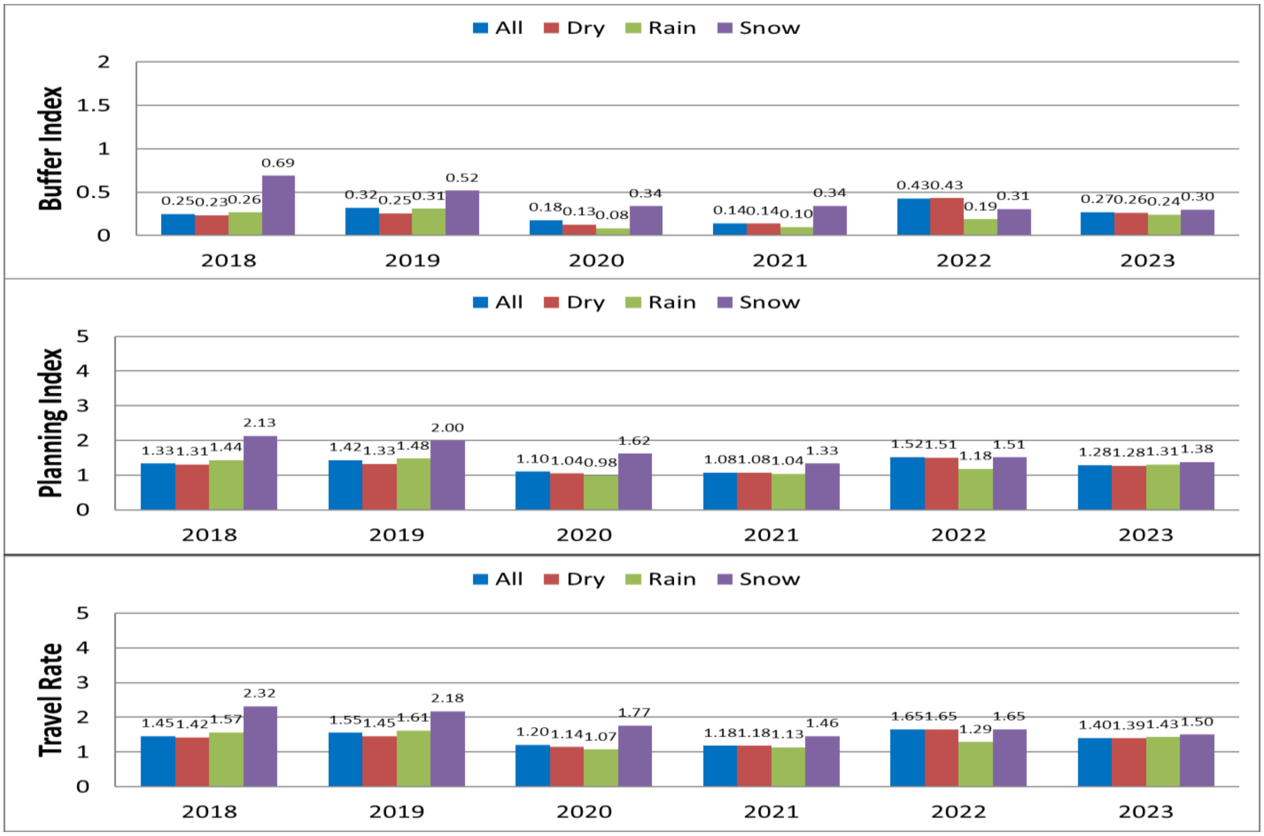
Effects of Incidents



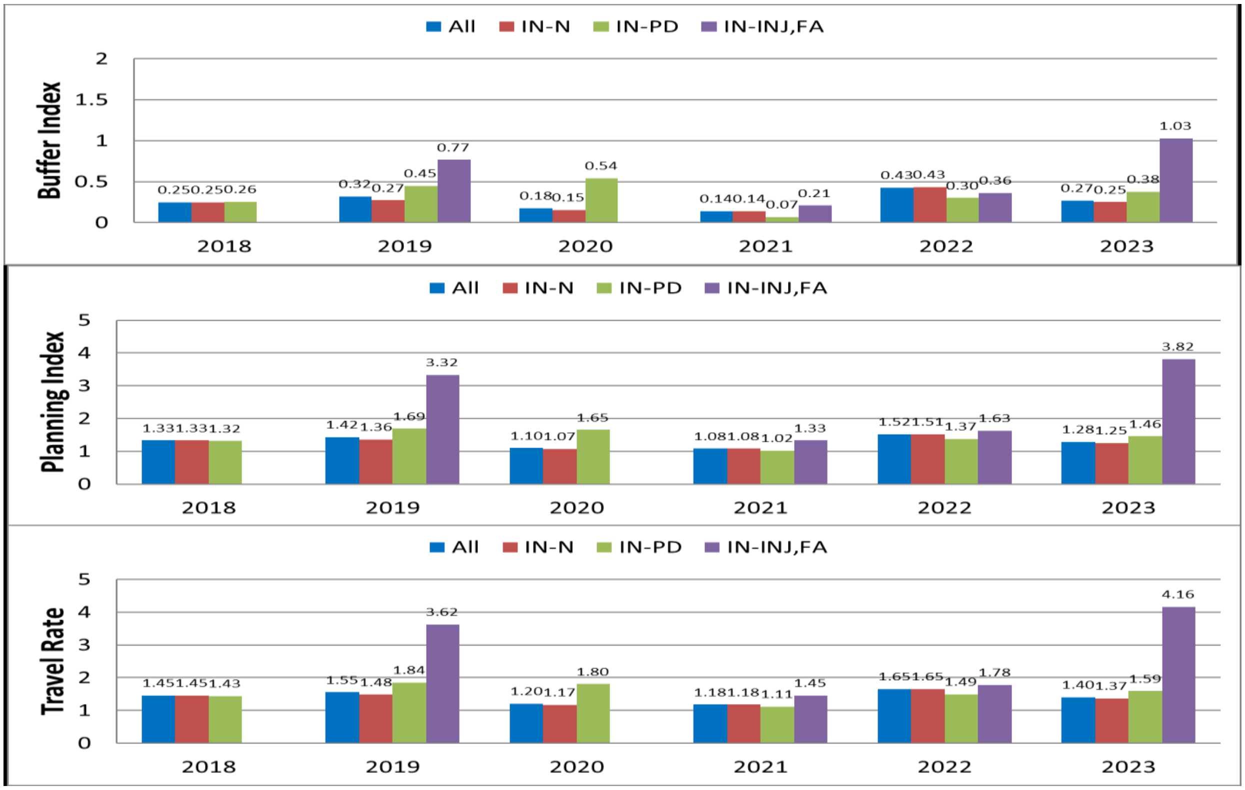
Effects of Work Zones



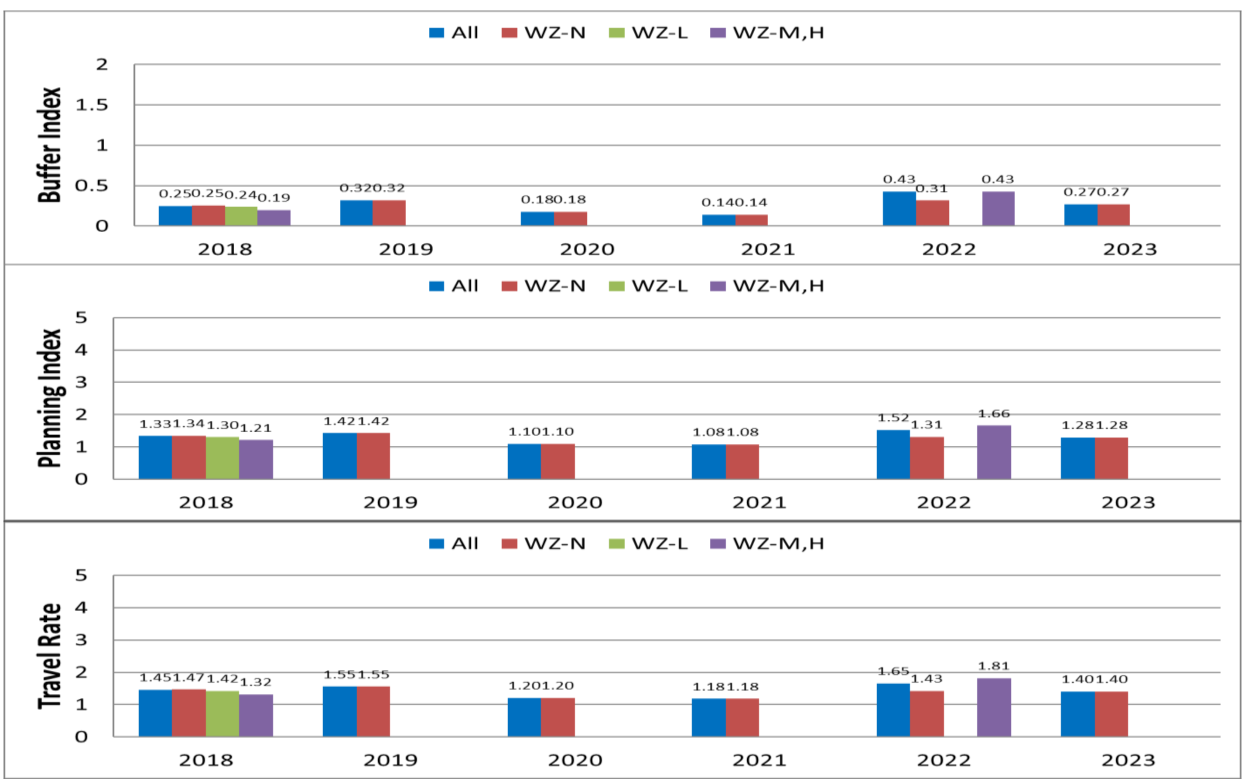
Yearly Variations - *Weather Effects*



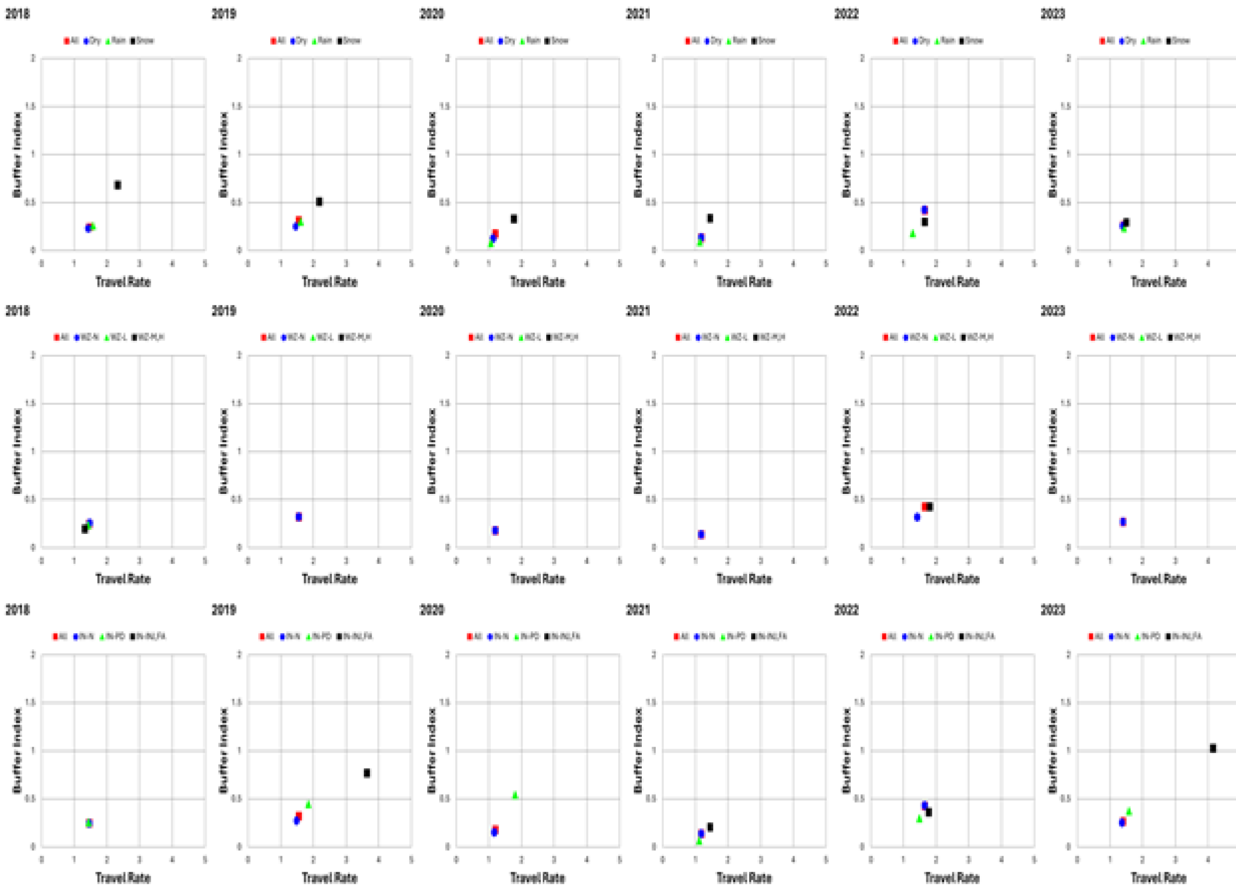
Incident Effects



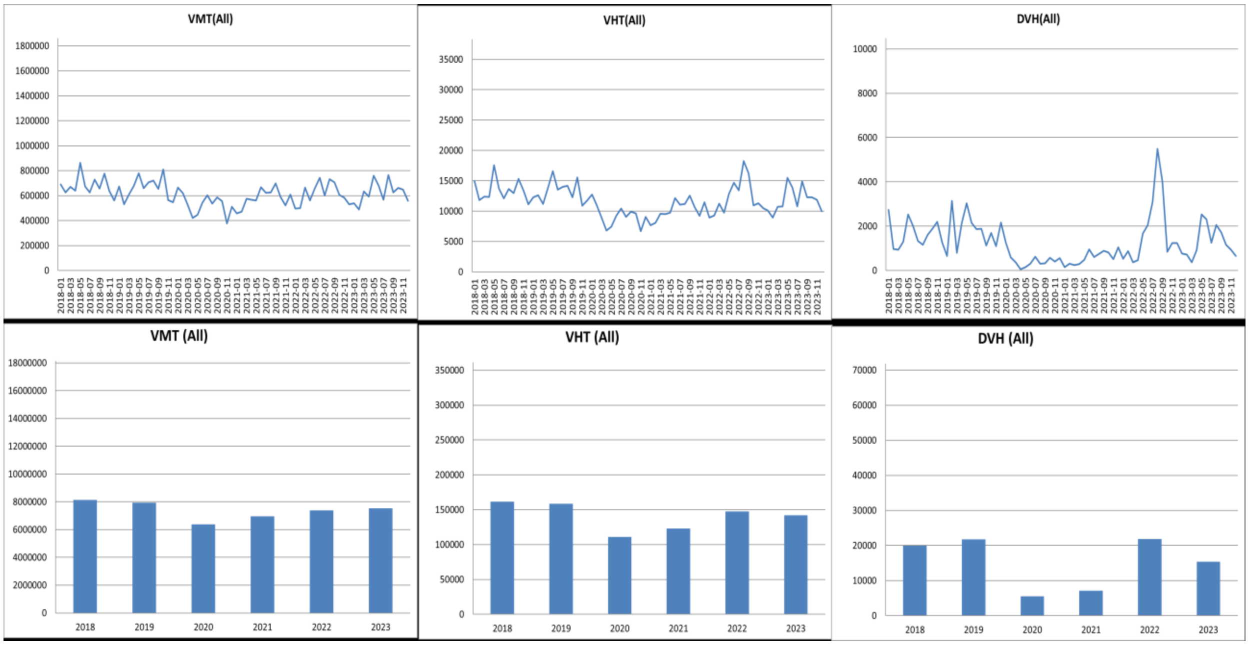
Work-Zone Effects



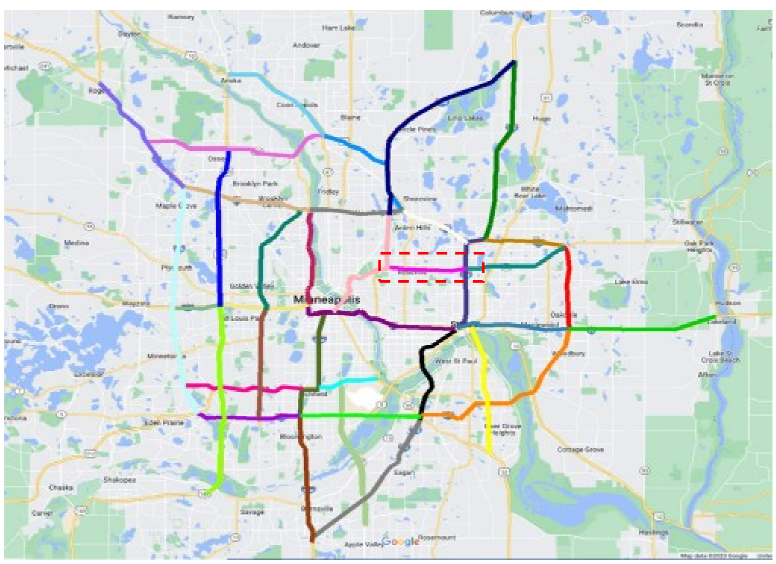
Yearly Variations of Buffer Index - Travel Rate Relationships



Variations of Traffic-Flow Measures

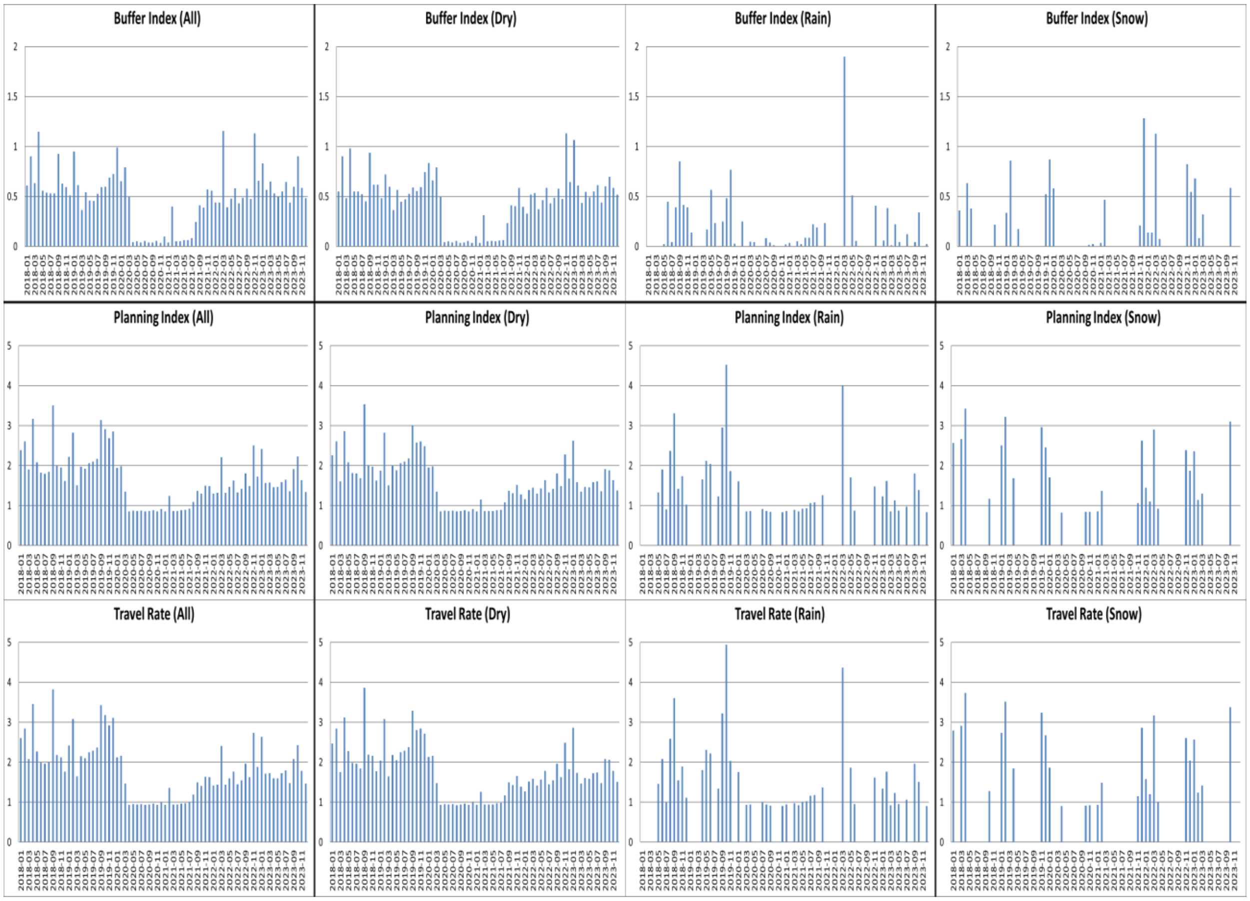


10) TH-36 Corridor B (I35E < -- > I35W)

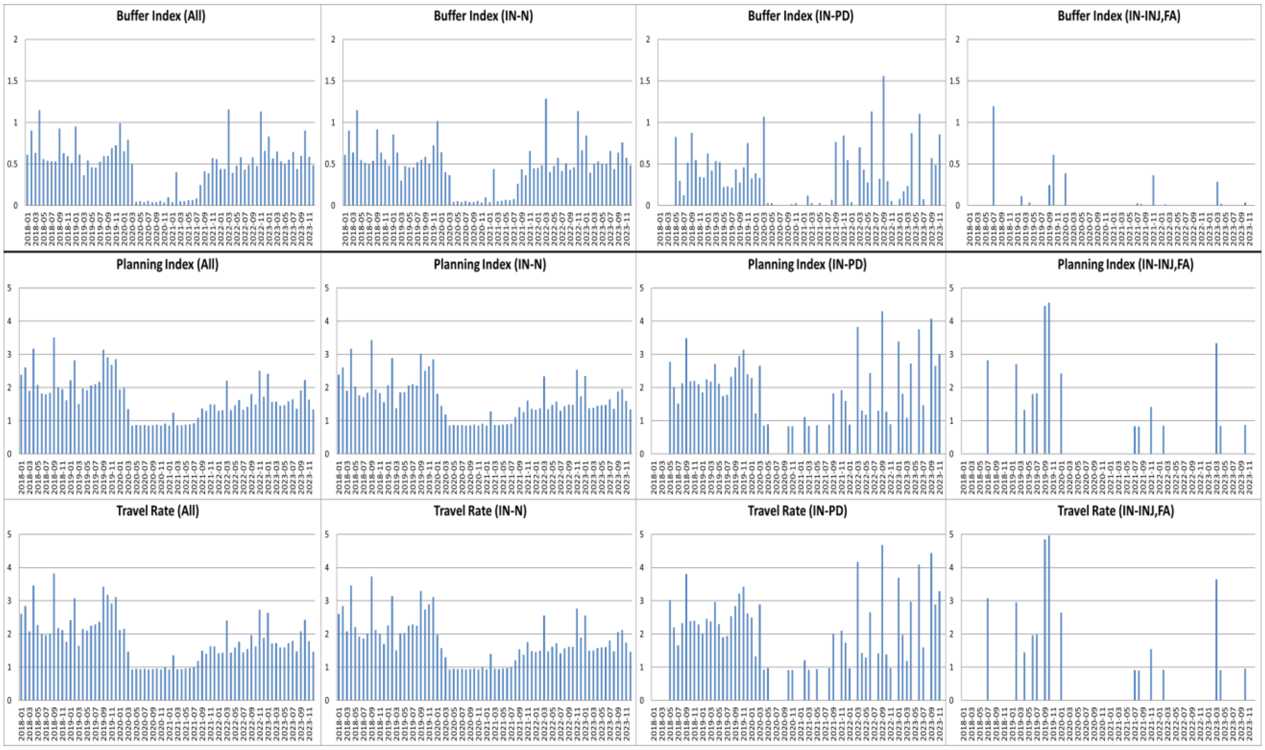


i) TH-36 Corridor B - WB I35E to I35W for Morning Peak Periods

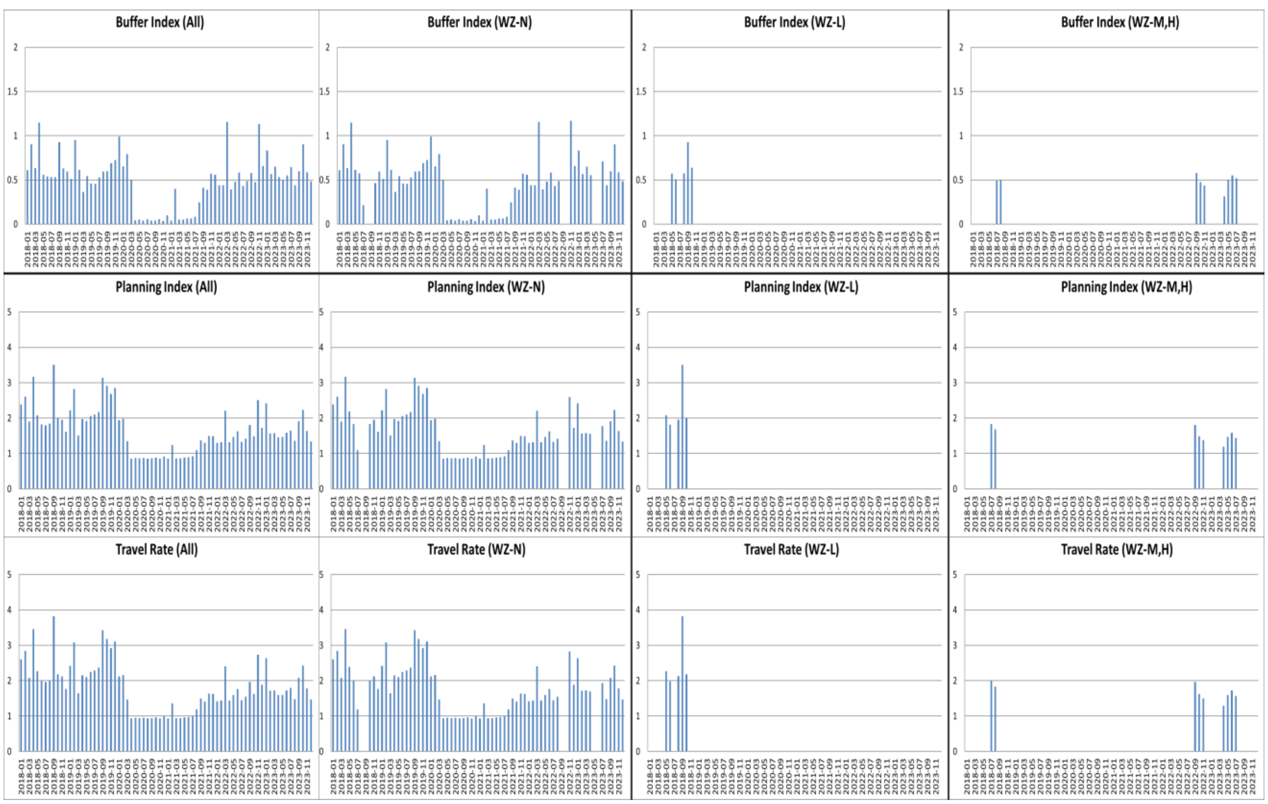
Effects of Weather conditions on Travel-Time Reliability



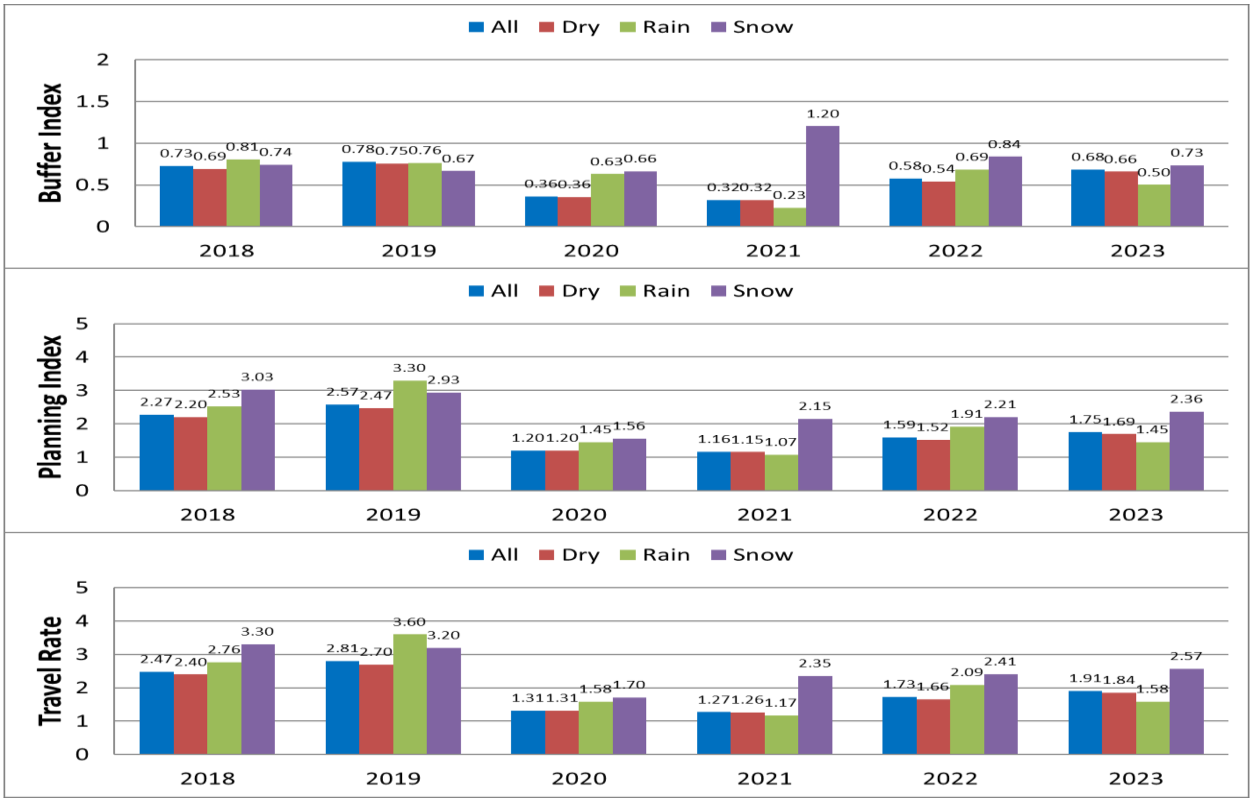
Effects of Incidents



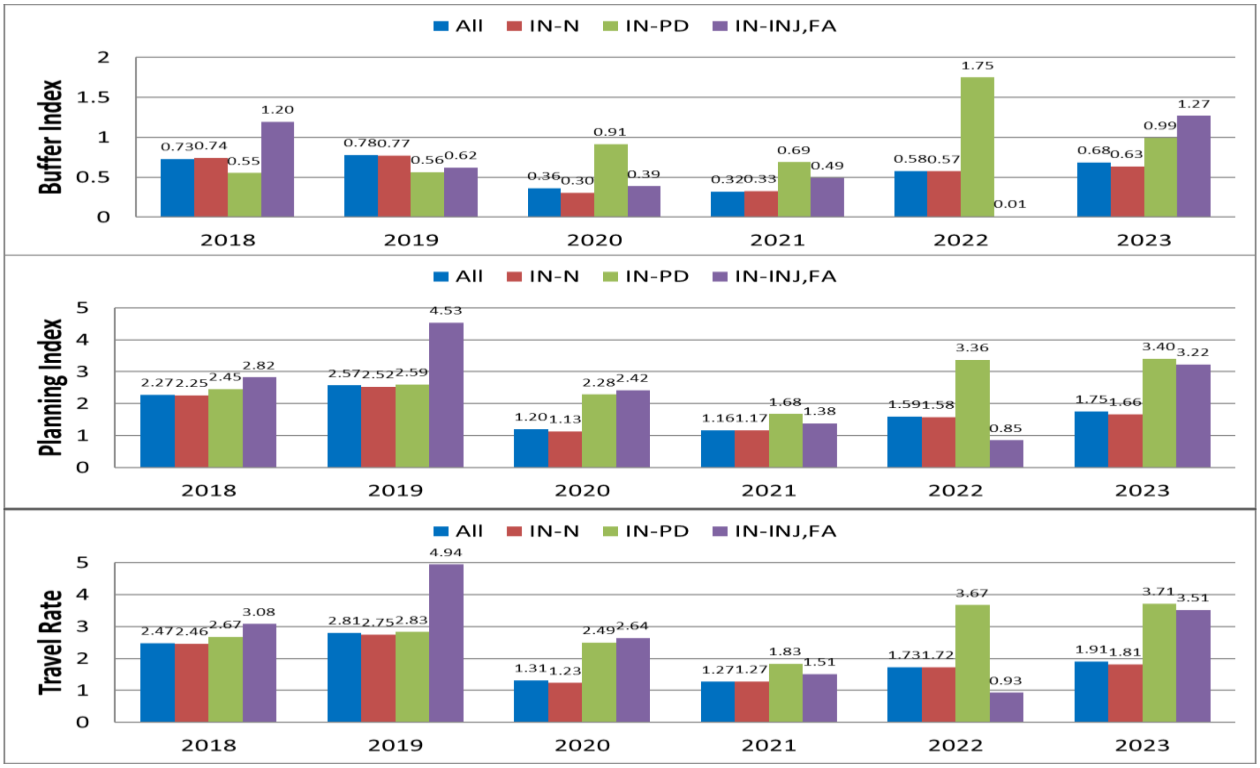
Effects of Work Zones



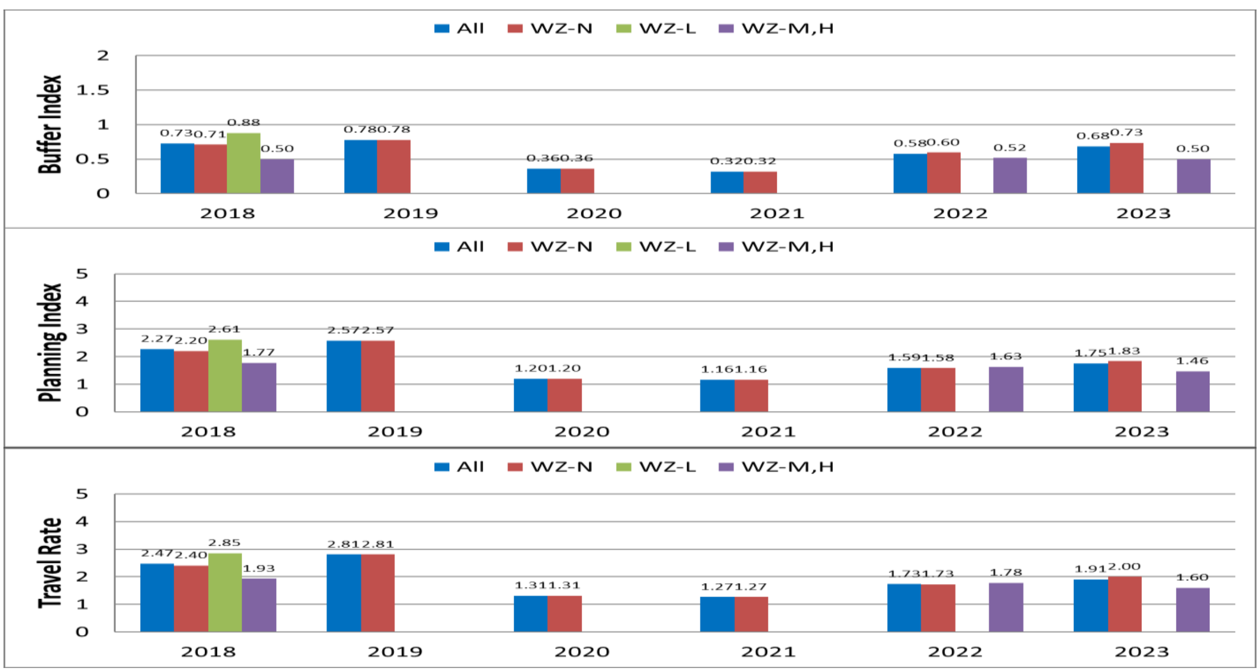
Yearly Variations - *Weather Effects*



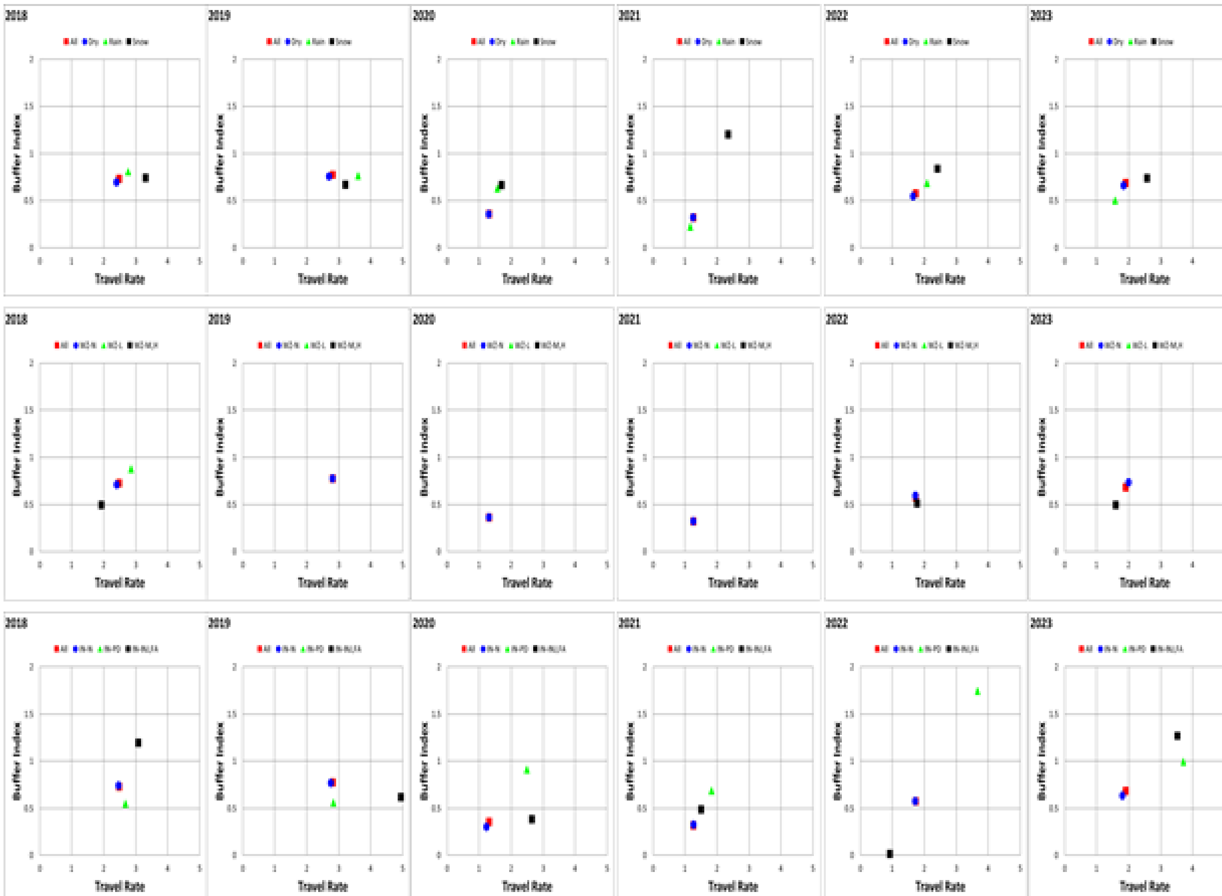
Incident Effects



Work-Zone Effects



Yearly Variations of Buffer Index - Travel Rate Relationships

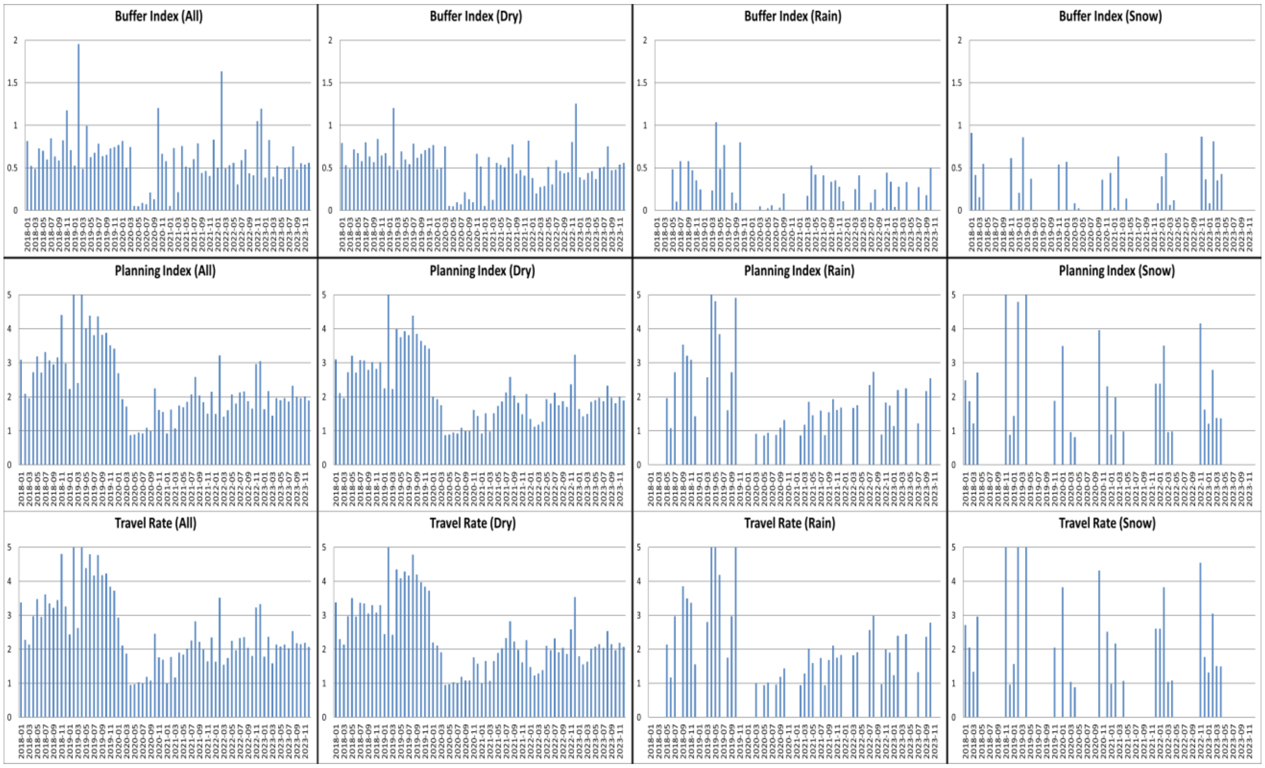


Variations of Traffic-Flow Measures

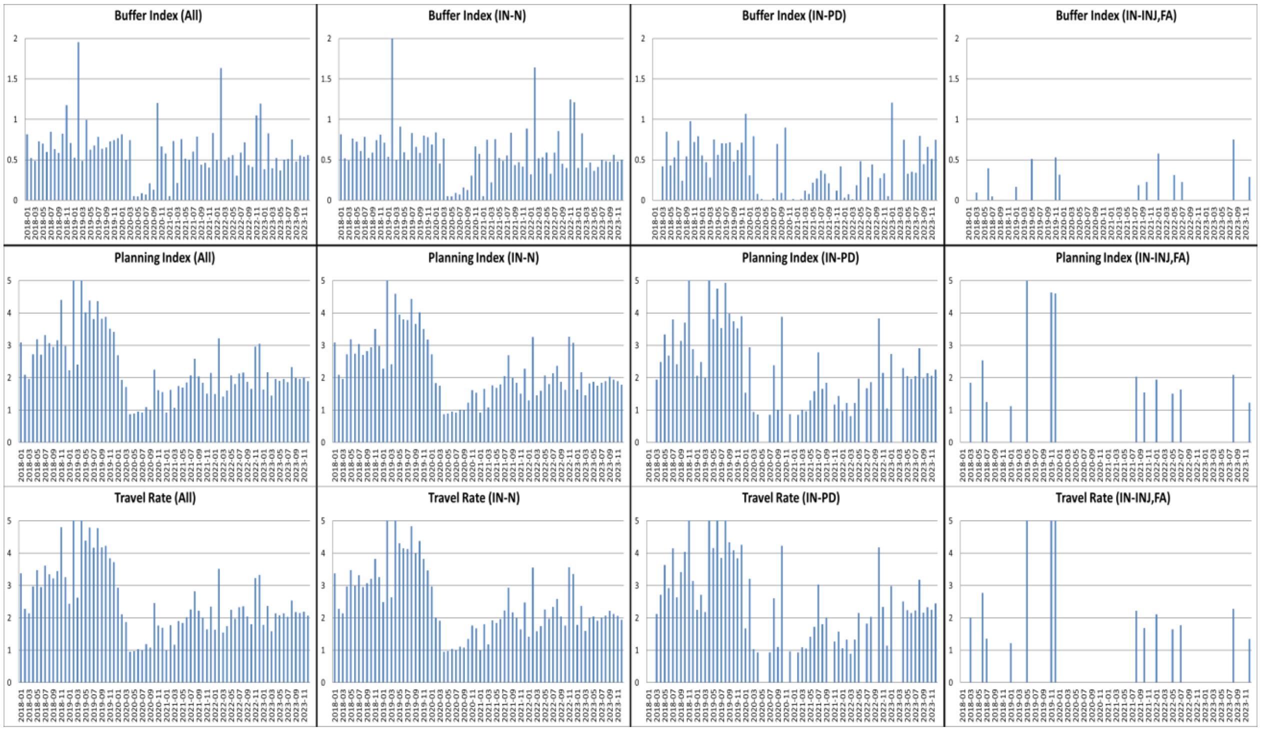

VMT(All)
VHT(All)
DVH(All)
VMT (All)
VHT (All)
DVH (All)
2018
2019
2020
2021
2022
2023

ii) TH-36 Corridor B - EB I35W to I35E for Afternoon Peak Period

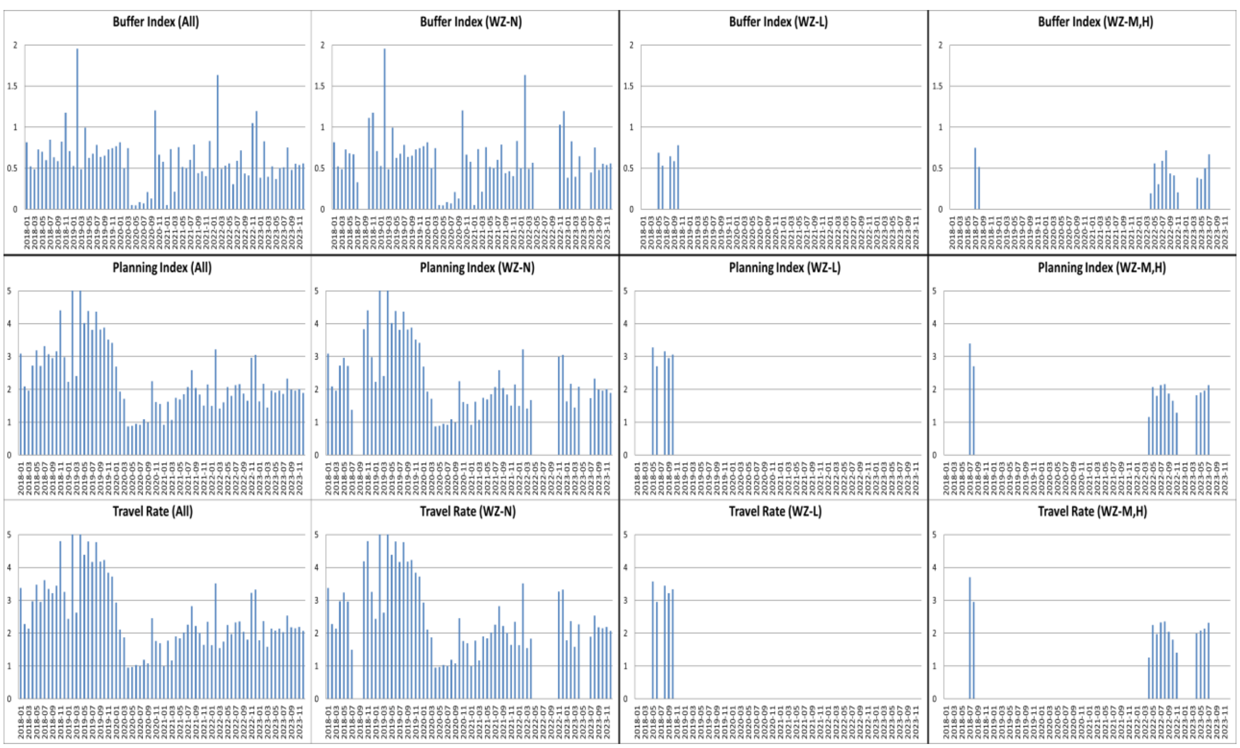
Effects of Weather conditions on Travel-Time Reliability



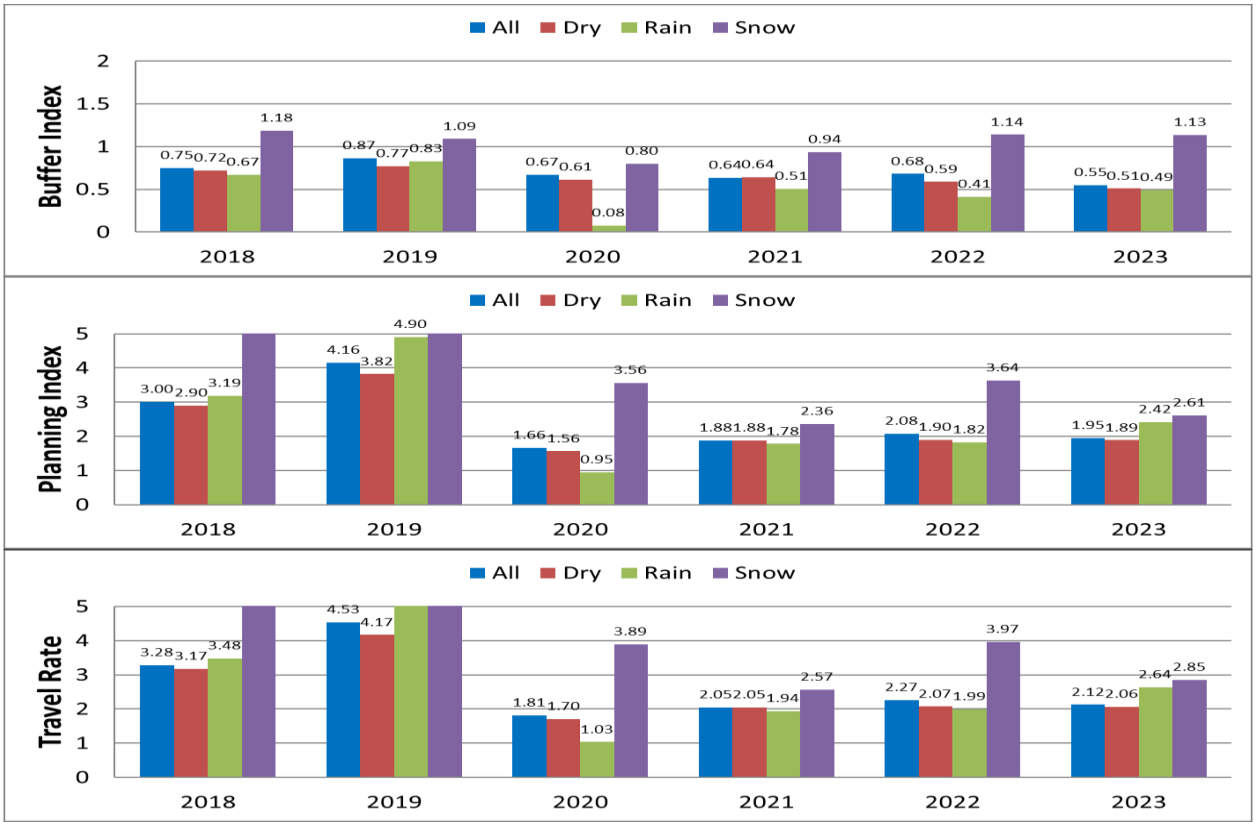
Effects of Incidents



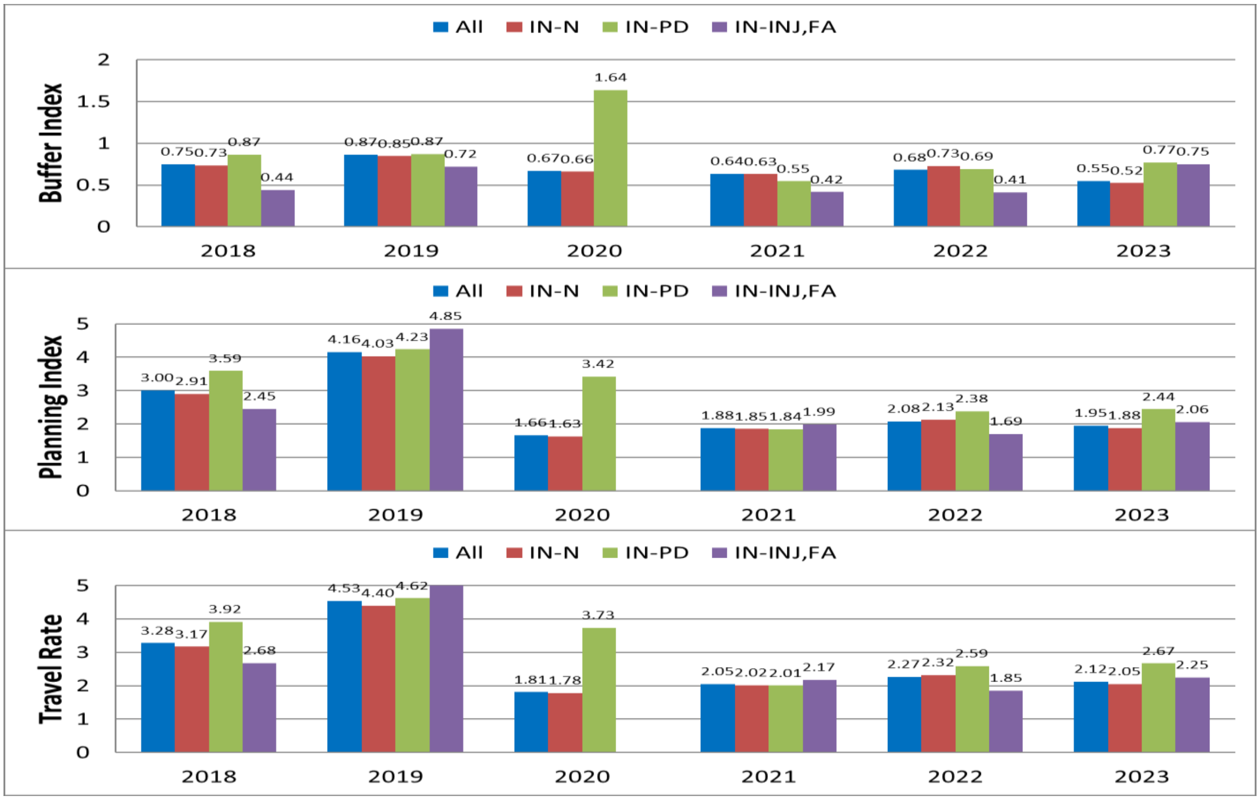
Effects of Work Zones



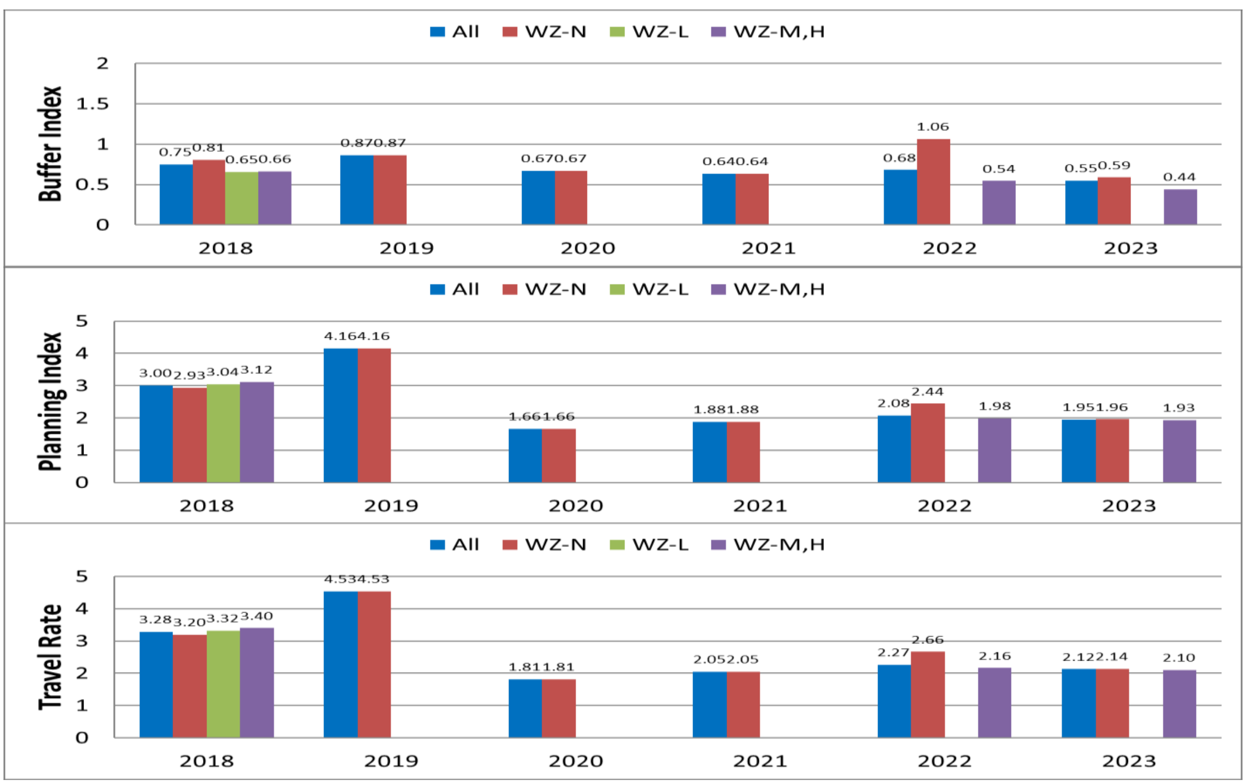
Yearly Variations - *Weather Effects*



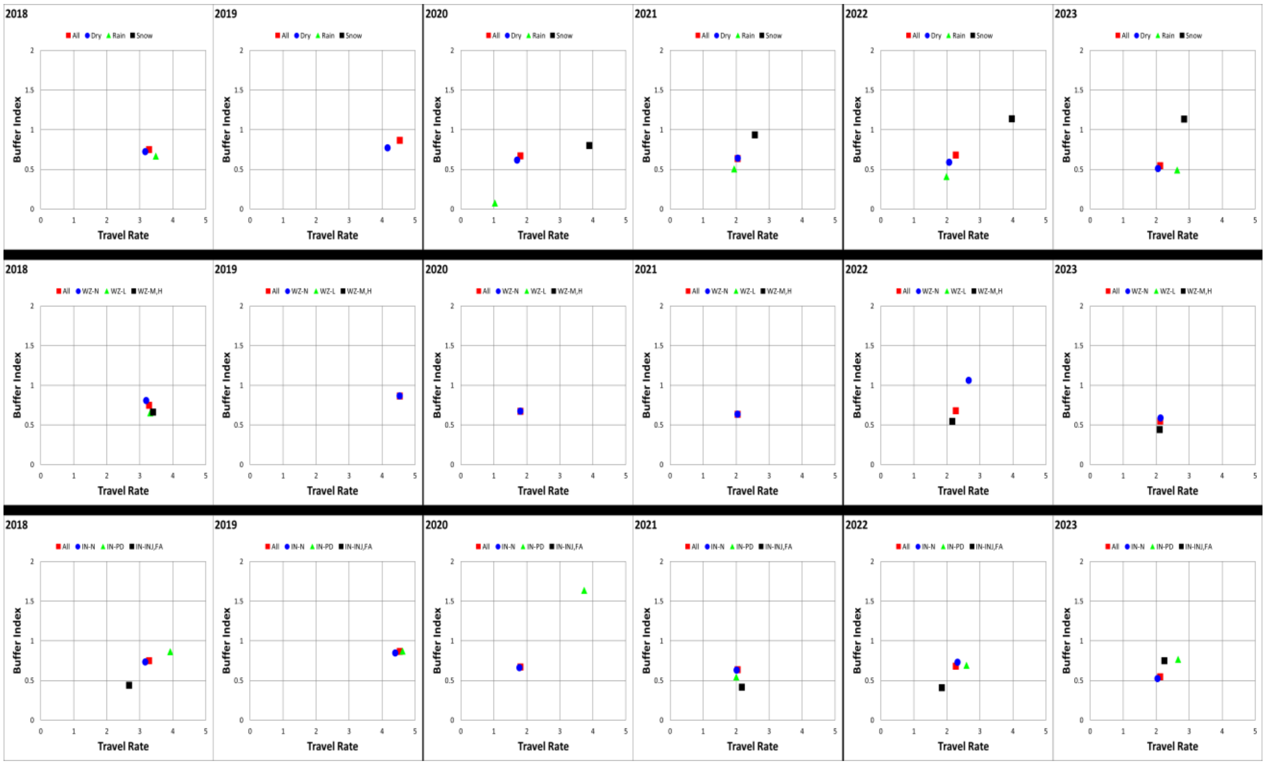
Incident Effects



Work-Zone Effects



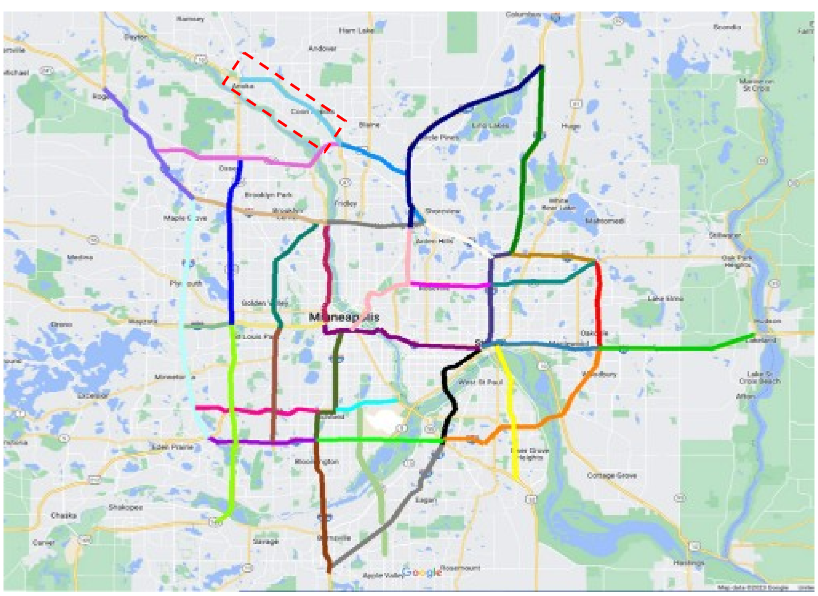
Yearly Variations of Buffer Index - Travel Rate Relationships



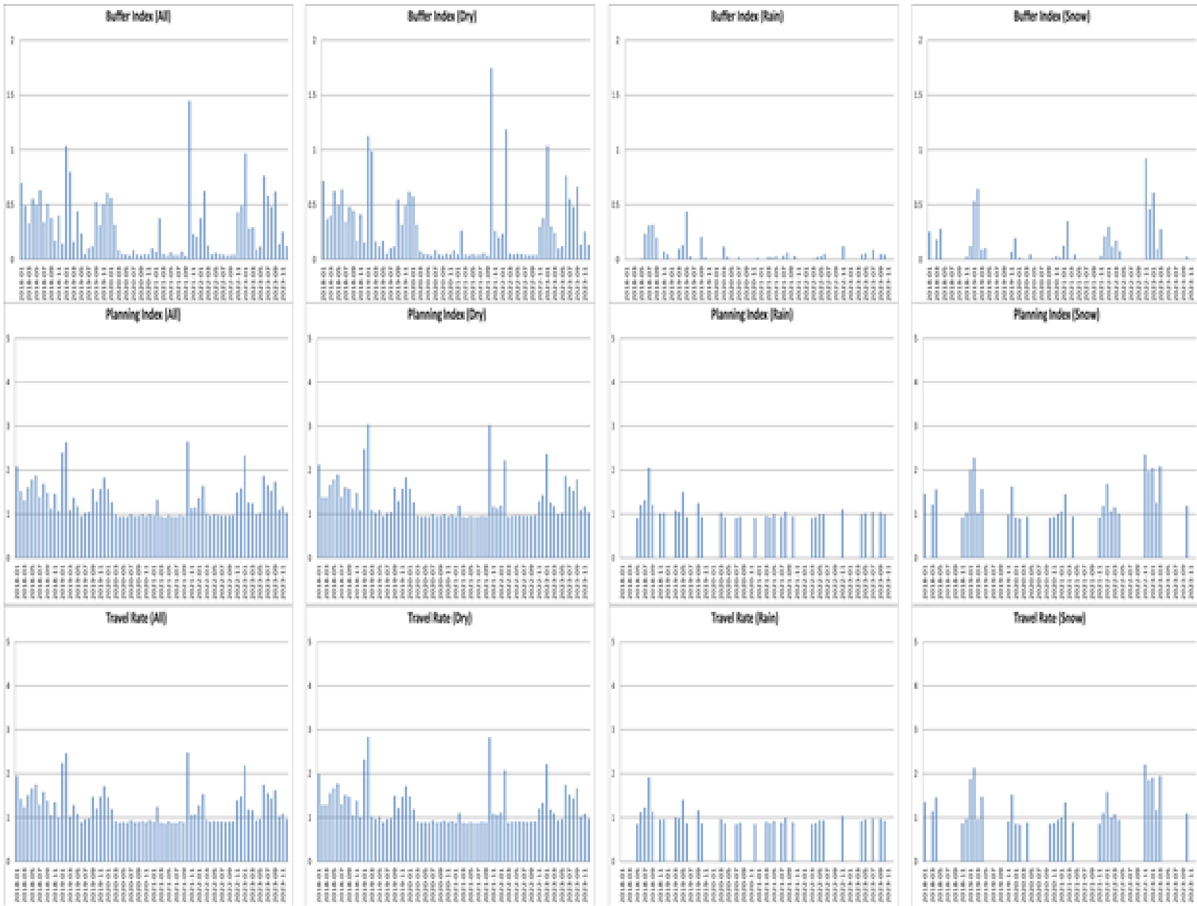
Variations of Traffic-Flow Measures

11) TH-10 Corridor A (TH169 < -- > TH610)

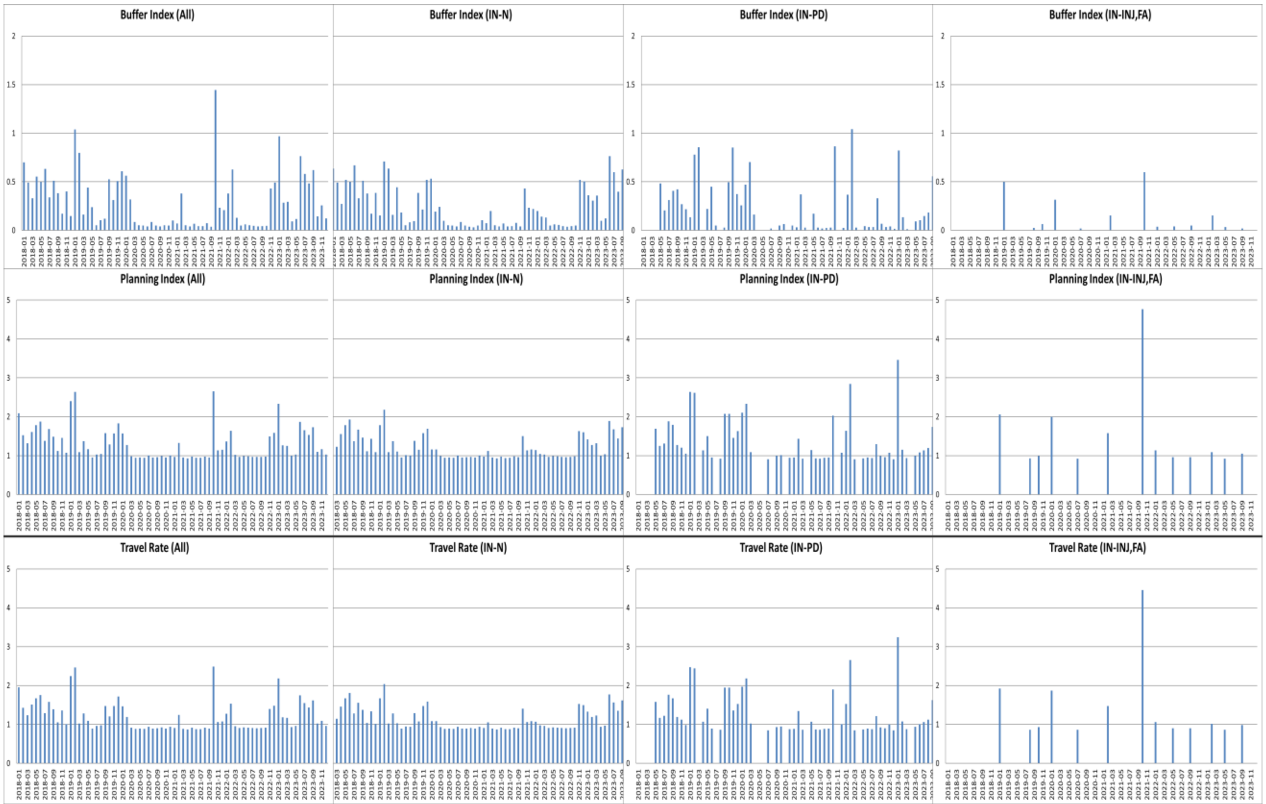
i) TH-10 Corridor A - EB TH169 to TH610 for Morning Peak Periods



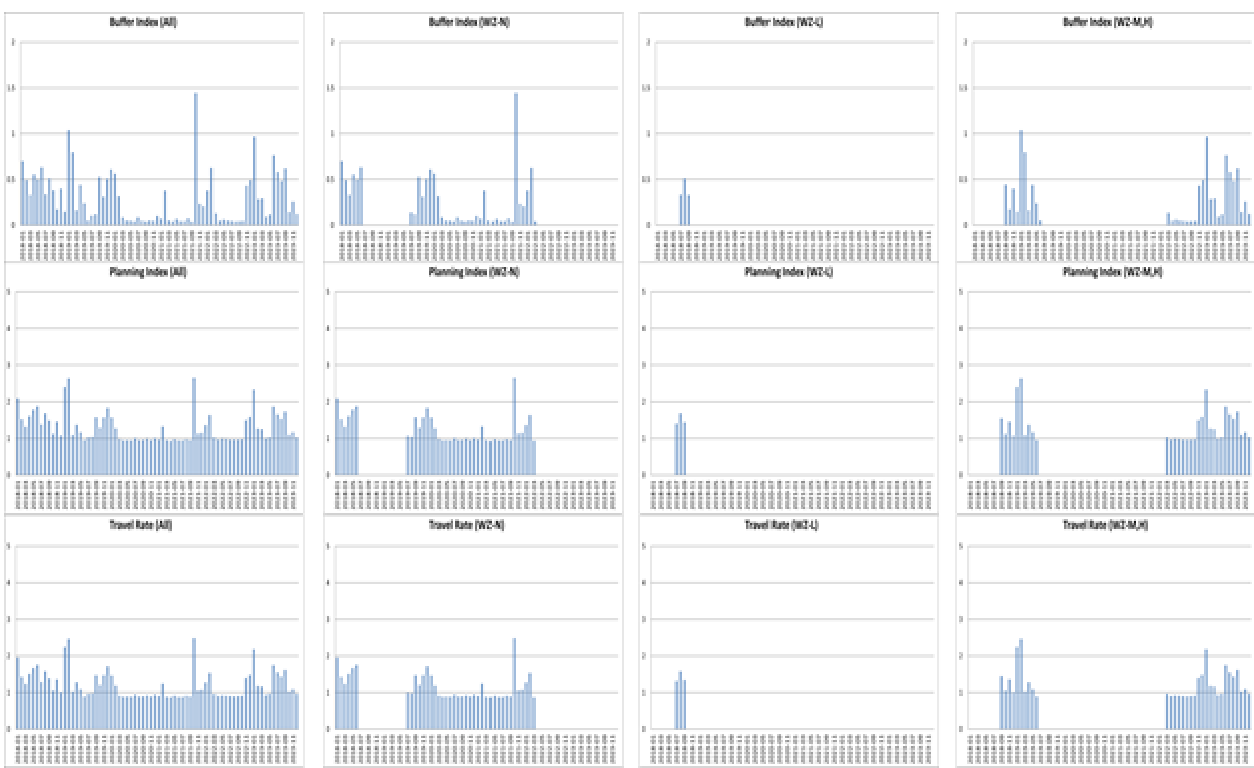
Effects of Weather conditions on Travel-Time Reliability



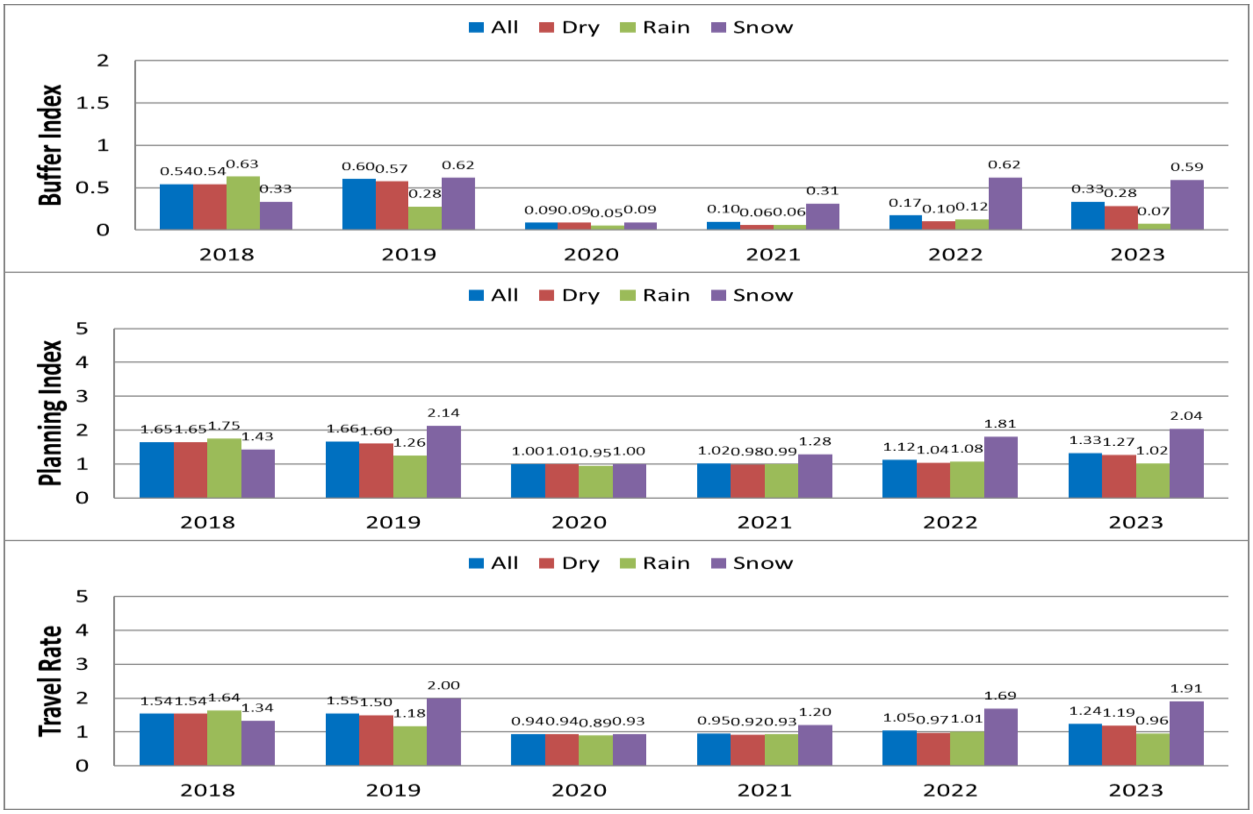
Effects of Incidents



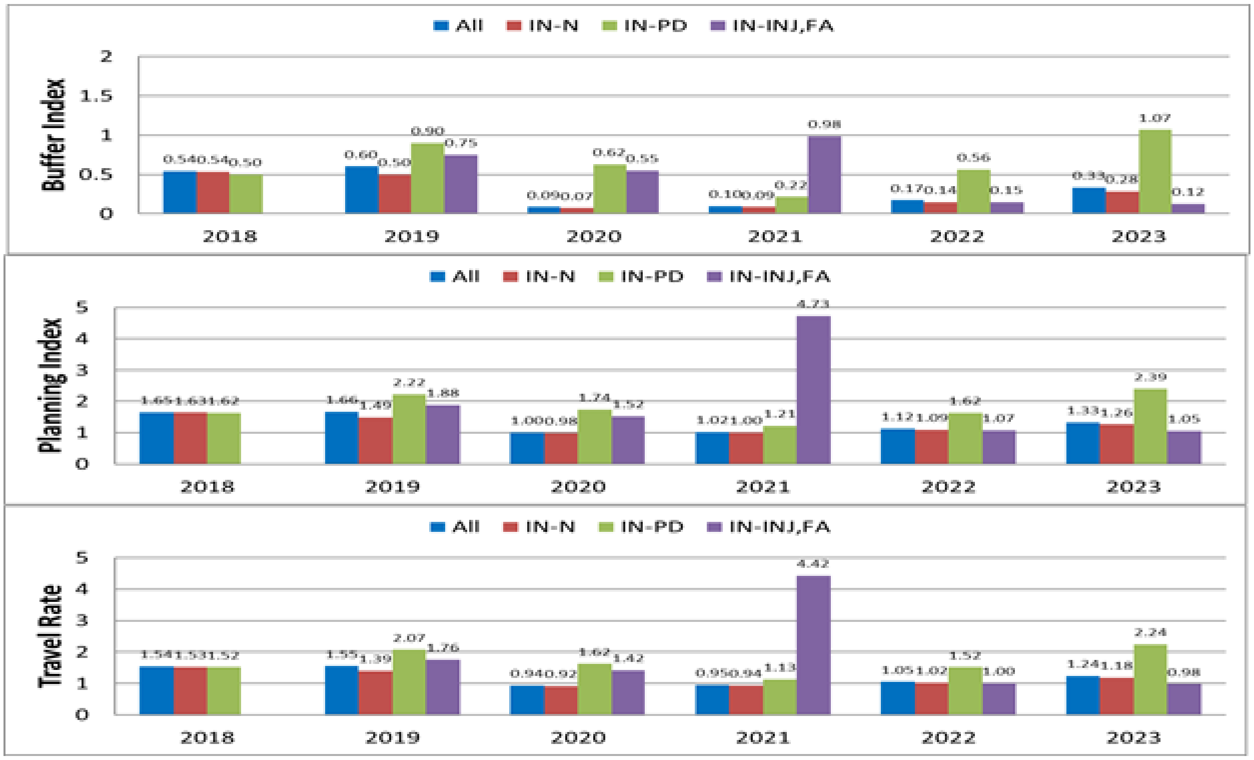
Effects of Work Zones



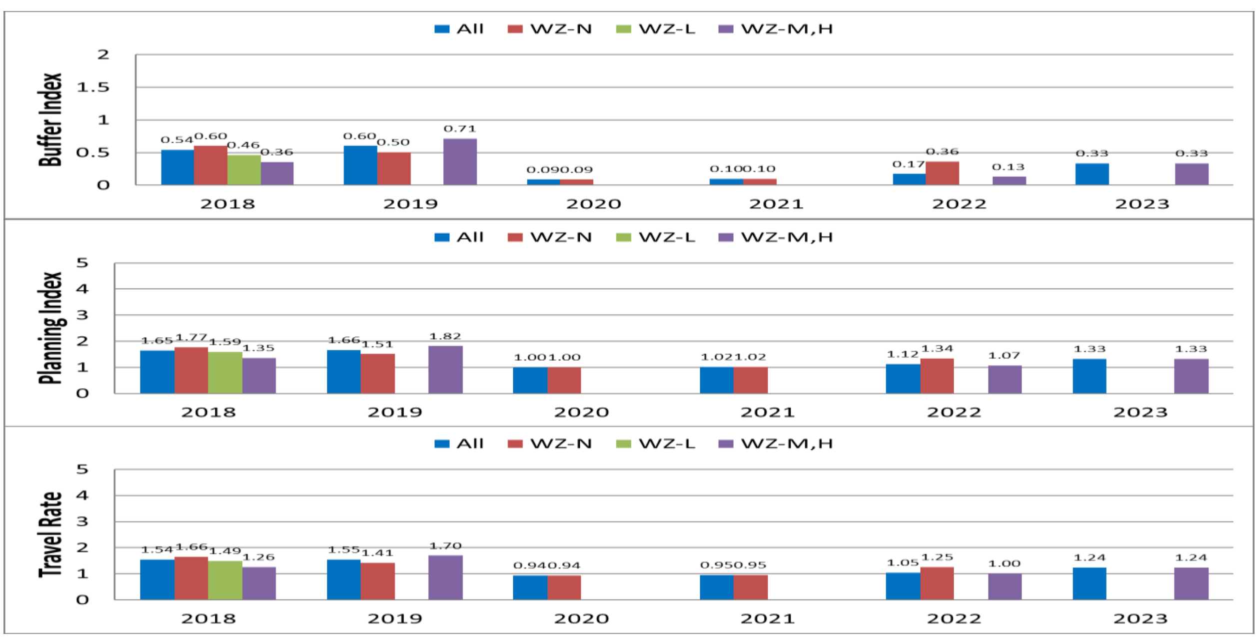
Yearly Variations - *Weather Effects*



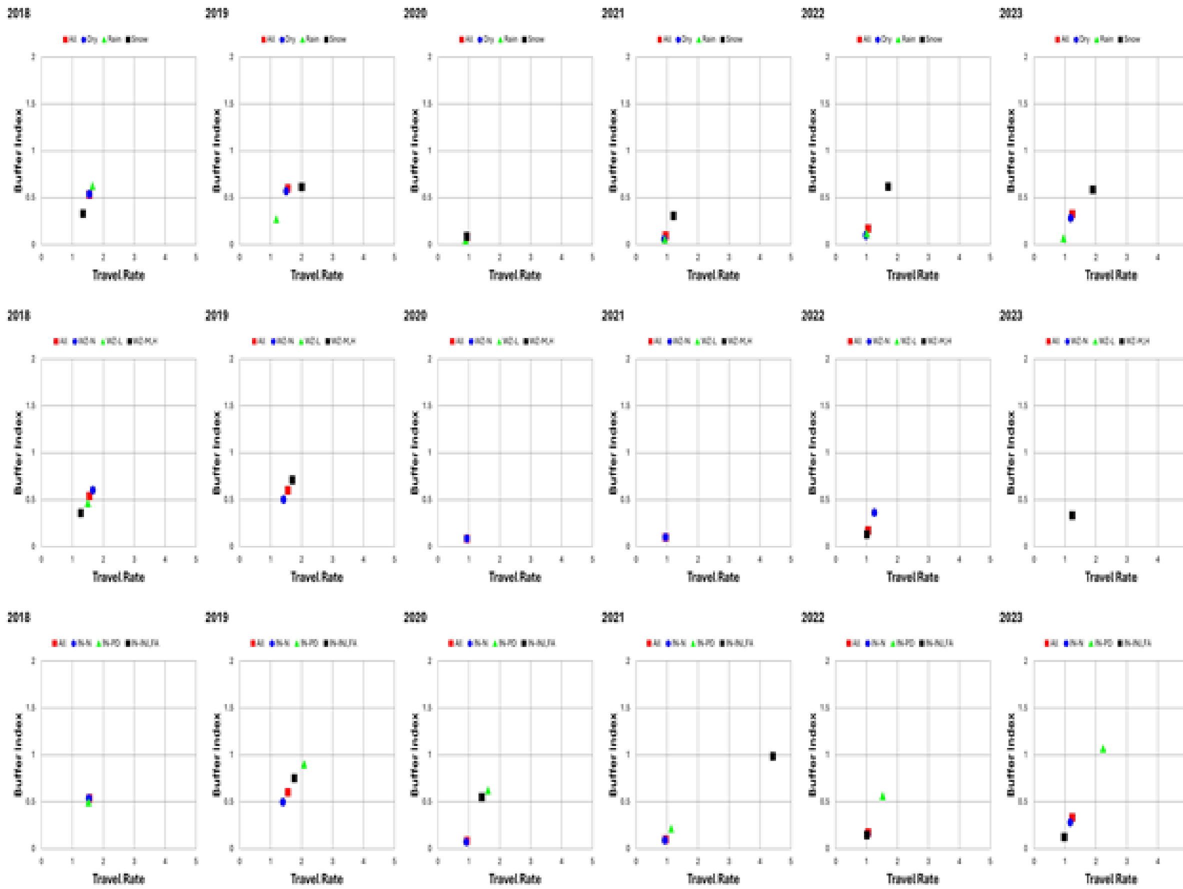
Incident Effects



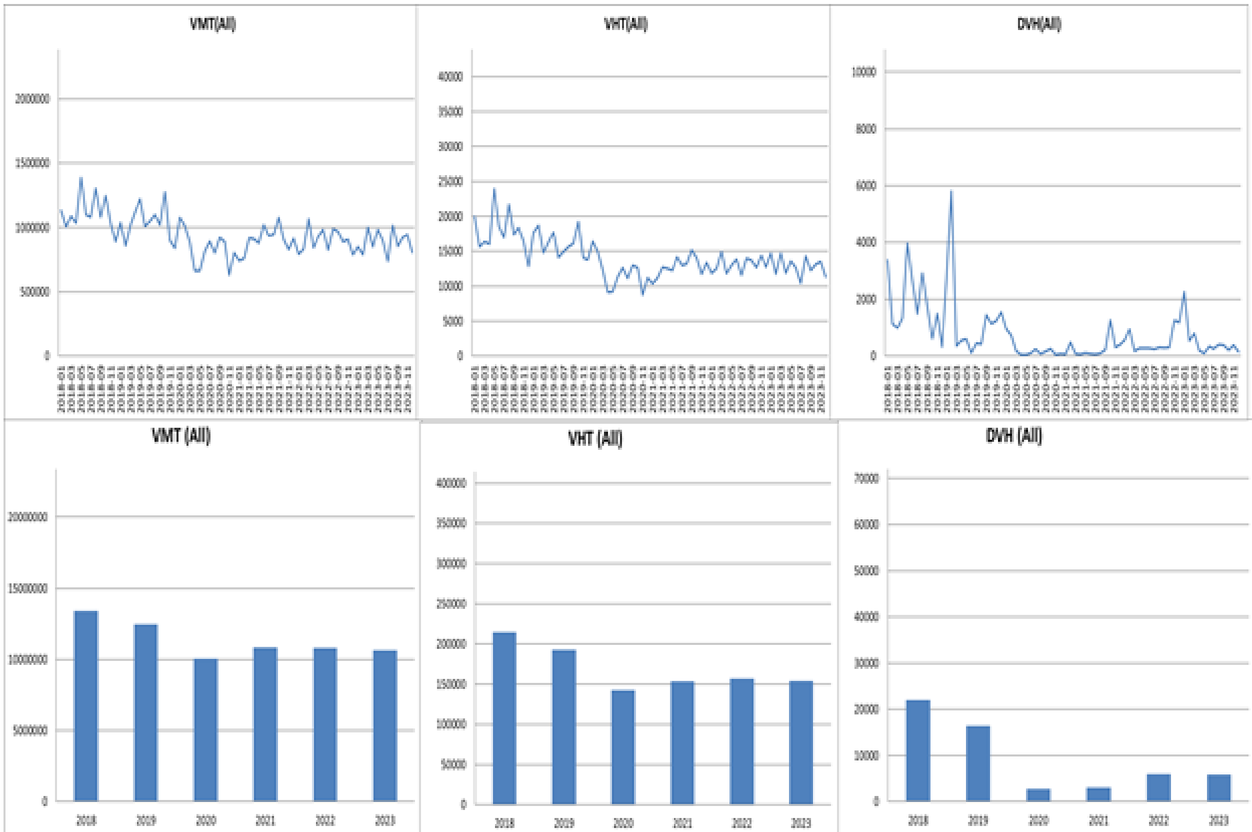
Work-Zone Effects



Yearly Variations of Buffer Index - Travel Rate Relationships



Variations of Traffic-Flow Measures



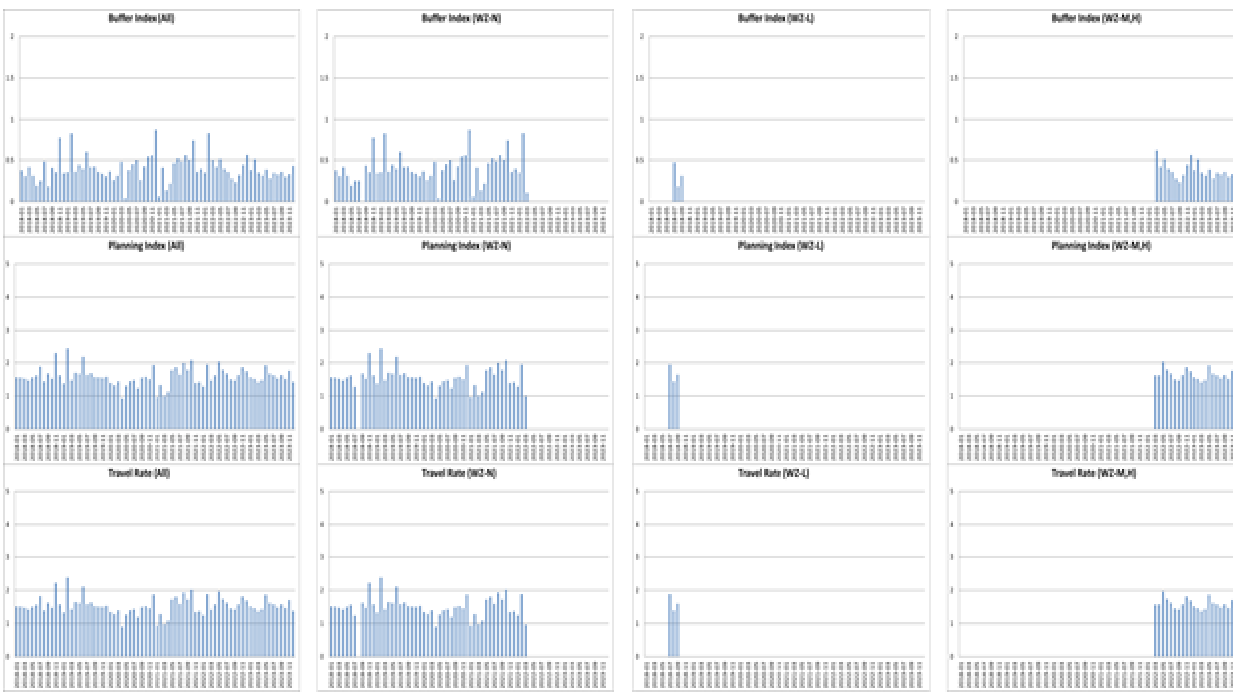
VMT(All)
VHT(All)
DVH(All)
VMT (All)
VHT (All)
DVH (All)
2018
2019
2020
2021
2022
2023

ii) TH-10 Corridor A - WB TH610 to TH169 for Afternoon Peak Periods

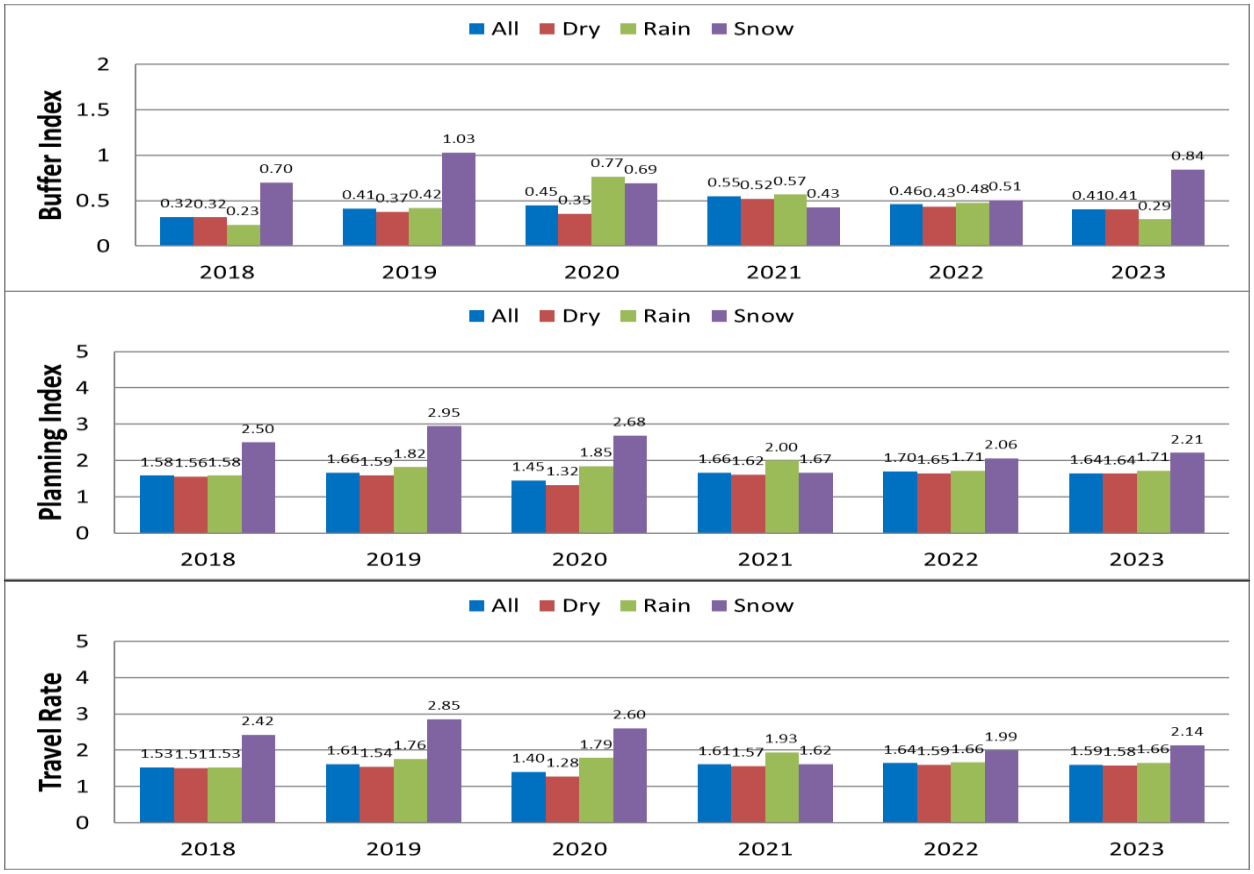
Effects of Weather conditions on Travel-Time Reliability

Effects of Incidents

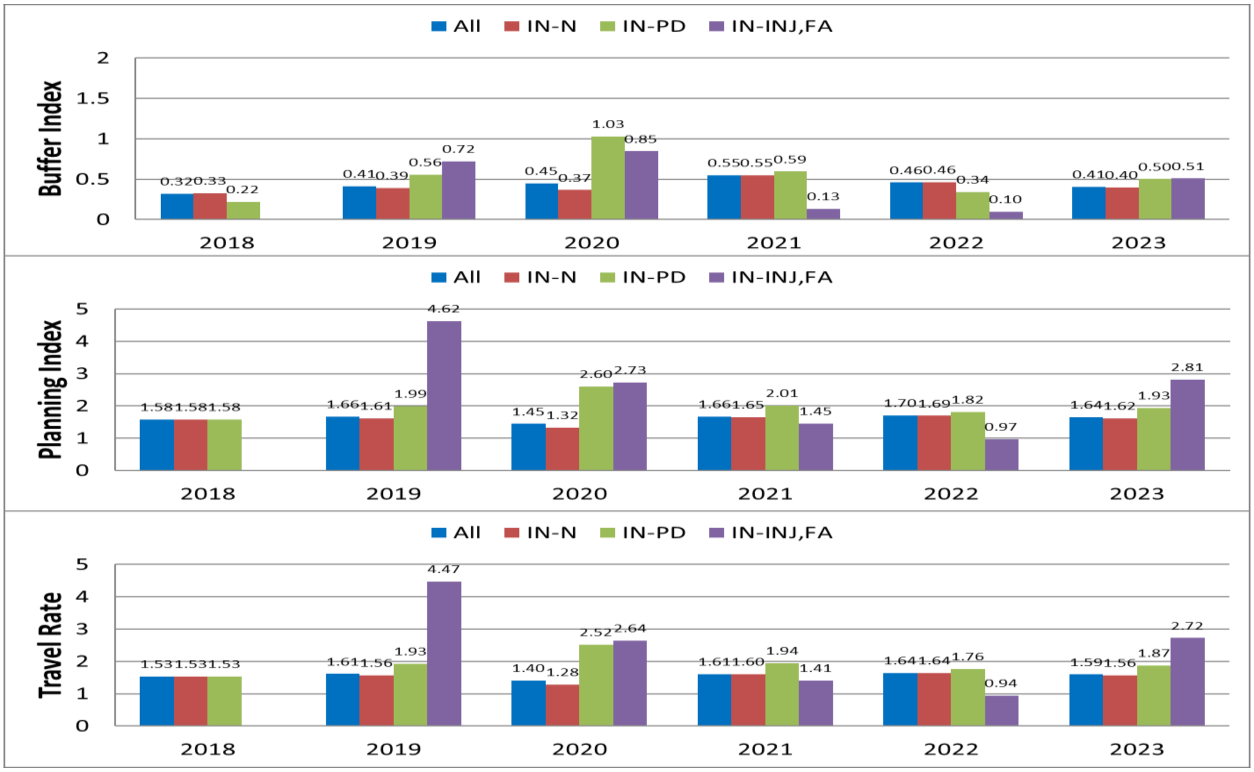
Effects of Work Zones



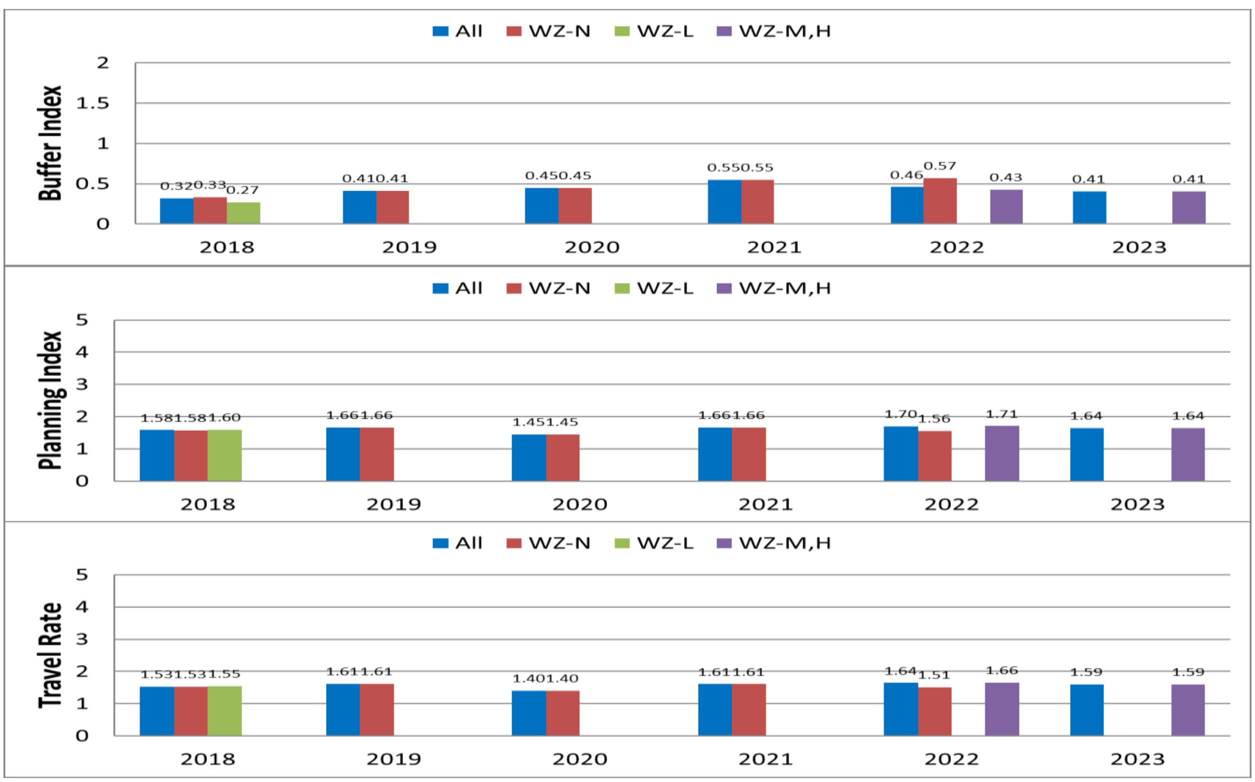
Yearly Variations - *Weather Effects*



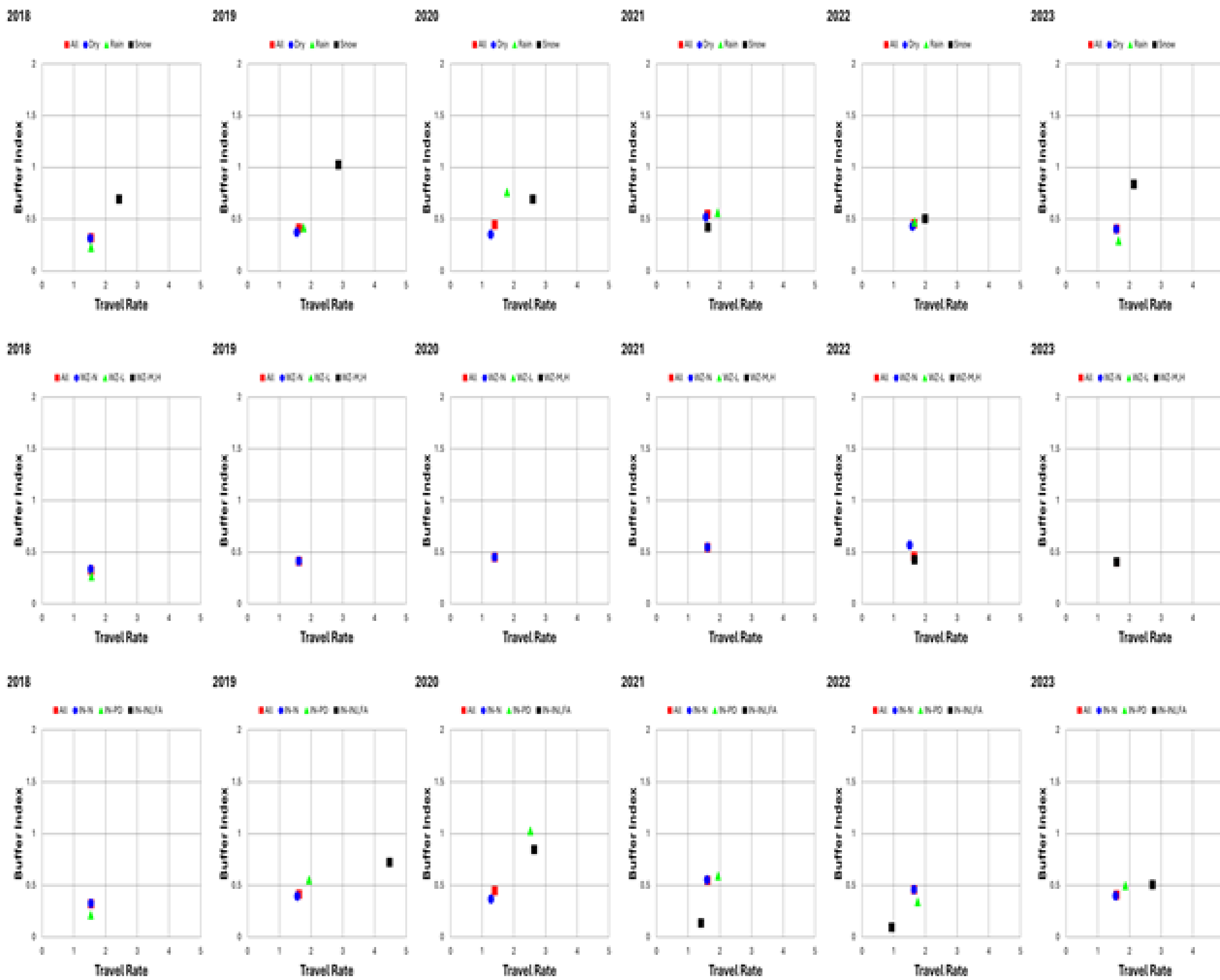
Incident Effects



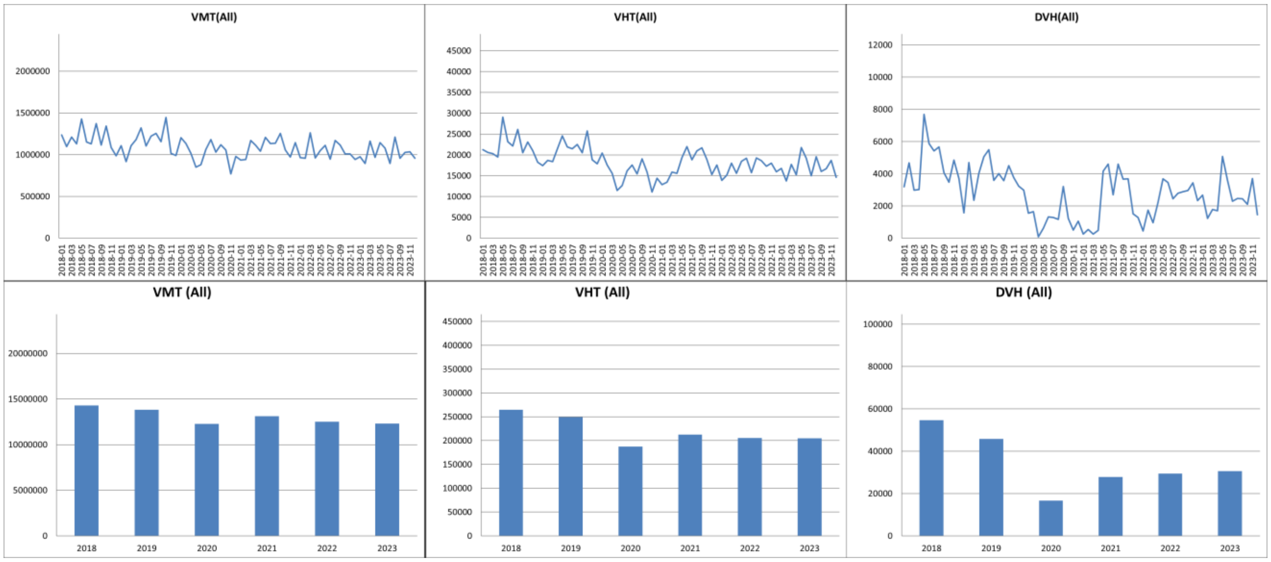
Work-Zone Effects



Yearly Variations of Buffer Index - Travel Rate Relationships

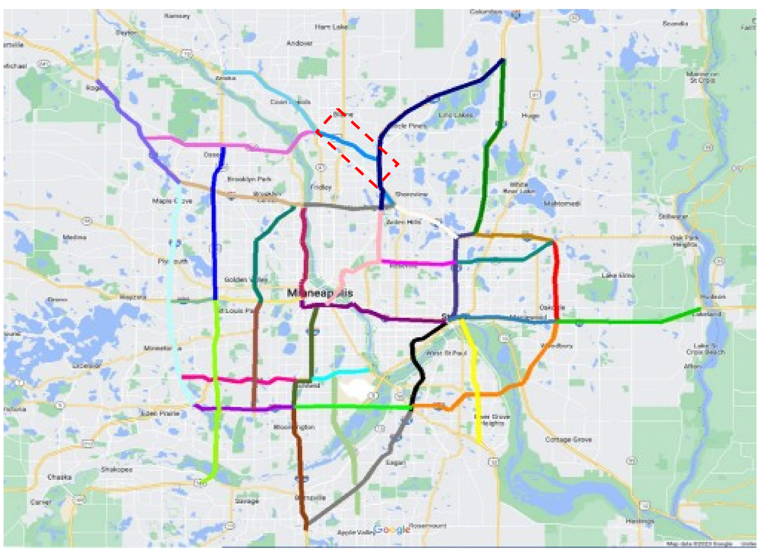


Variations of Traffic-Flow Measures

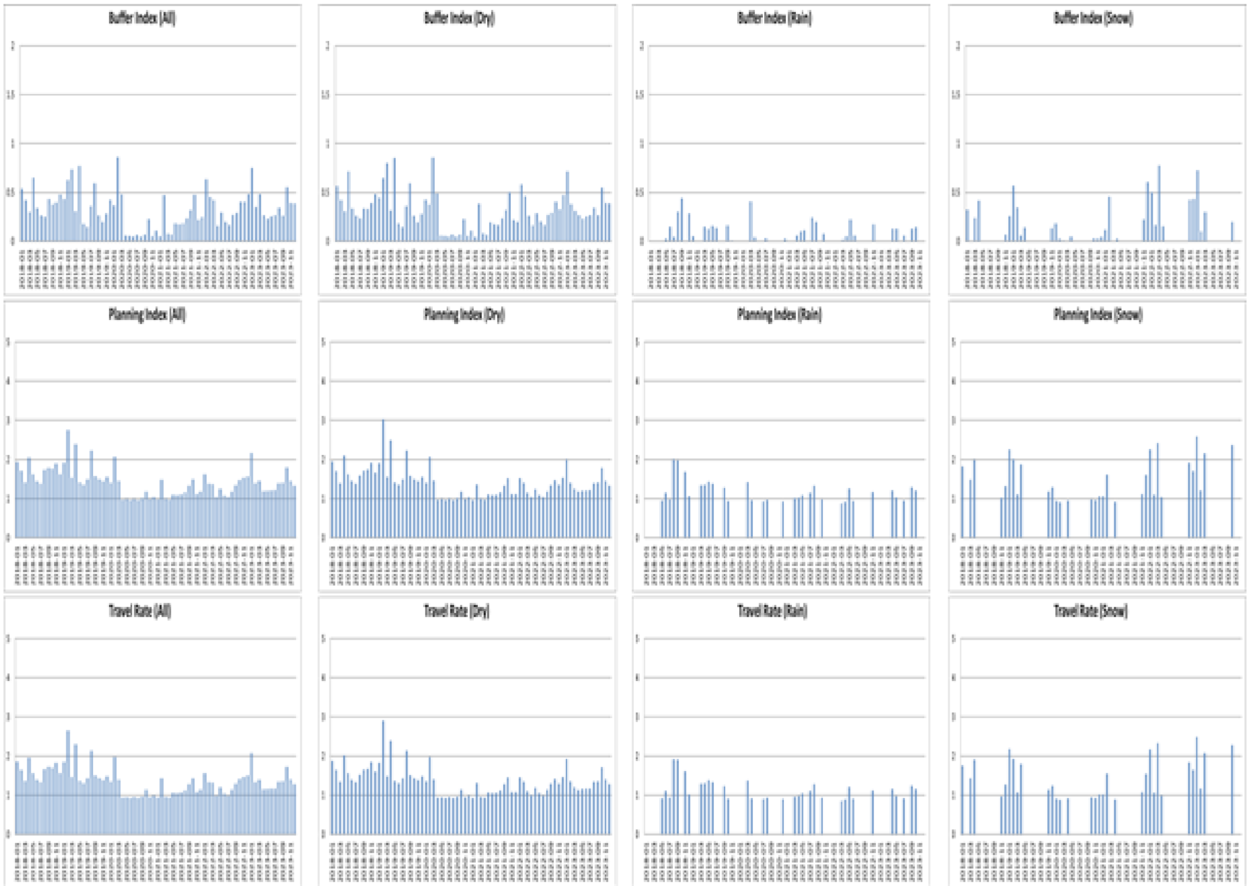


12) TH-10 Corridor B (TH610 < -- > I694)

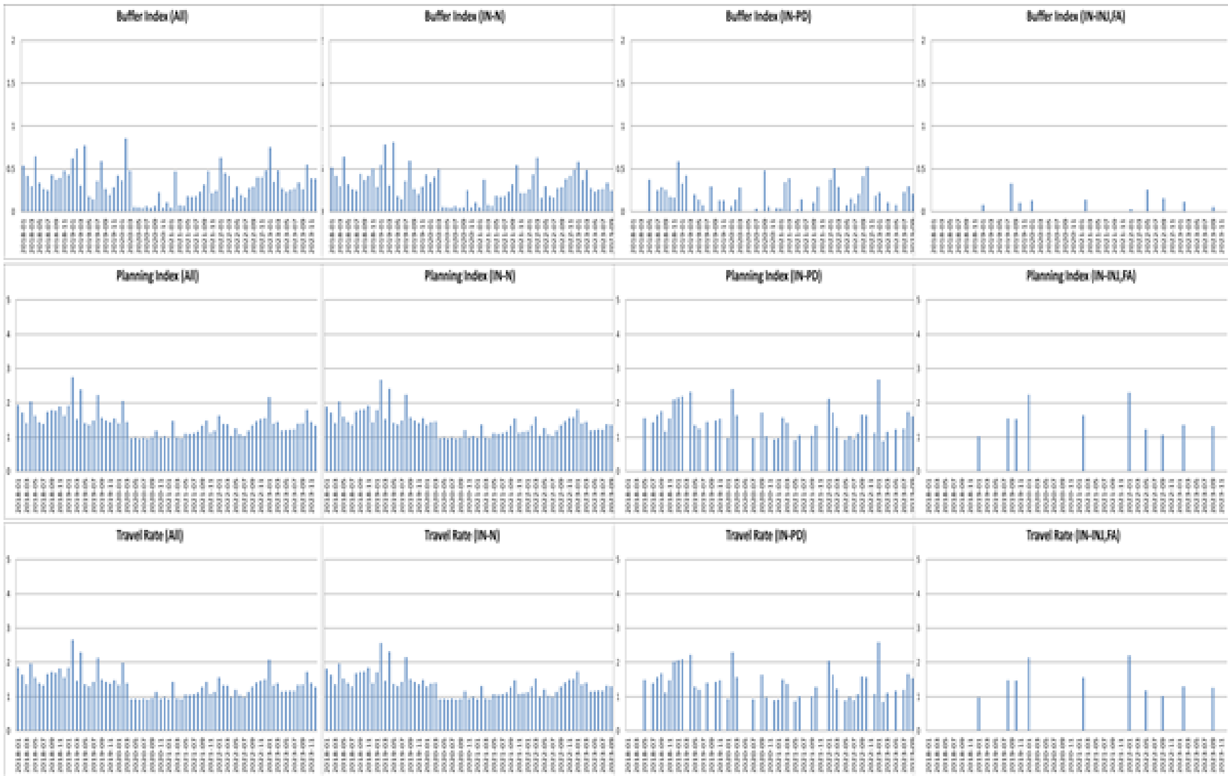
i) TH-10 Corridor B -- EB TH610 to I694 for Morning Peak Periods



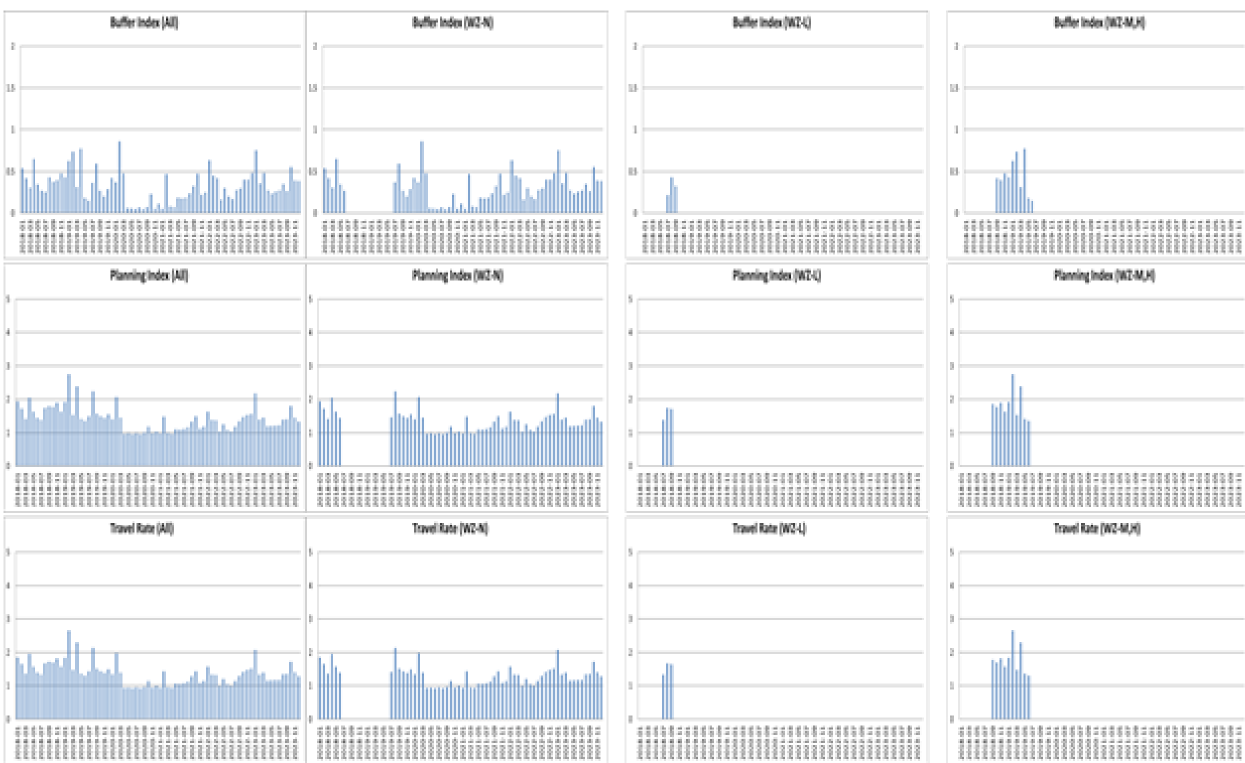
Effects of Weather conditions on Travel-Time Reliability



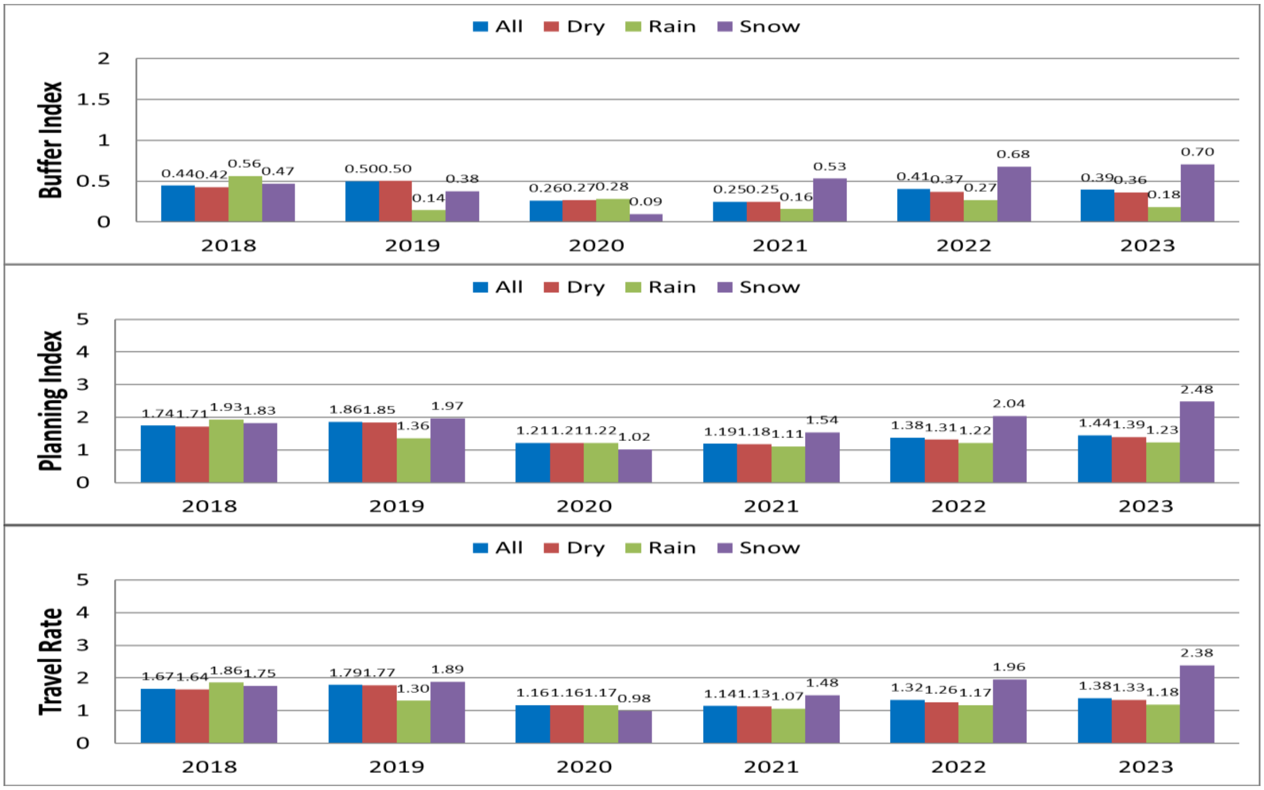
Effects of Incidents



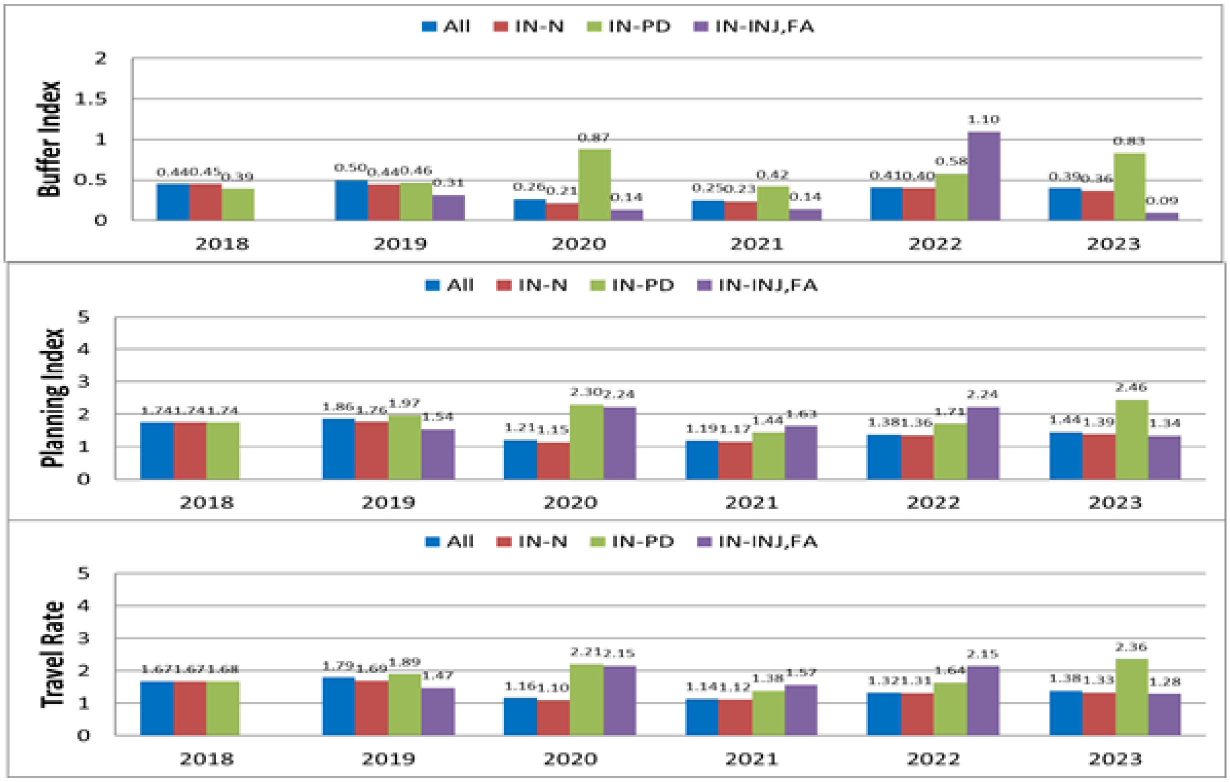
Effects of Work Zones



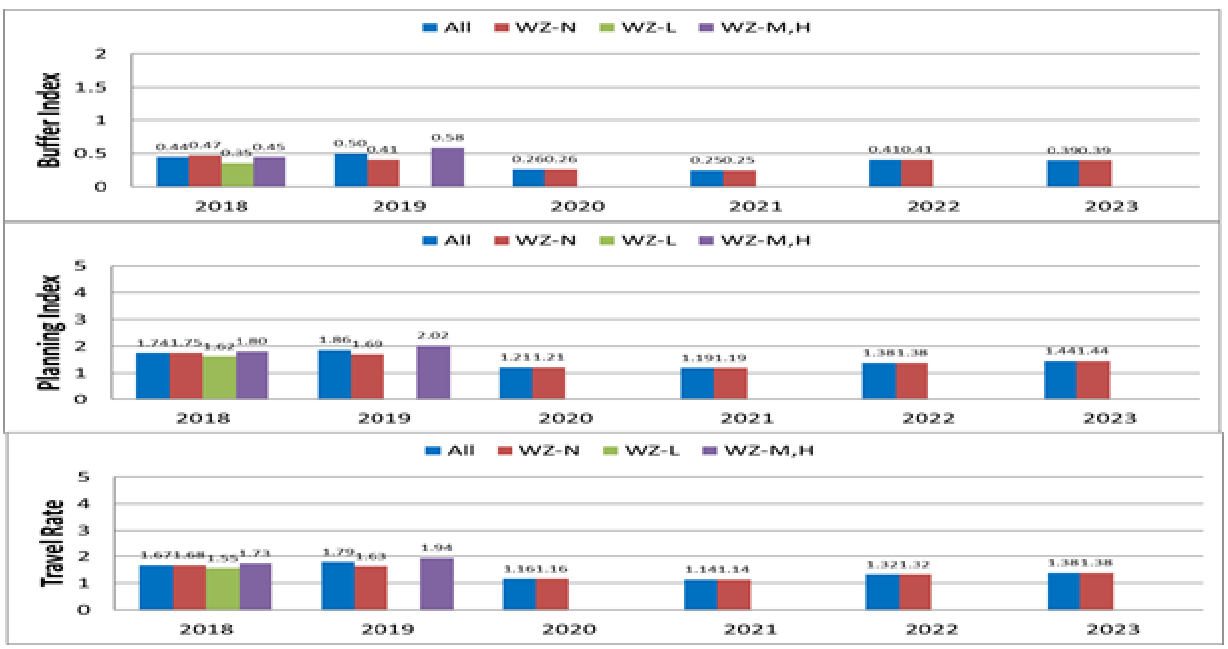
Yearly Variations - *Weather Effects*



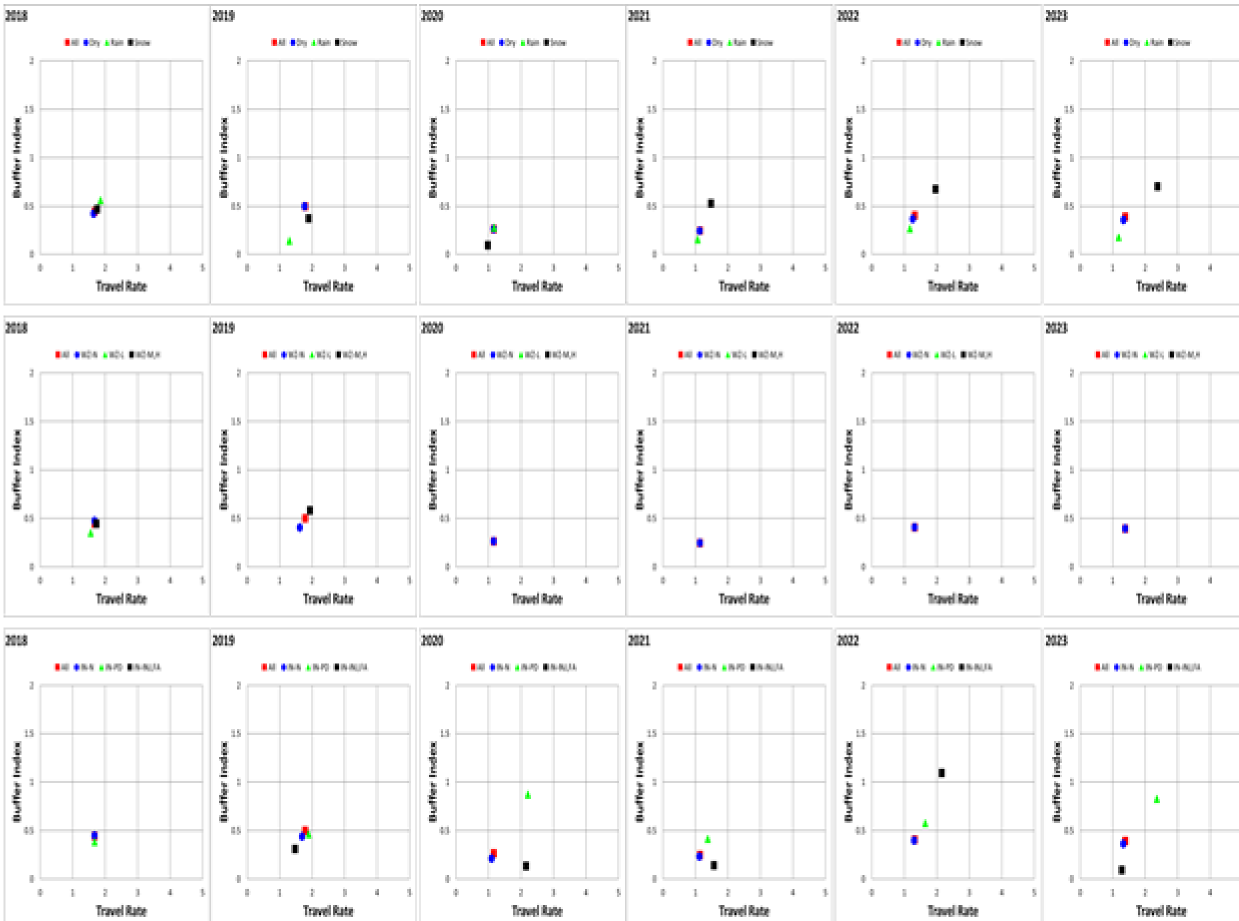
Incident Effects



Work-Zone Effects



Yearly Variations of Buffer Index - Travel Rate Relationships

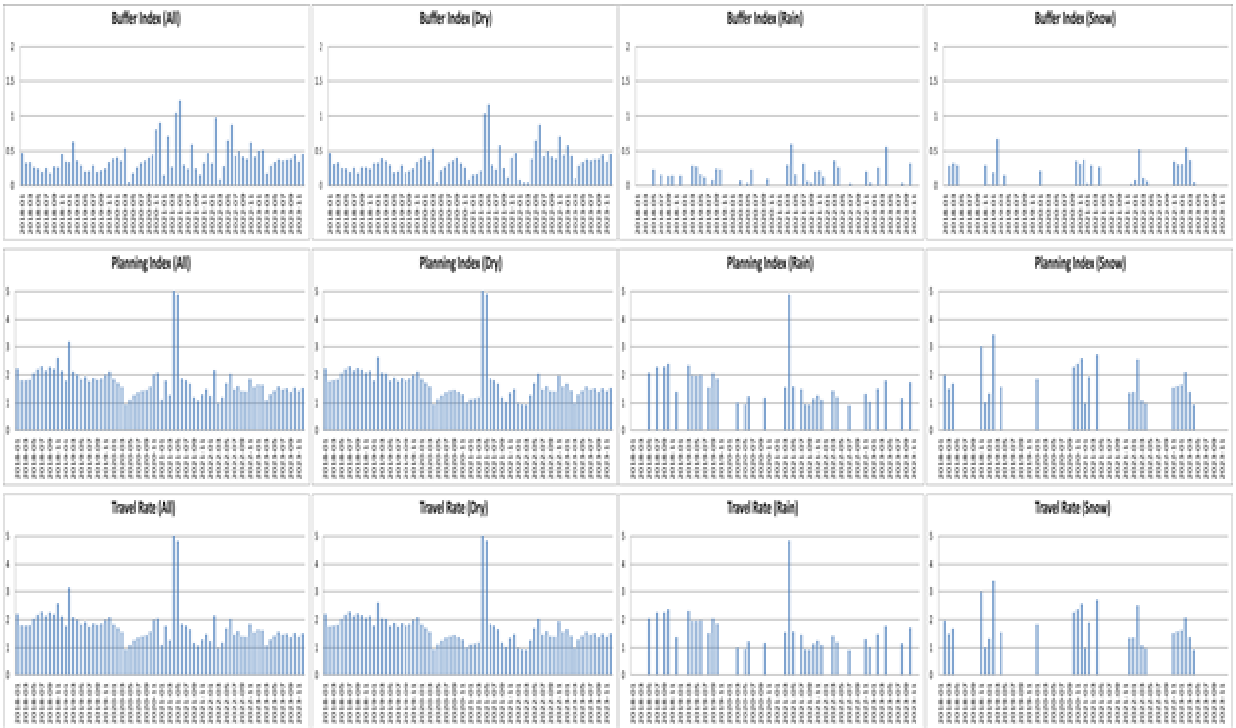


Variations of Traffic-Flow Measures

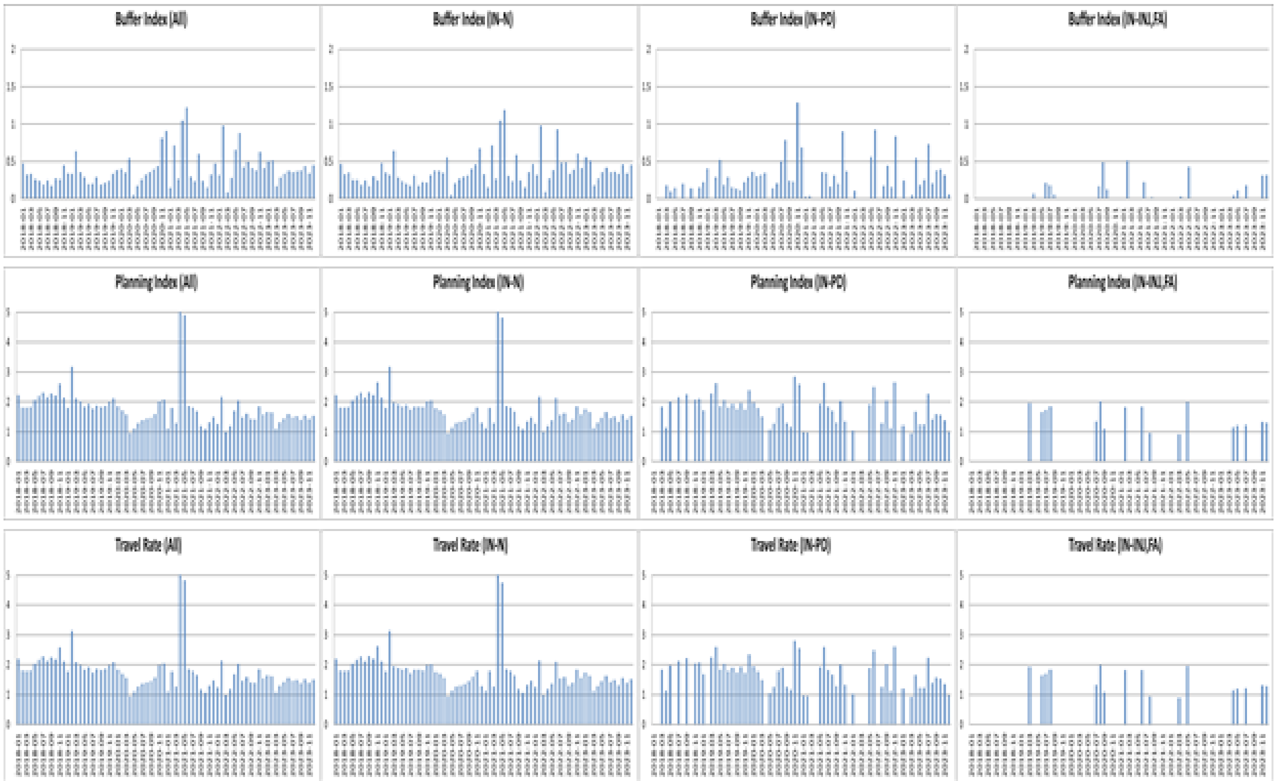

VMT(All)
VHT(All)
DVH(All)
VMT (All)
VHT (All)
DVH (All)

ii) TH-10 Corridor B - WB I694 to TH 610 for Afternoon Peak Periods

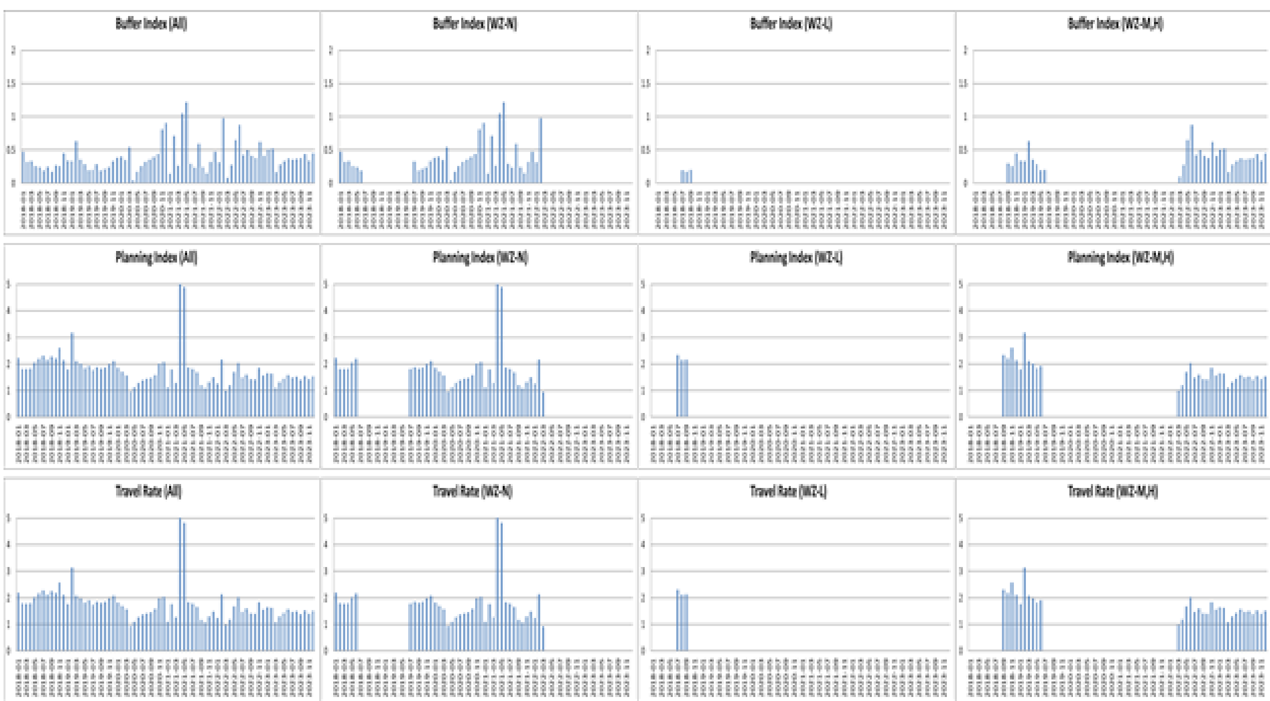
Effects of Weather conditions on Travel-Time Reliability



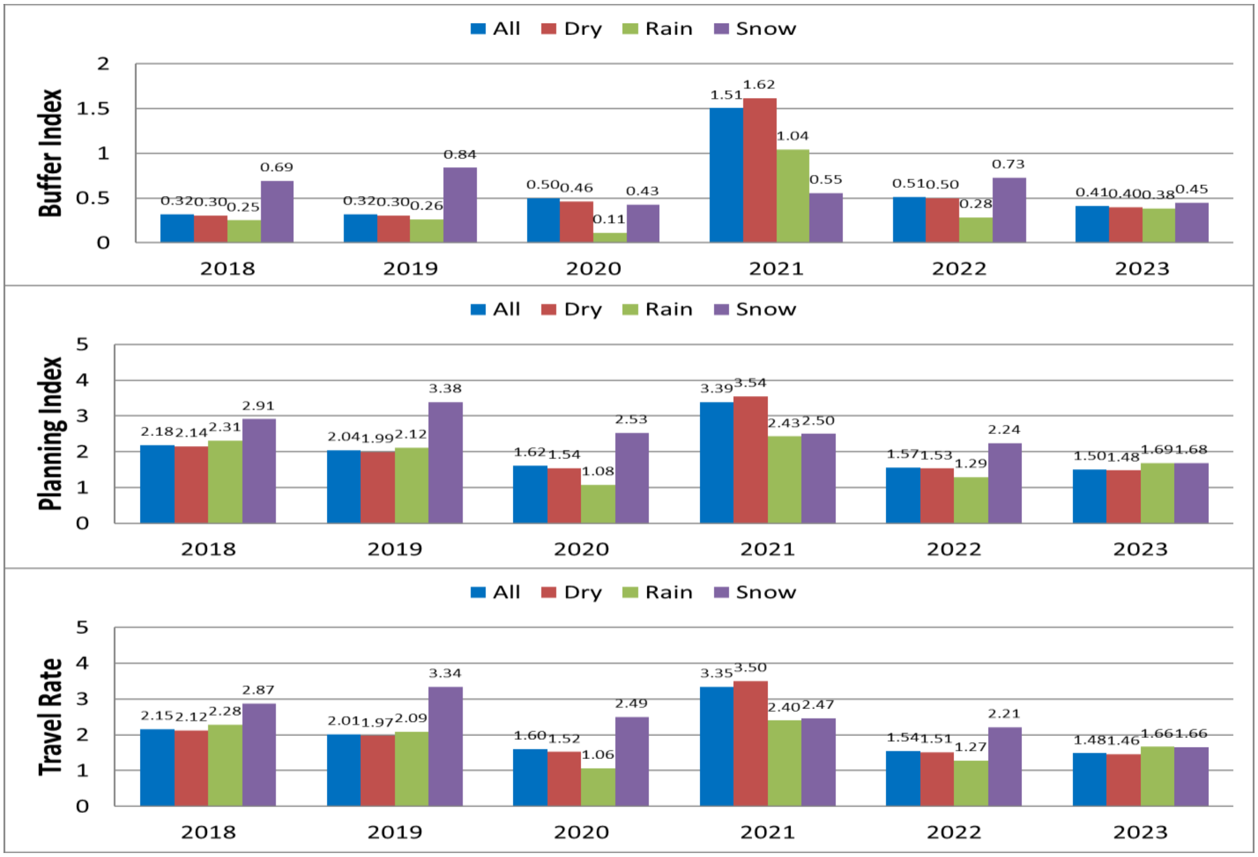
Effects of Incidents



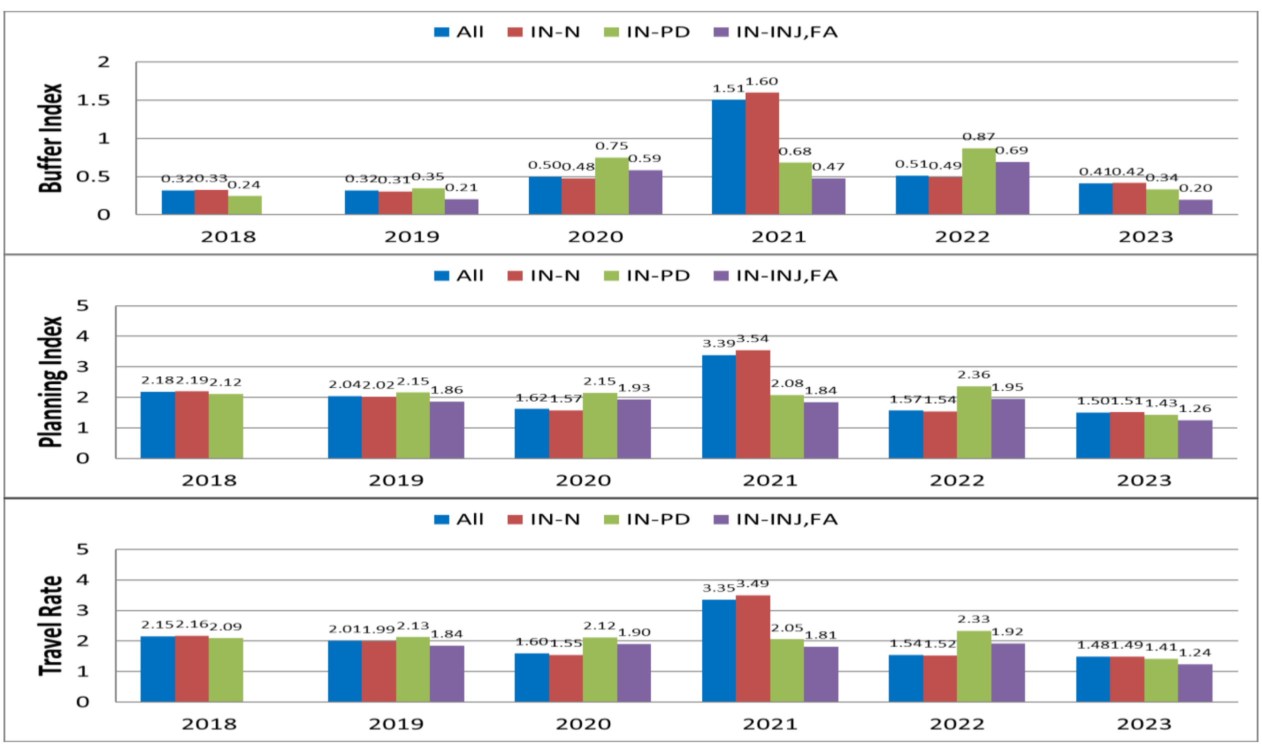
Effects of Work Zones



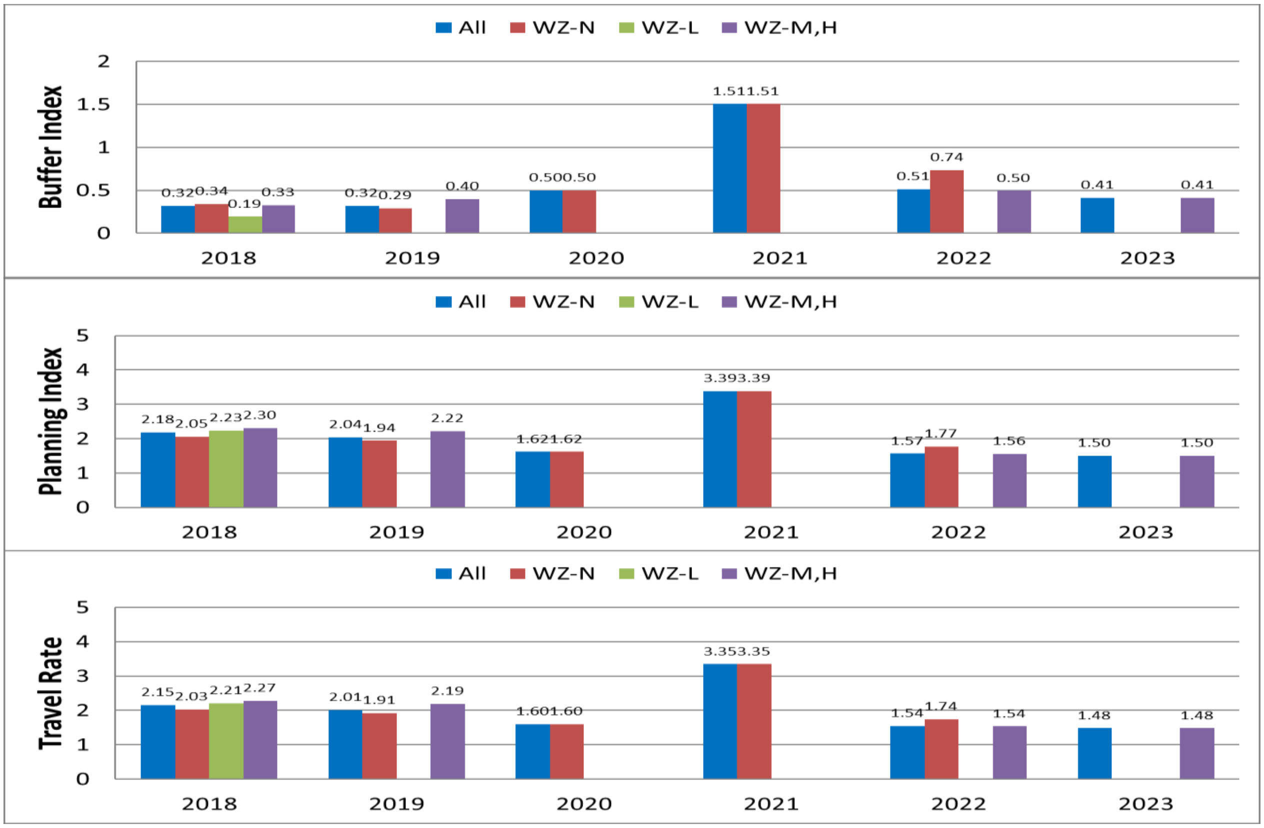
Yearly Variations - *Weather Effects*



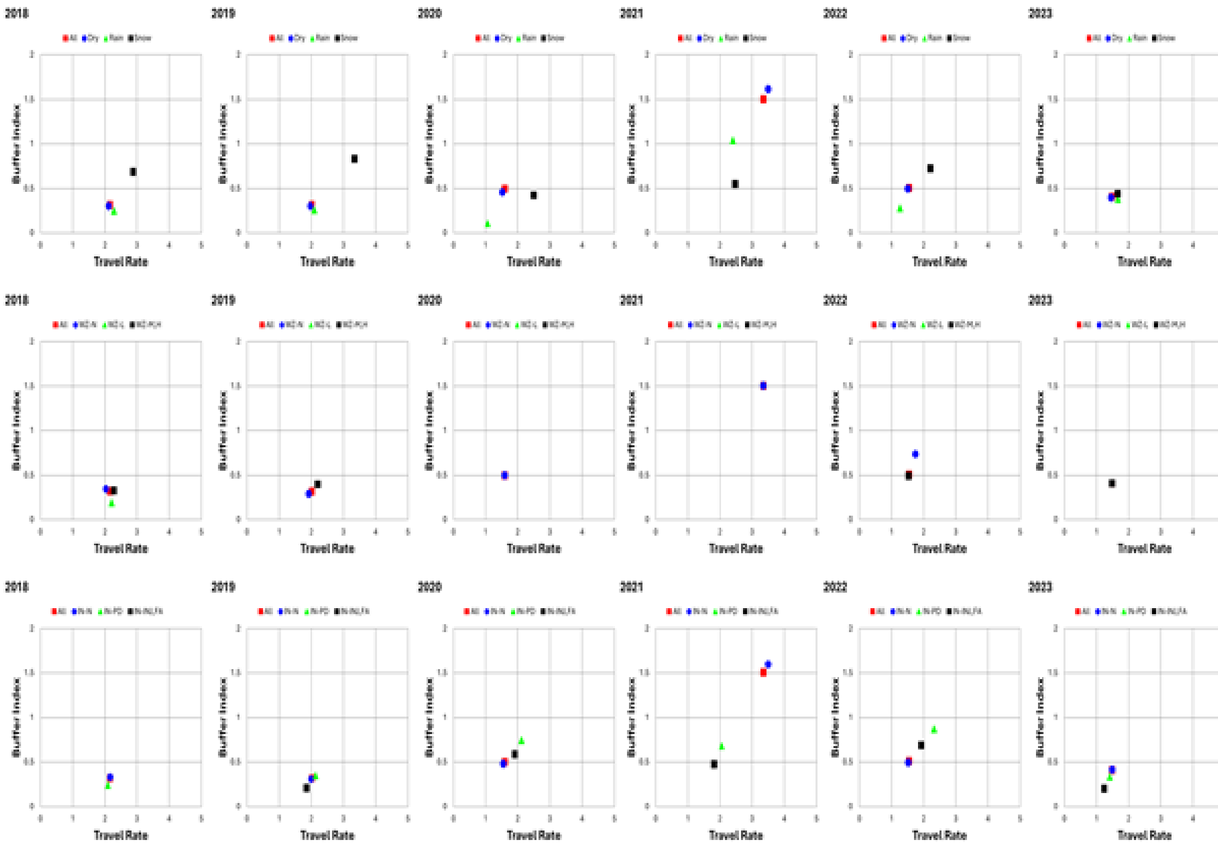
Incident Effects



Work-Zone Effects



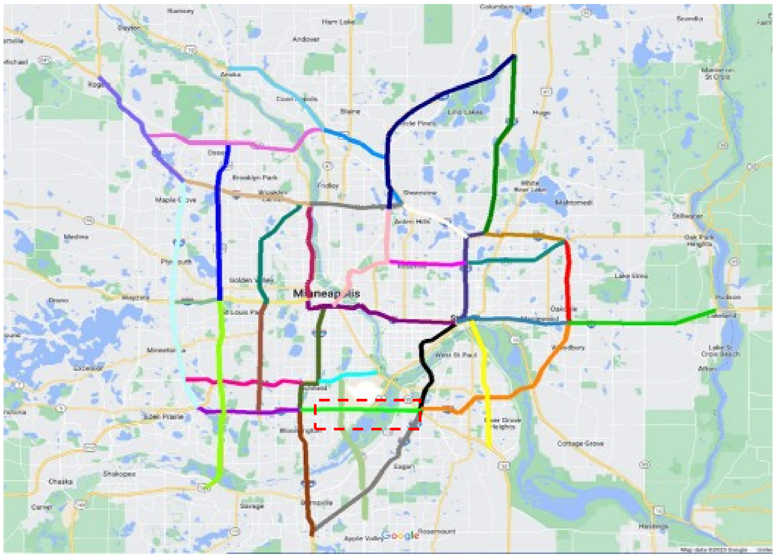
Yearly Variations of Buffer Index - Travel Rate Relationships



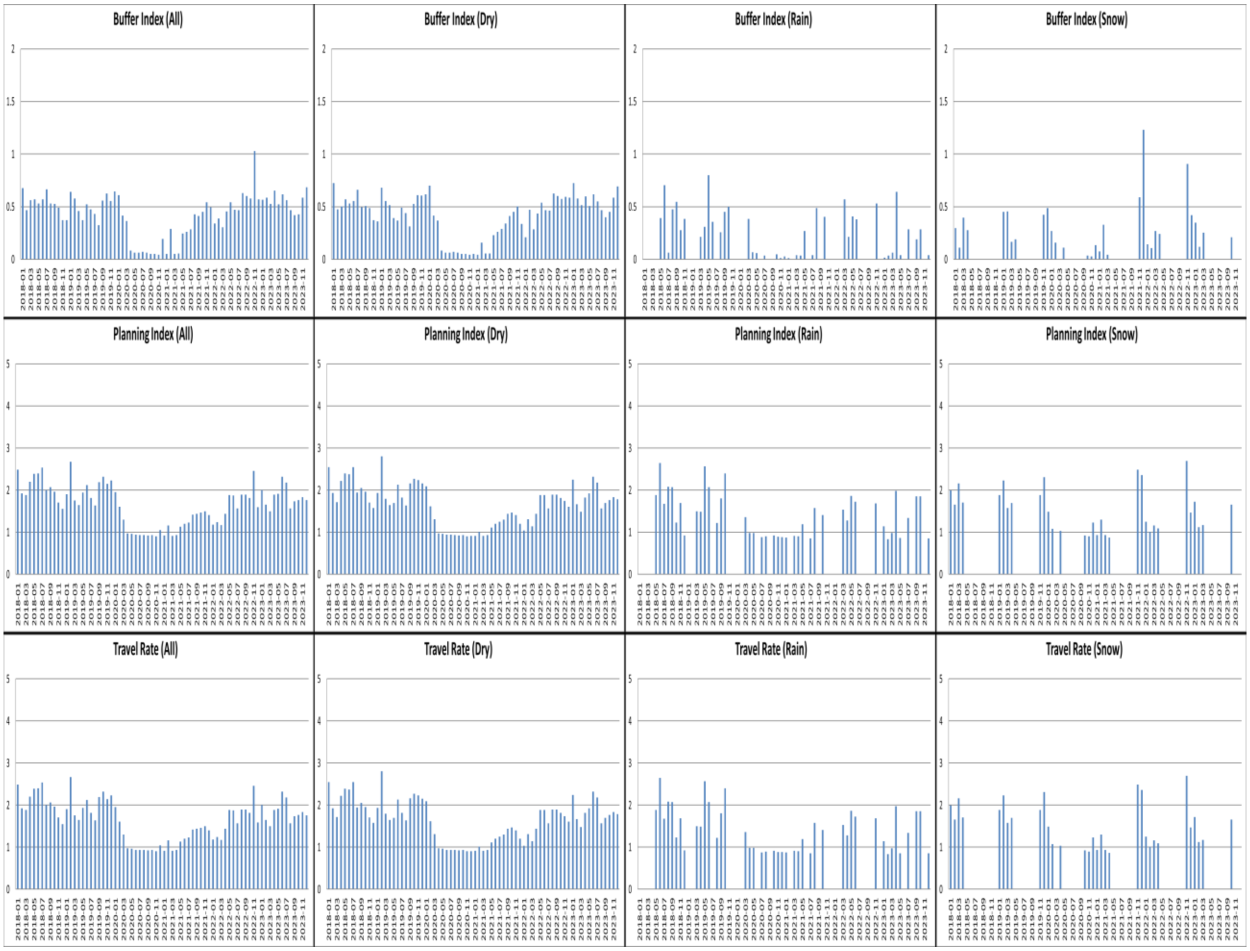
Variations of Traffic-Flow Measures

13) I-494 Corridor A (I35E to I35W)

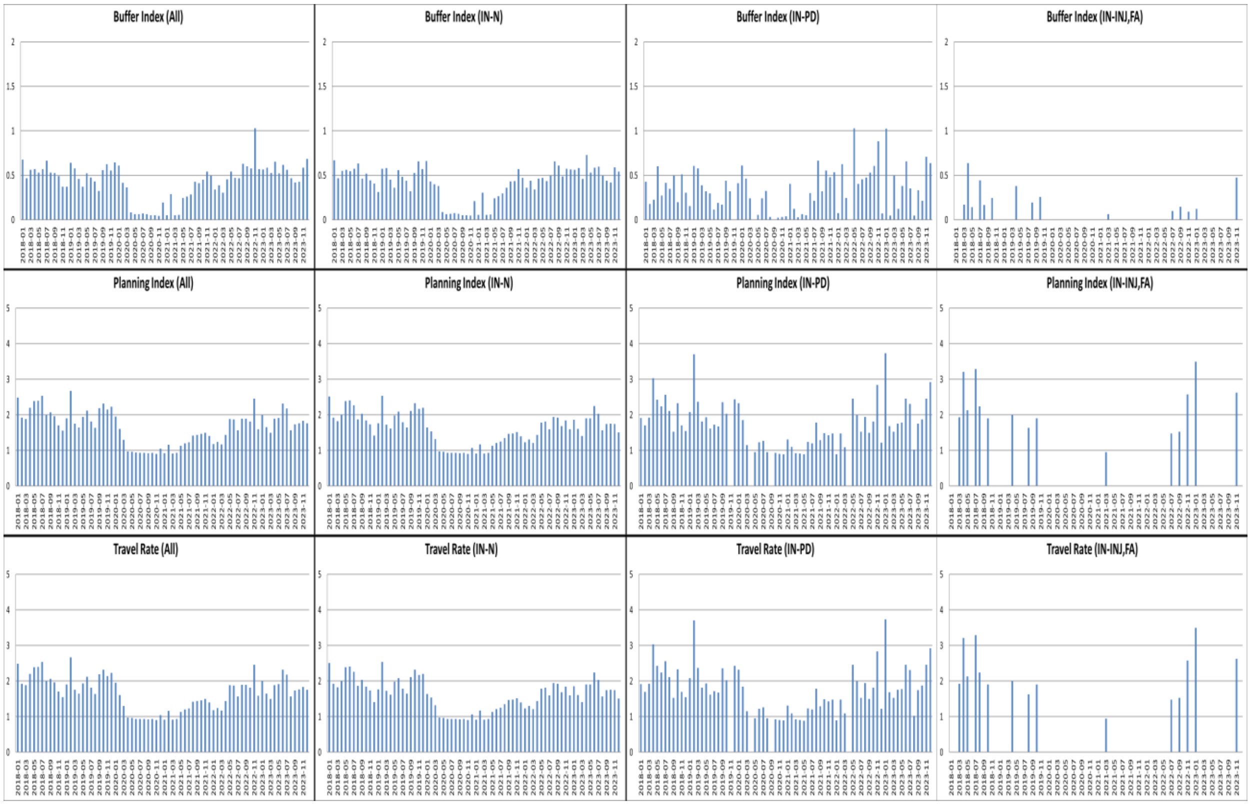
i) I-494 Corridor A - WB for I-35e -> I-35w, Morning Peak Periods



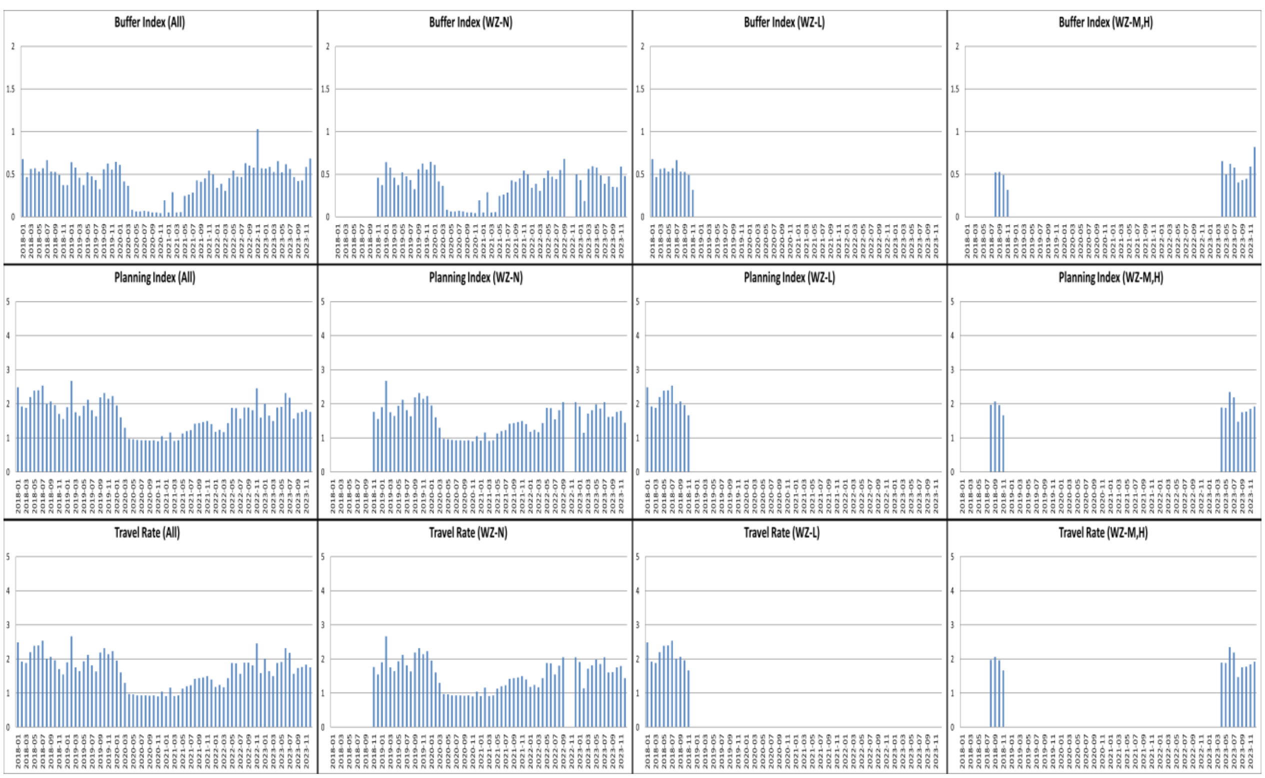
Effects of Weather conditions on Travel-Time Reliability



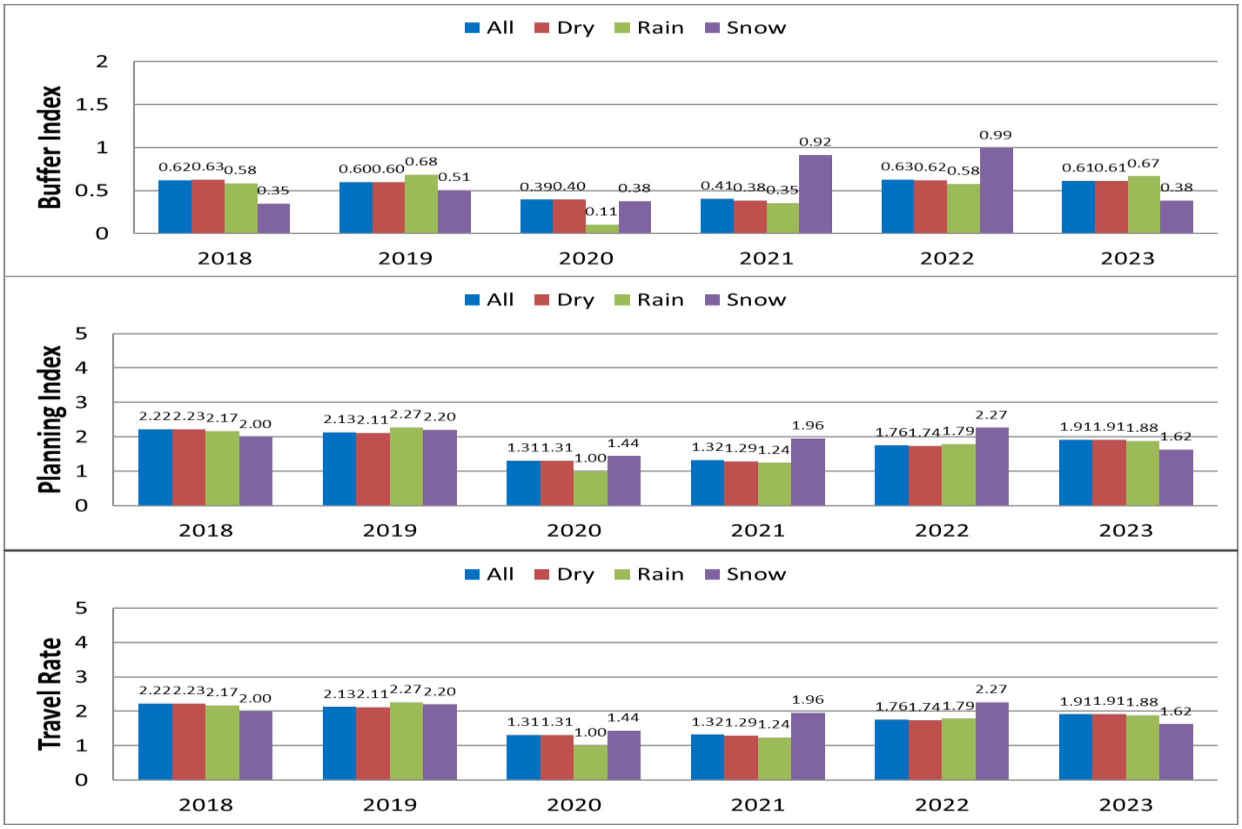
Effects of Incidents



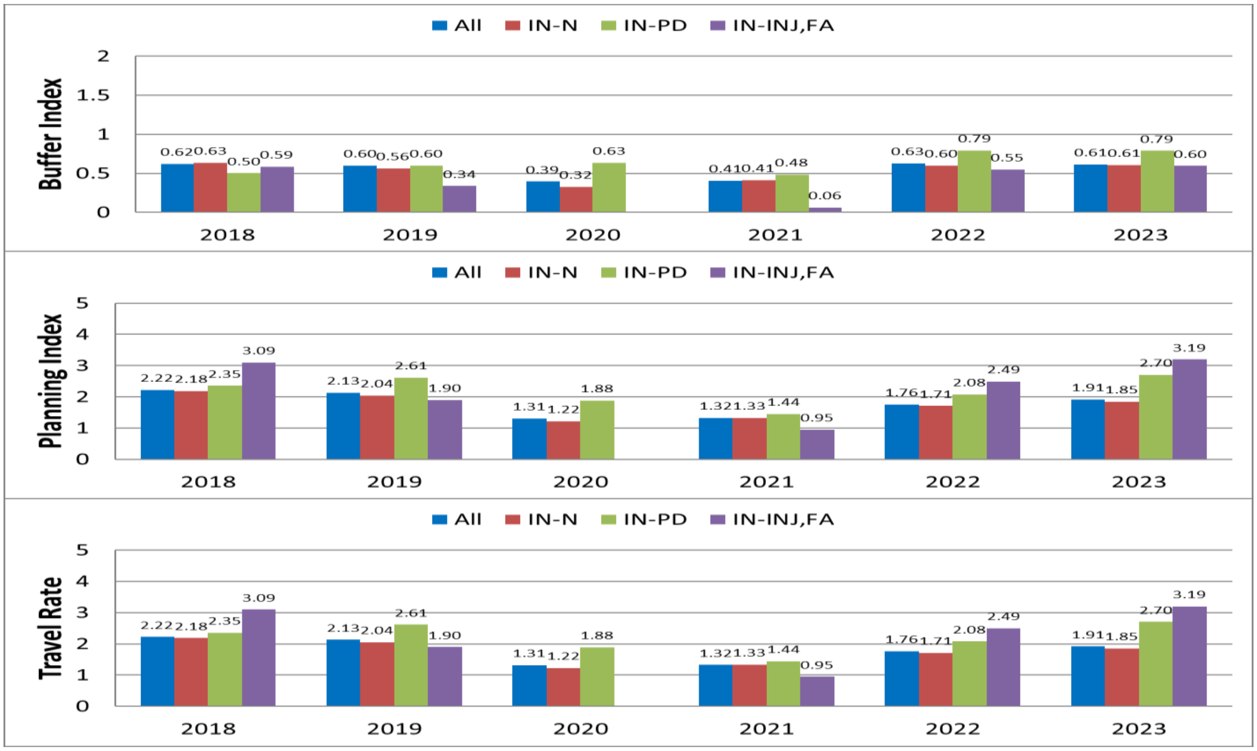
Effects of Work Zones



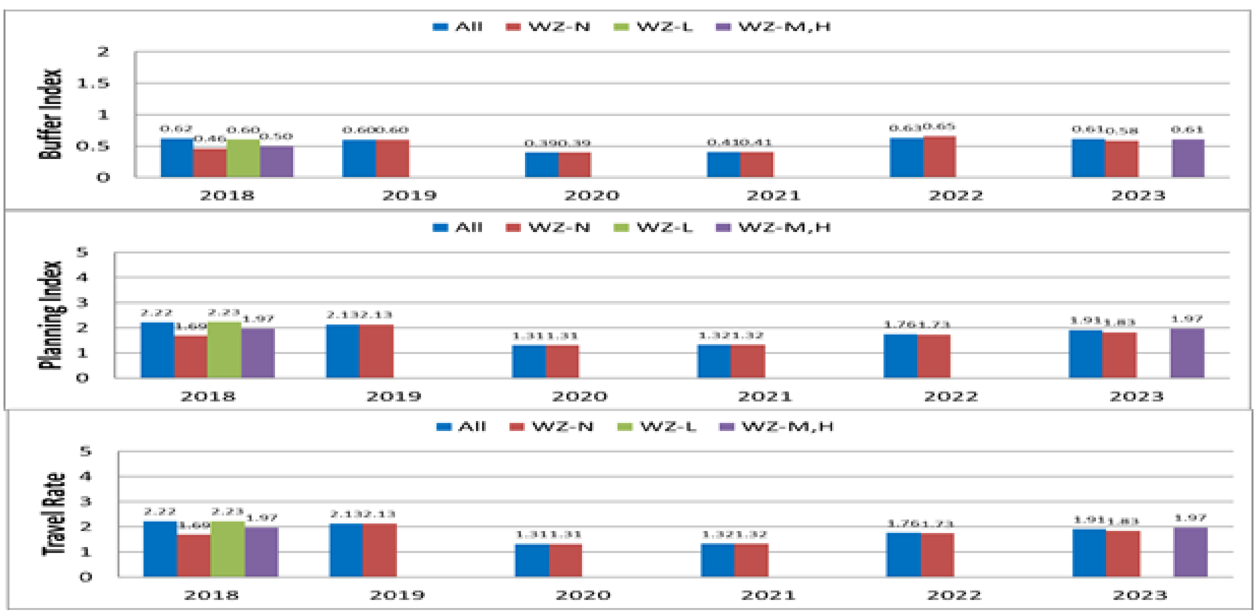
Yearly Variations - *Weather Effects*



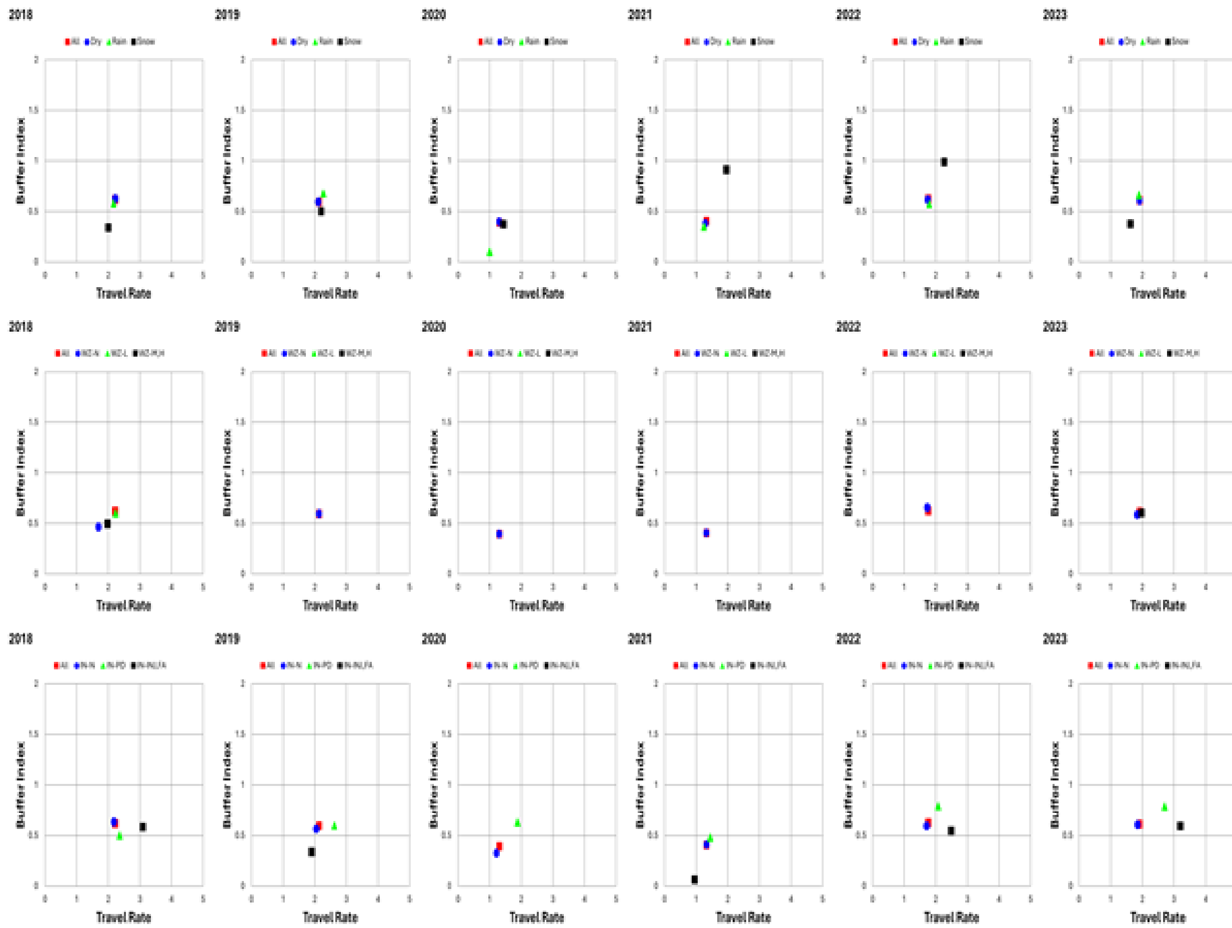
Incident Effects



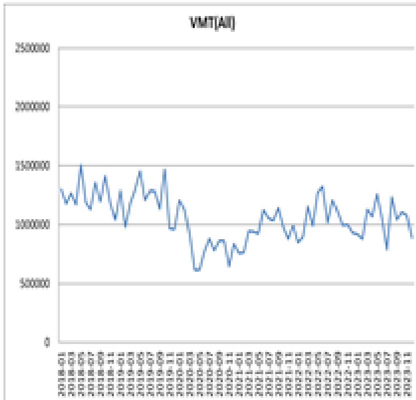
Work-Zone Effects

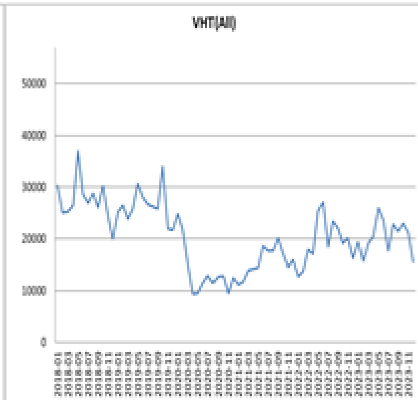


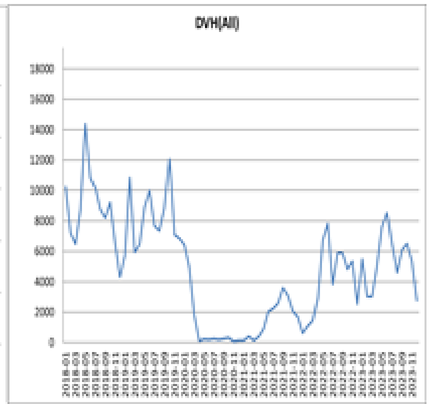
Yearly Variations of Buffer Index - Travel Rate Relationships

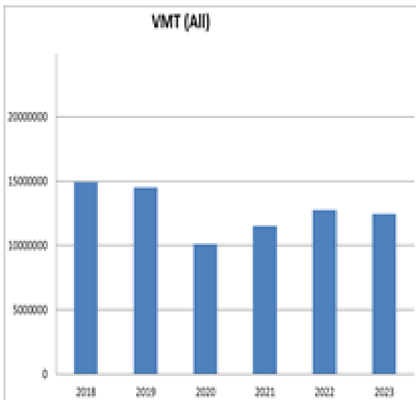


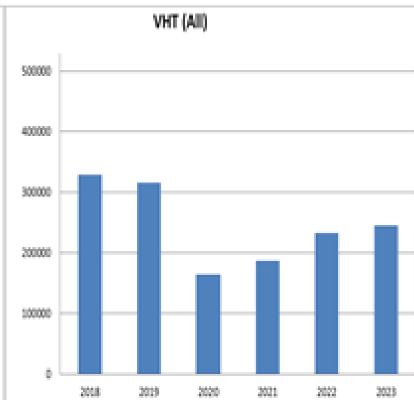
Variations of Traffic-Flow Measures

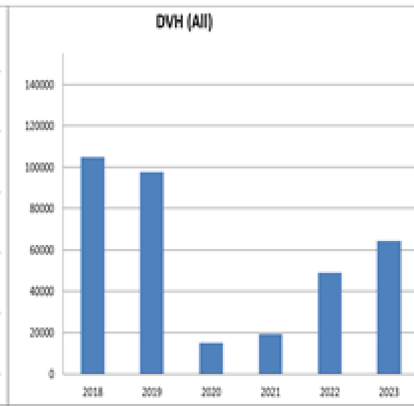

VMT(All)


VHT(All)


DVH(All)

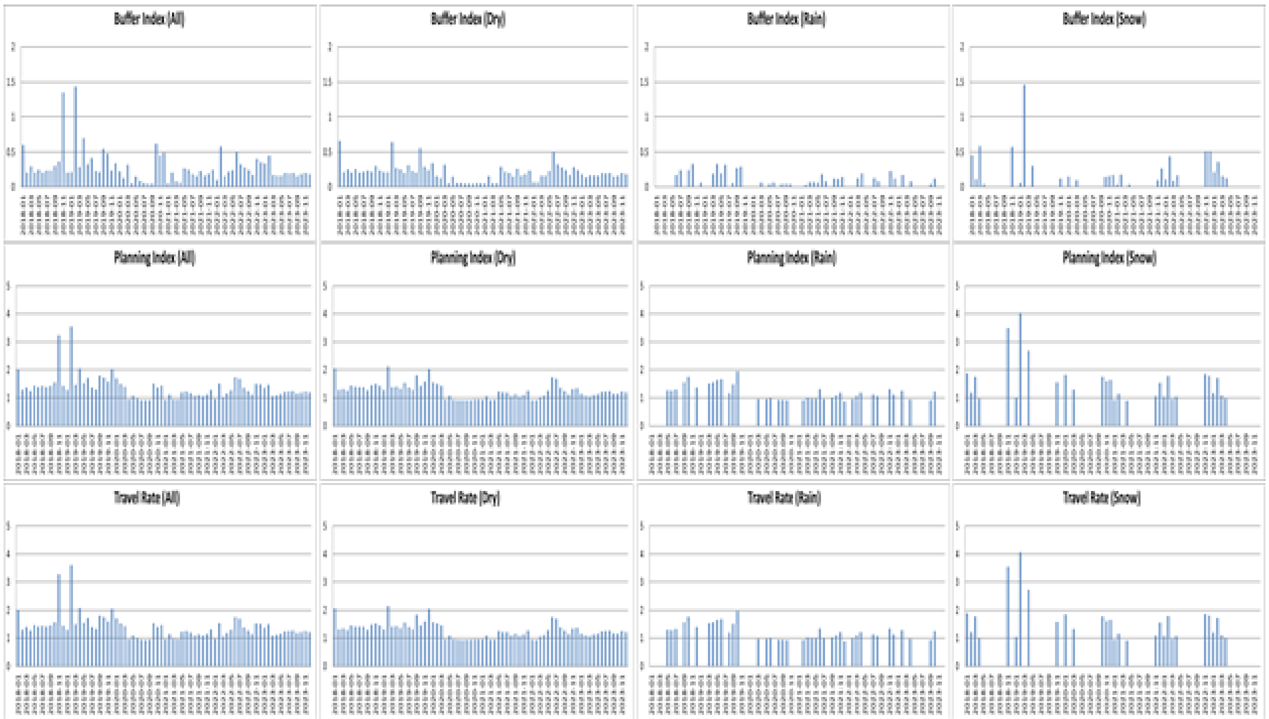

VMT (All)


VHT (All)

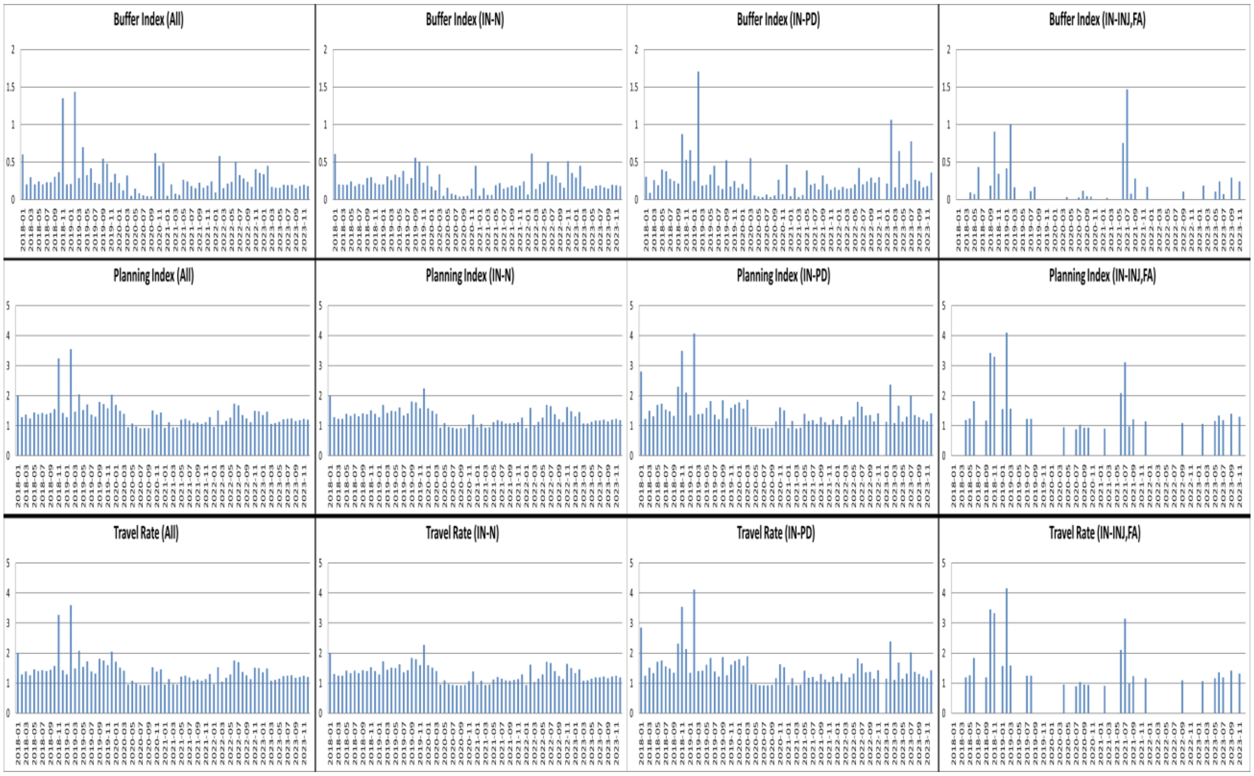

DVH (All)

ii) I-494 Corridor A - EB I-35w to I-35E for Afternoon Peak Periods

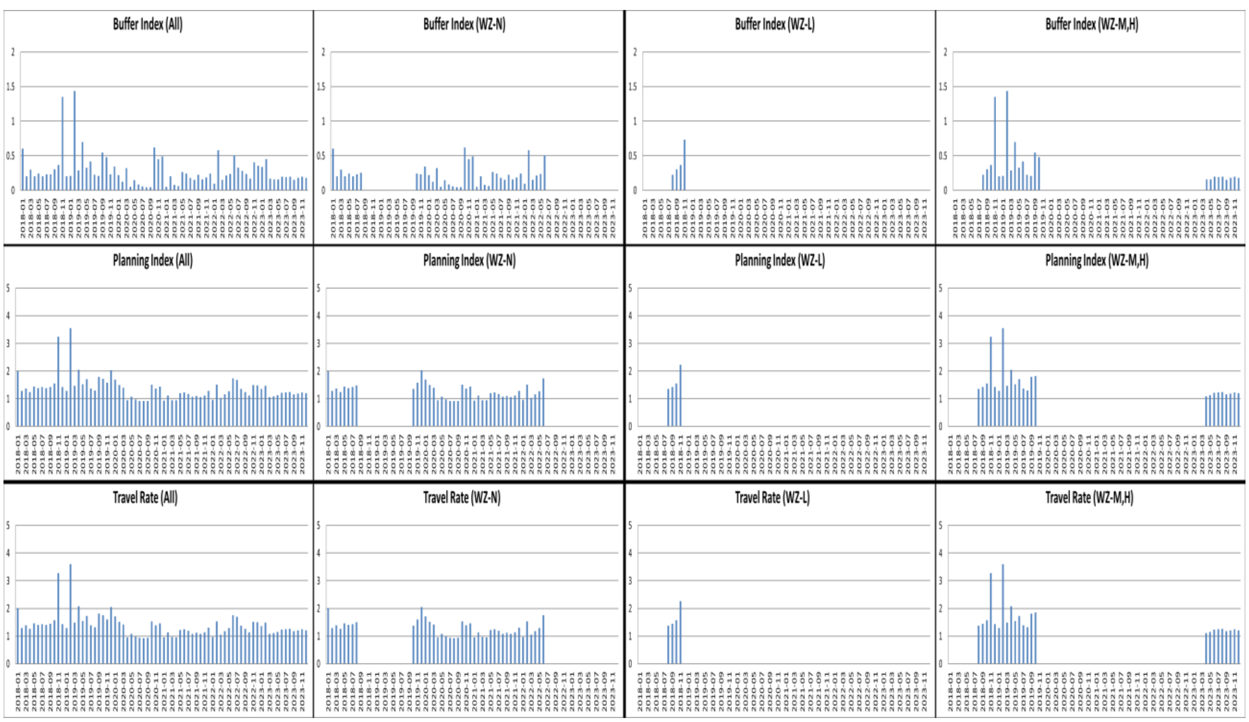
Effects of Weather conditions on Travel-Time Reliability



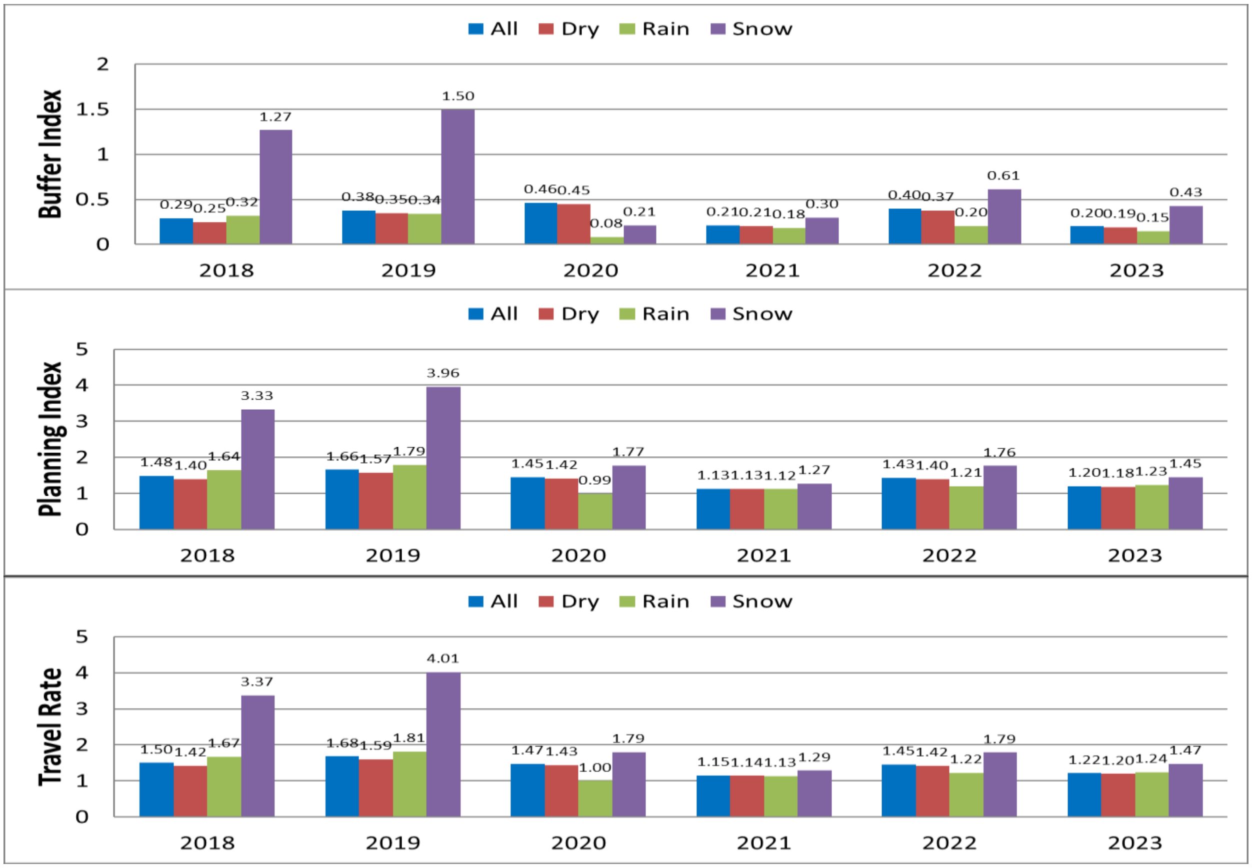
Effects of Incidents



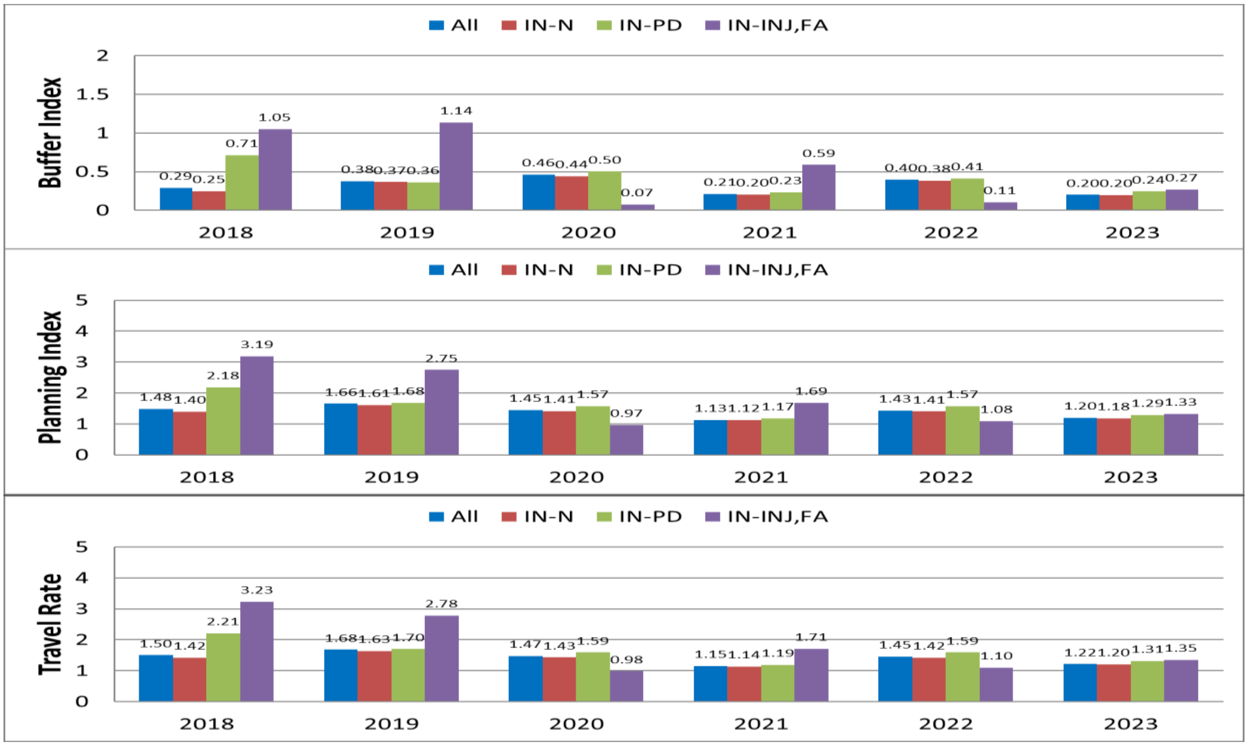
Effects of Work Zones



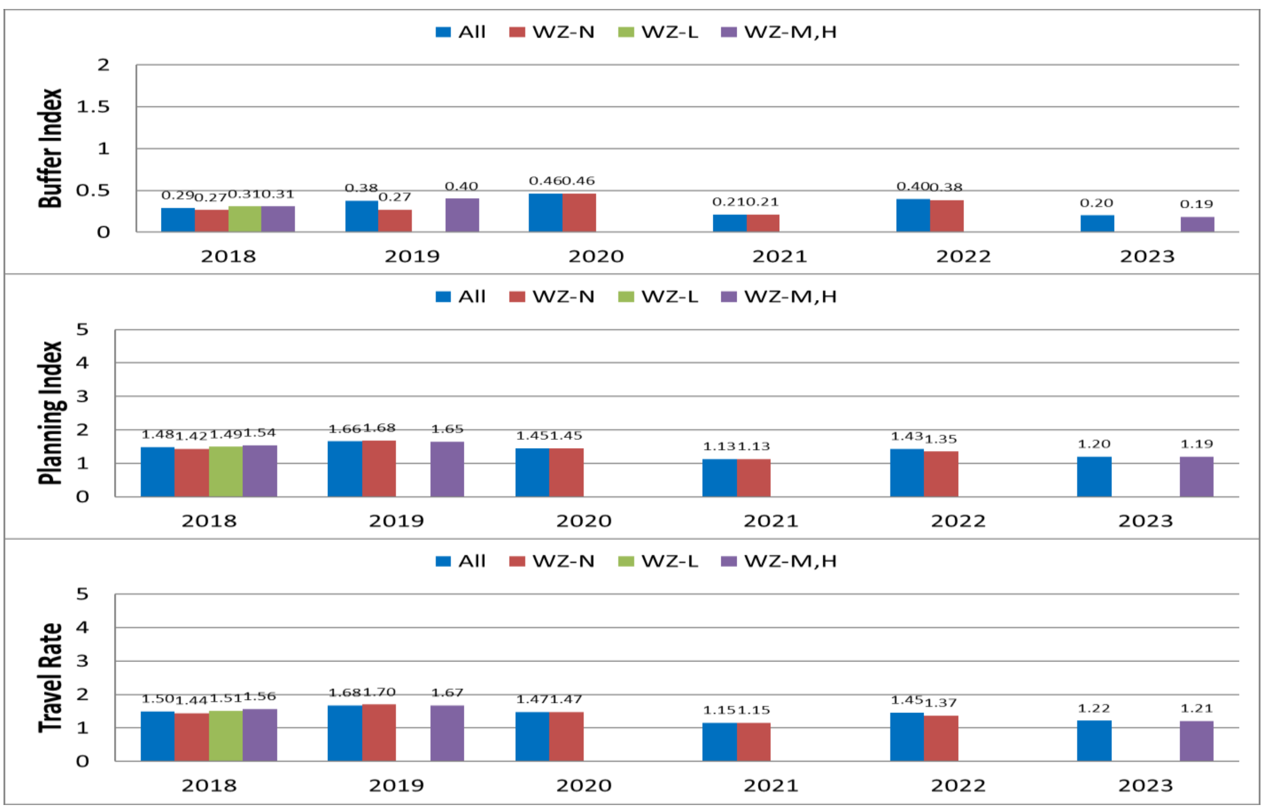
Yearly Variations - *Weather Effects*



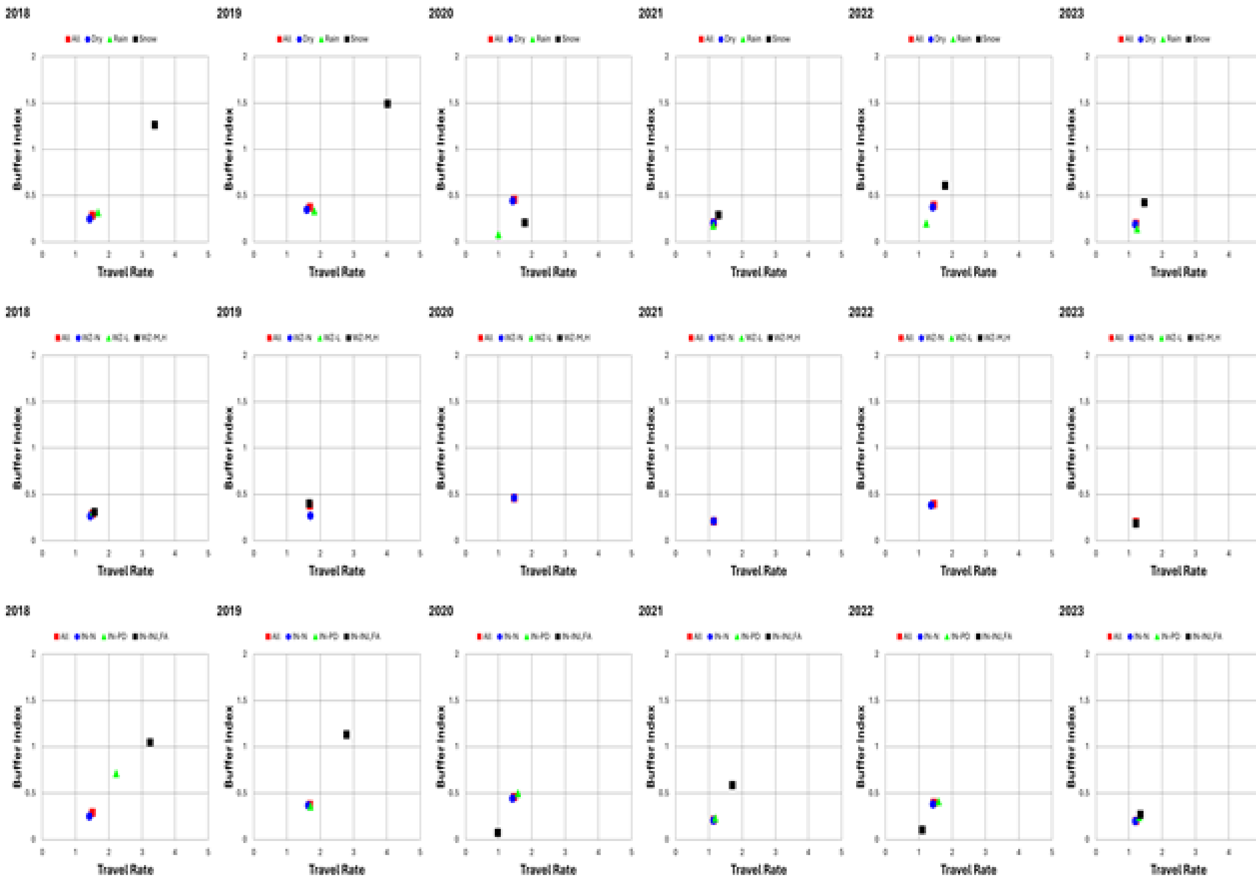
Incident Effects



Work-Zone Effects

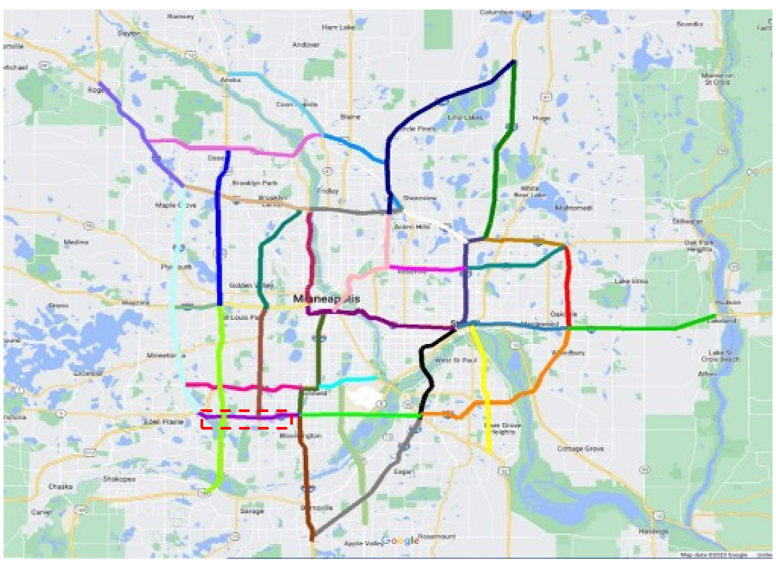


Yearly Variations of Buffer Index - Travel Rate Relationships



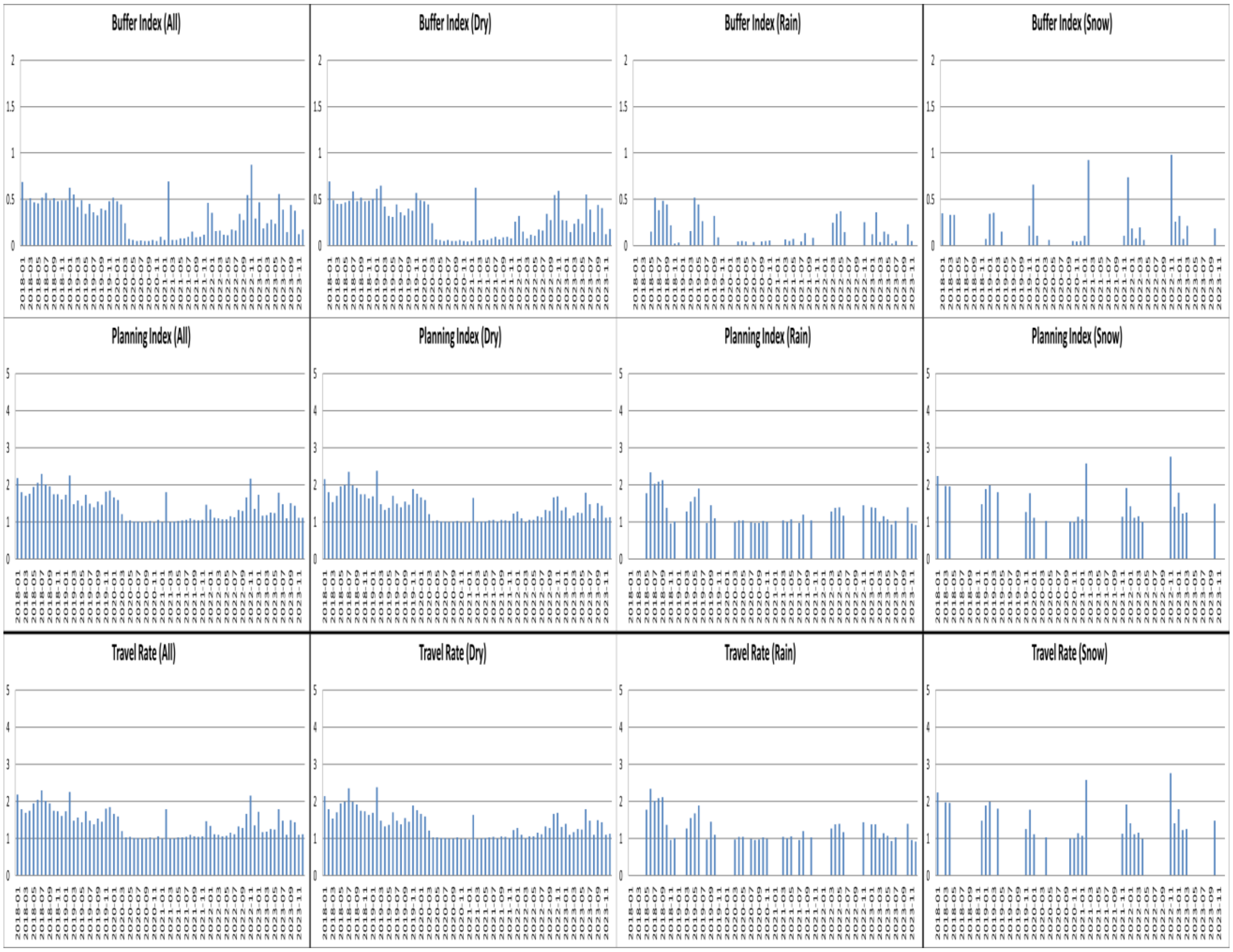
Variations of Traffic-Flow Measures

14) I-494 Corridor B (I35W < -- > TH212)

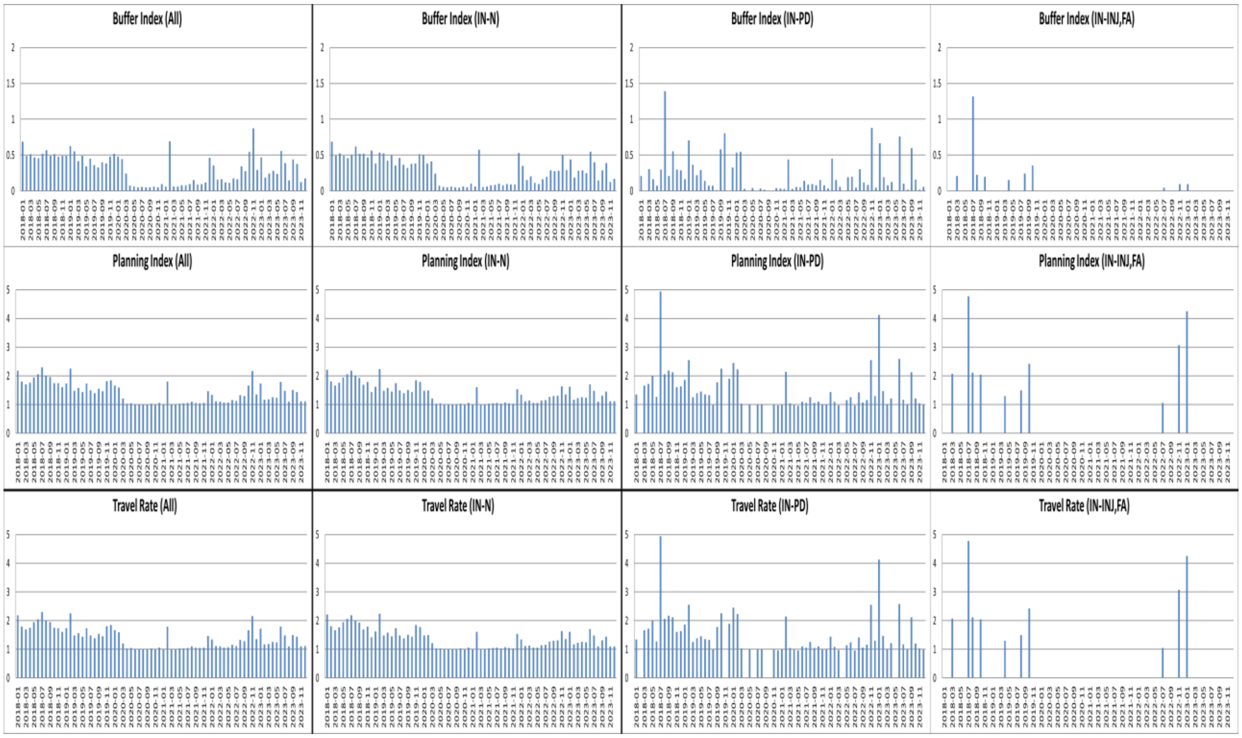


i) I-494 Corridor B - WB (I-35W to TH 212) for Morning Peak Periods

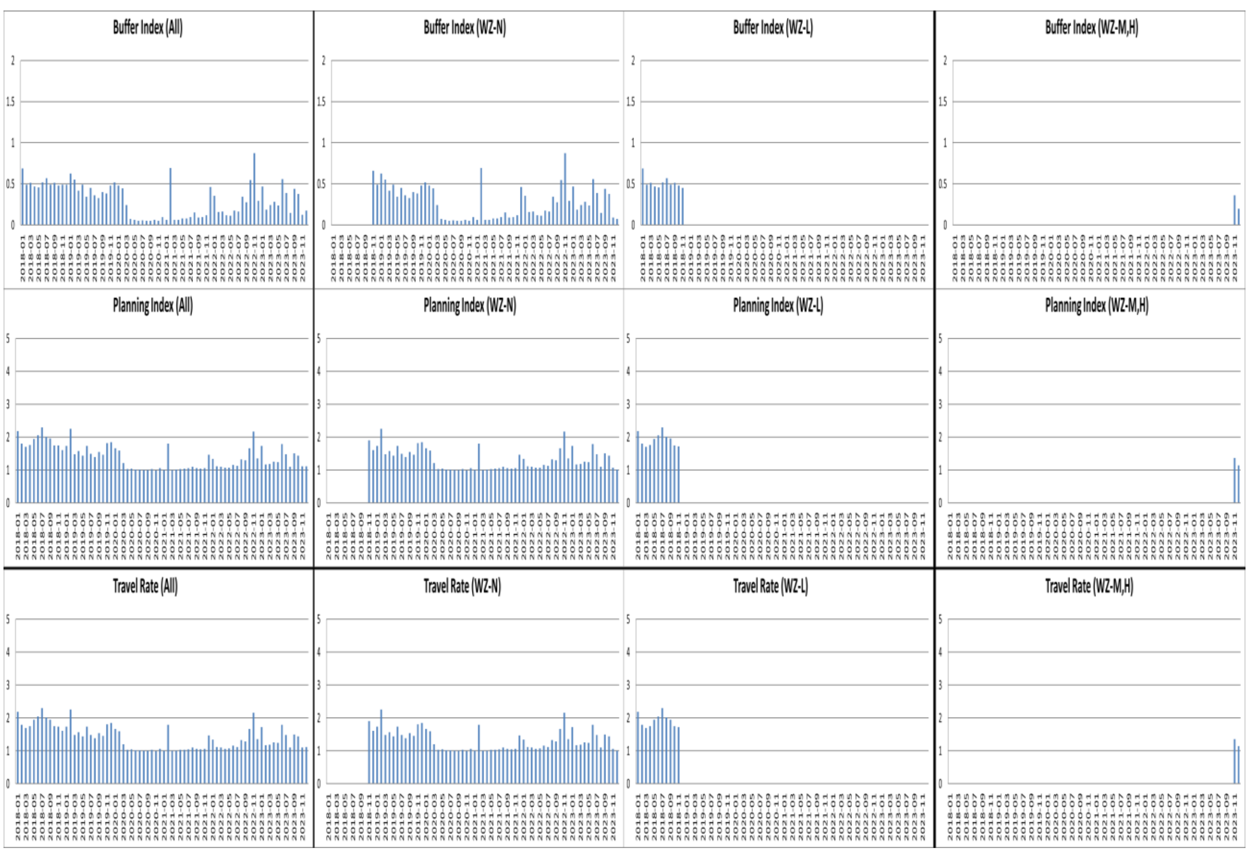
Effects of Weather conditions on Travel-Time Reliability



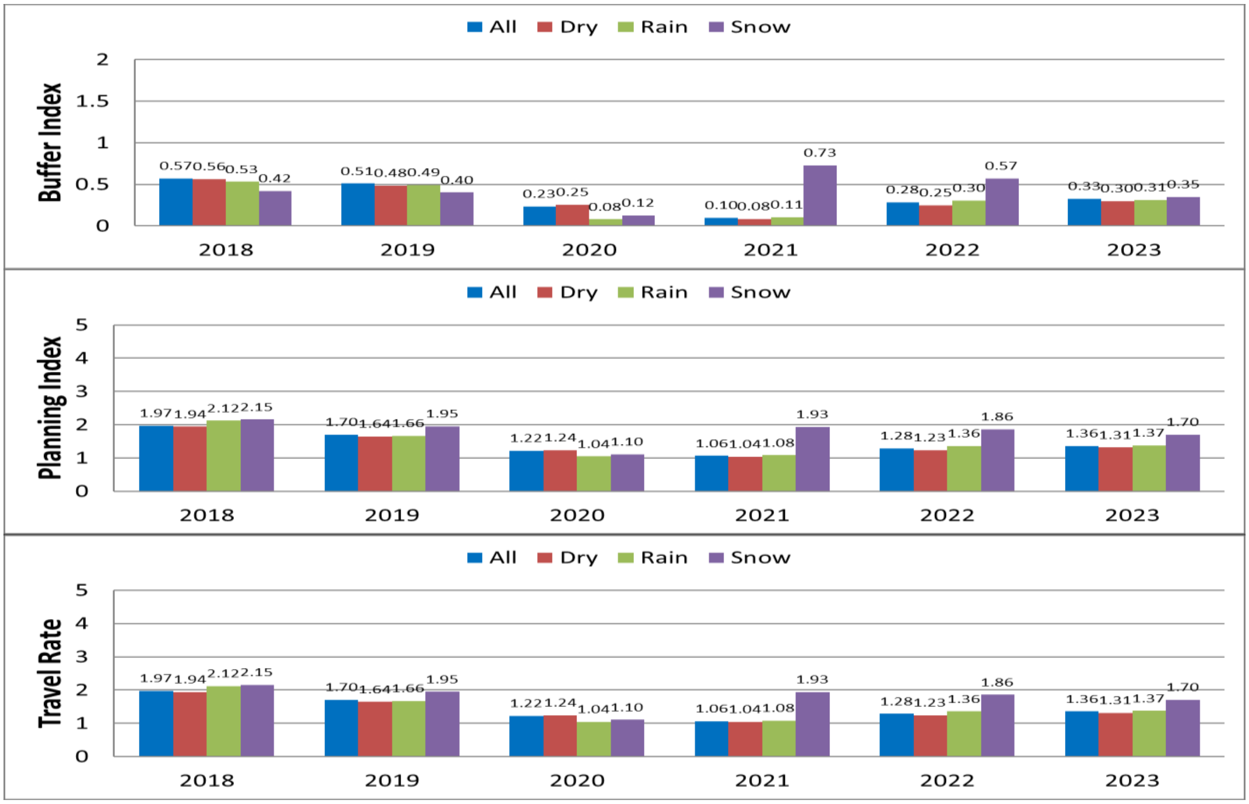
Effects of Incidents



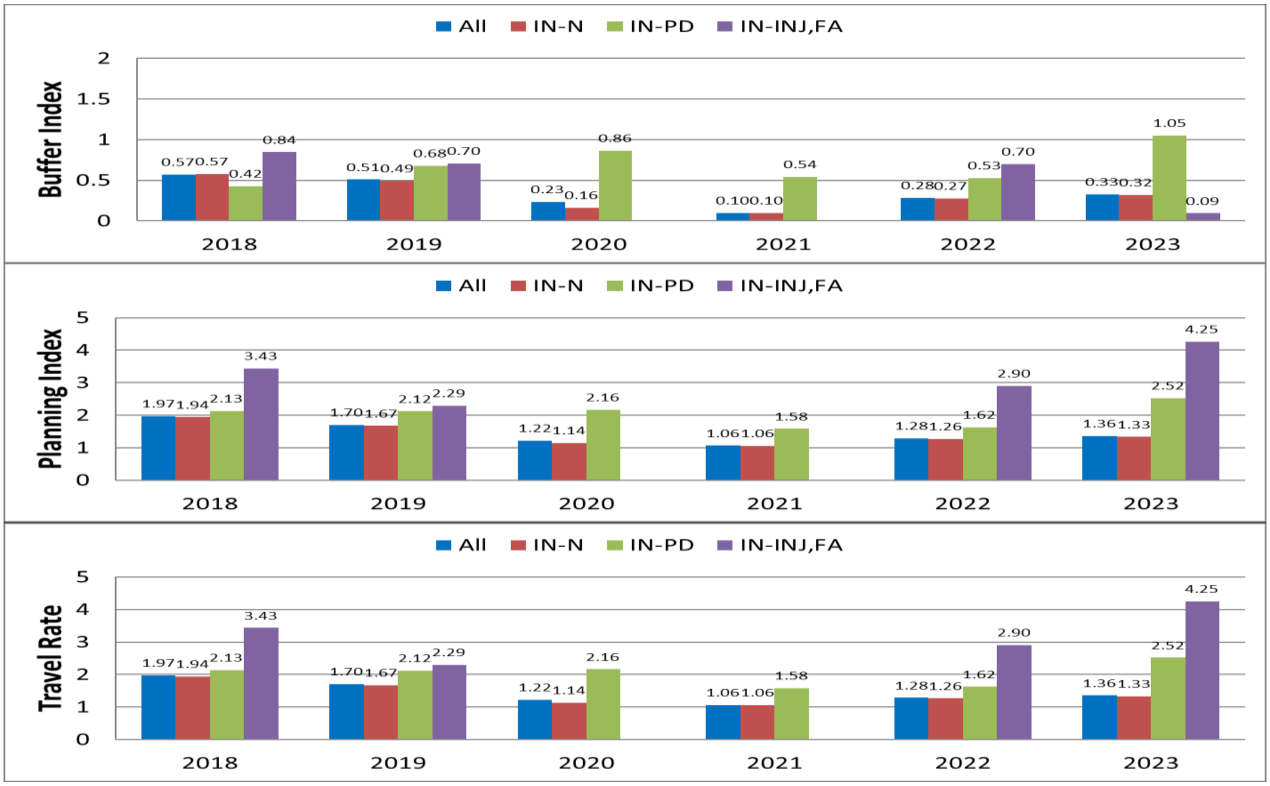
Effects of Work Zones



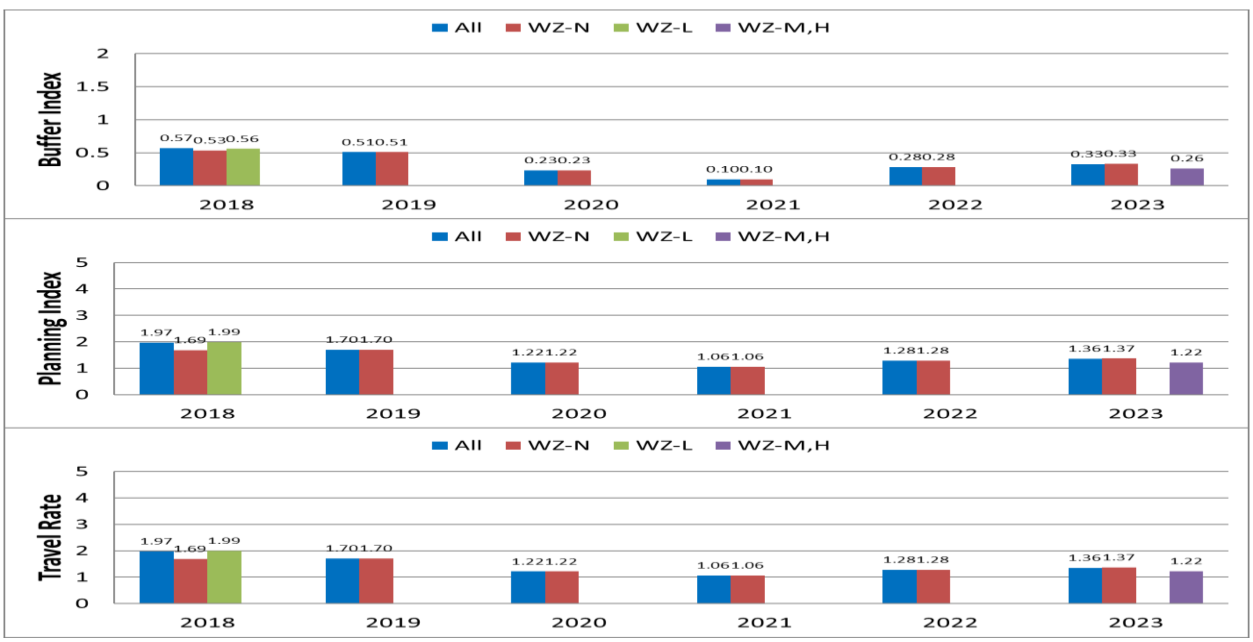
Yearly Variations - *Weather Effects*



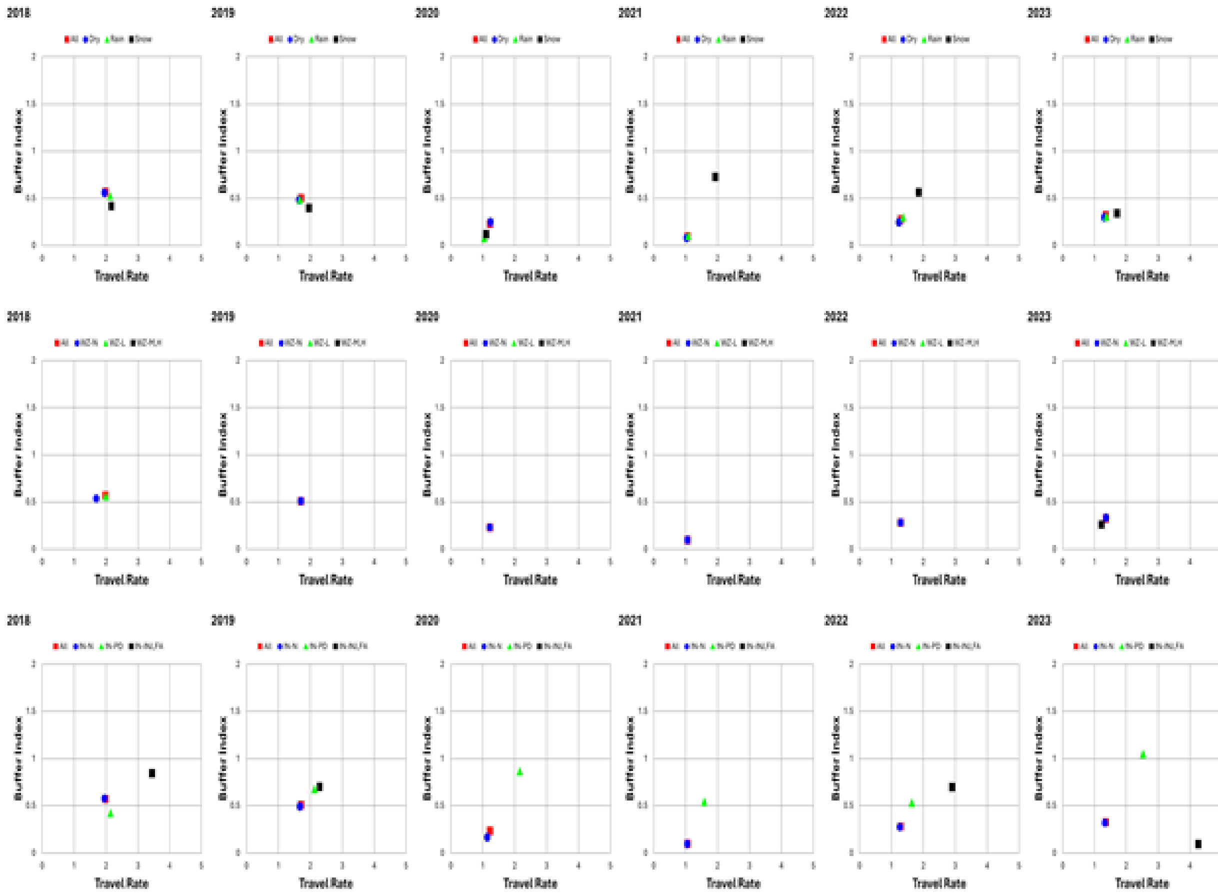
Incident Effects



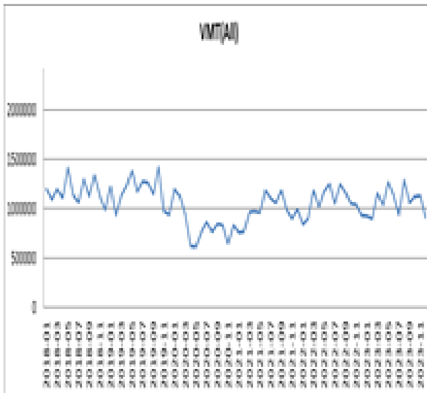
Work-Zone Effects

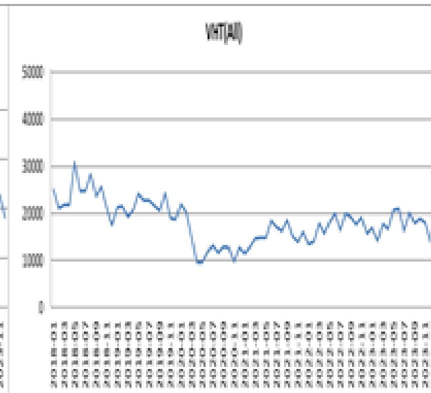


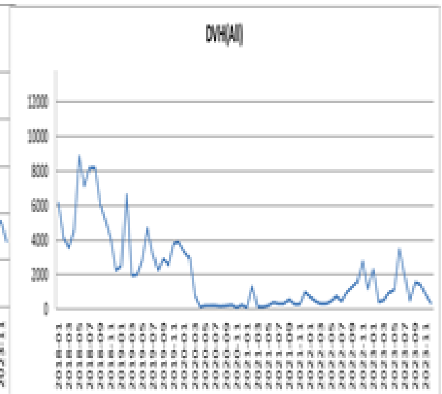
Yearly Variations of Buffer Index - Travel Rate Relationships

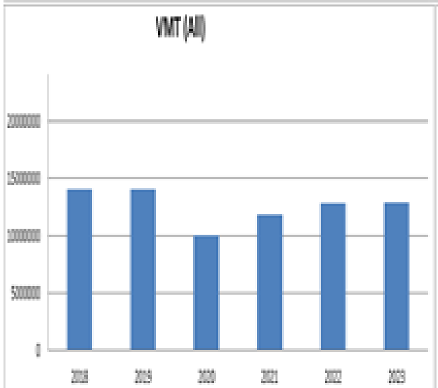


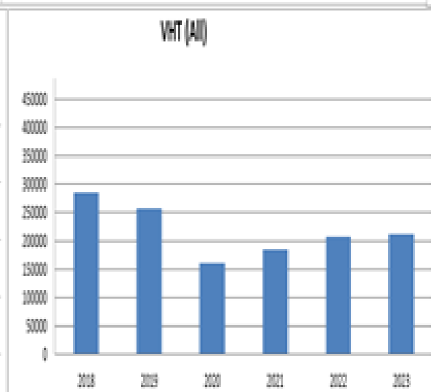
Variations of Traffic-Flow Measures

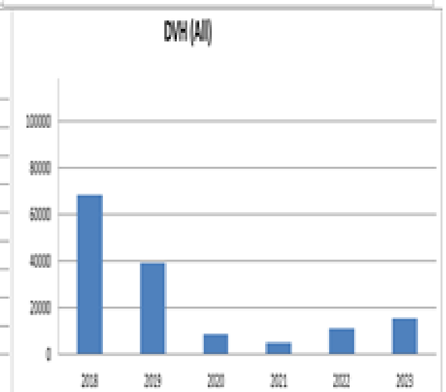

VMT(All)
2000000
1500000
1000000
500000
0


VHT(All)
50000
40000
30000
20000
10000
0


DVH(All)
12000
10000
8000
6000
4000
2000
0

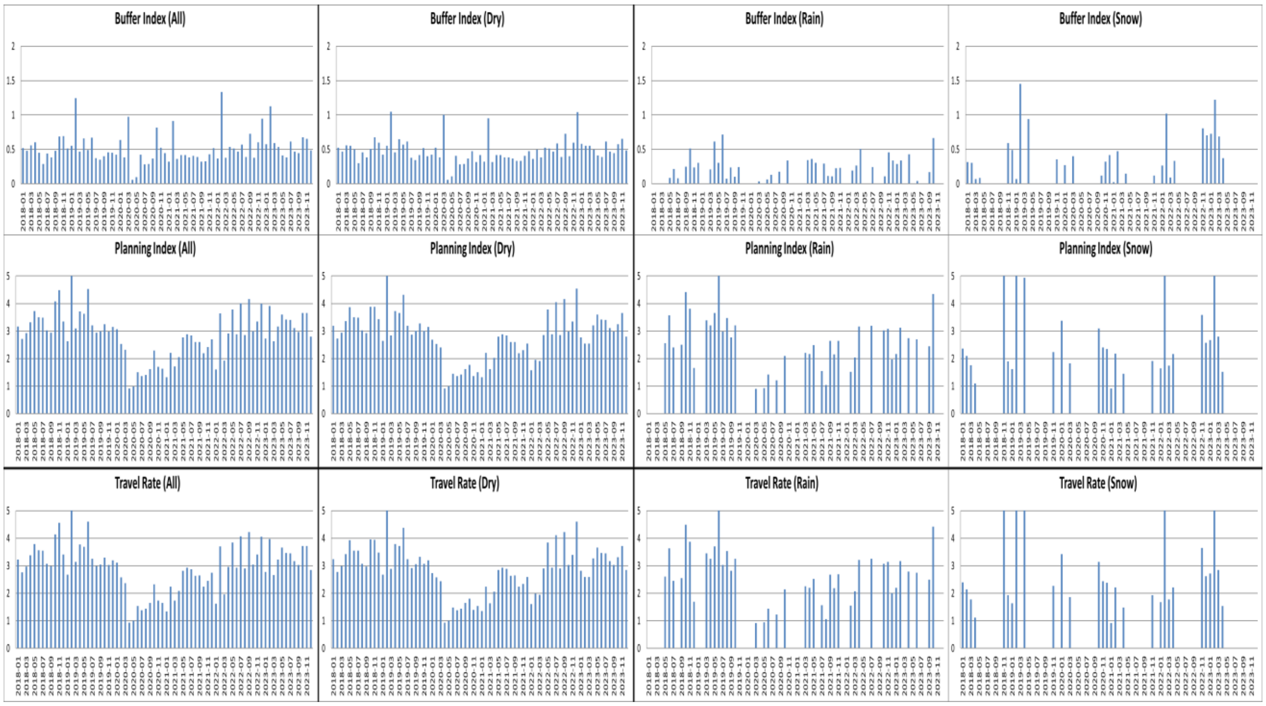

VMT (All)
20000000
15000000
10000000
5000000
0
2018
2019
2020
2021
2022
2023


VHT (All)
450000
400000
350000
300000
250000
200000
150000
100000
50000
0
2018
2019
2020
2021
2022
2023

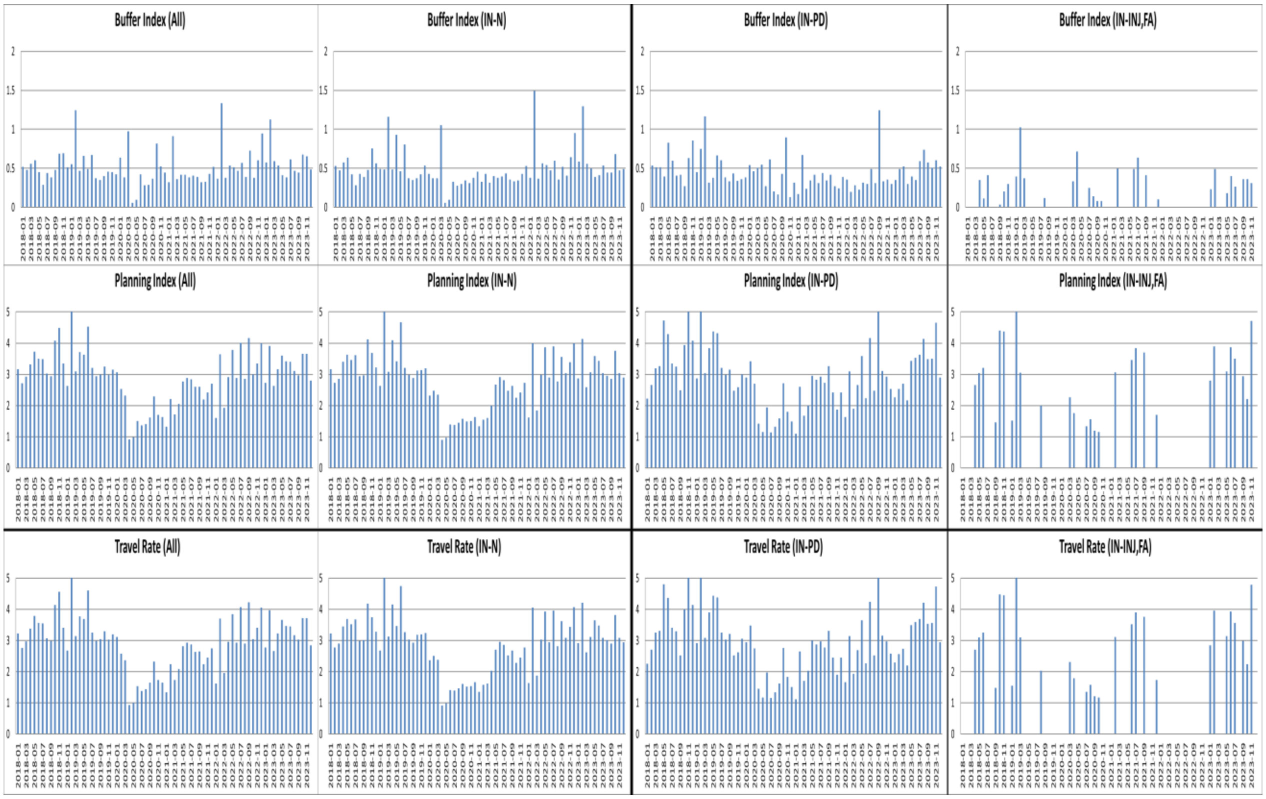

DVH (All)
100000
80000
60000
40000
20000
0
2018
2019
2020
2021
2022
2023

ii) I-494 Corridor B - EB TH 212 to I-35w for Afternoon Peak Period

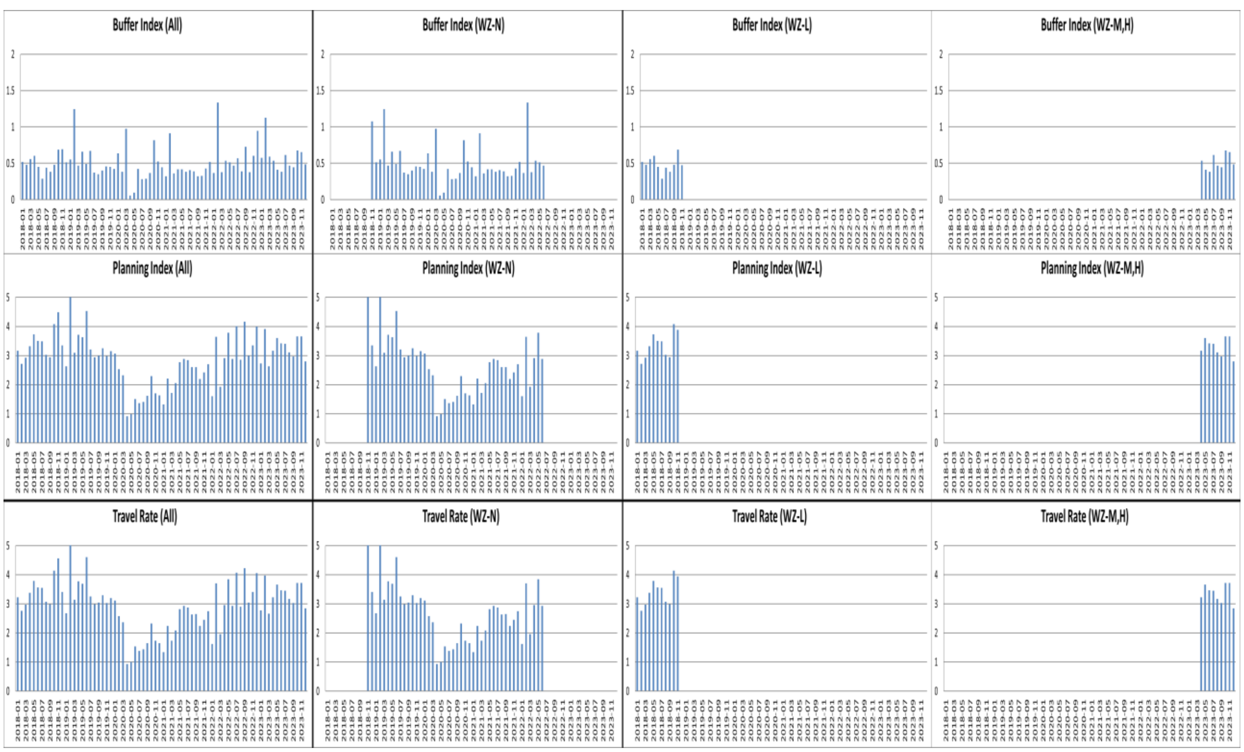
Effects of Weather conditions on Travel-Time Reliability



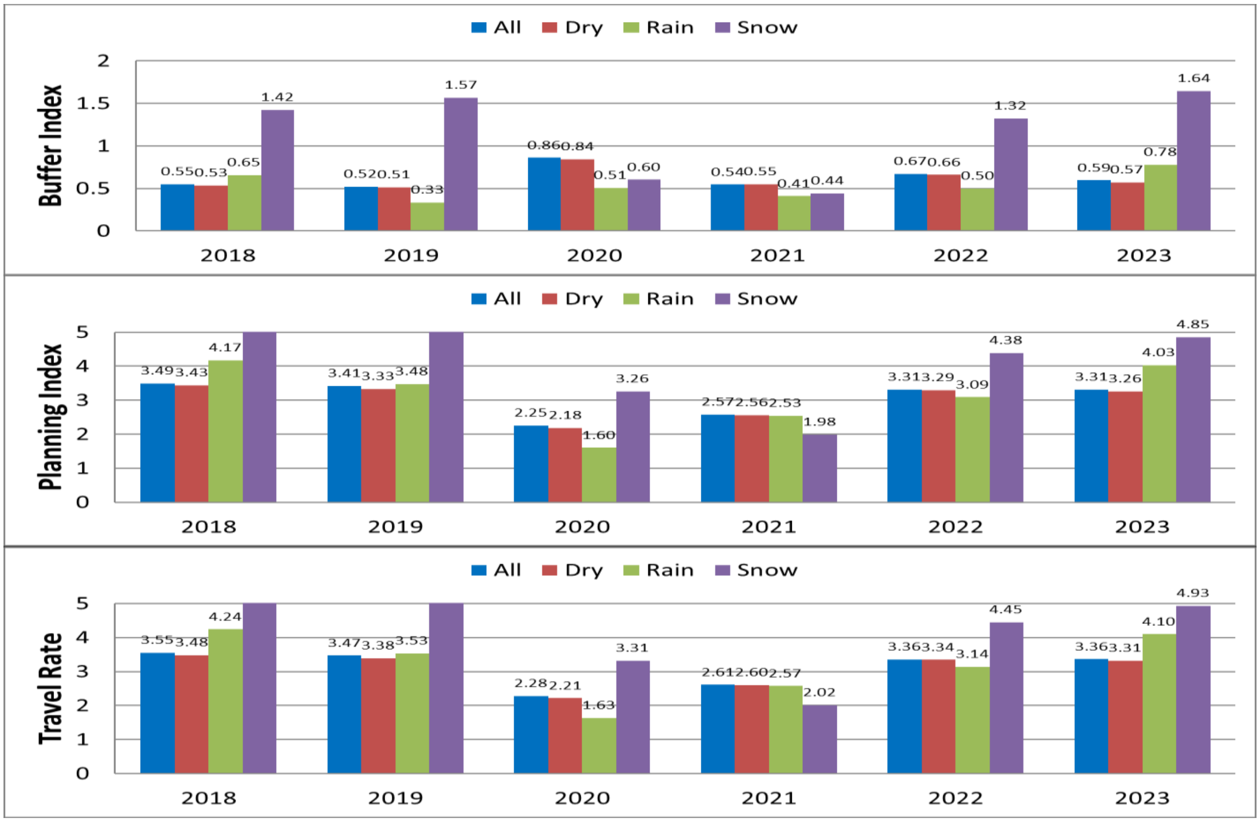
Effects of Incidents



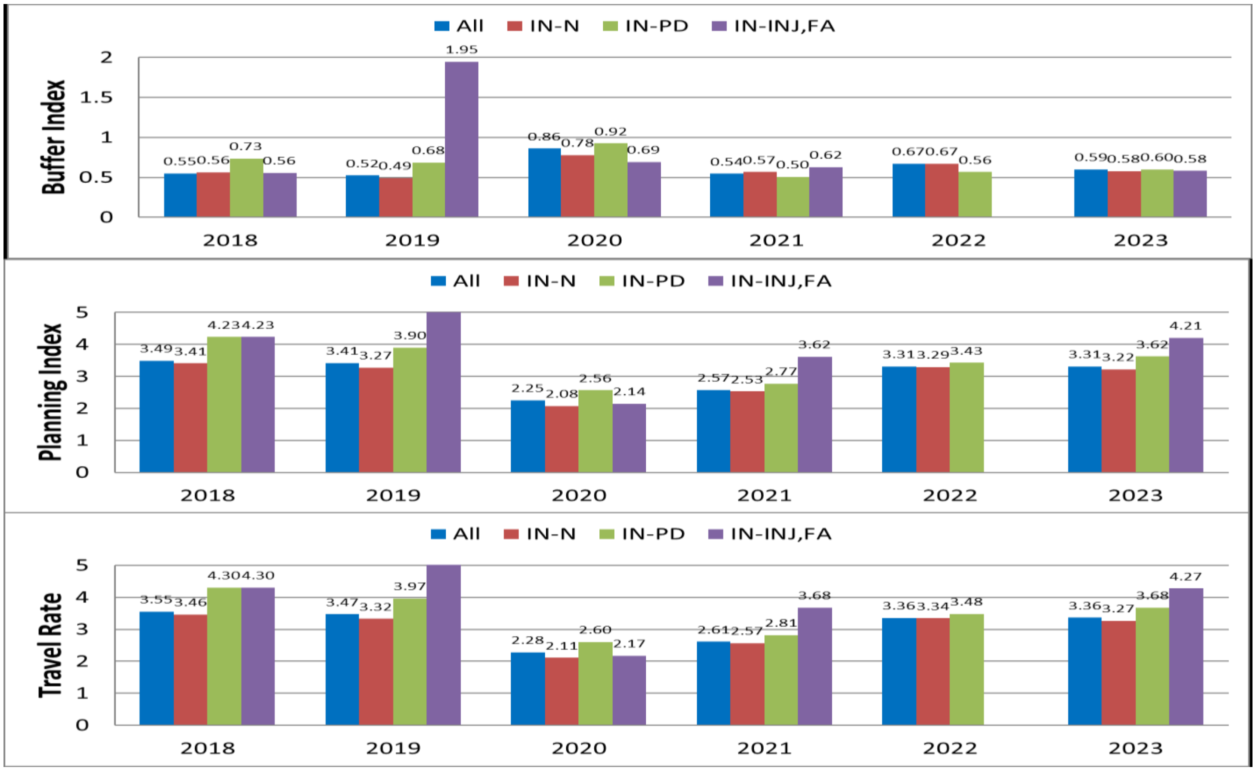
Effects of Work Zones



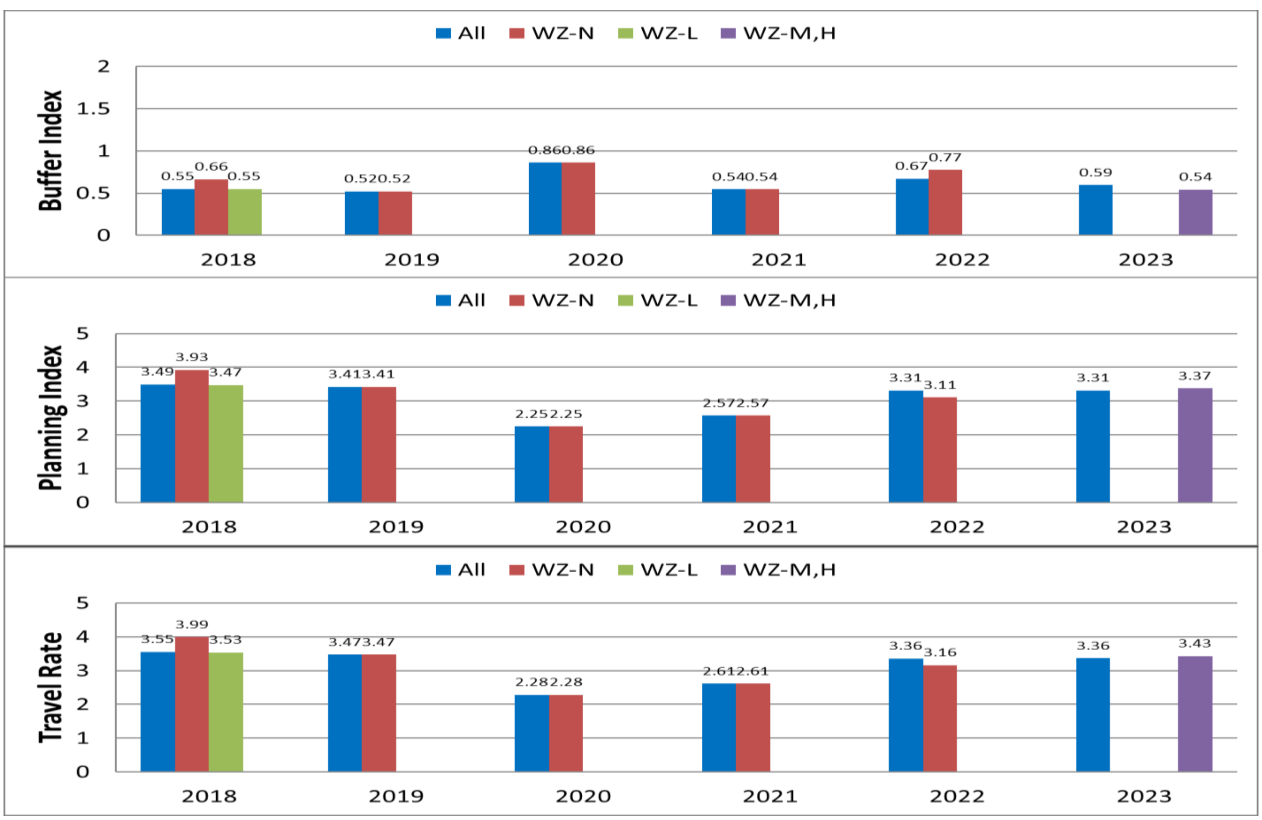
Yearly Variations - ***Weather Effects***



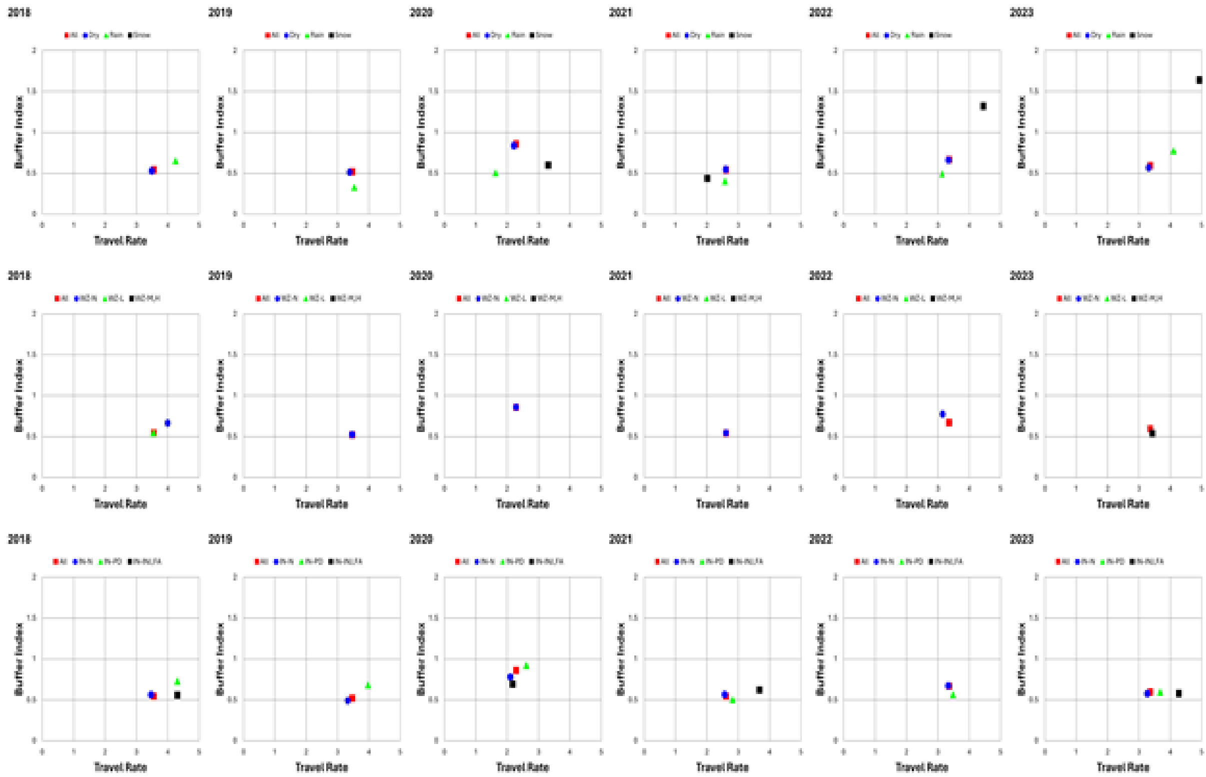
Incident Effects



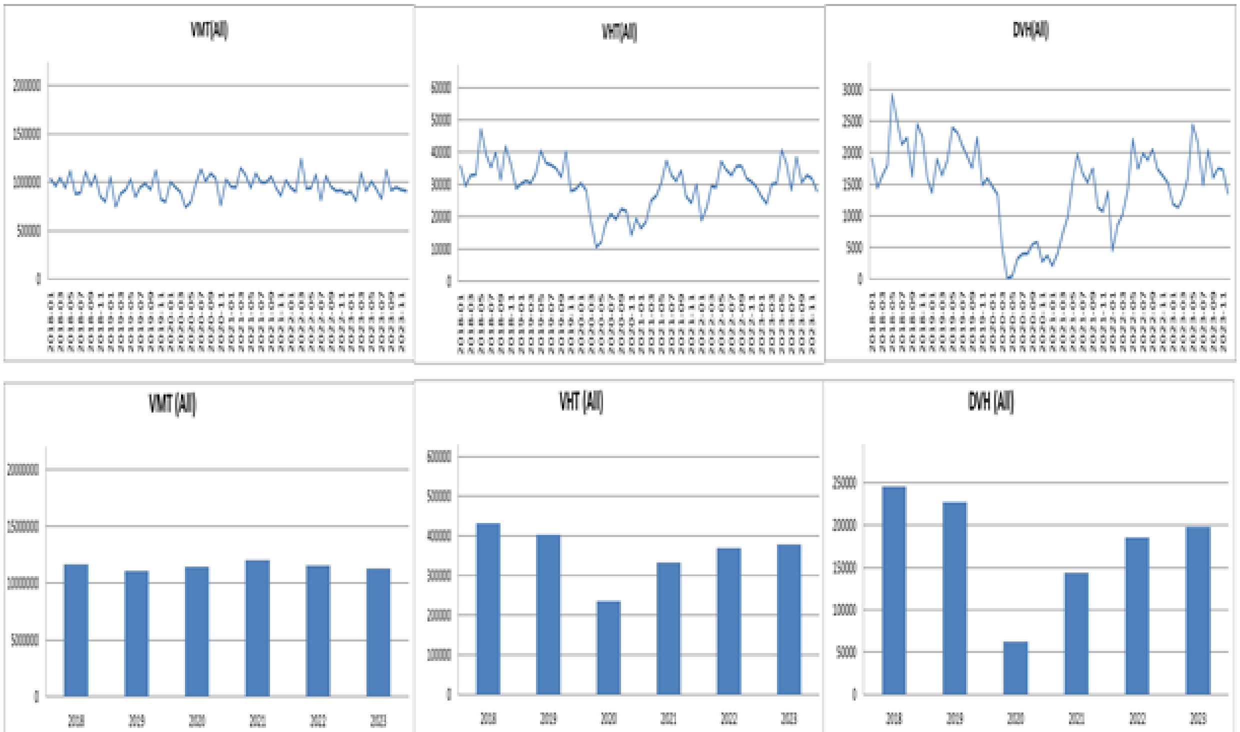
Work-Zone Effects



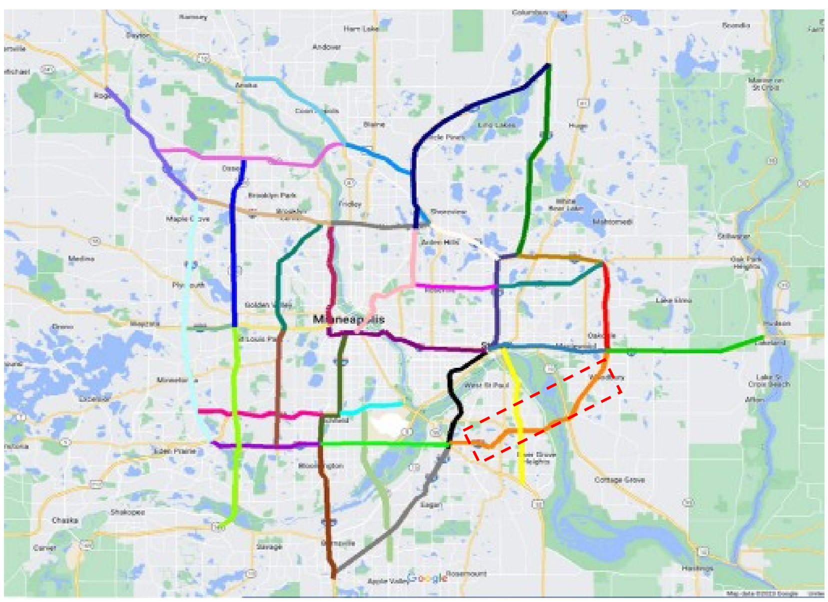
Yearly Variations of Buffer Index - Travel Rate Relationships



Variations of Traffic-Flow Measures

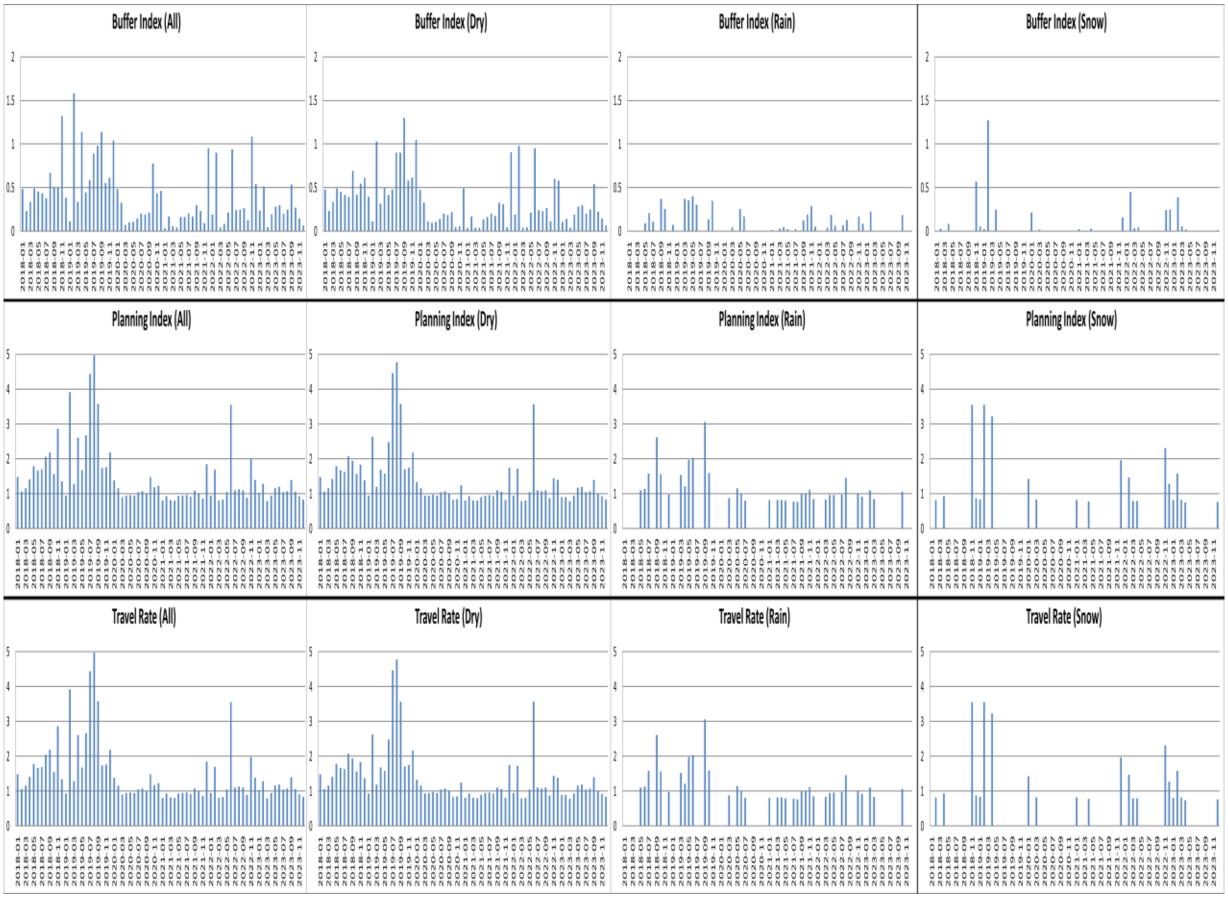


15) I-494 Corridor C (I35E < -- > I94)

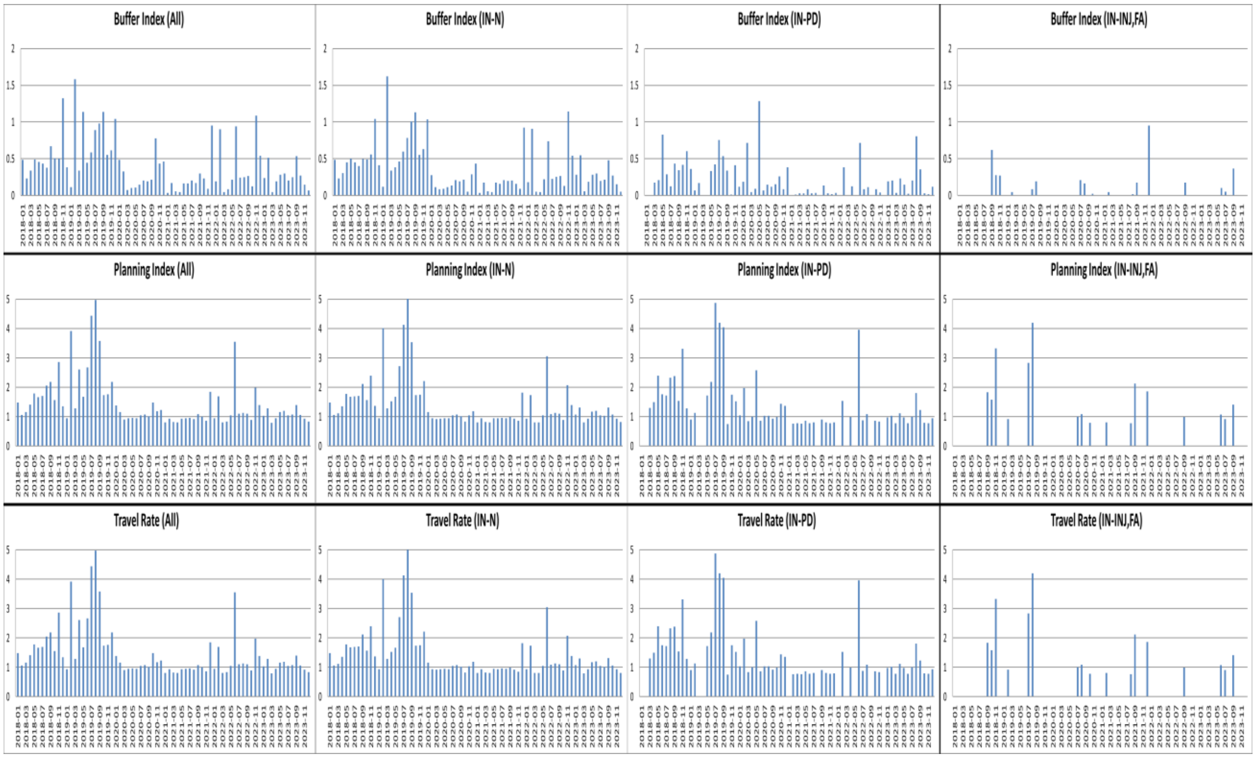


i) I-494 Corridor C - EB I-35E to I-94 for Afternoon Peak Periods

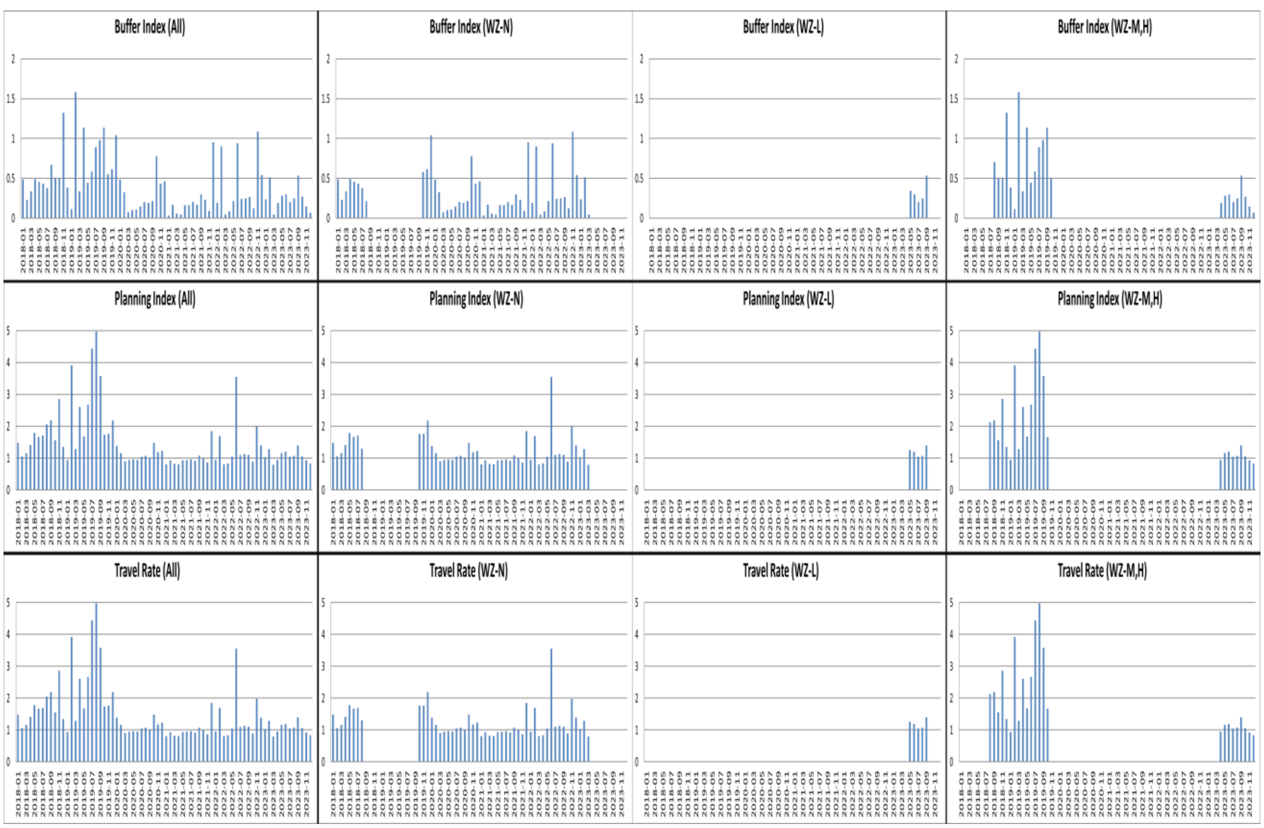
Effects of Weather conditions on Travel-Time Reliability



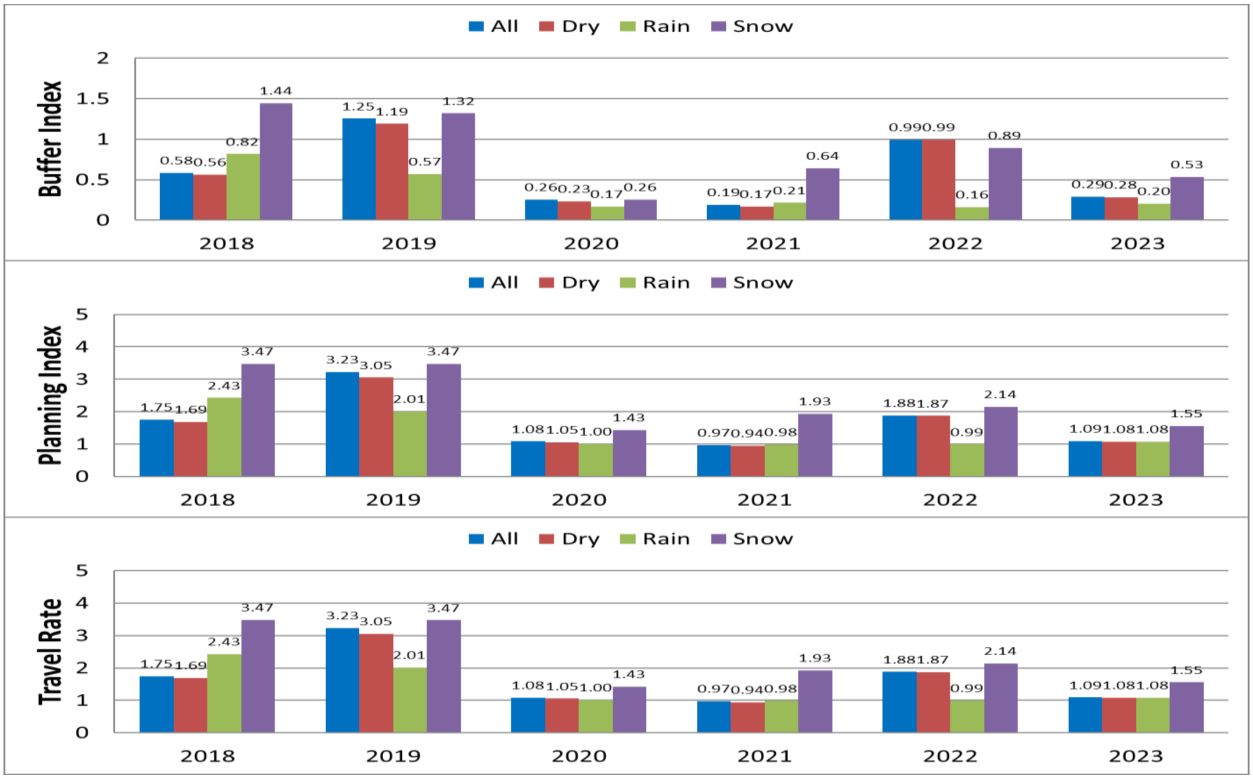
Effects of Incidents



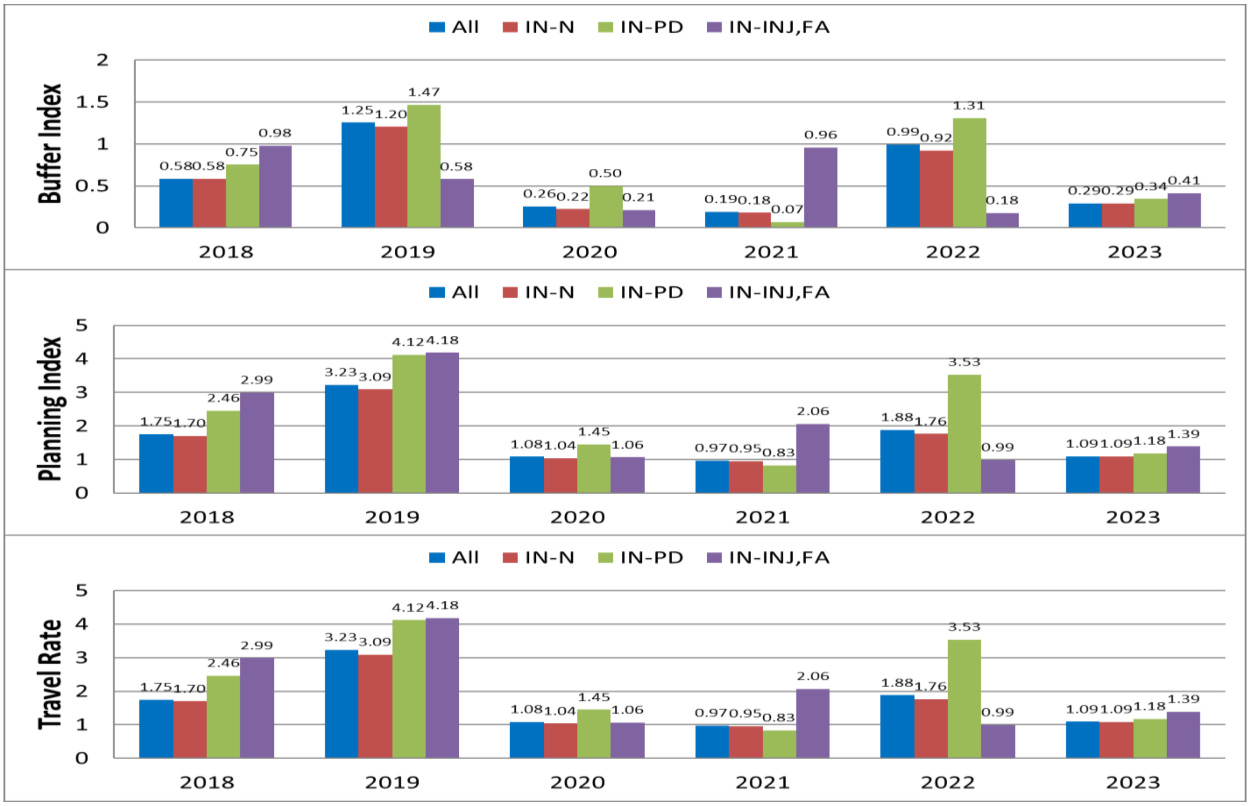
Effects of Work Zones



Yearly Variations - *Weather Effects*

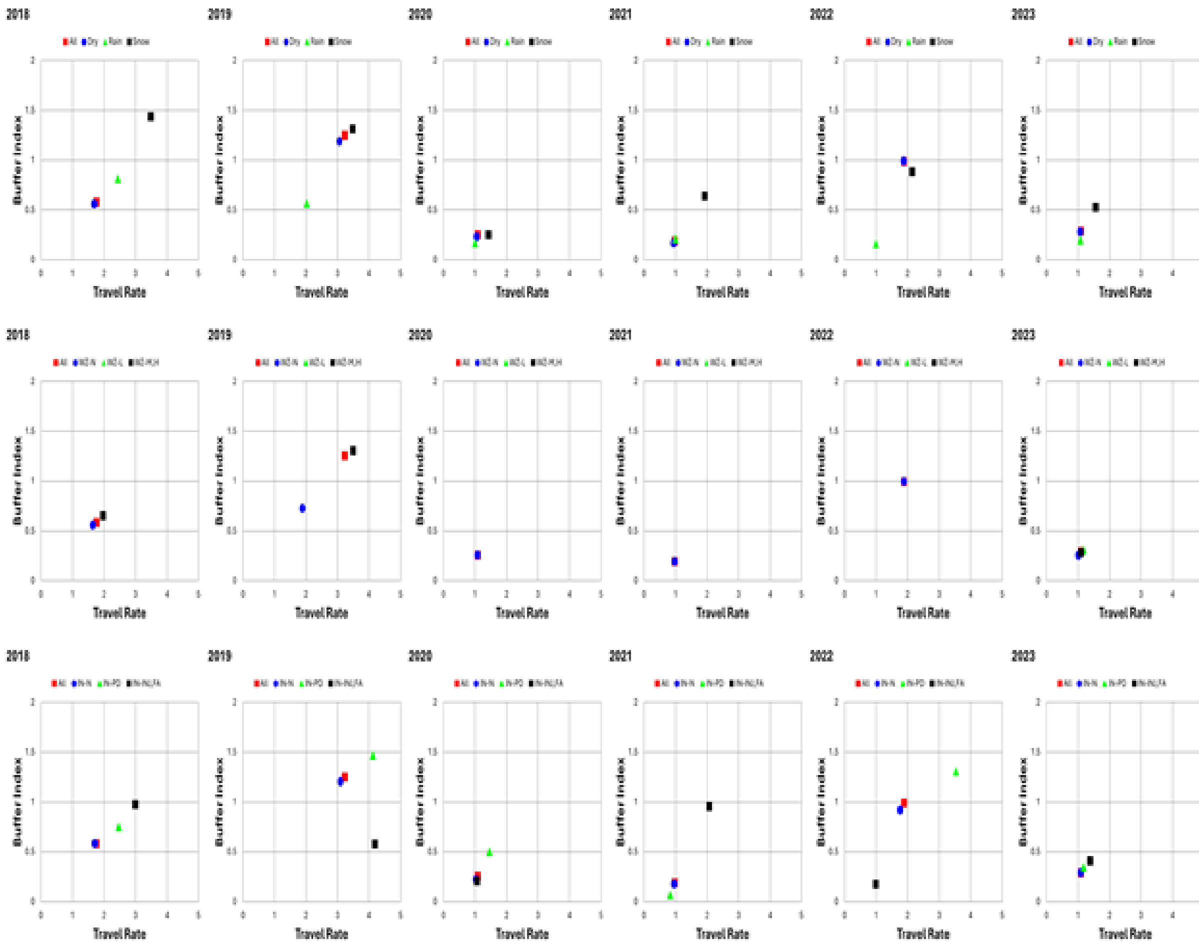


Incident Effects



Work-Zone Effects

Yearly Variations of Buffer Index - Travel Rate Relationships

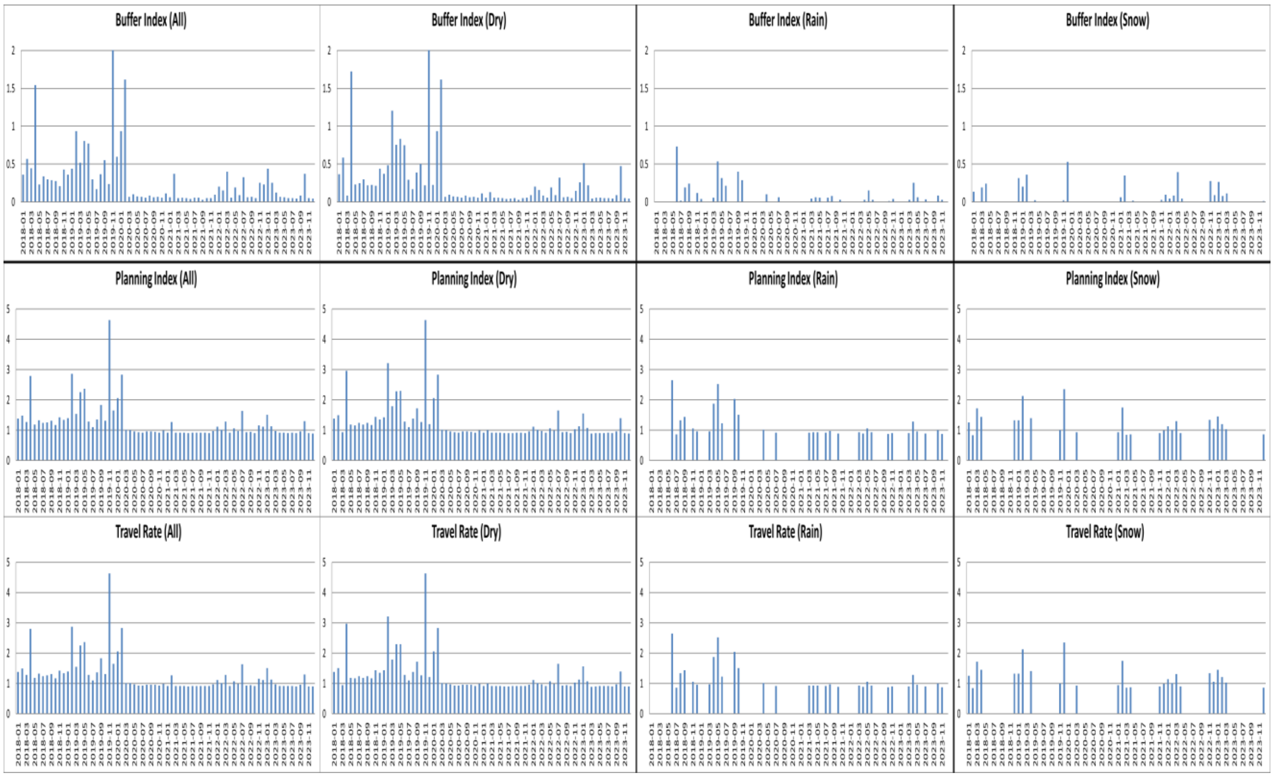


Variations of Traffic-Flow Measures


VMT(All)
VHT(All)
DVH(All)
VMT (All)
VHT (All)
DVH (All)
2018
2019
2020
2021
2022
2023

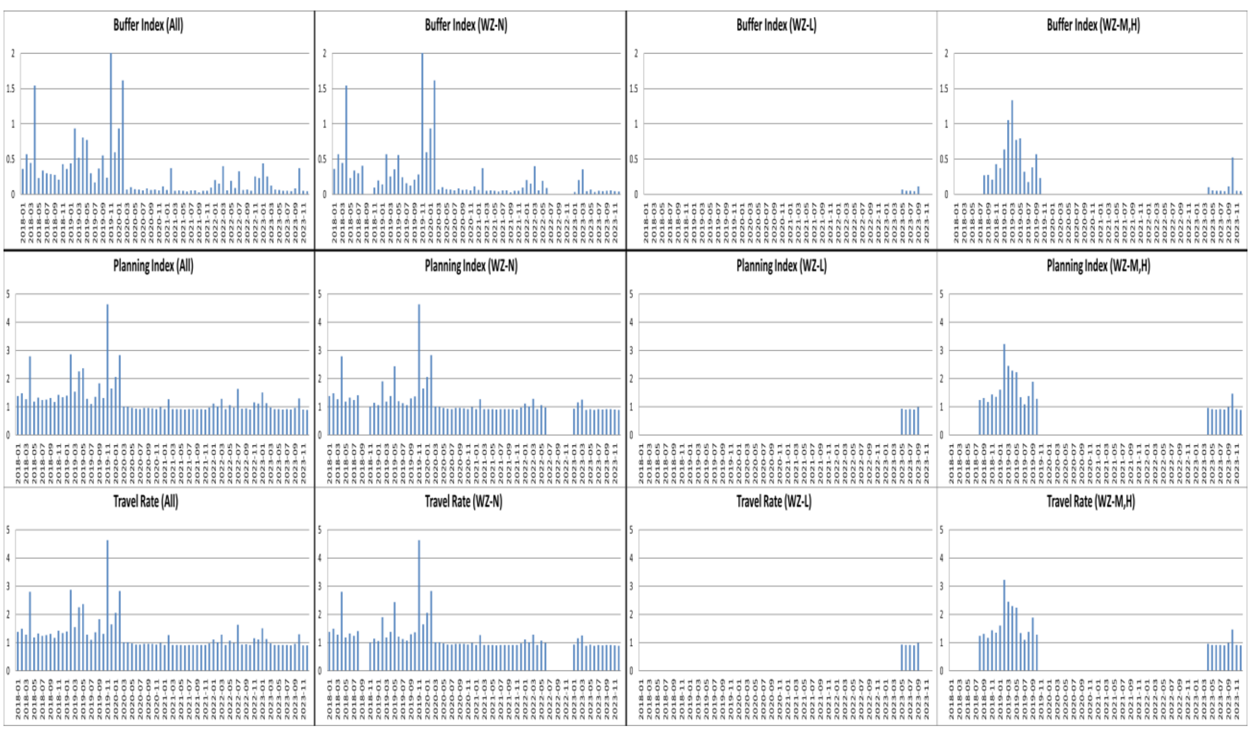
ii) I-494 Corridor C - WB I-94 to I-35E for Morning Peak Periods

Effects of Weather conditions on Travel-Time Reliability

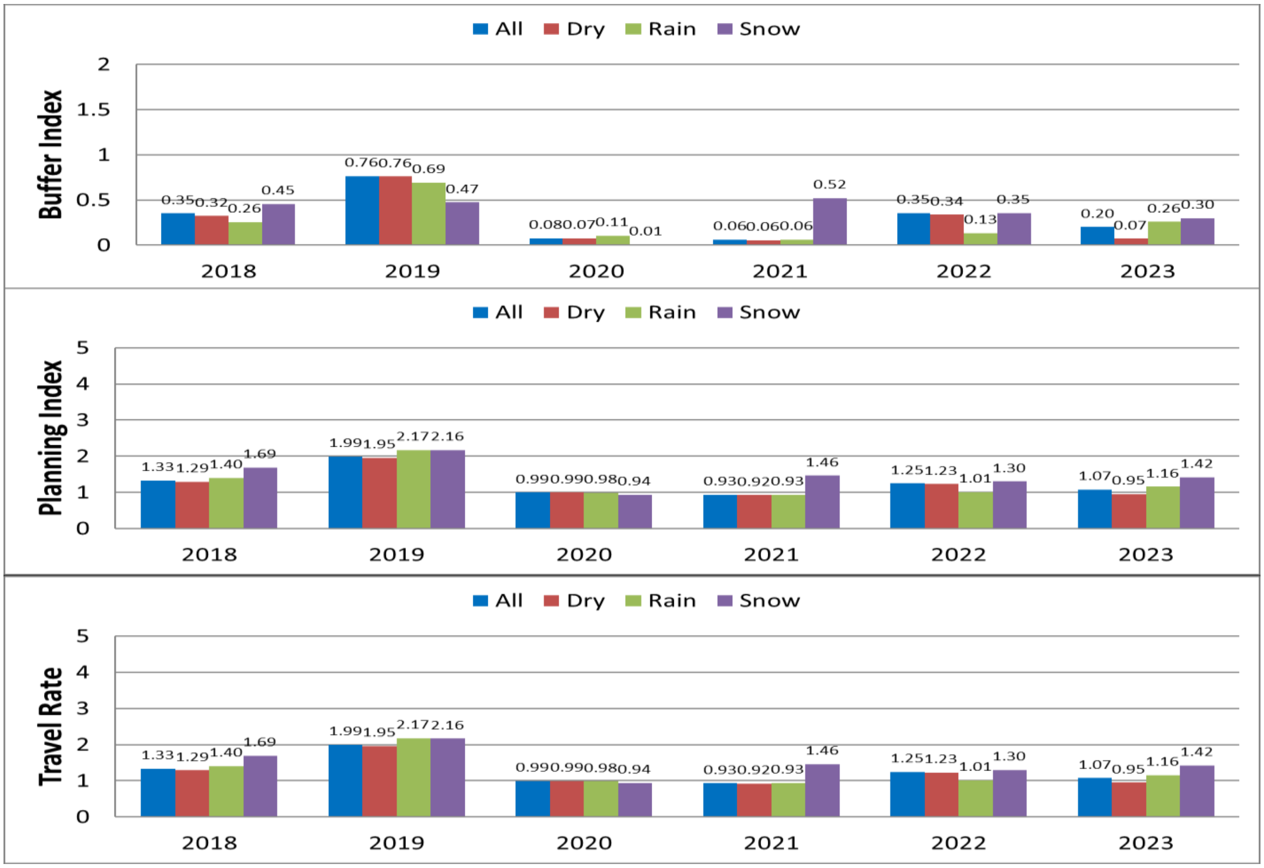


Effects of Incidents

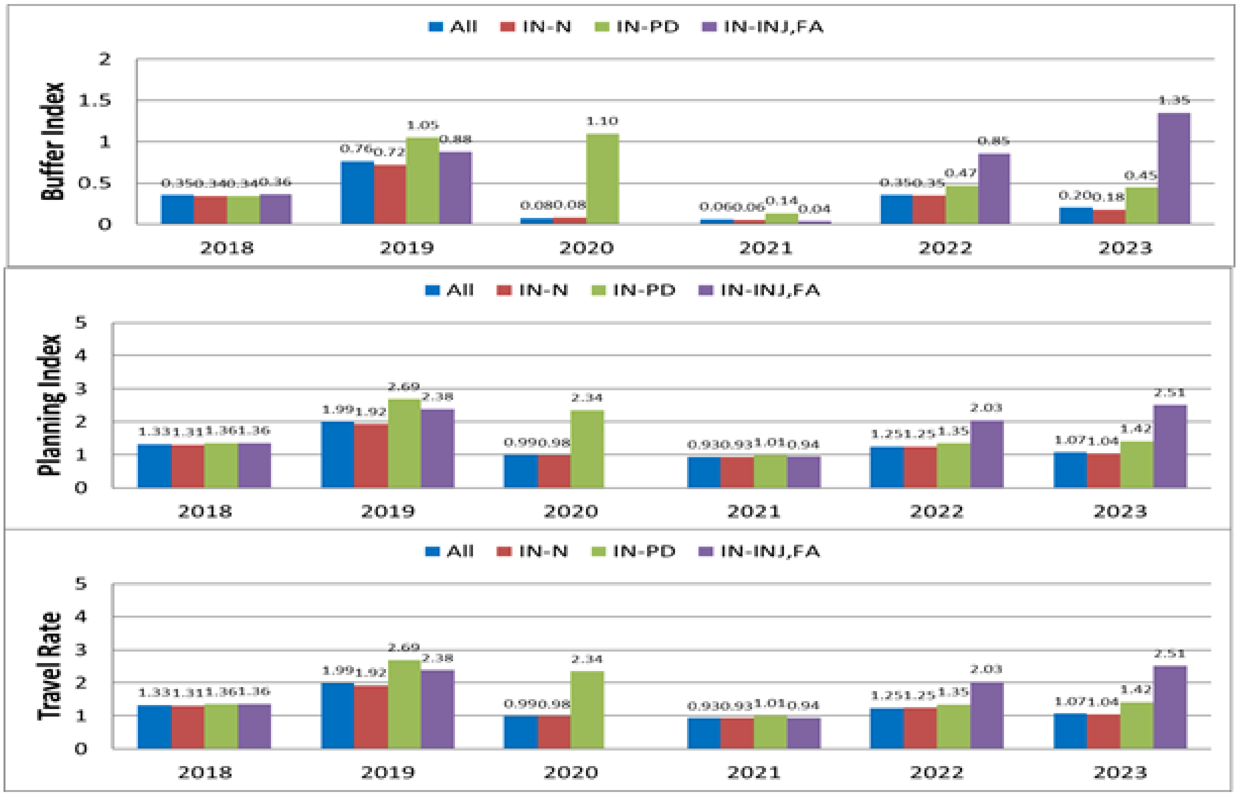
Effects of Work Zones



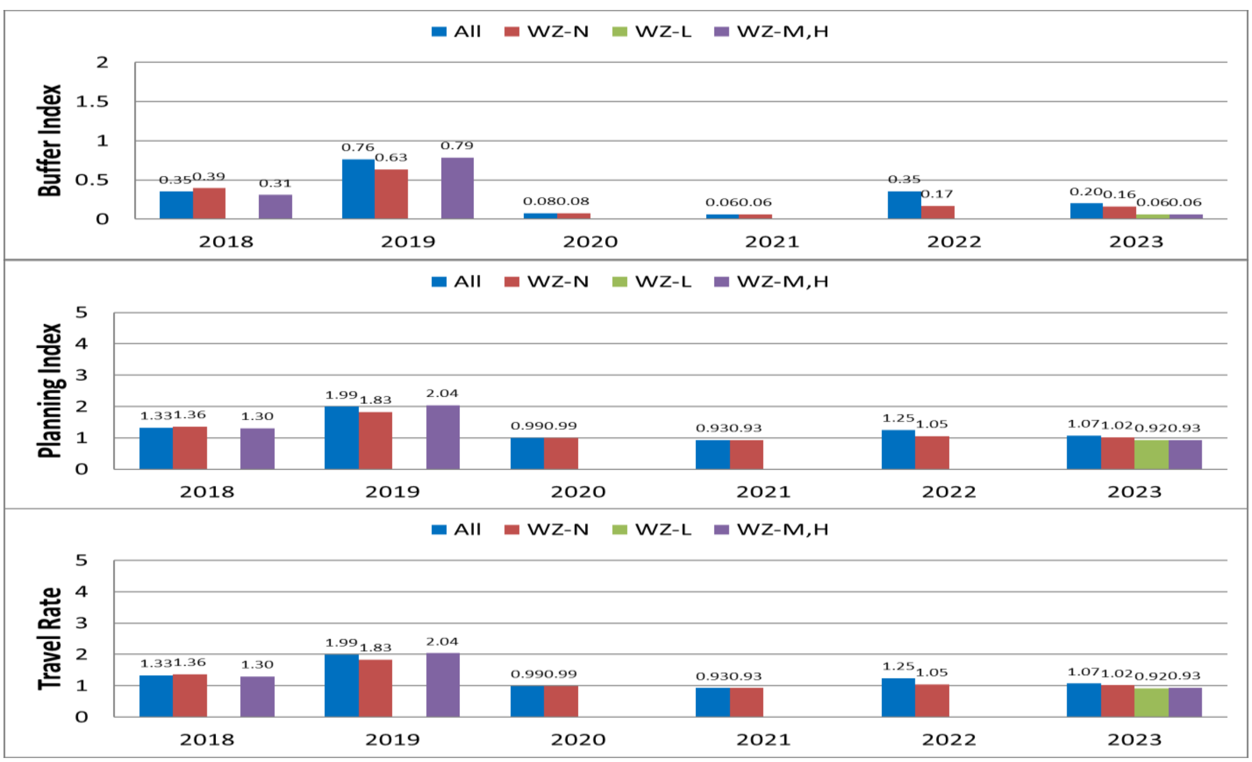
Yearly Variations - *Weather Effects*



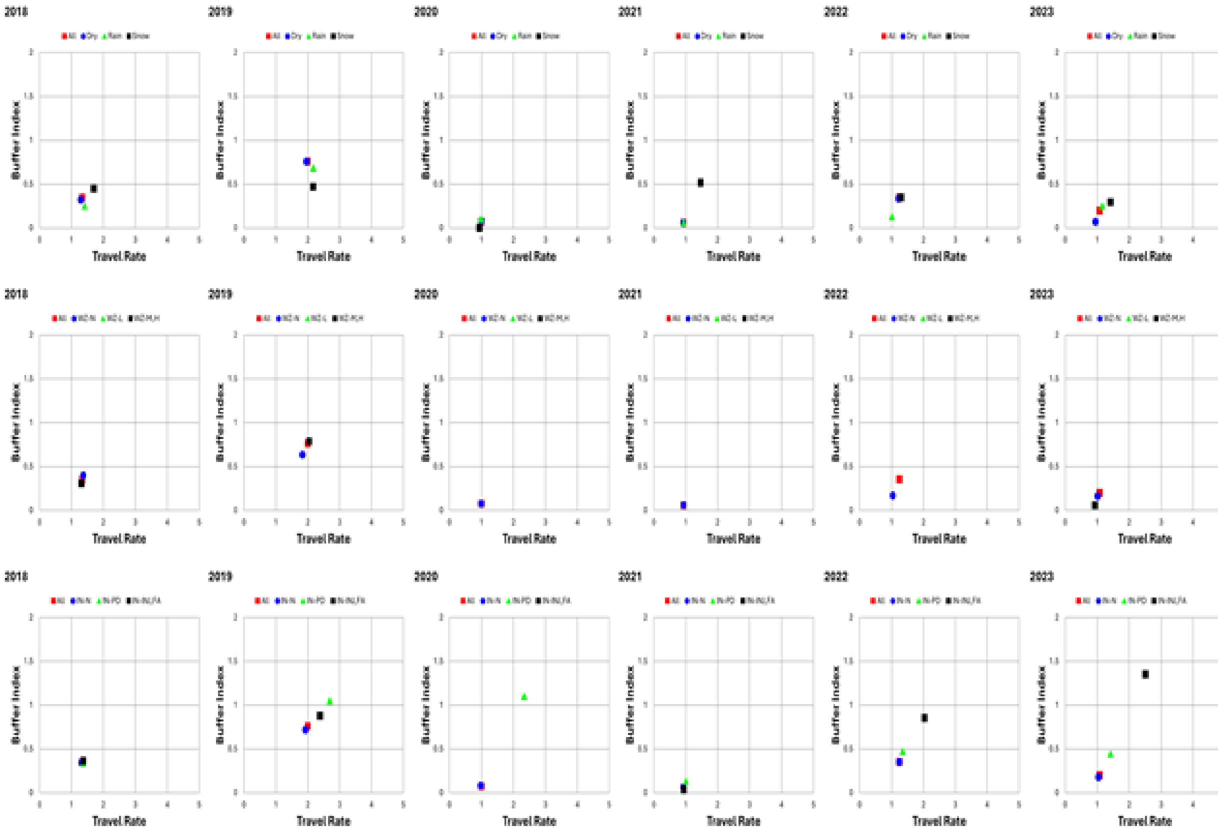
Incident Effects



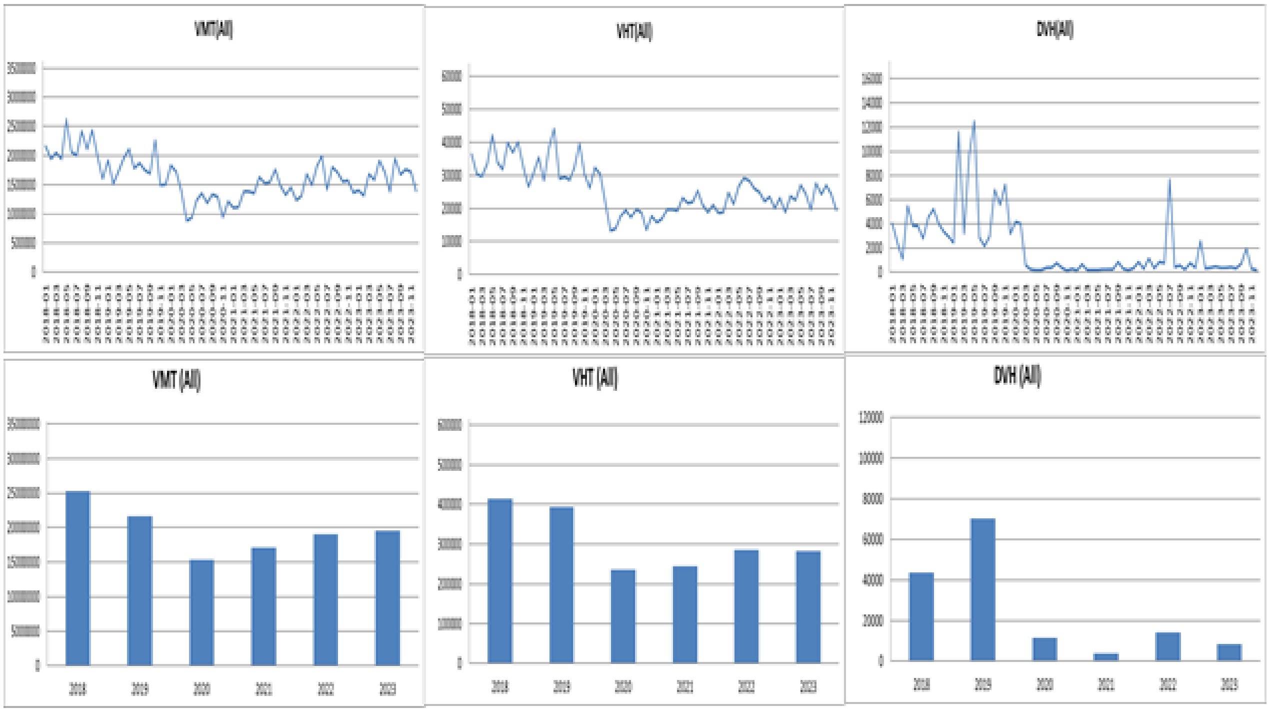
Work-Zone Effects



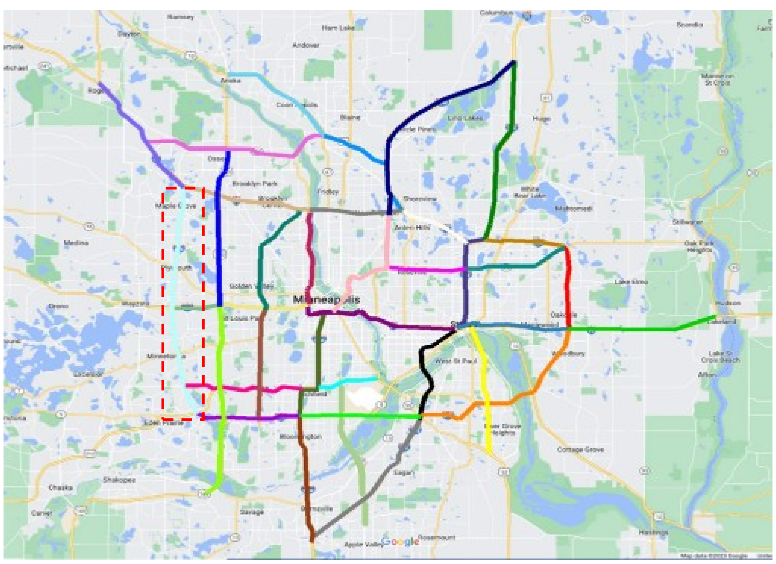
Yearly Variations of Buffer Index - Travel Rate Relationships



Variations of Traffic-Flow Measures

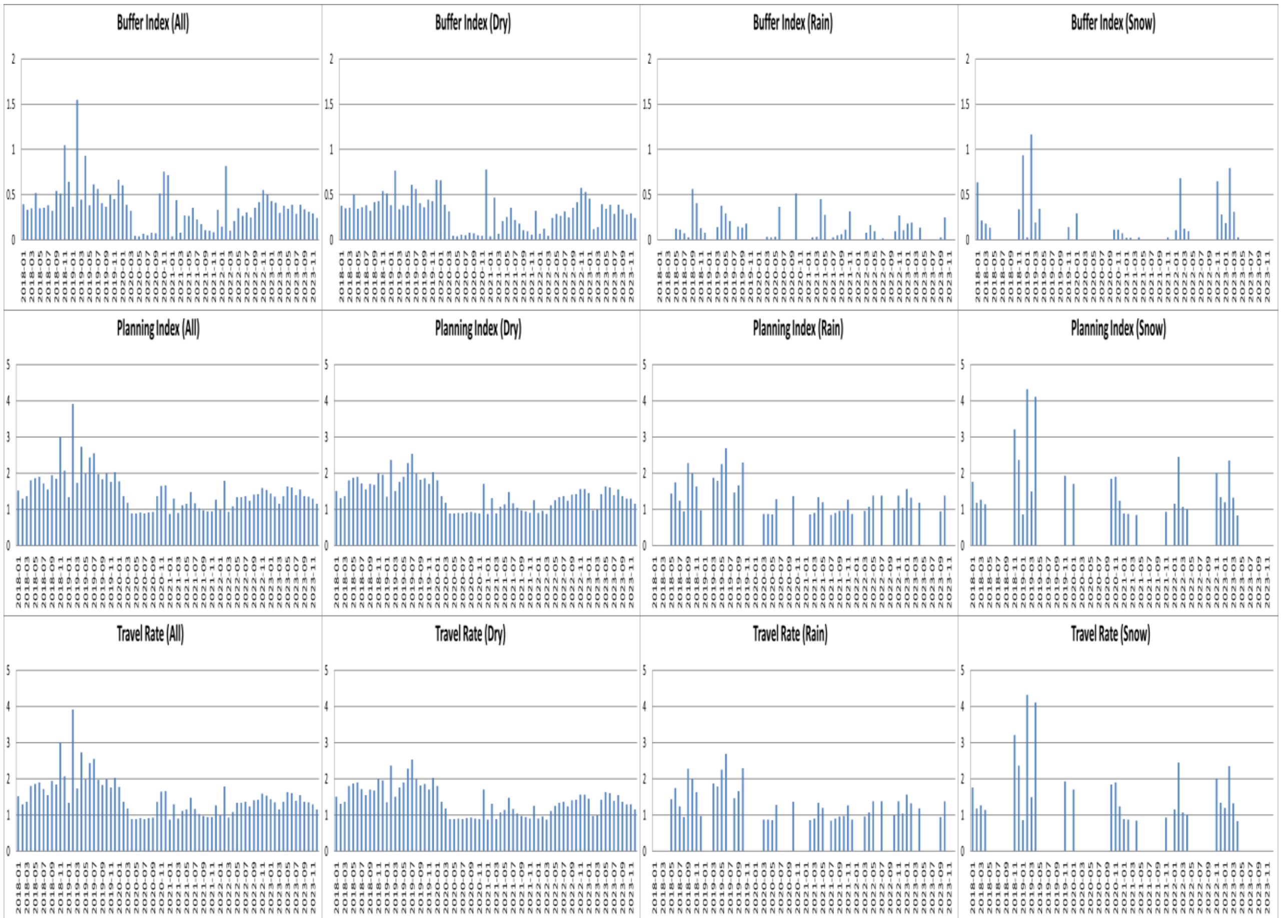


16) I-494 Corridor D (TH212 < -- > I694)



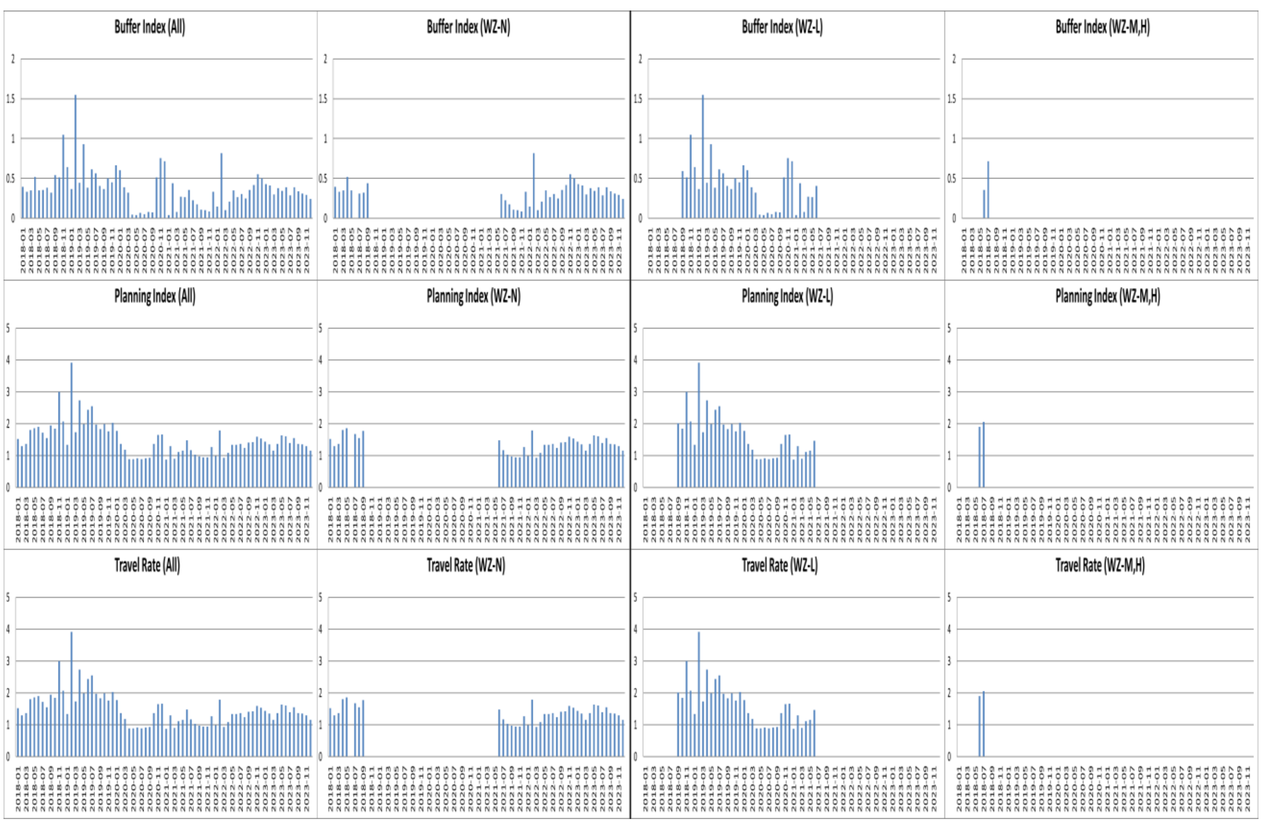
i) I-494 Corridor D - NB TH 212 to I-694 for Afternoon Peak Periods

Effects of Weather conditions on Travel-Time Reliability

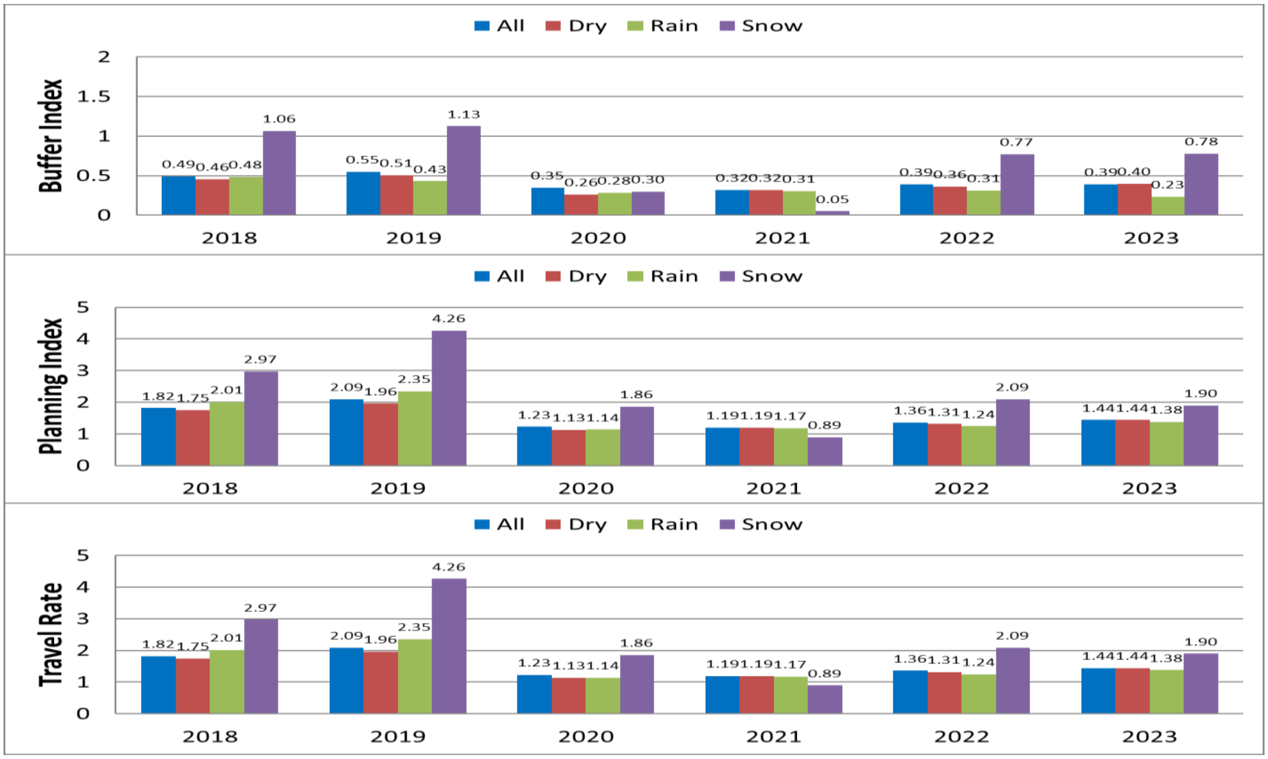


Effects of Incidents

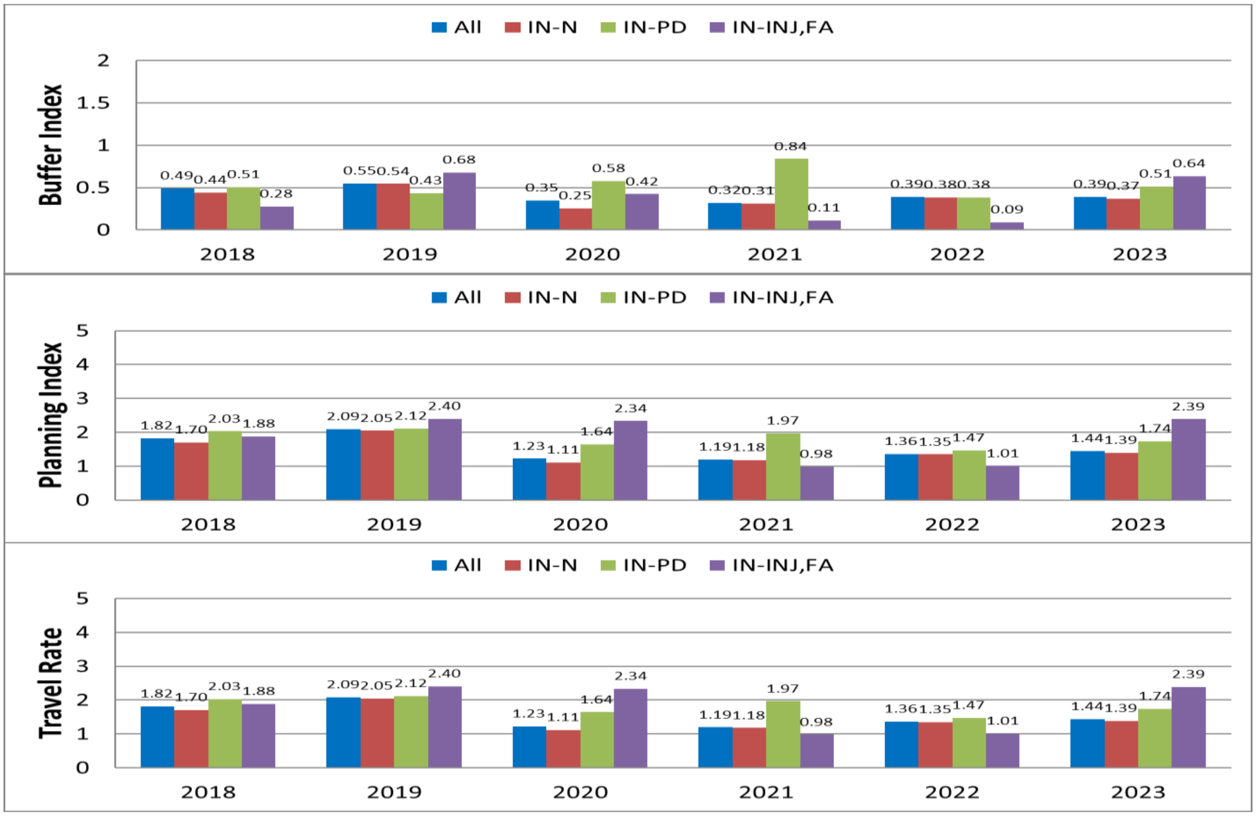
Effects of Work Zones



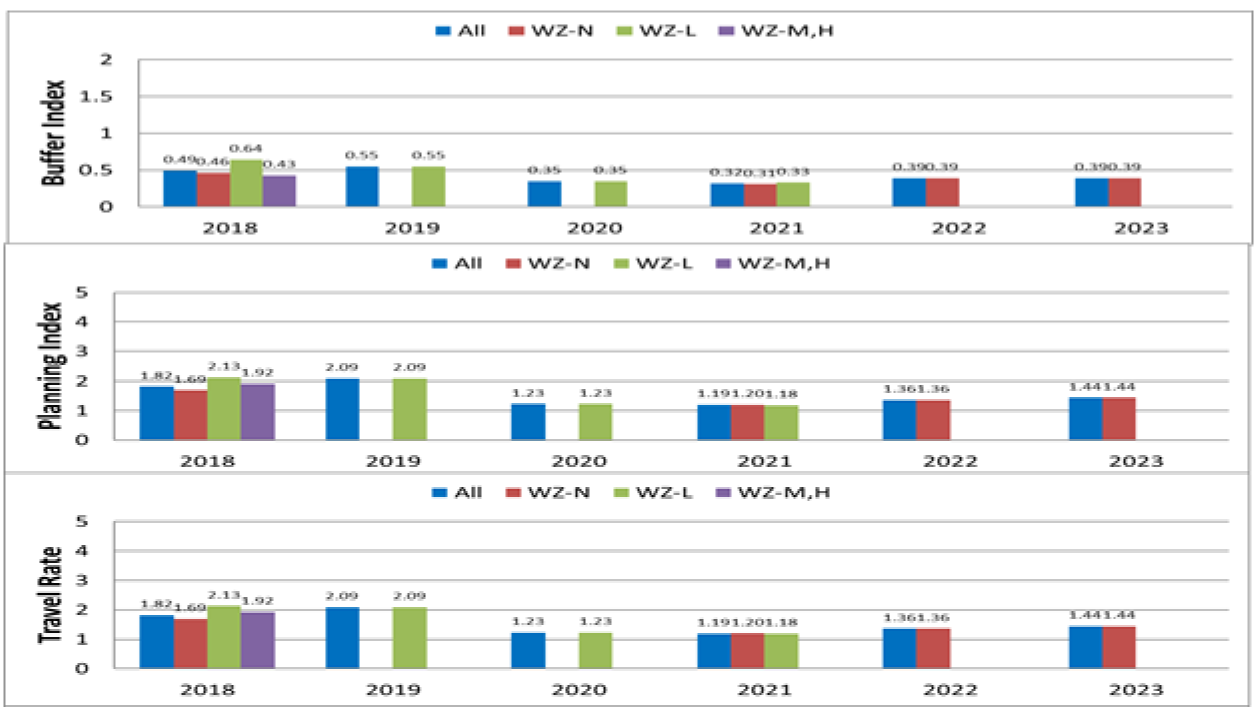
Yearly Variations - *Weather Effects*



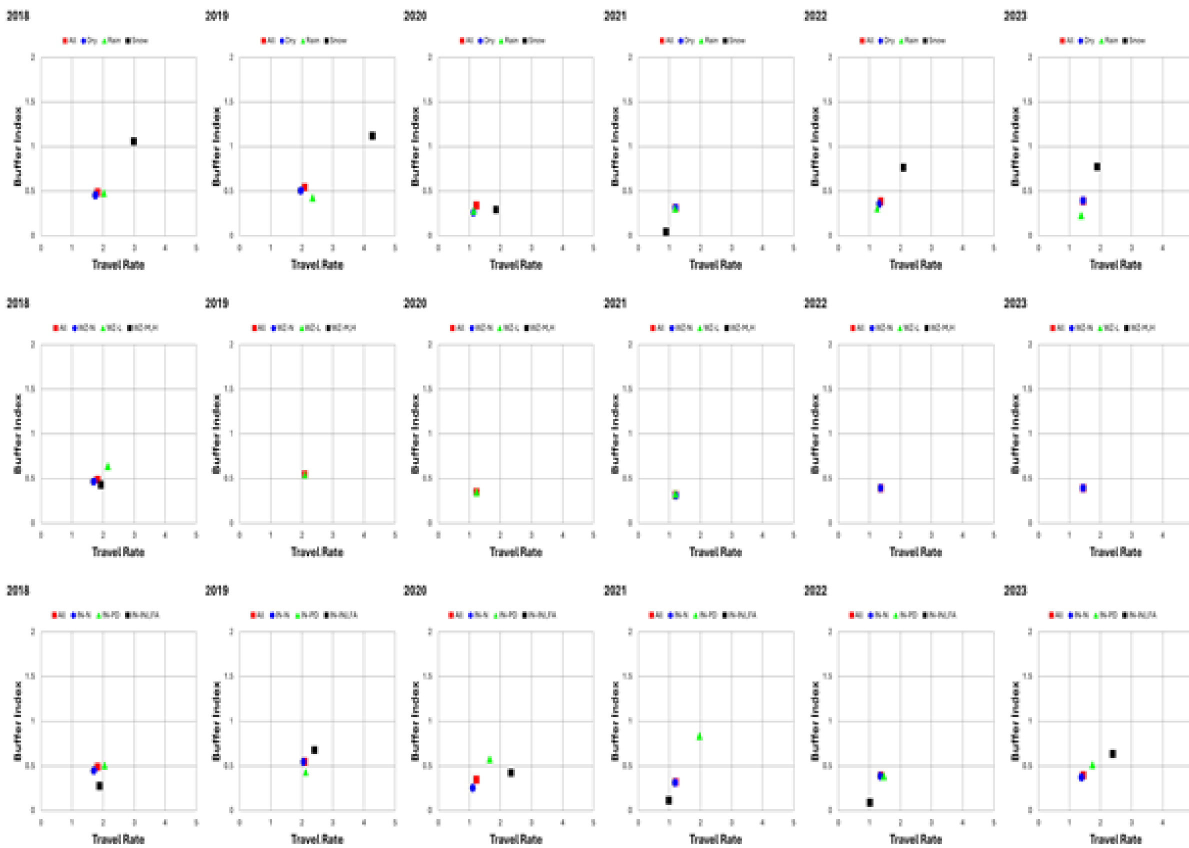
Incident Effects



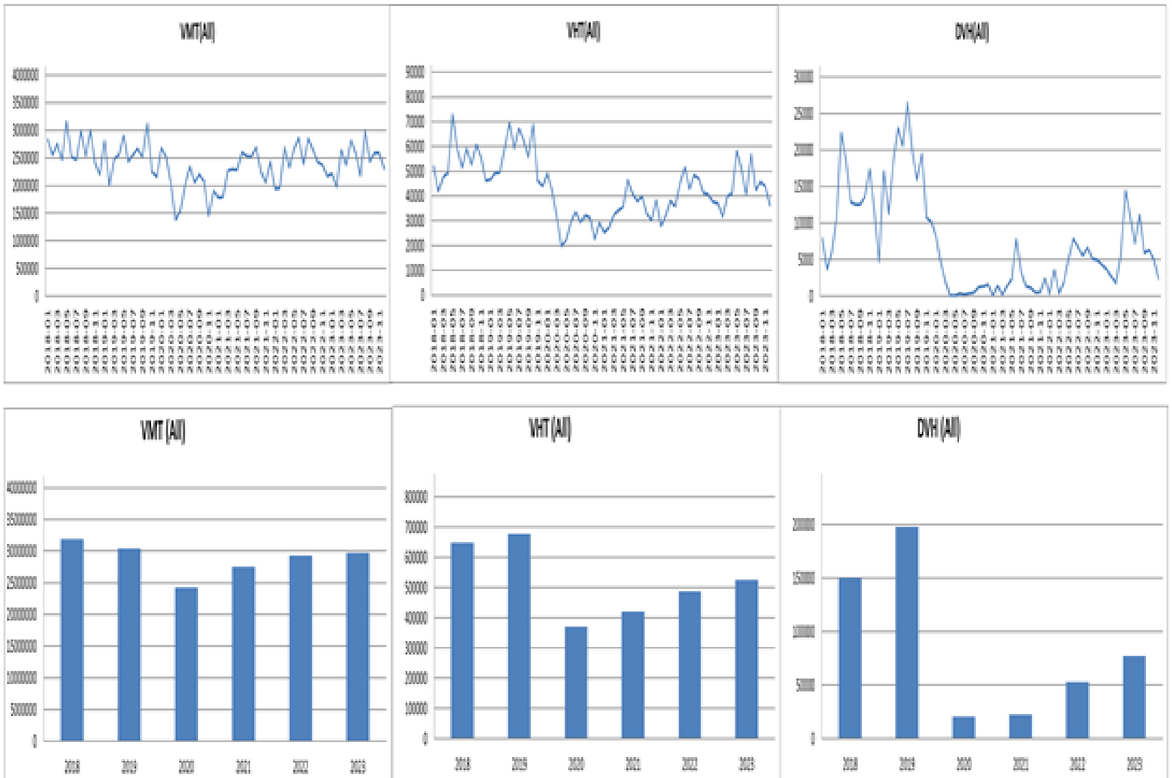
Work-Zone Effects



Yearly Variations of Buffer Index - Travel Rate Relationships

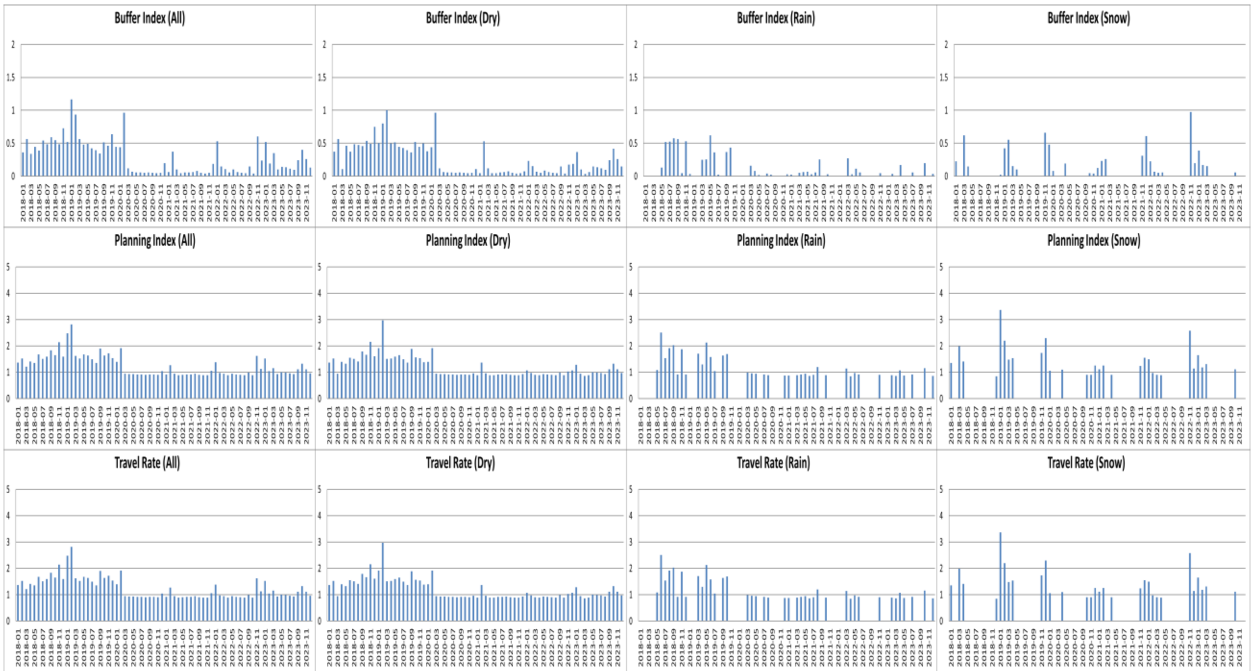


Variations of Traffic-Flow Measures

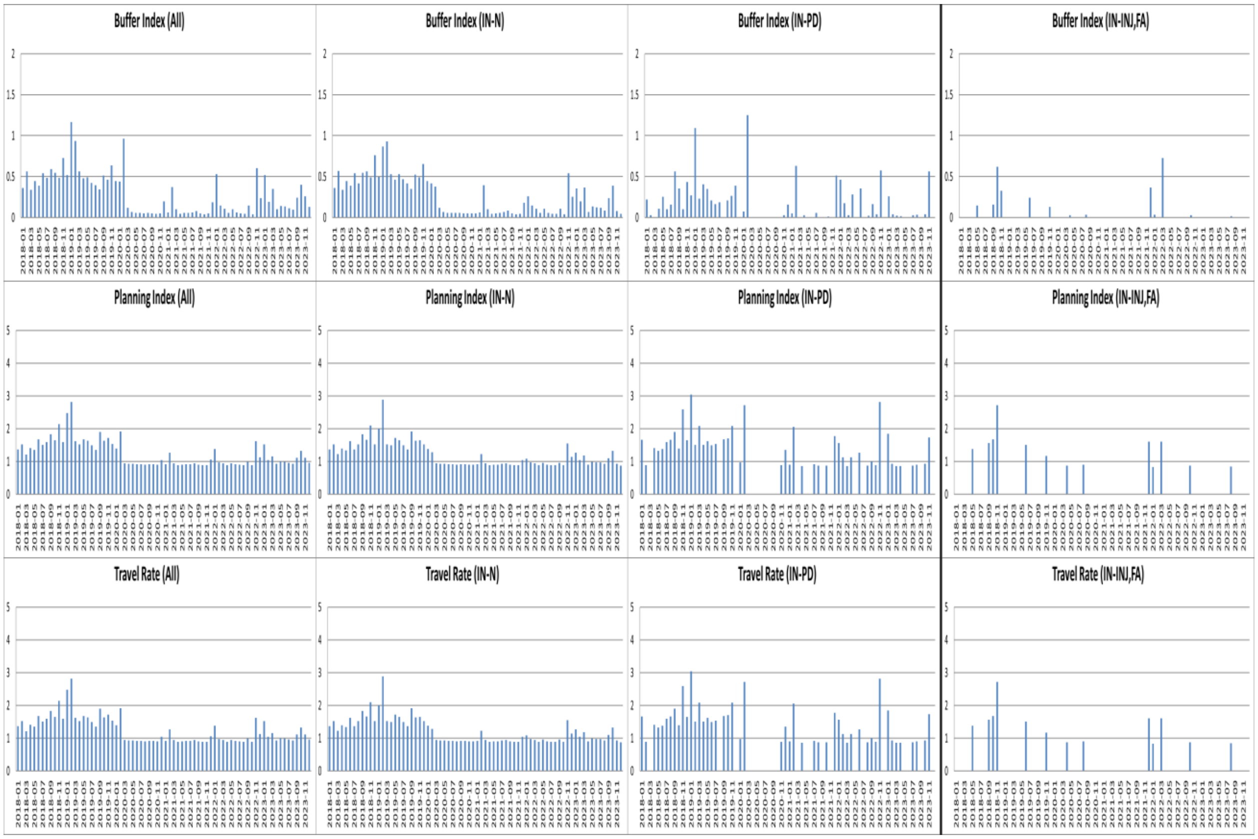

VMT(All)
VHT(All)
DVH(All)
VMT (All)
VHT (All)
DVH (All)

ii) I-494 Corridor D - SB I-694 to TH 212 for Morning Peak Periods

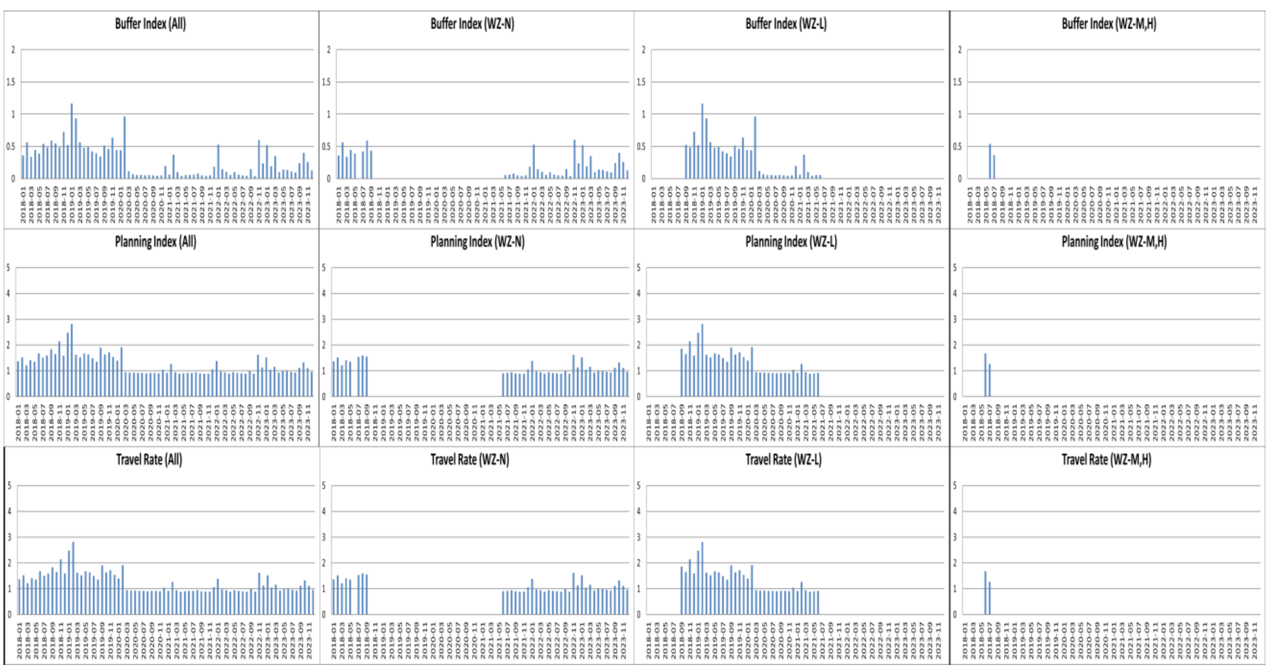
Effects of Weather conditions on Travel-Time Reliability



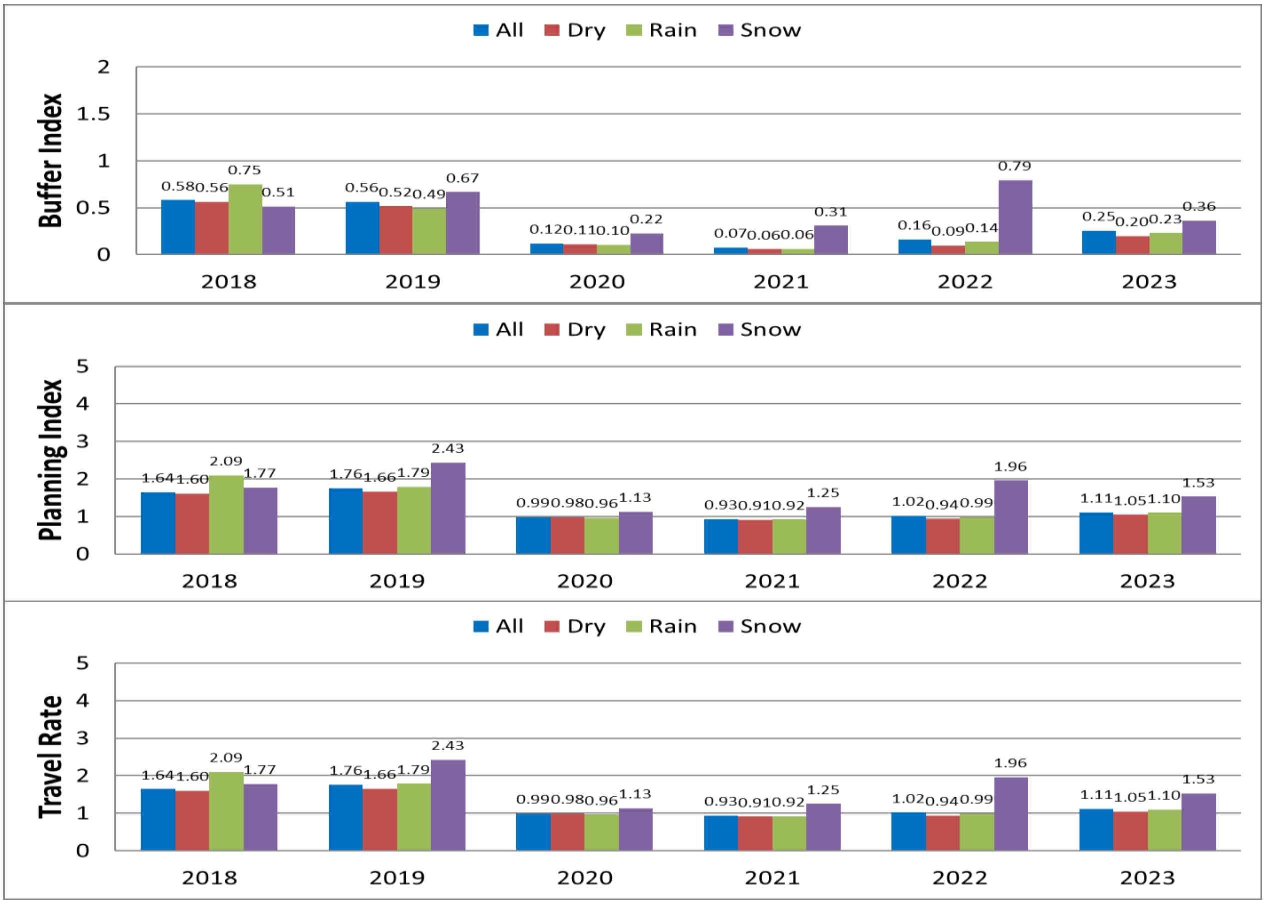
Effects of Incidents



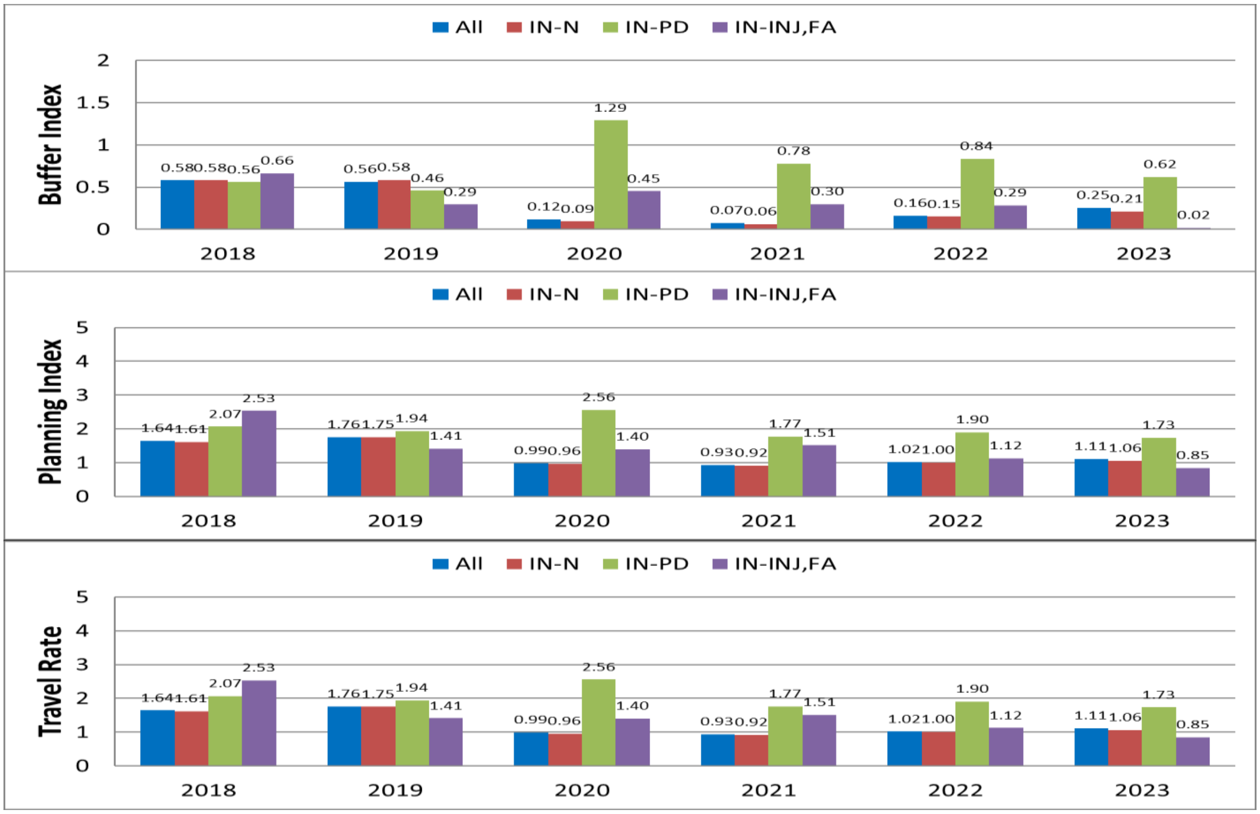
Effects of Work Zones



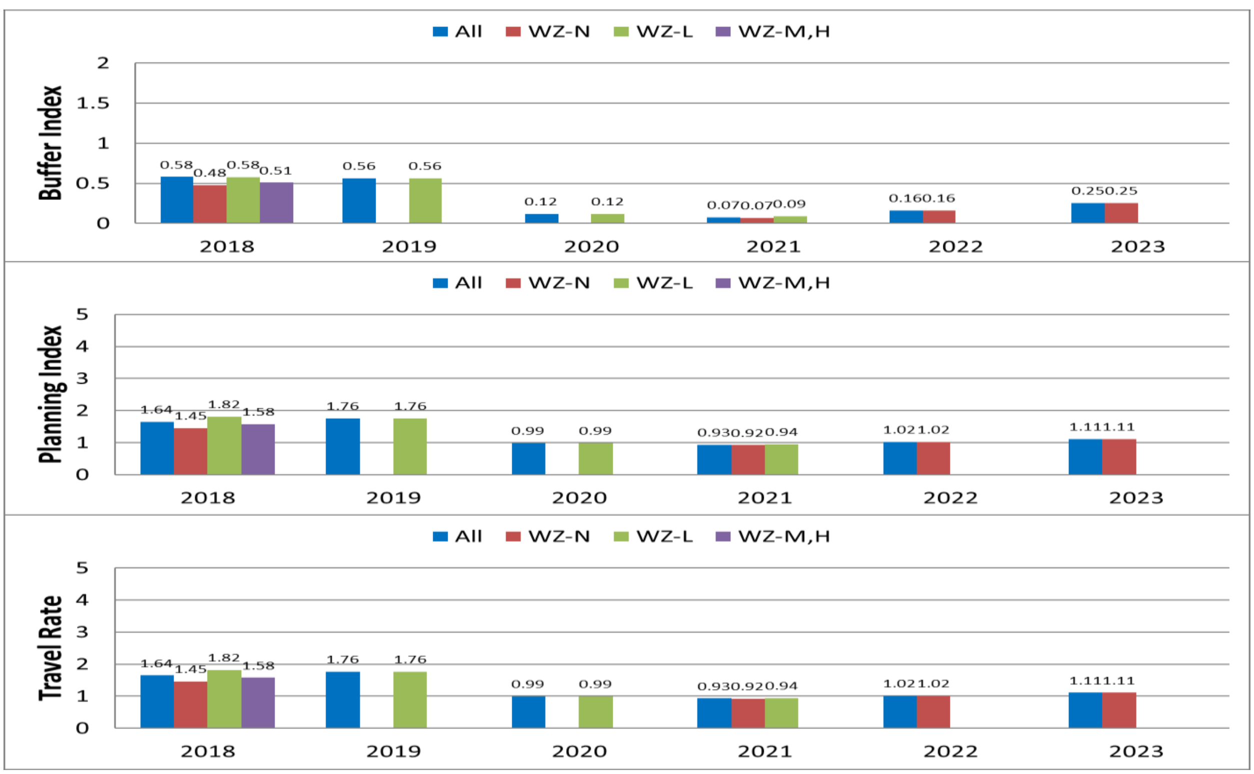
Yearly Variations - *Weather Effects*



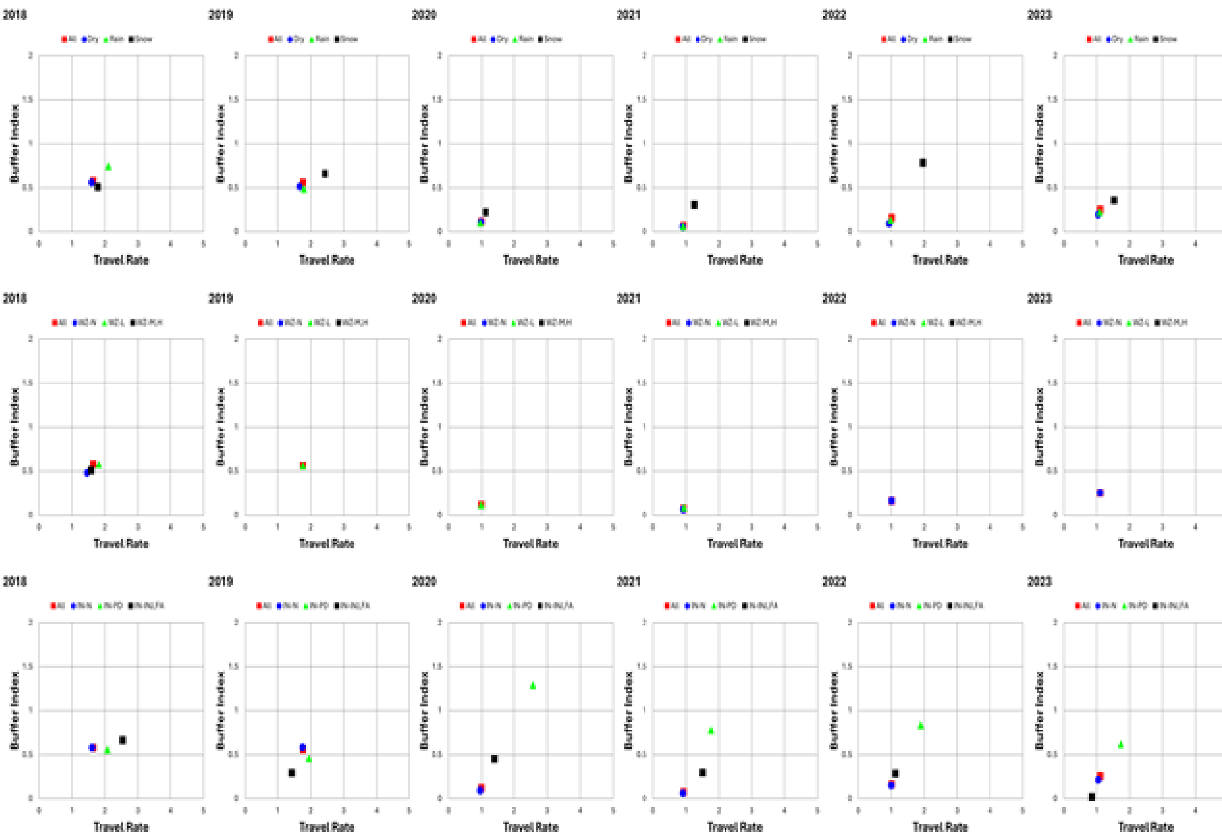
Incident Effects



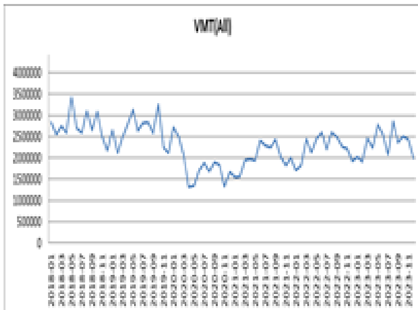
Work-Zone Effects

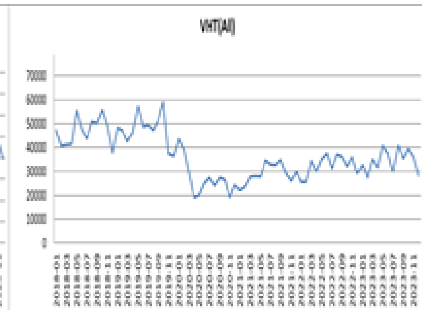


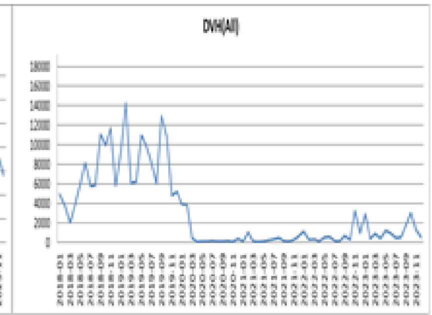
Yearly Variations of Buffer Index - Travel Rate Relationships

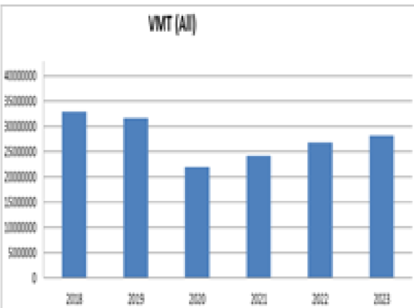


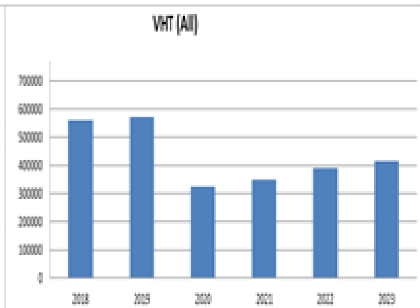
Variations of Traffic-Flow Measures

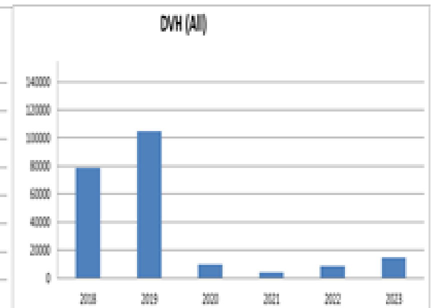






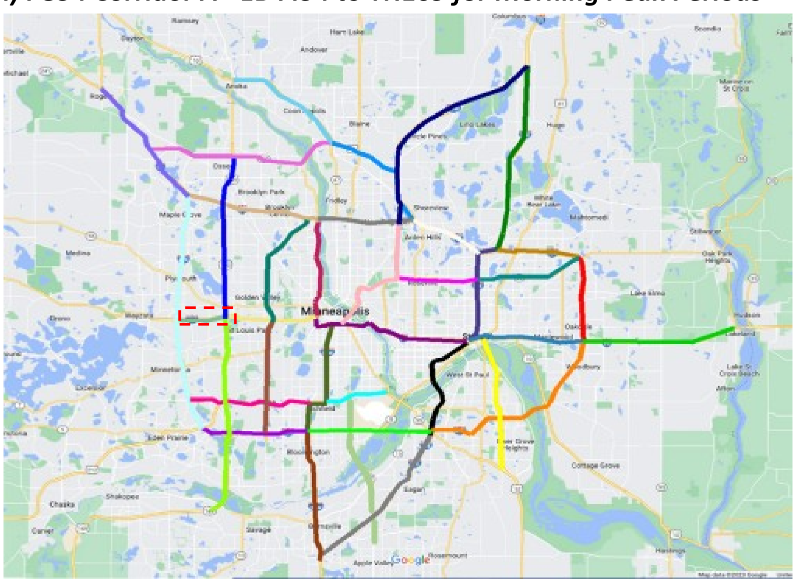




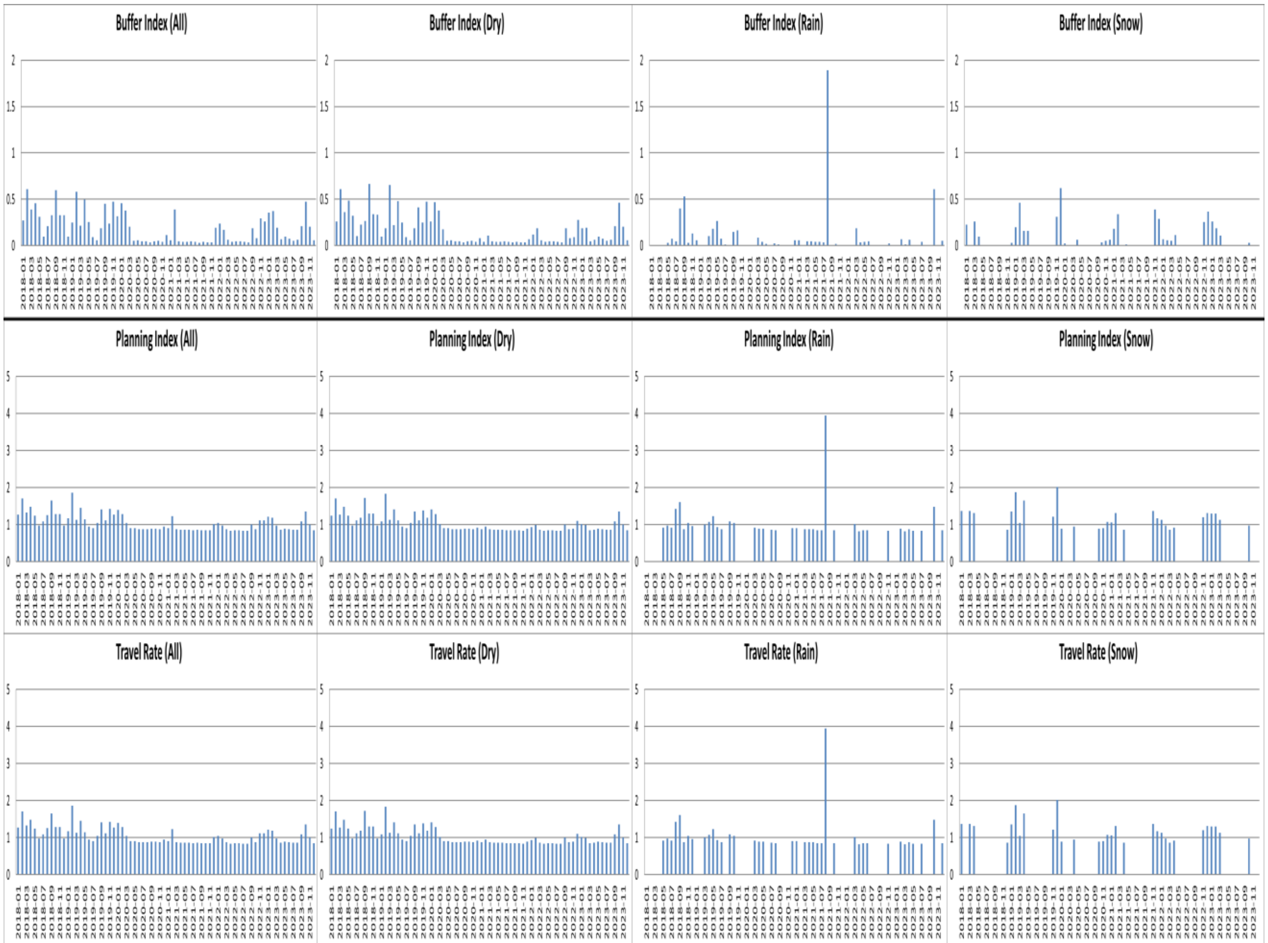


17) I-394 Corridor A (I494 < -- > TH169)

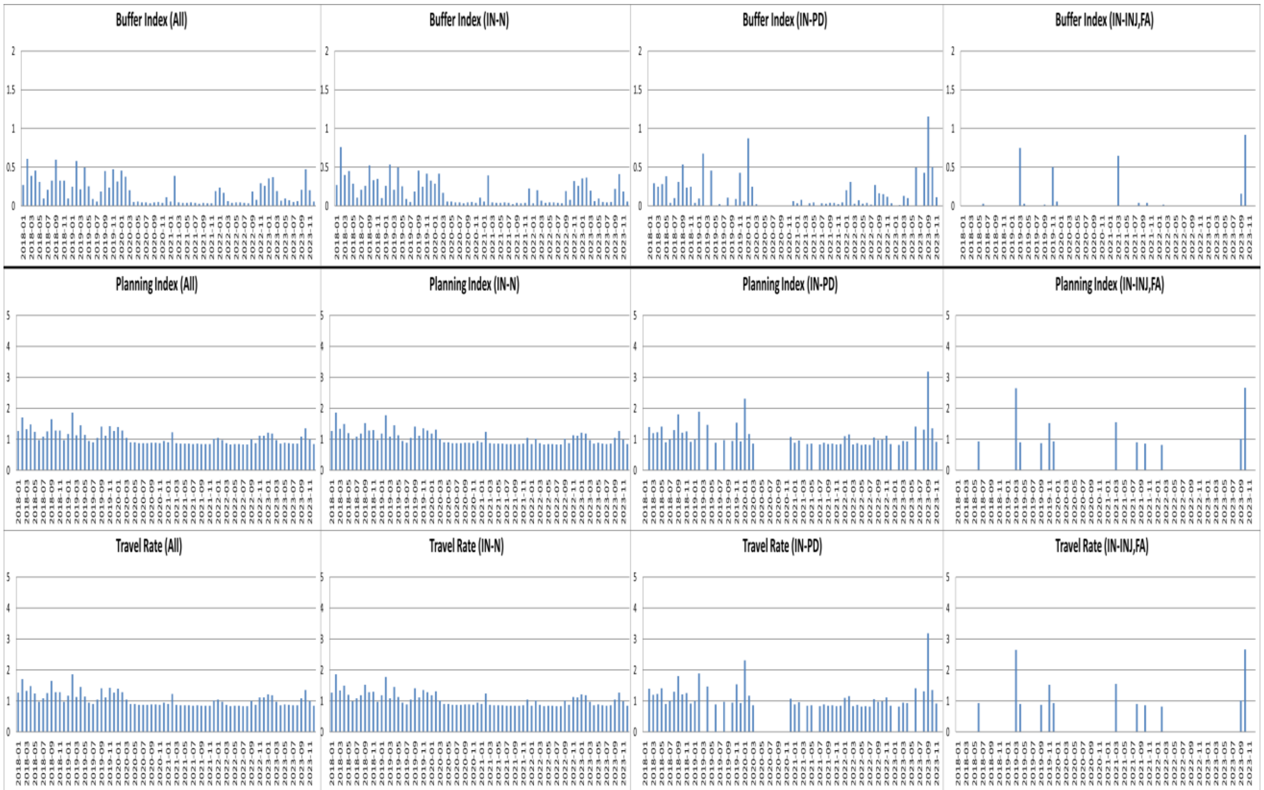
i) I-394 Corridor A - EB I494 to TH169 for Morning Peak Periods



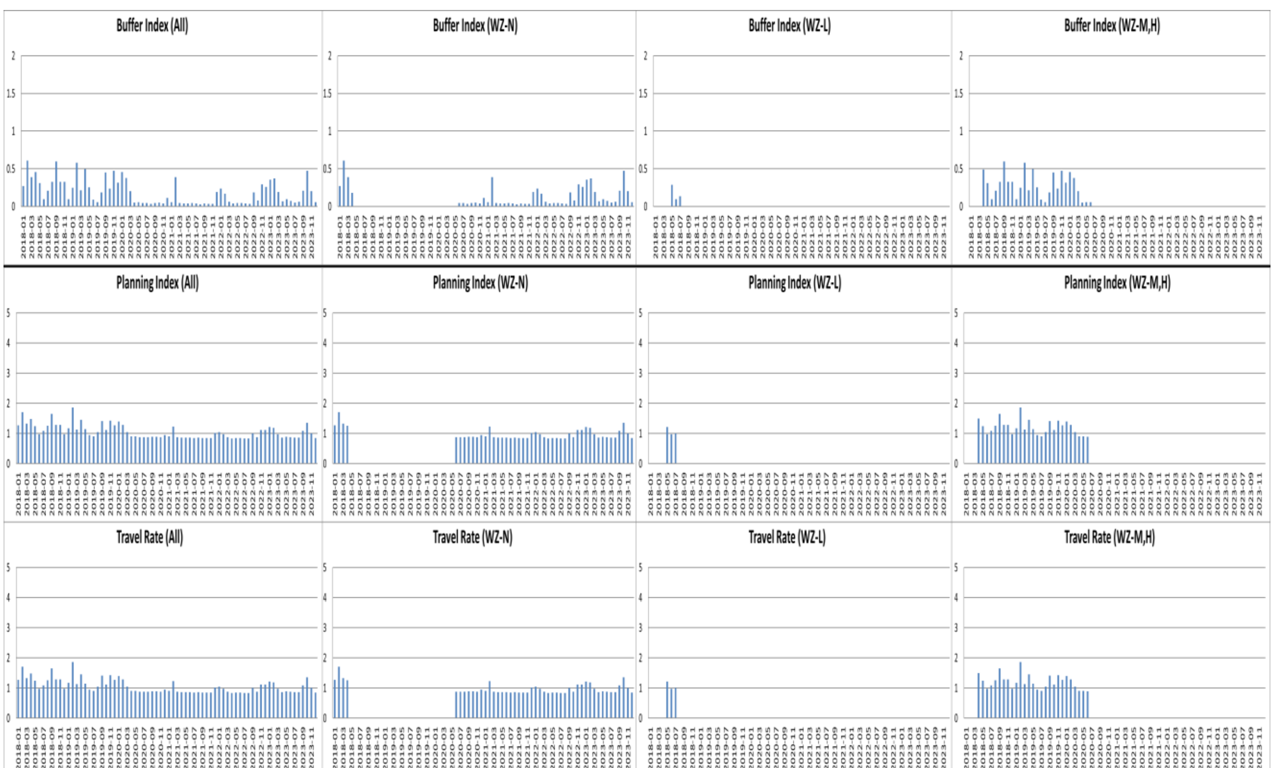
Effects of Weather conditions on Travel-Time Reliability



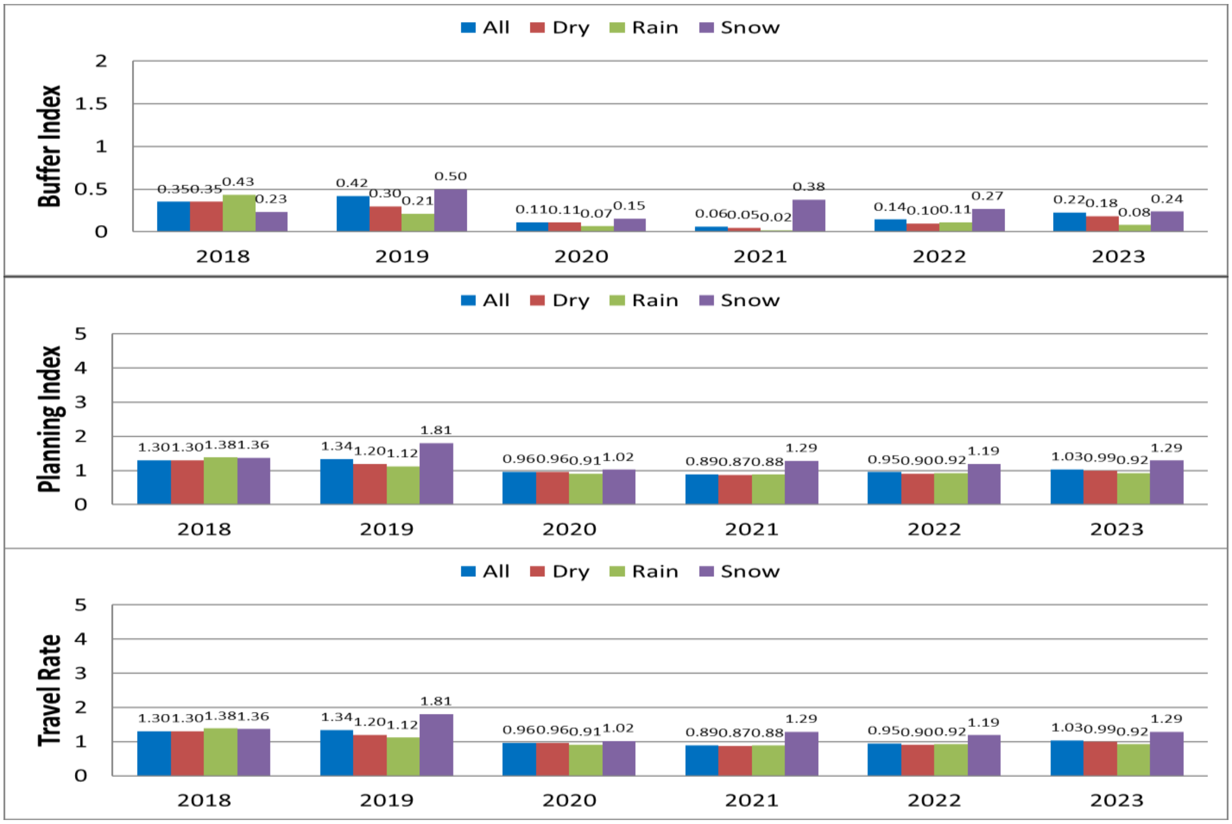
Effects of Incidents



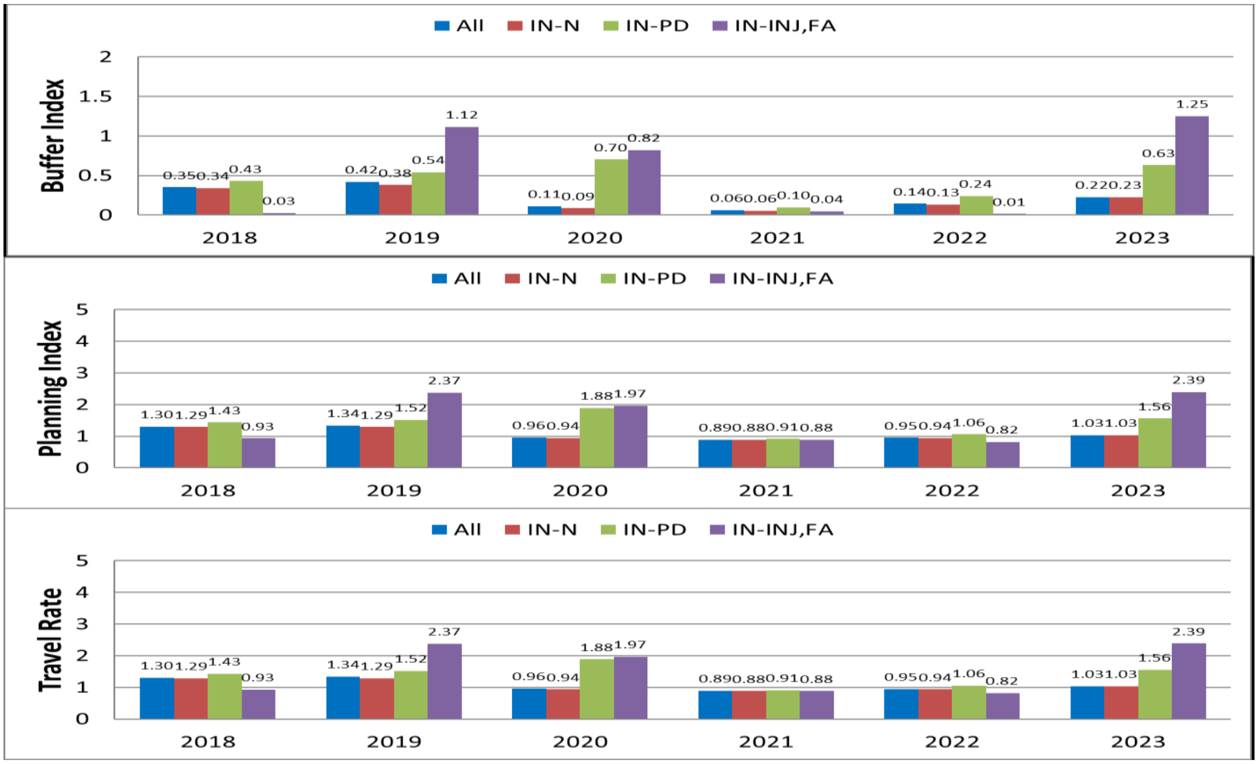
Effects of Work Zones



Yearly Variations - *Weather Effects*

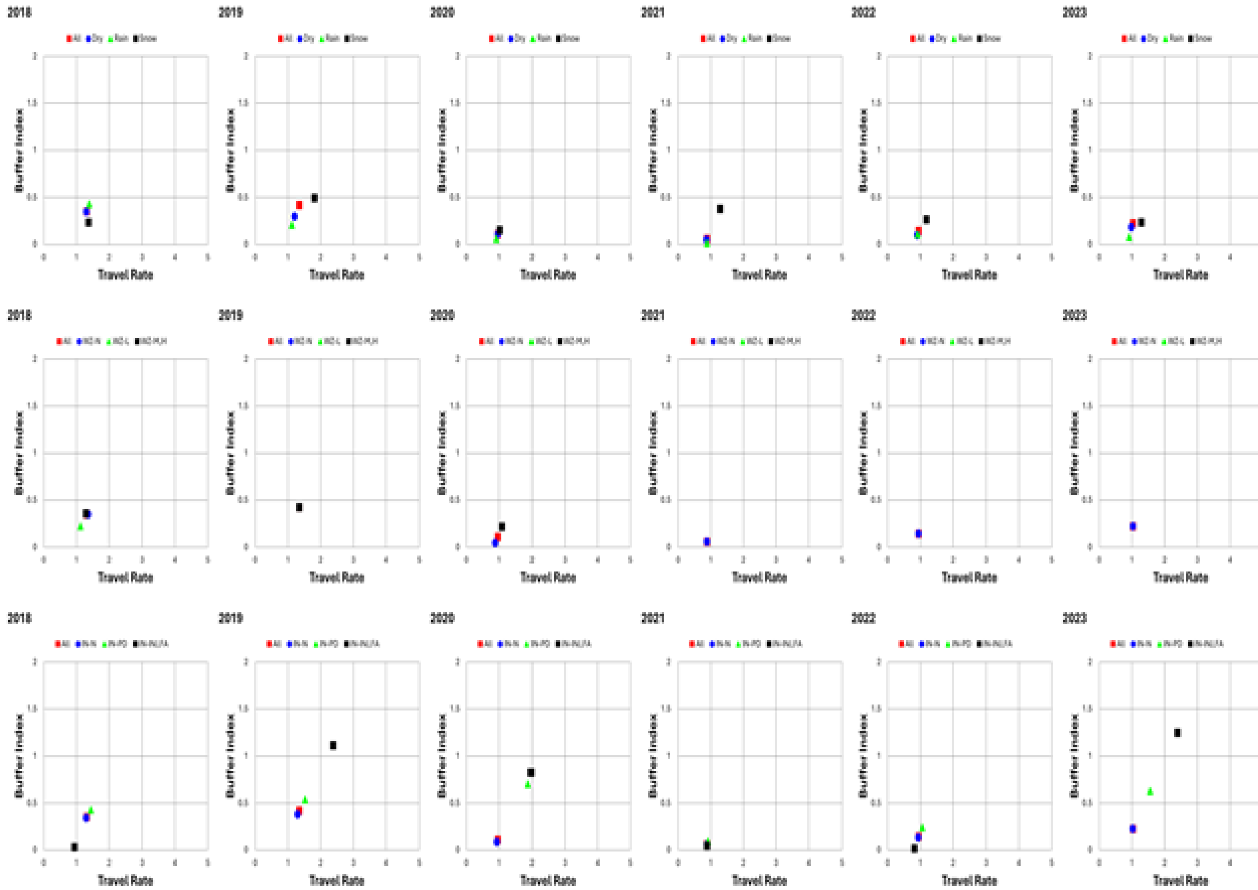


Incident Effects

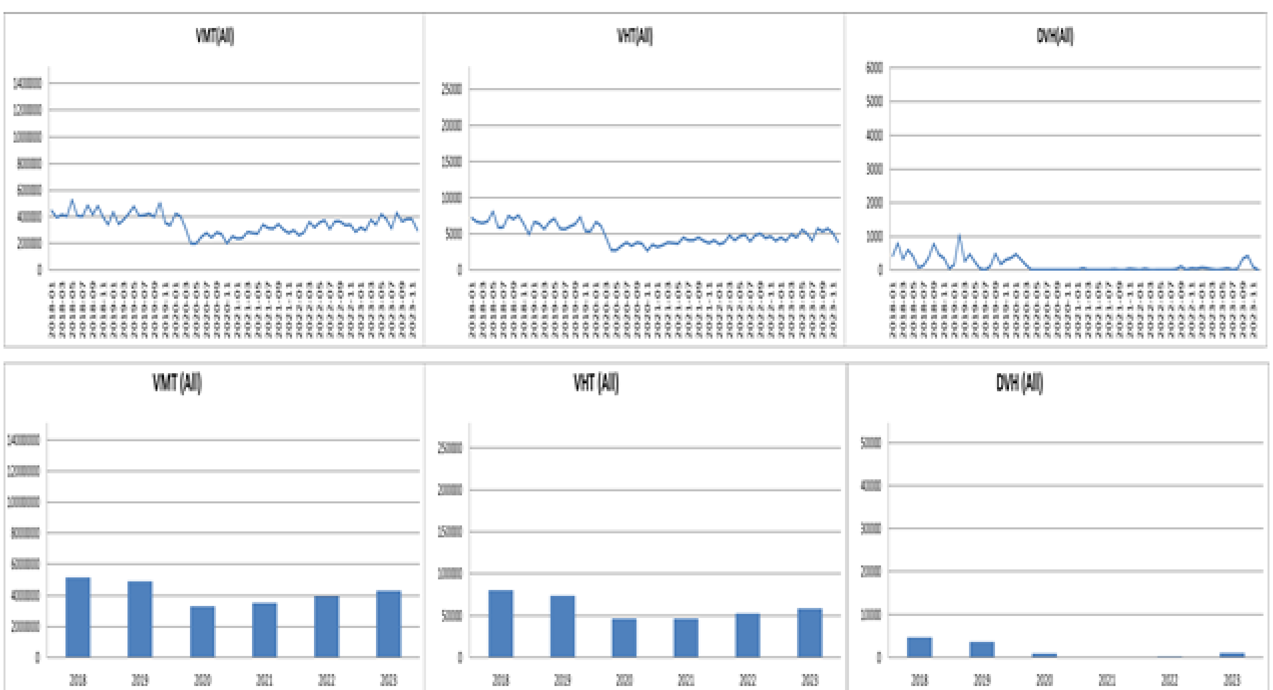


Work-Zone Effects

Yearly Variations of Buffer Index - Travel Rate Relationships

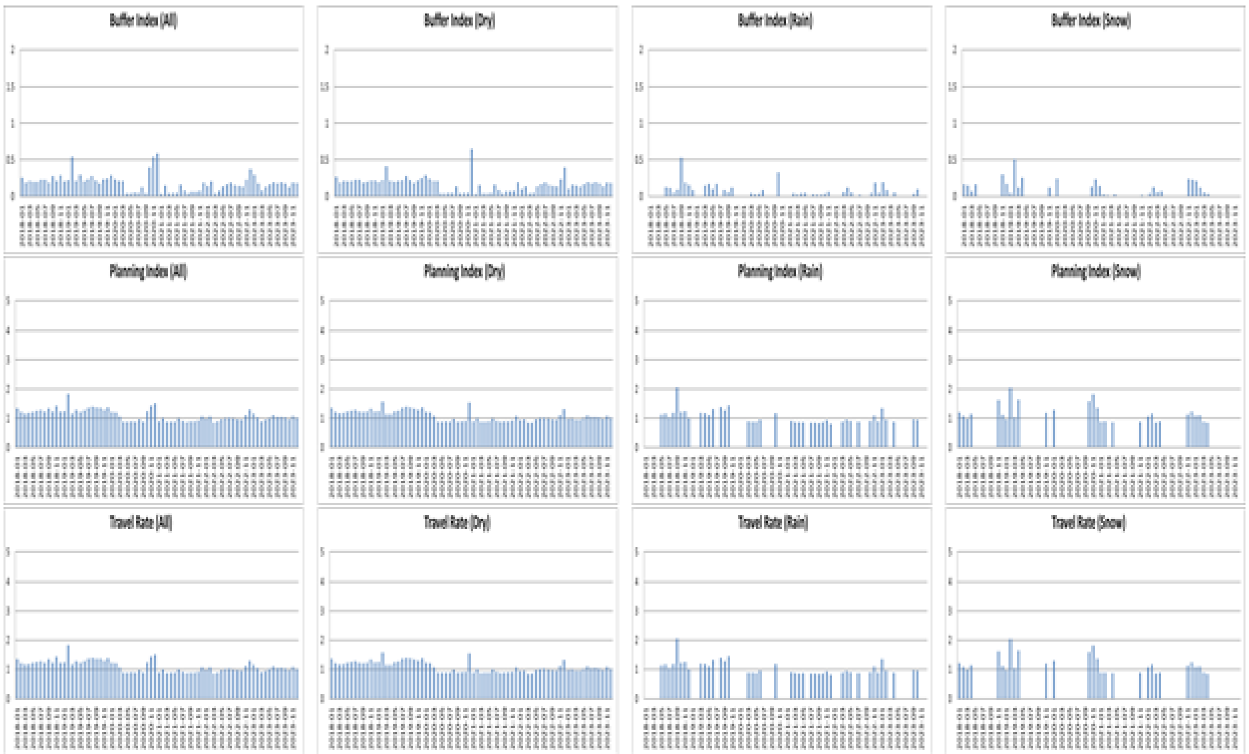


Variations of Traffic-Flow Measures

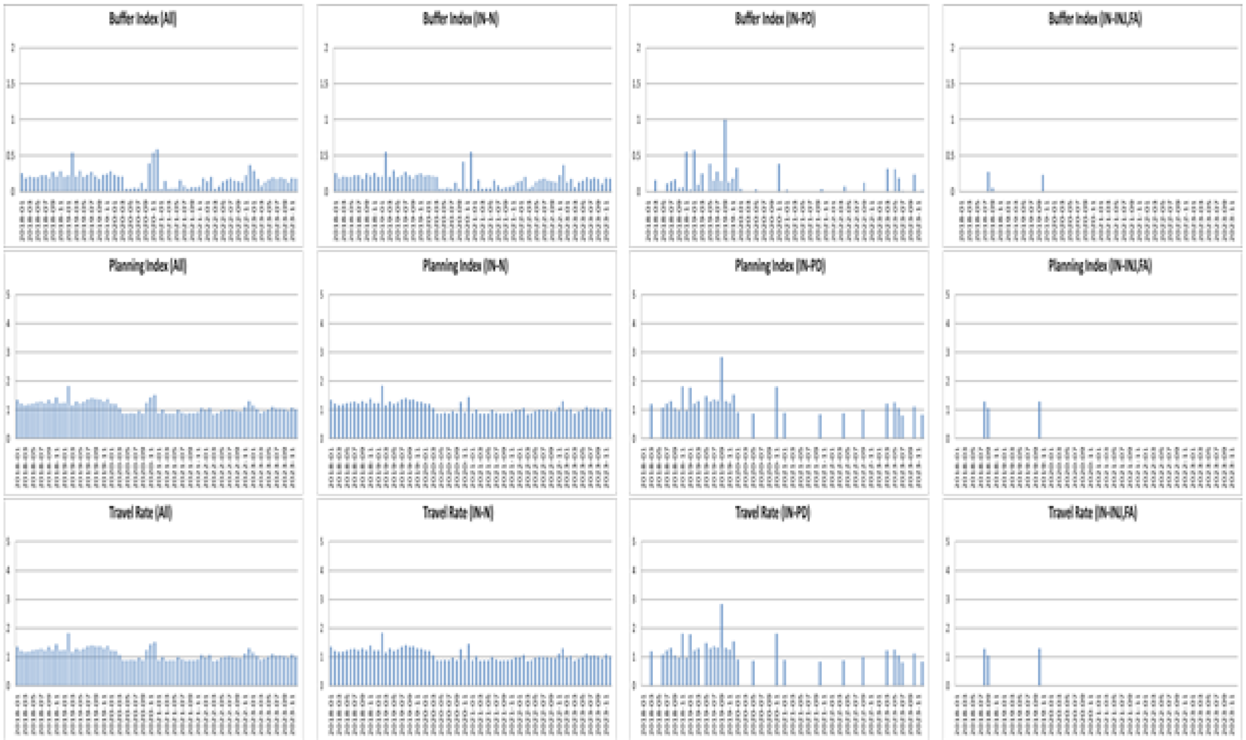


ii) I-394 Corridor A - WB TH169 to I494 for Afternoon Peak Periods

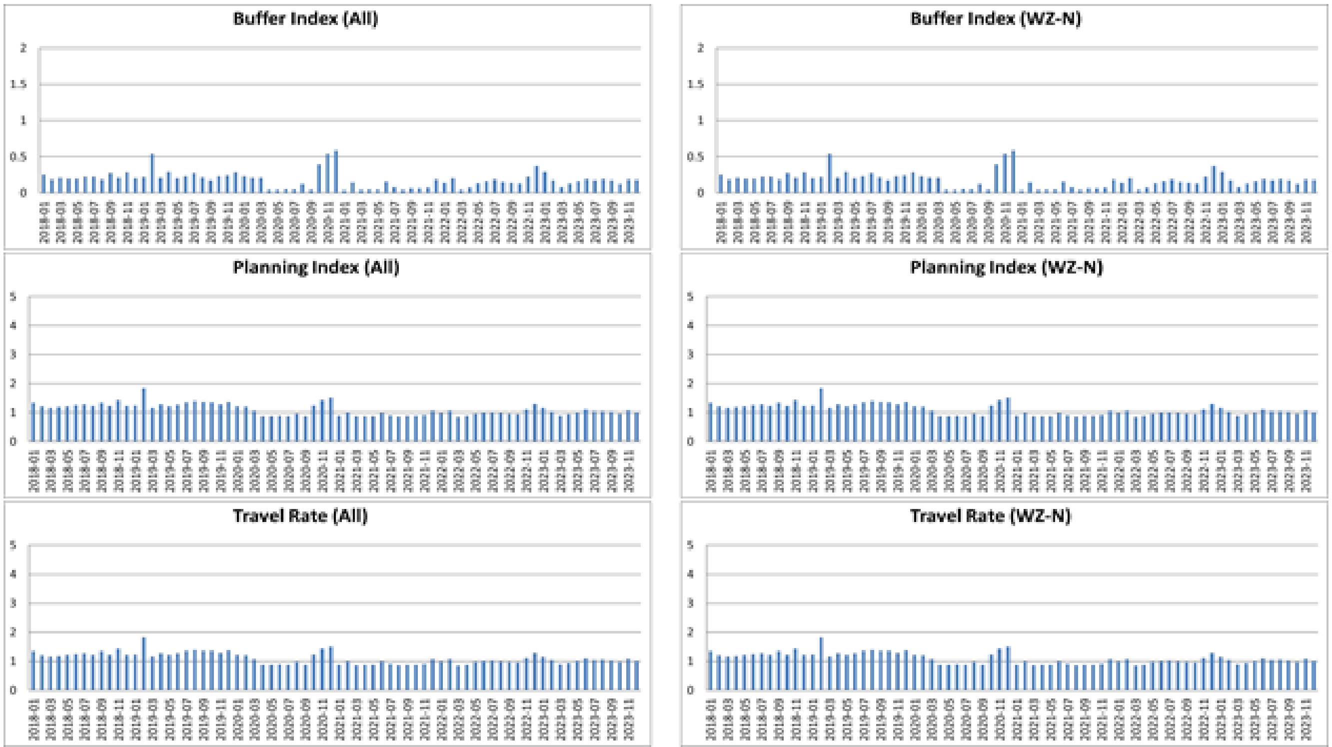
Effects of Weather conditions on Travel-Time Reliability



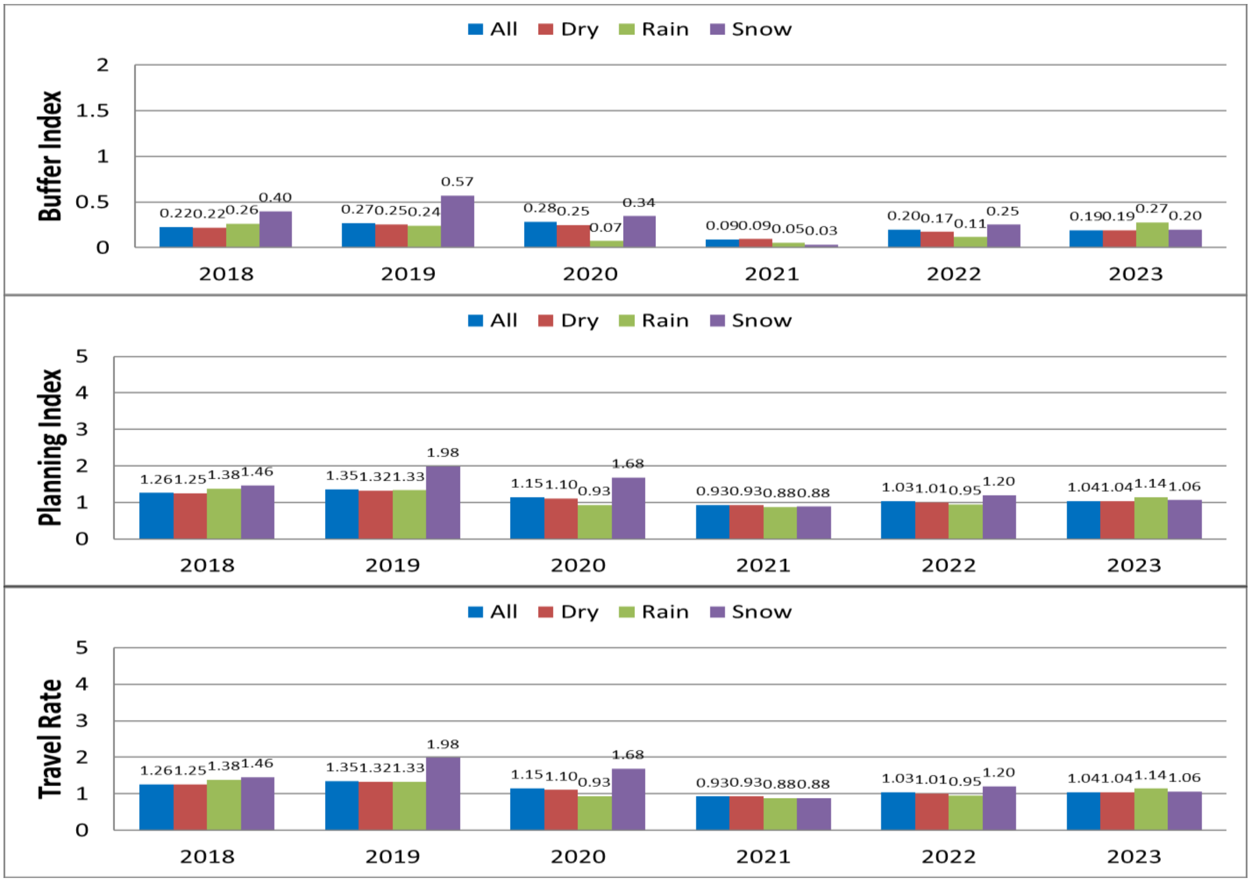
Effects of Incidents



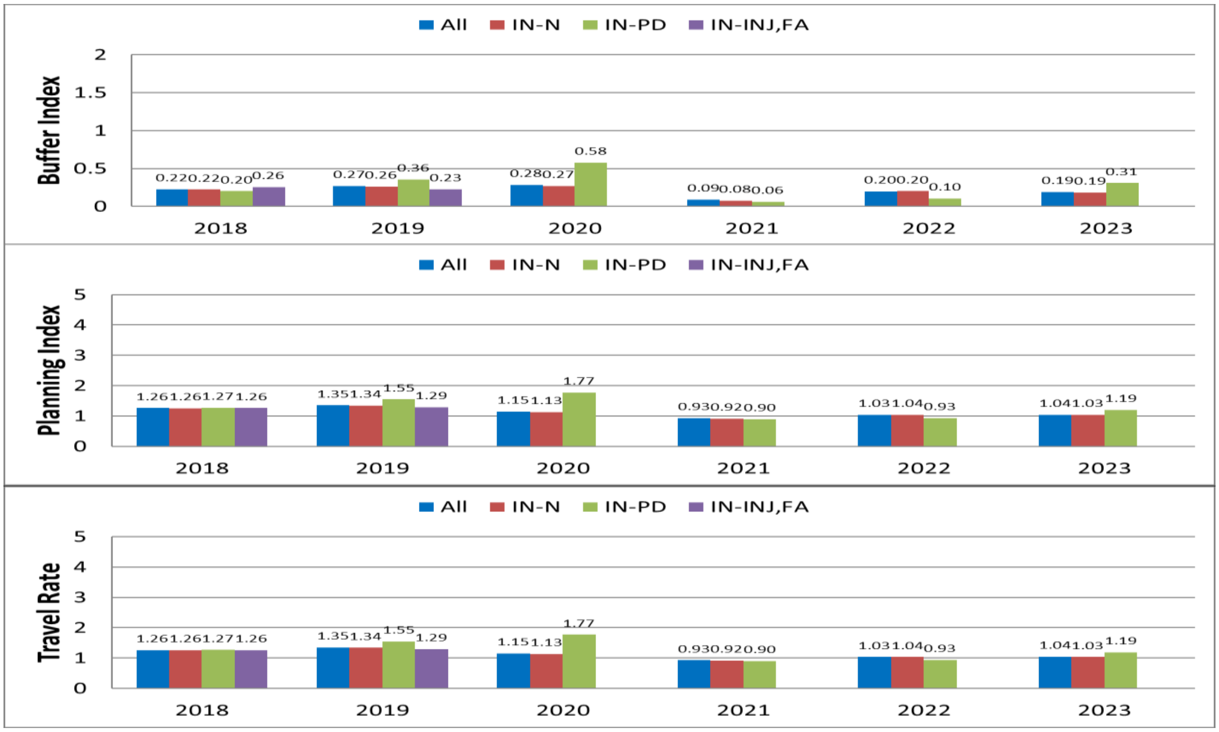
Effects of Work Zones



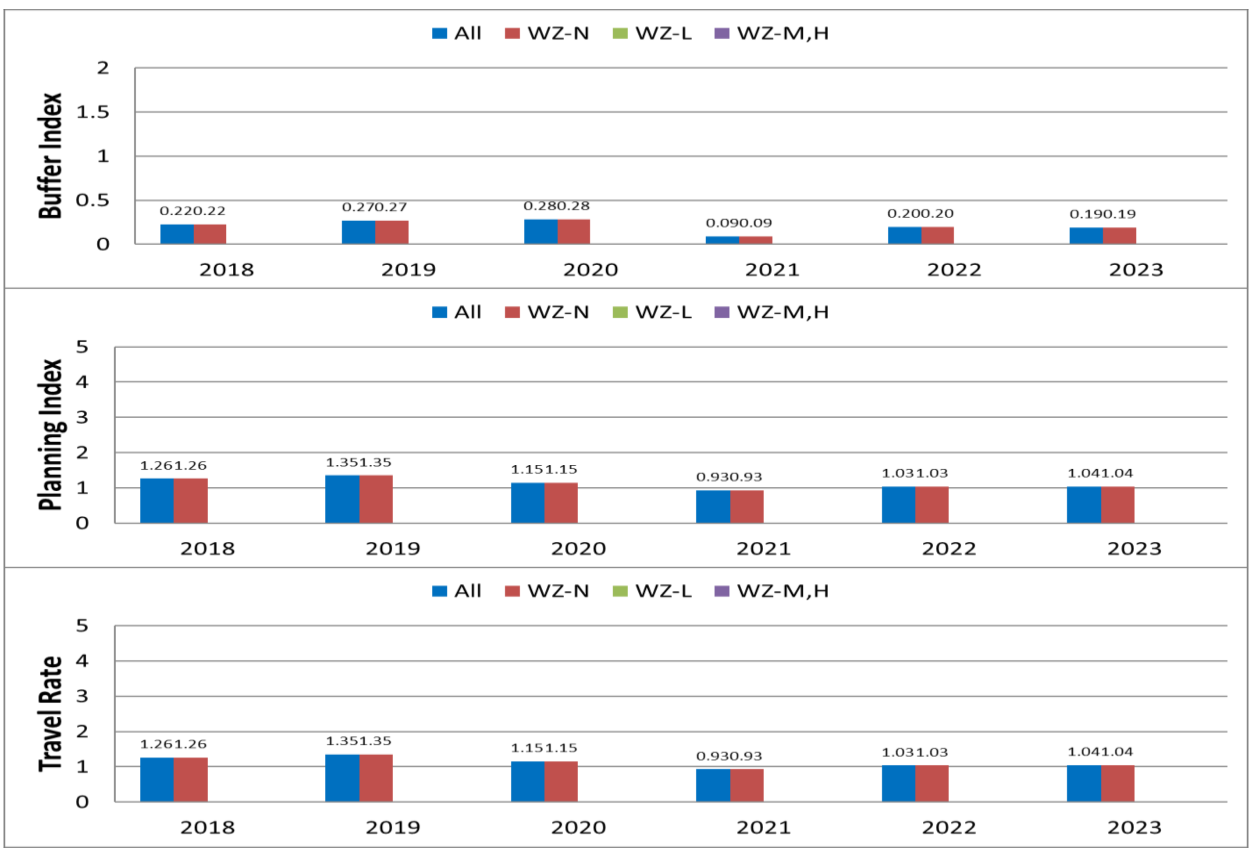
Yearly Variations - *Weather Effects*



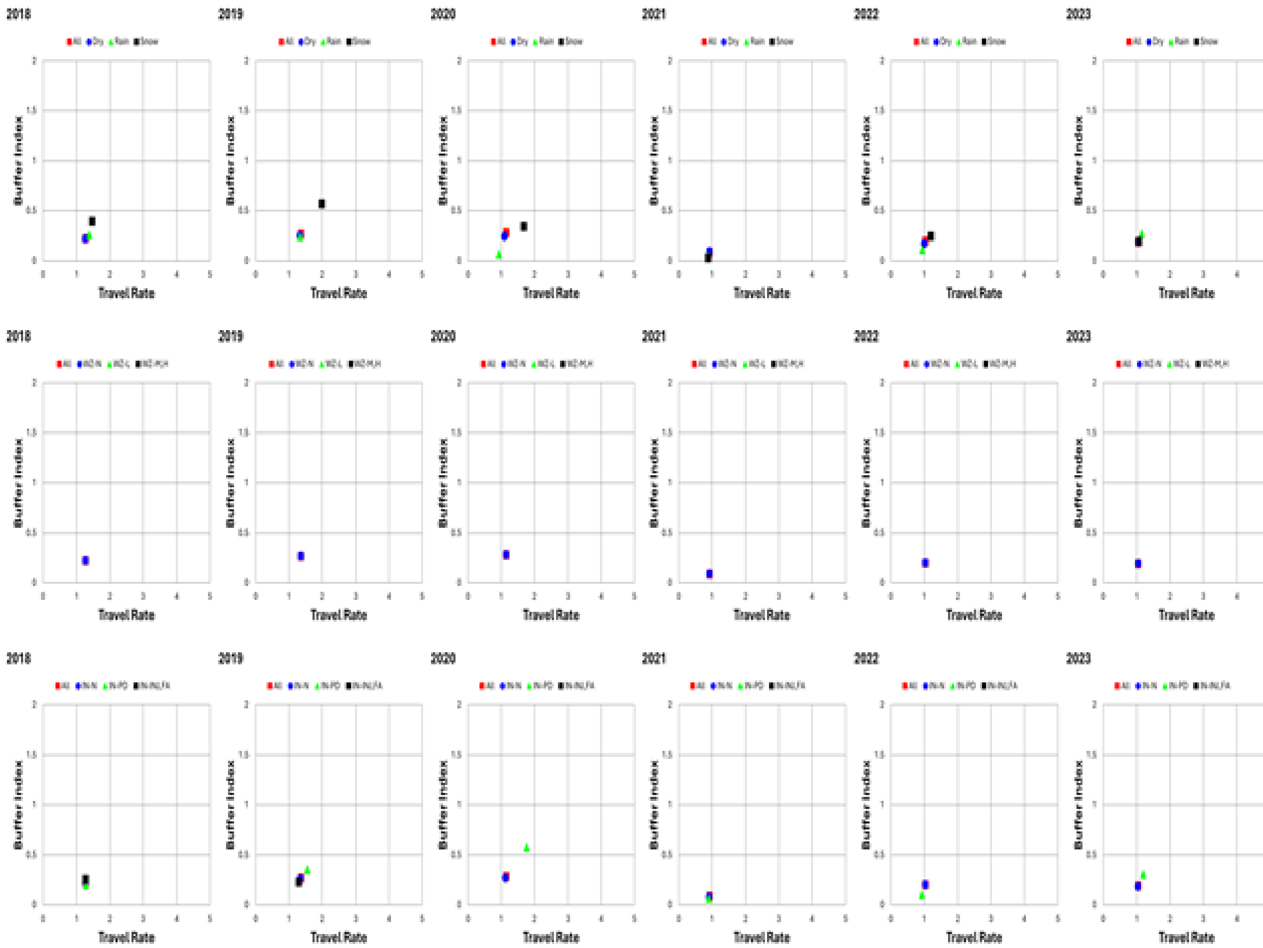
Incident Effects



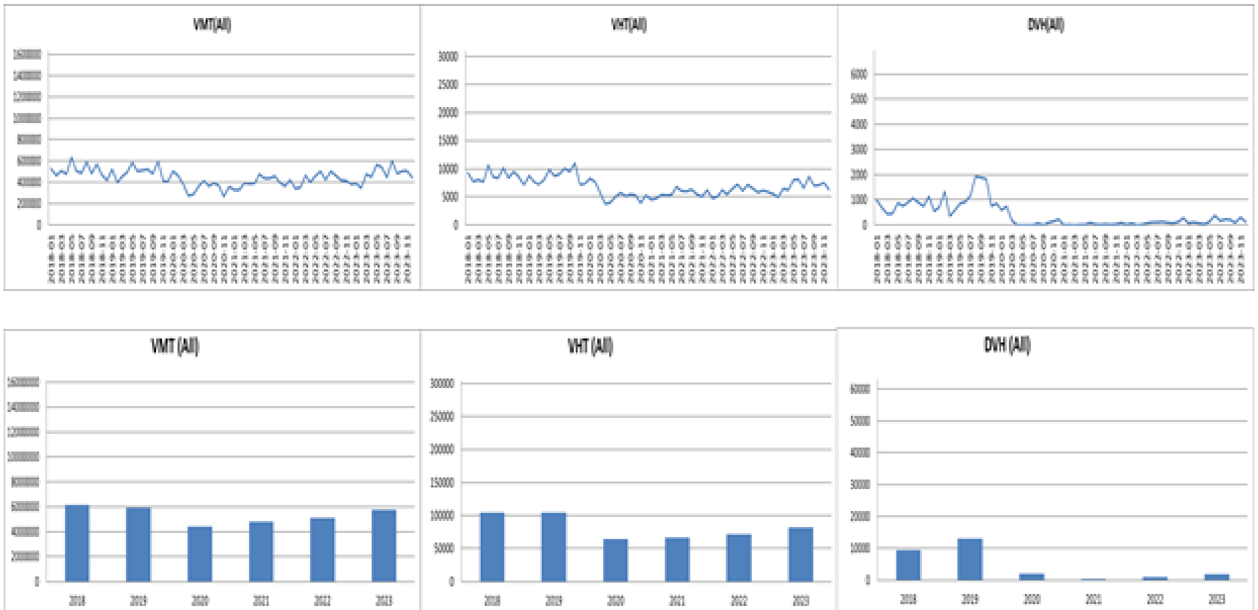
Work-Zone Effects



Yearly Variations of Buffer Index - Travel Rate Relationships

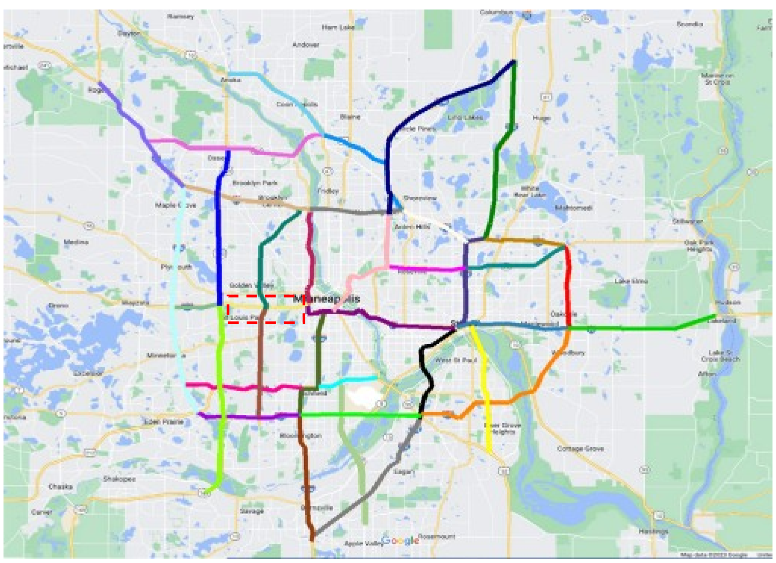


Variations of Traffic-Flow Measures

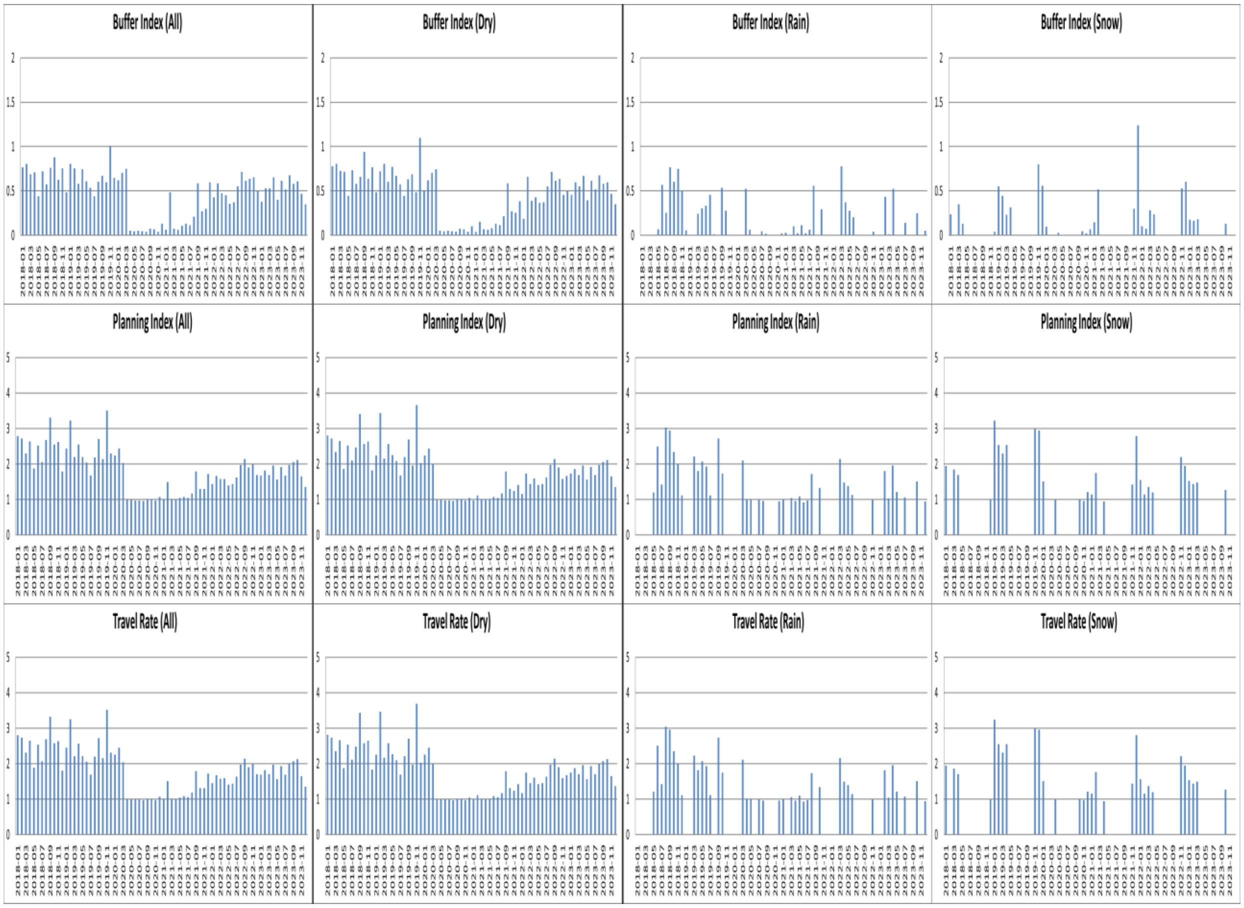


18) I-394 Corridor B (TH169 < -- > MPLS)

i) I-394 Corridor B – EB TH169 to Minneapolis DT for Morning Peak Periods

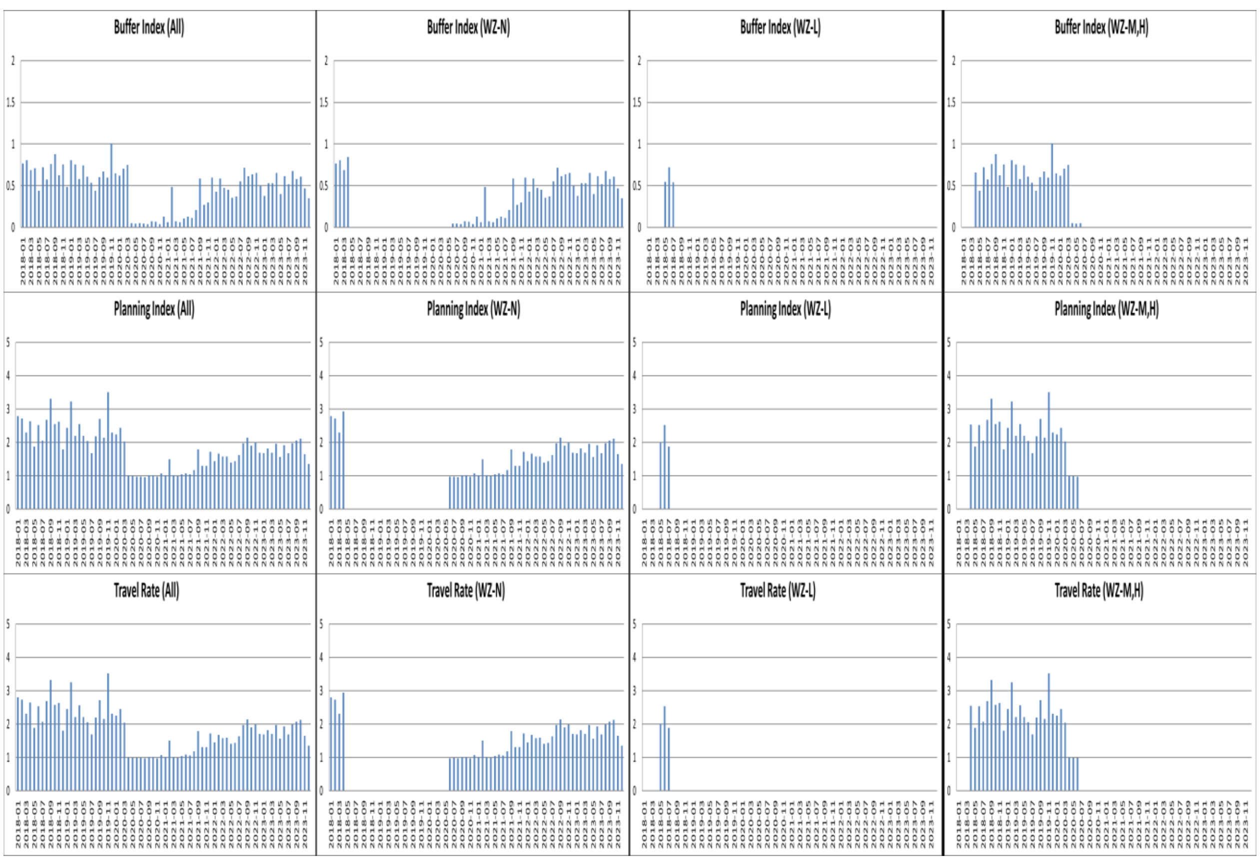


Effects of Weather conditions on Travel-Time Reliability

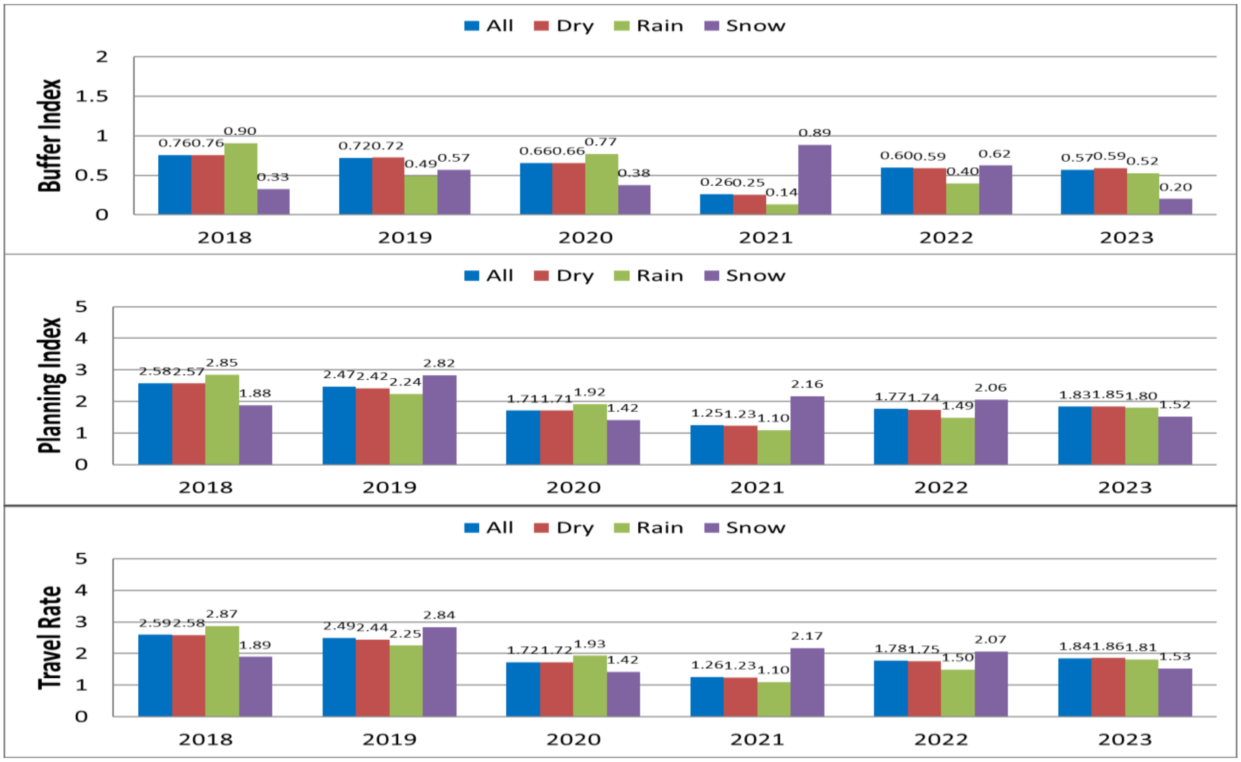


Effects of Incidents

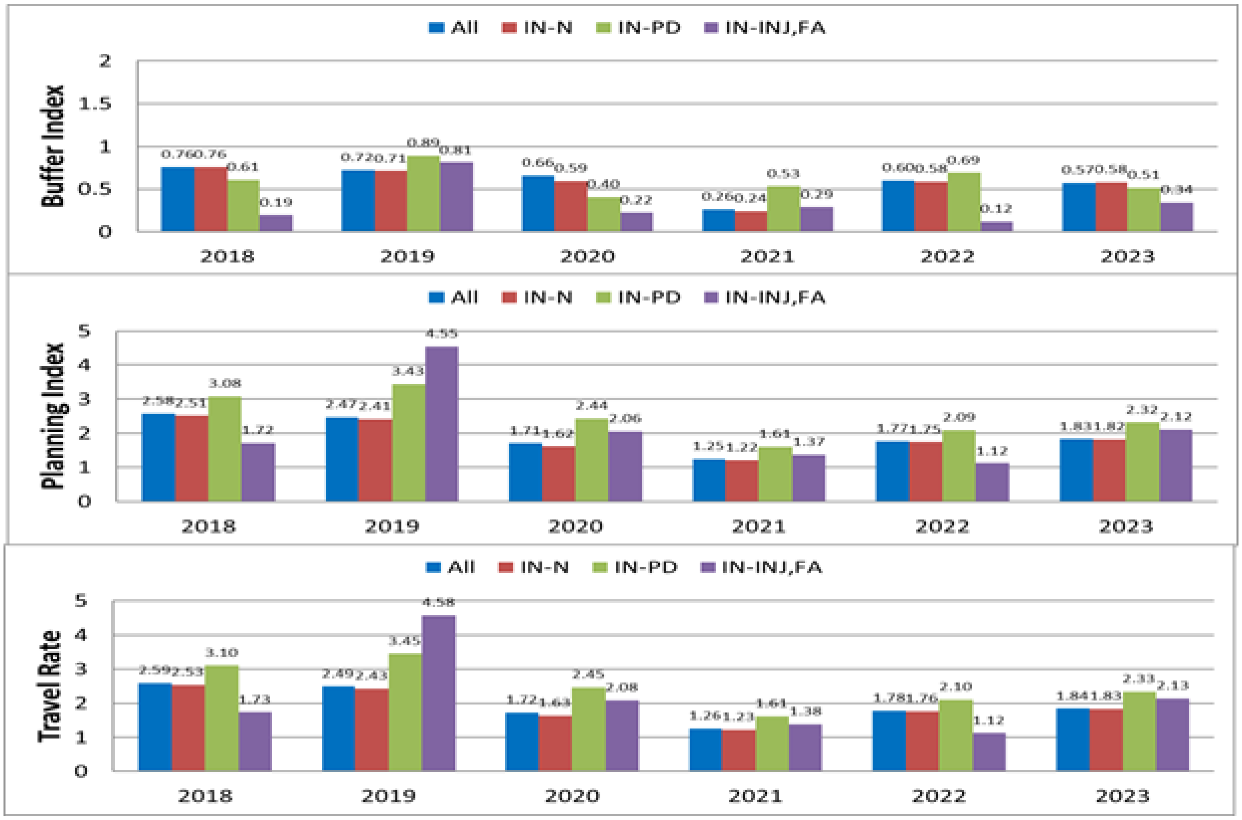
Effects of Work Zones



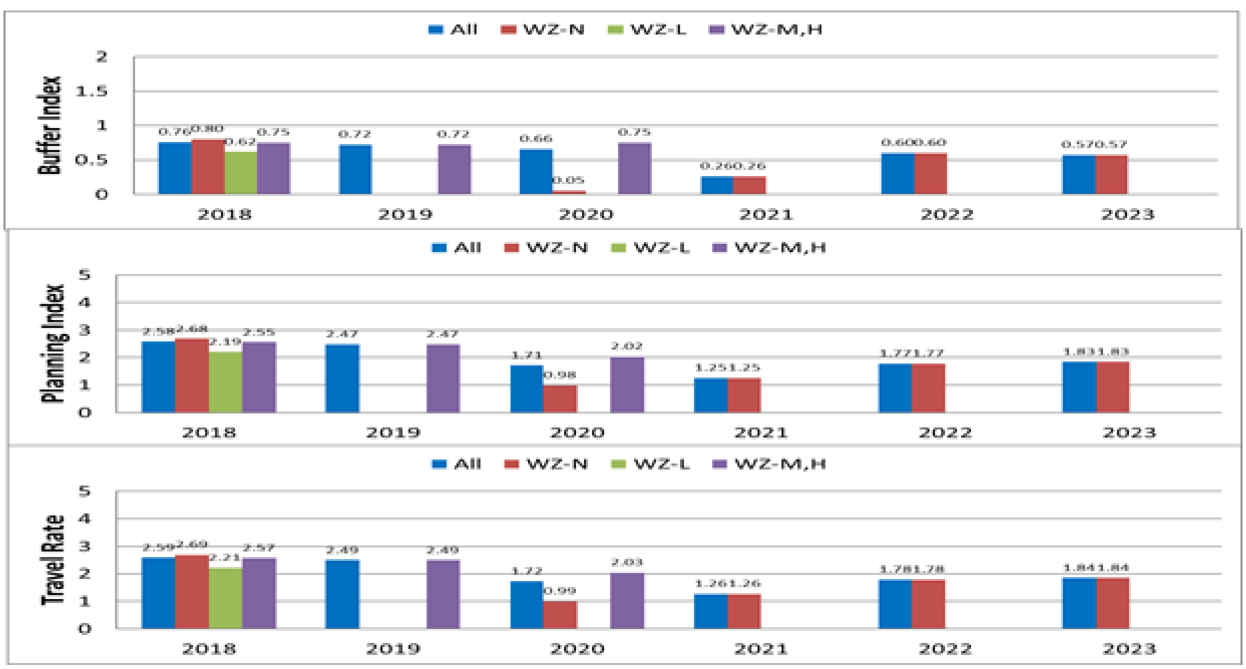
Yearly Variations - *Weather Effects*



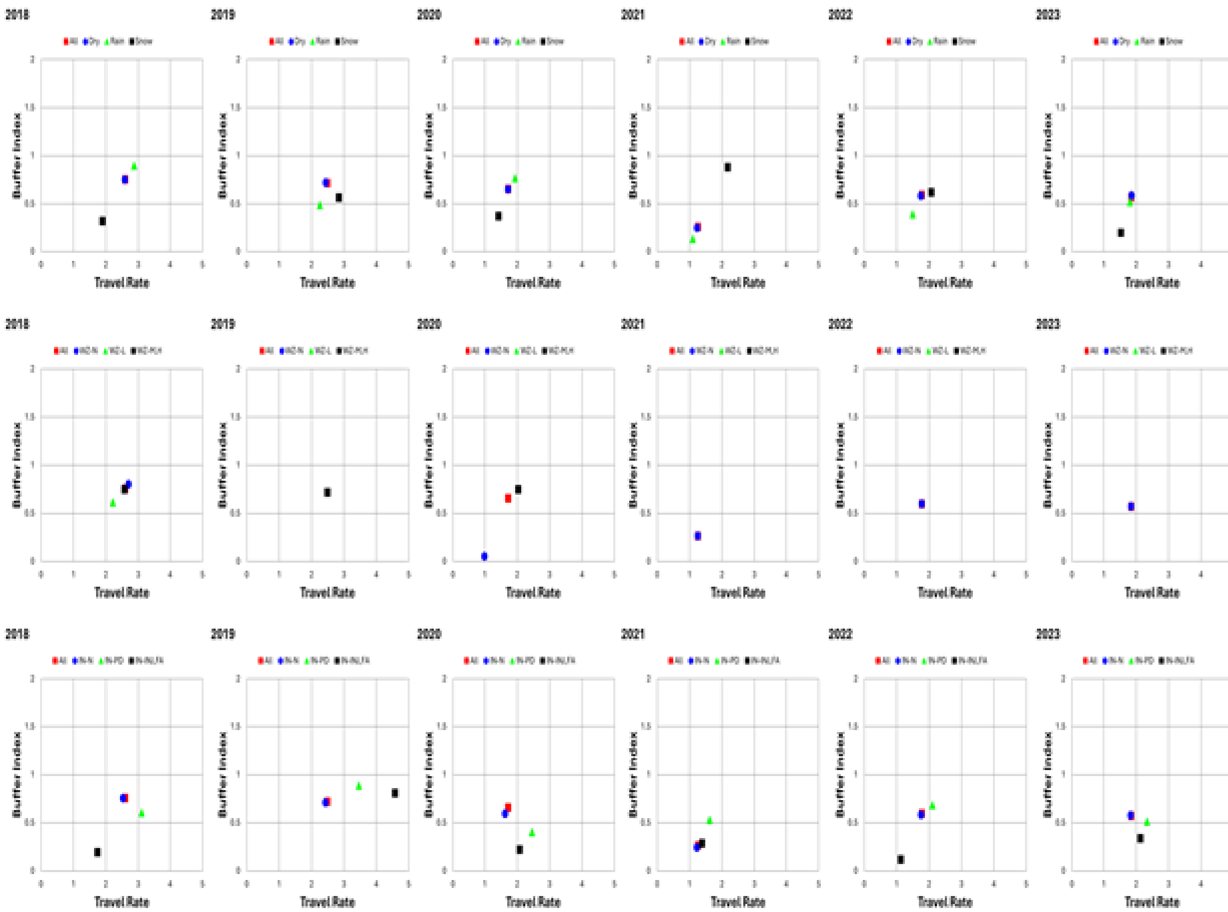
Incident Effects



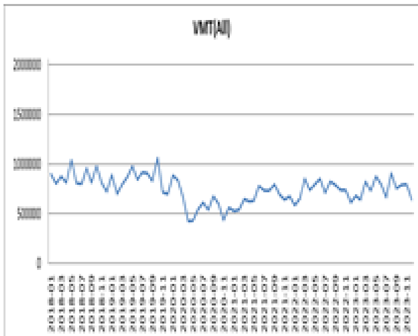
Work-Zone Effects

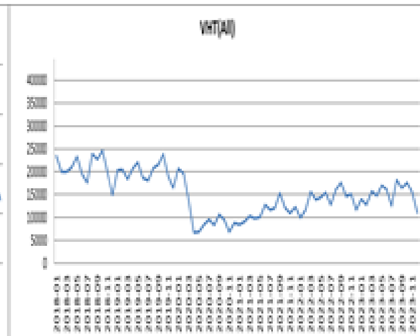


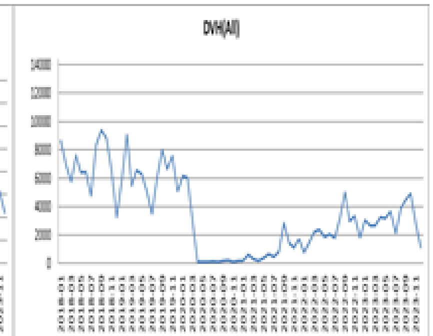
Yearly Variations of Buffer Index - Travel Rate Relationships

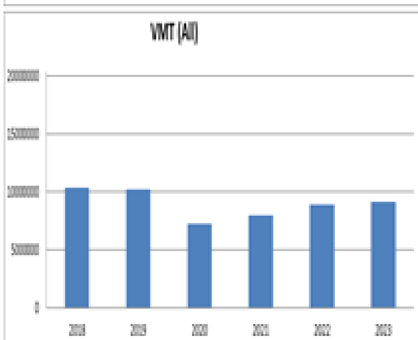


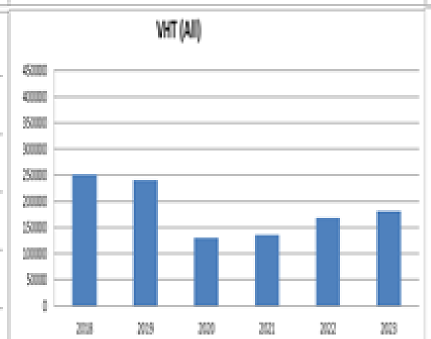
Variations of Traffic-Flow Measures

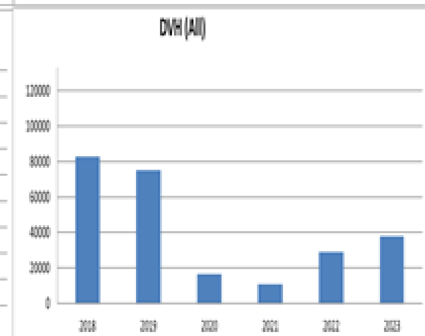

VMT(All)


VHT(All)


DVH(All)

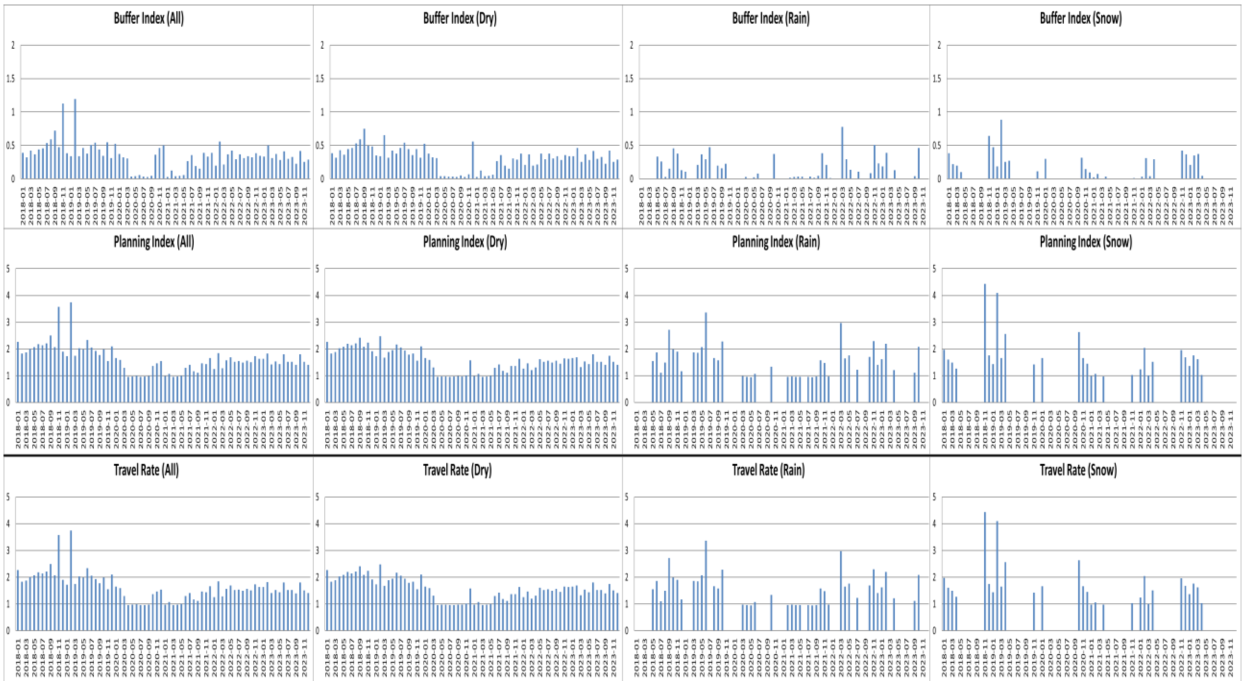

VMT (All)


VHT (All)

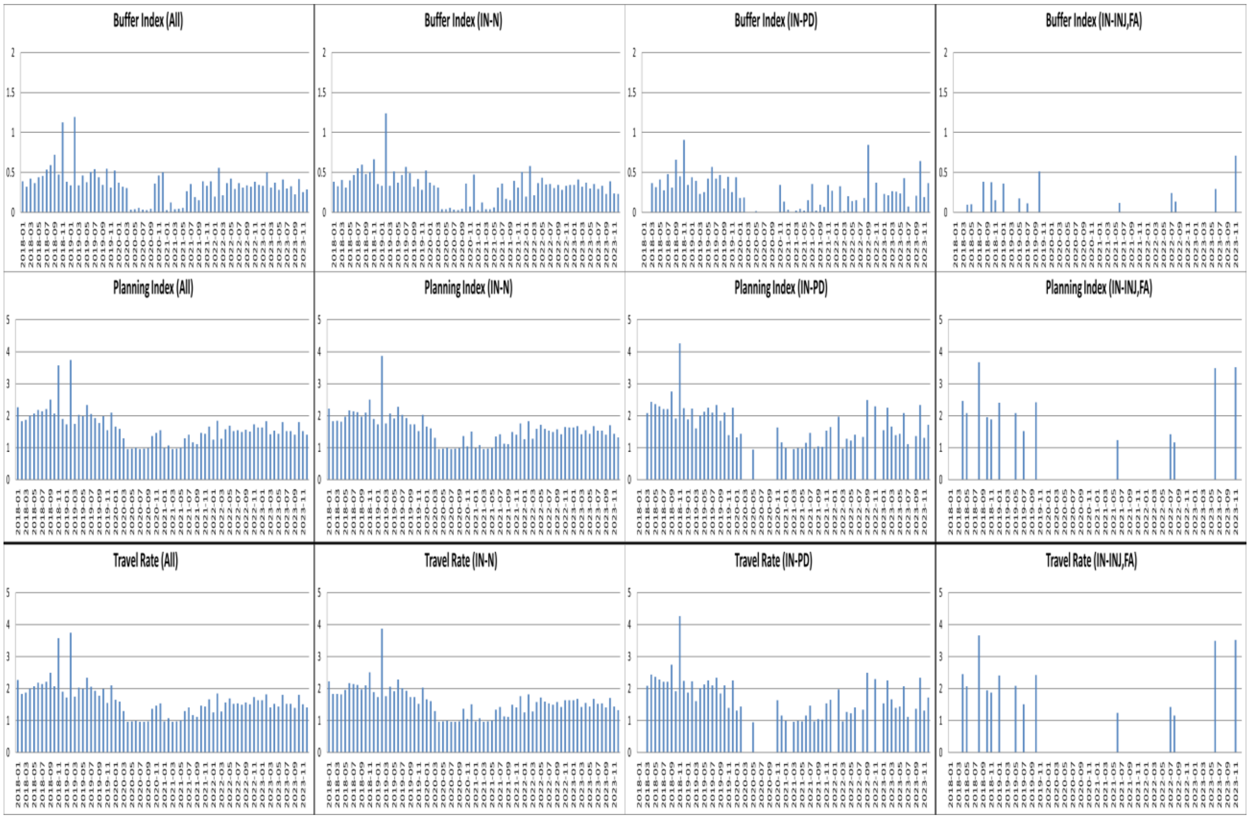

DVH (All)

ii) I-394 Corridor B - WB Minneapolis DT to TH169 for Afternoon Peak Periods

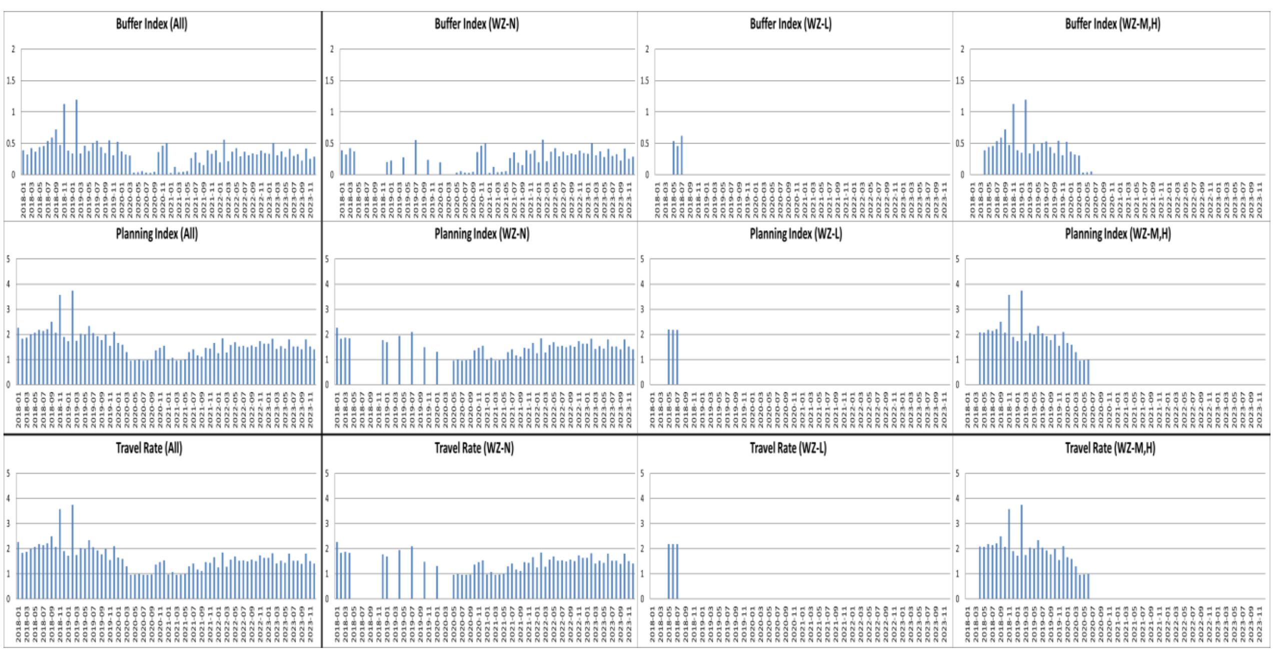
Effects of Weather conditions on Travel-Time Reliability



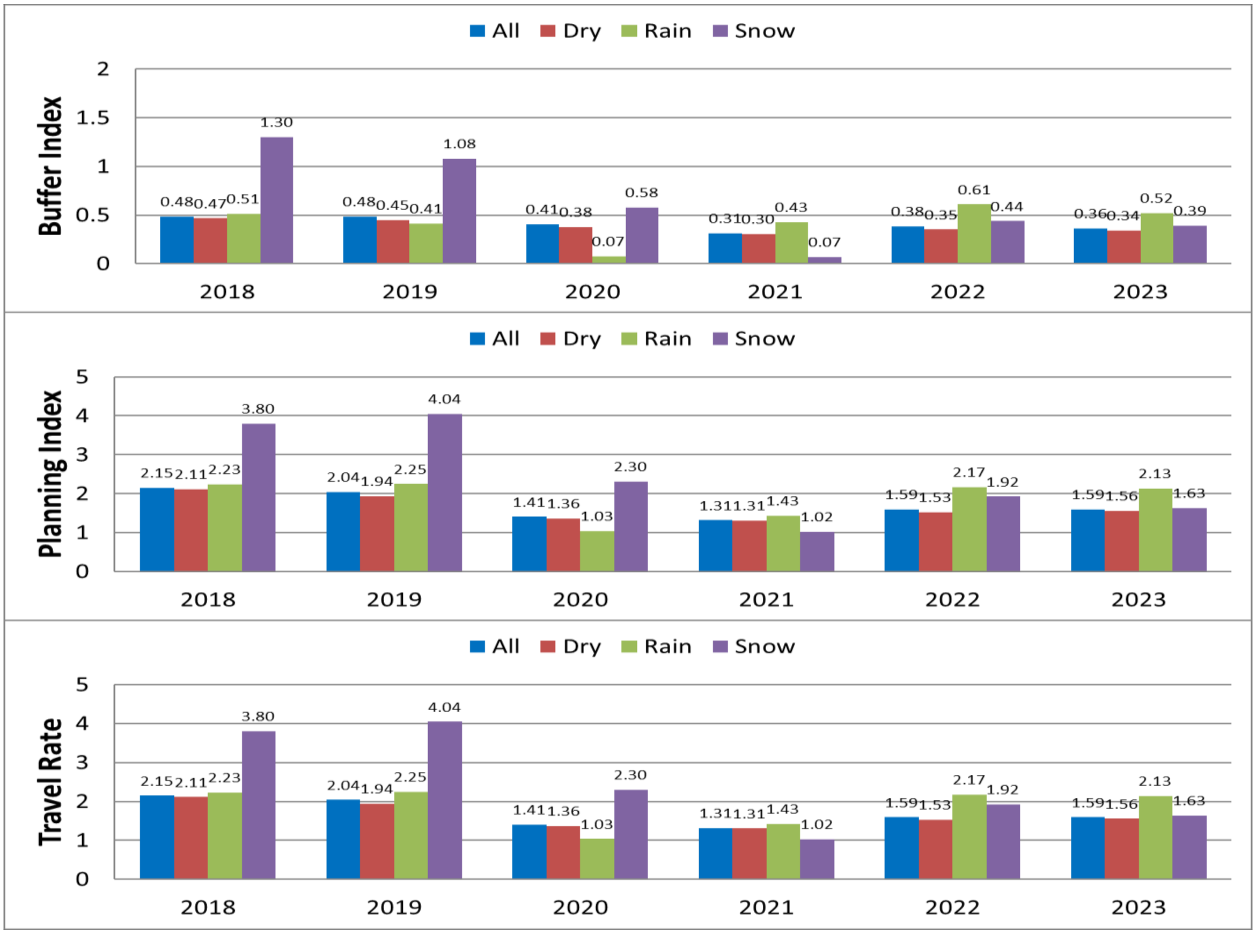
Effects of Incidents



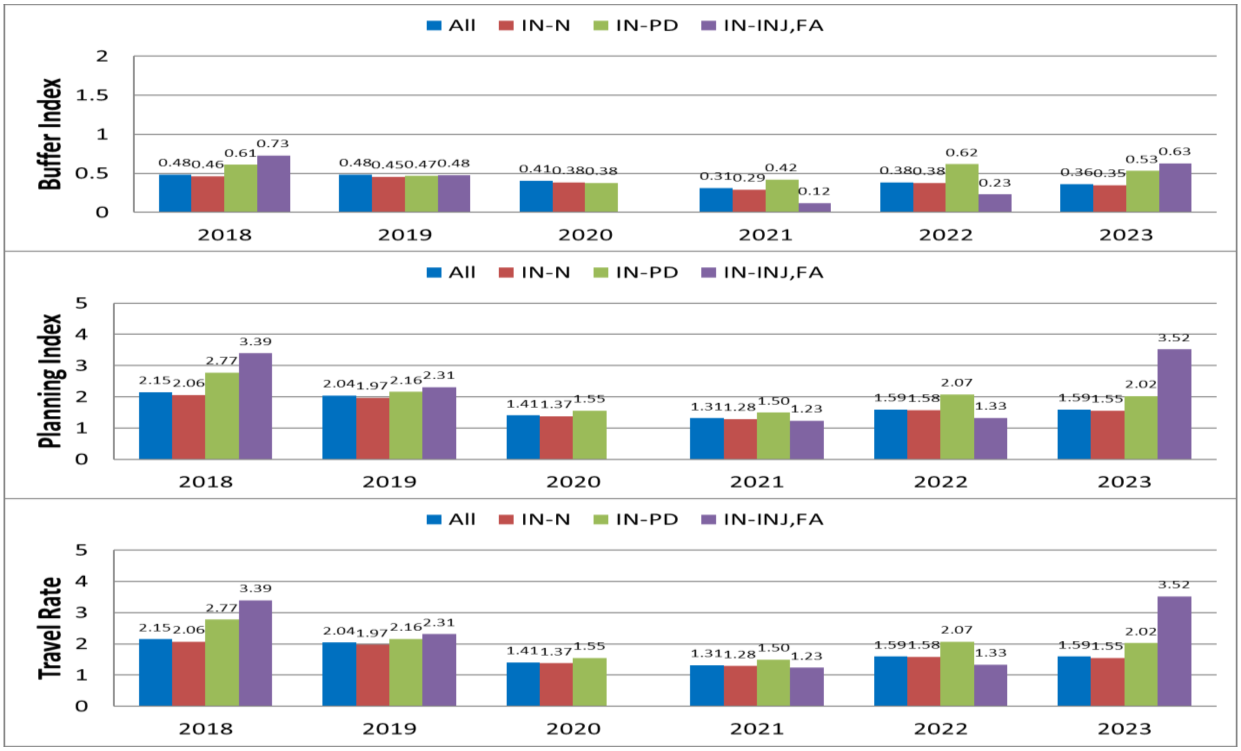
Effects of Work Zones



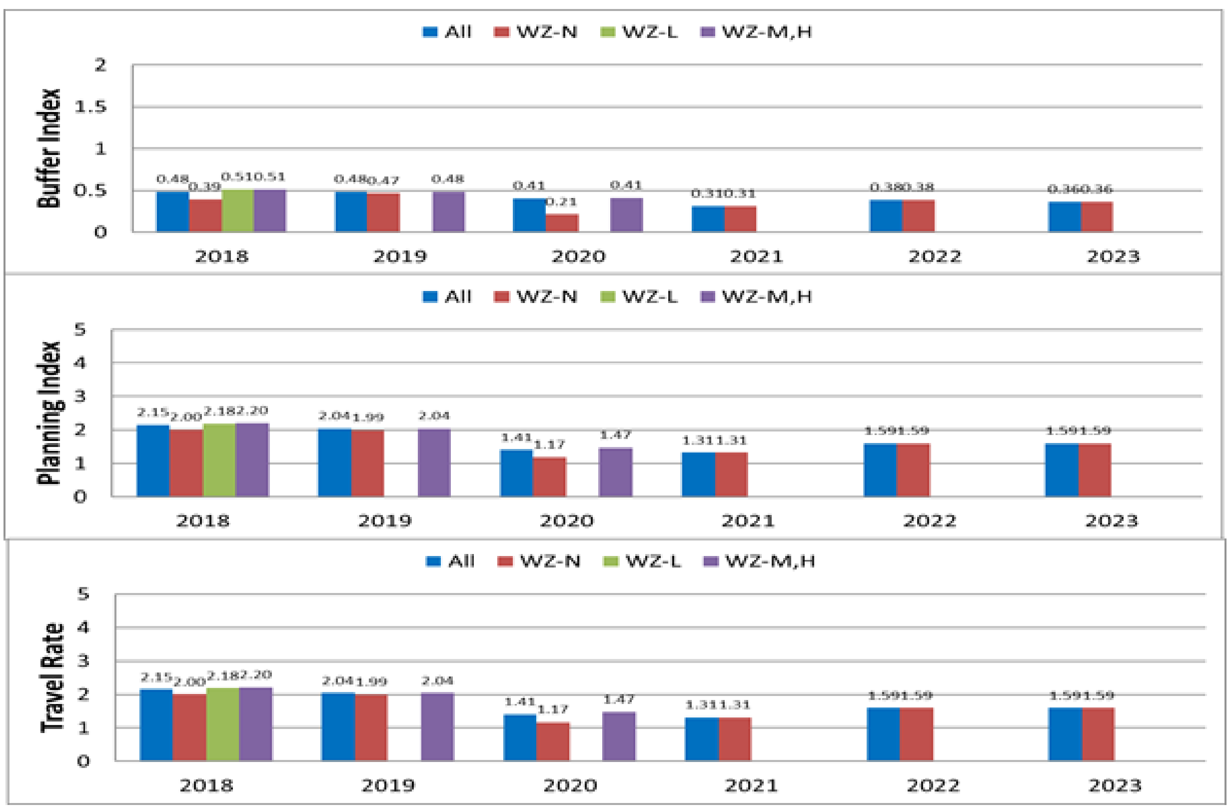
Yearly Variations - *Weather Effects*



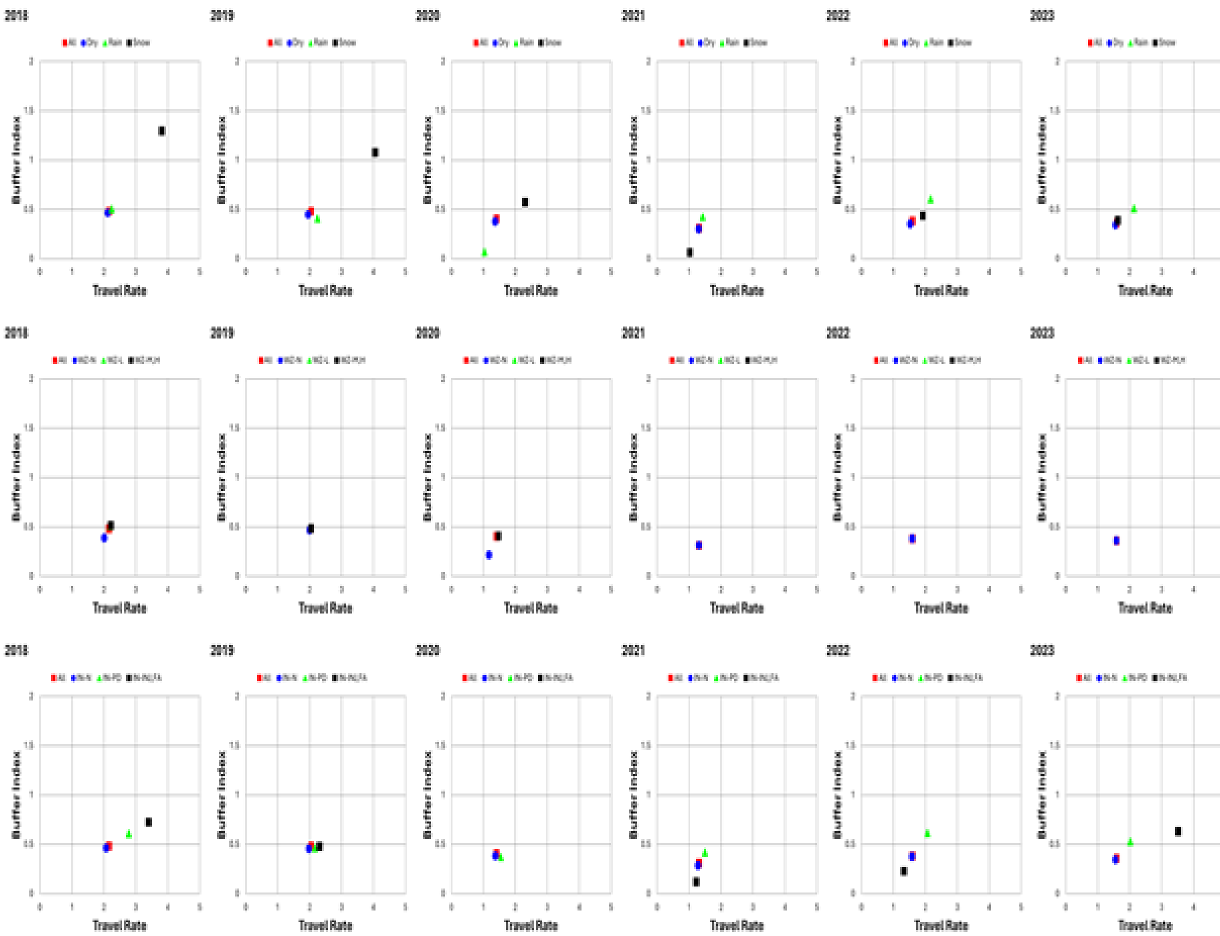
Incident Effects



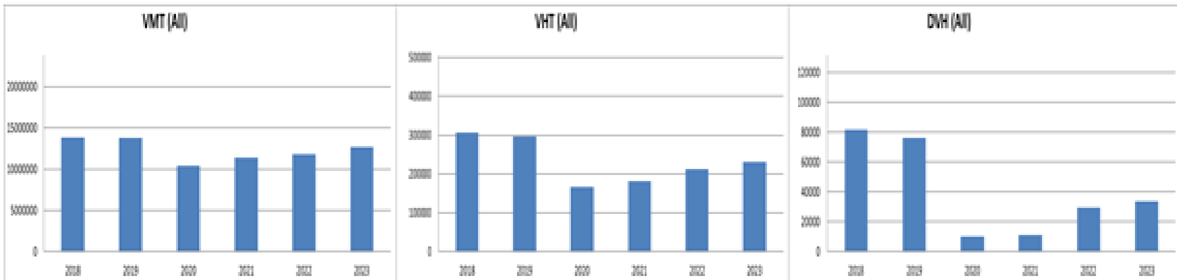
Work-Zone Effects



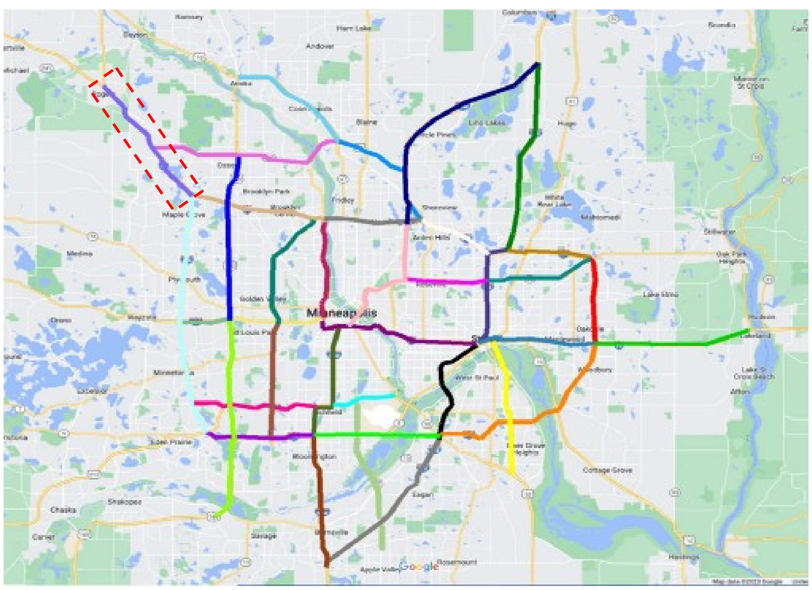
Yearly Variations of Buffer Index - Travel Rate Relationships



Variations of Traffic-Flow Measures

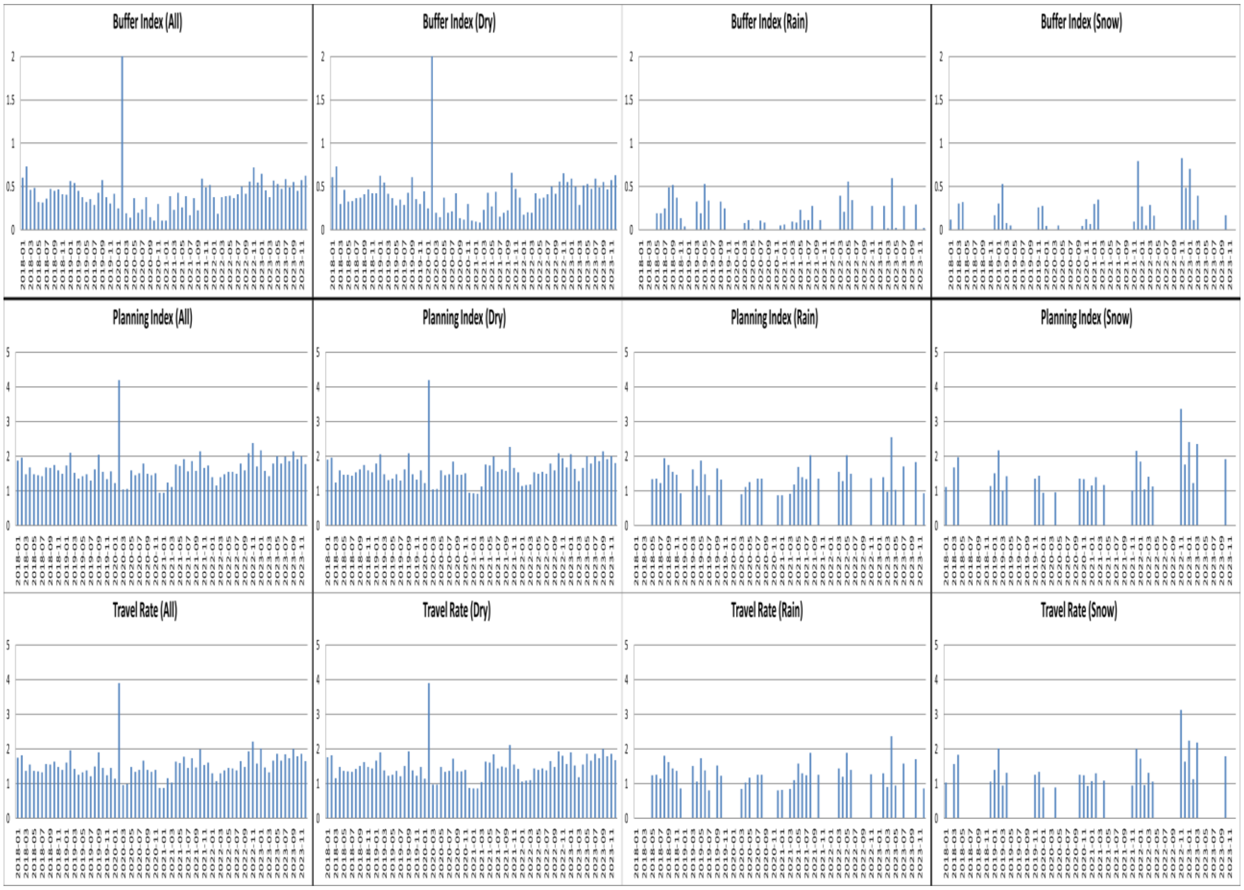


19) I-94 Corridor A (Rogers < -- > I494)



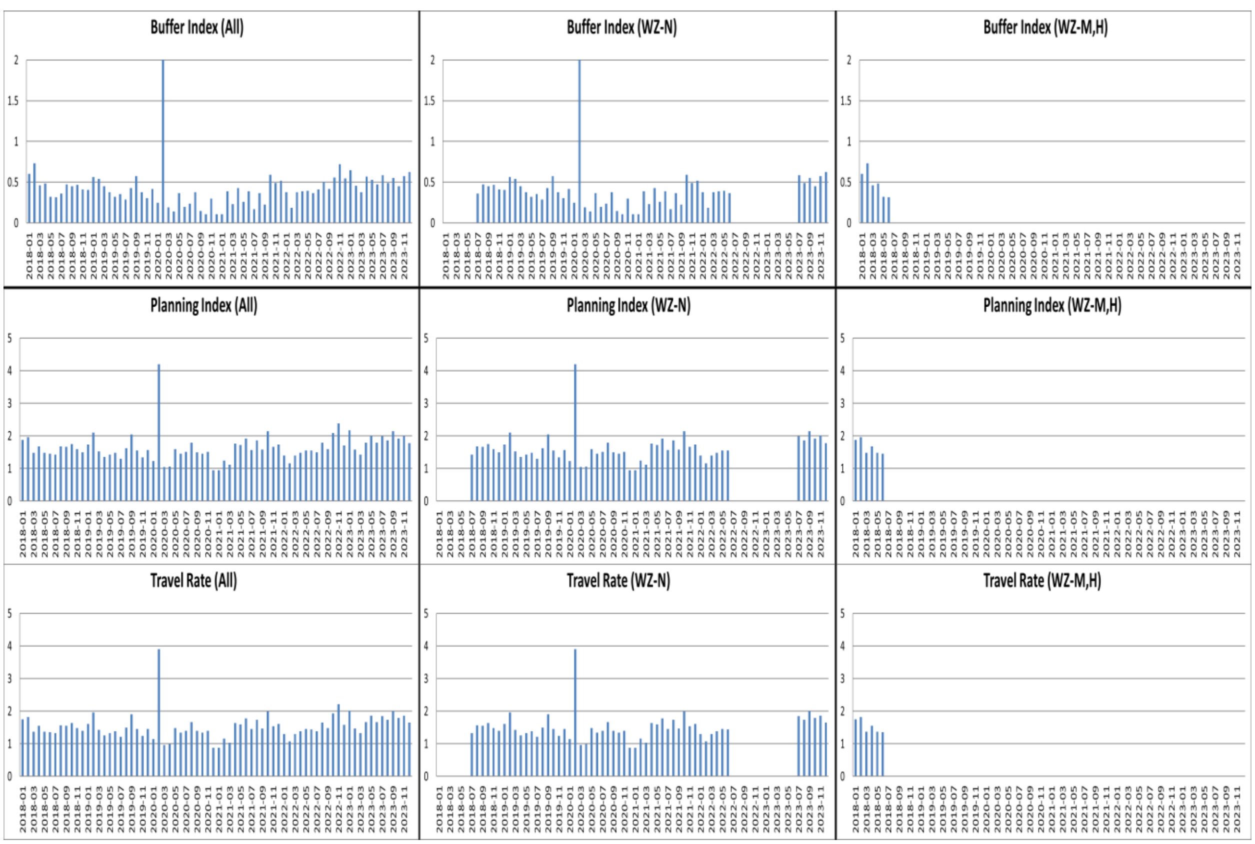
i) I-94 Corridor A - EB Rogers to I494 for Morning Peak Periods

Effects of Weather conditions on Travel-Time Reliability

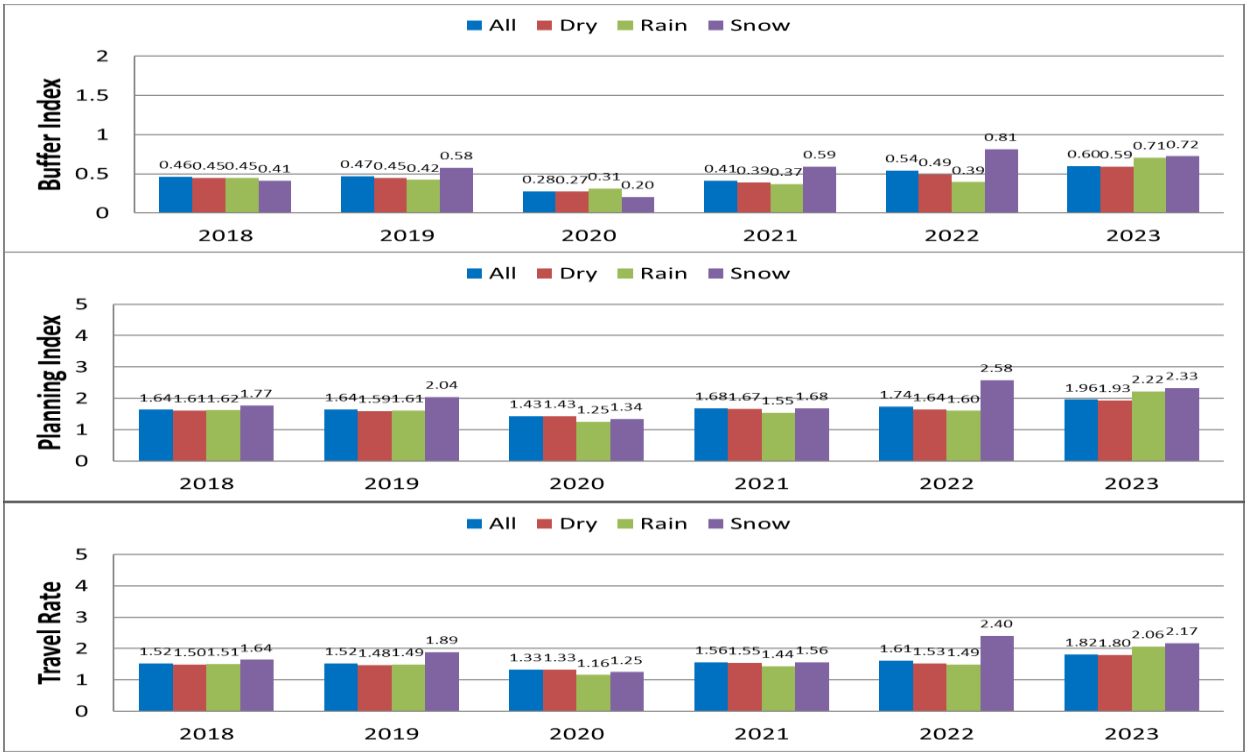


Effects of Incidents

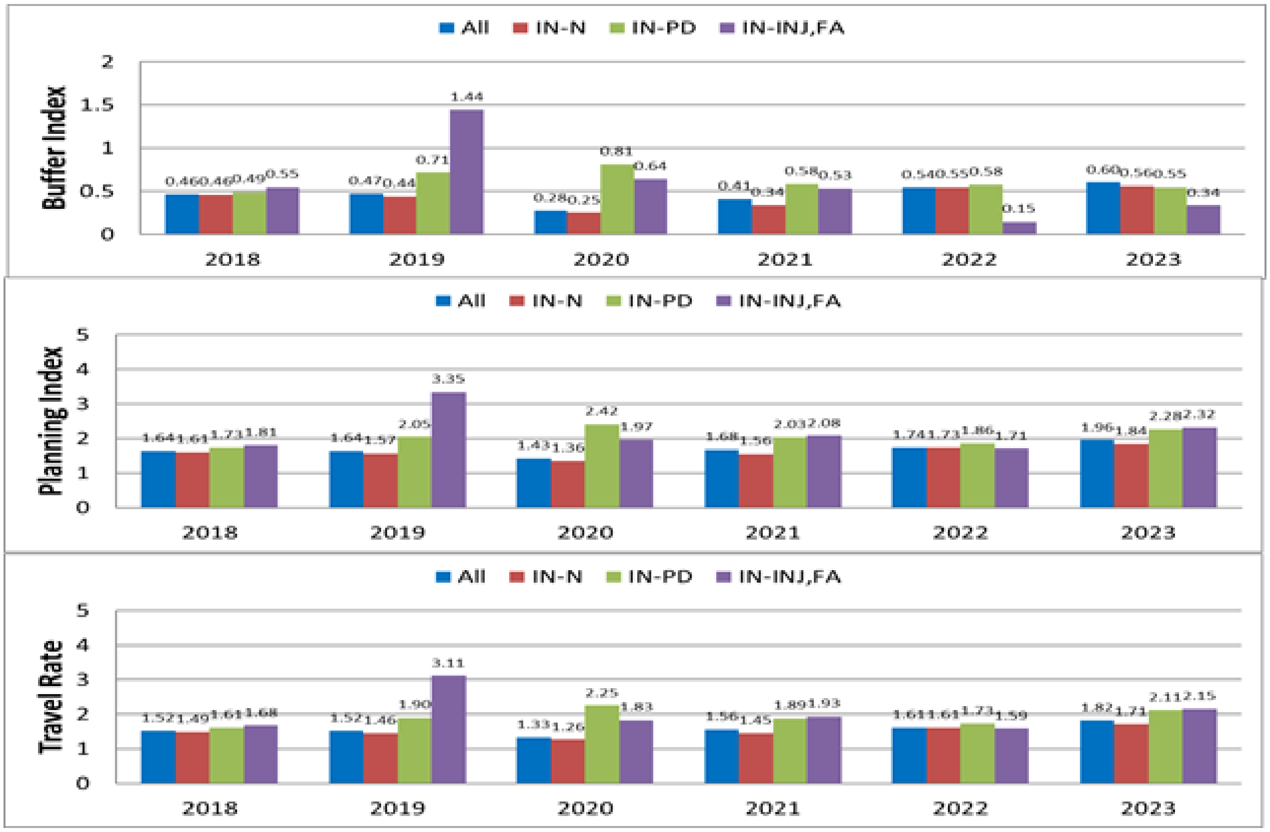
Effects of Work Zones



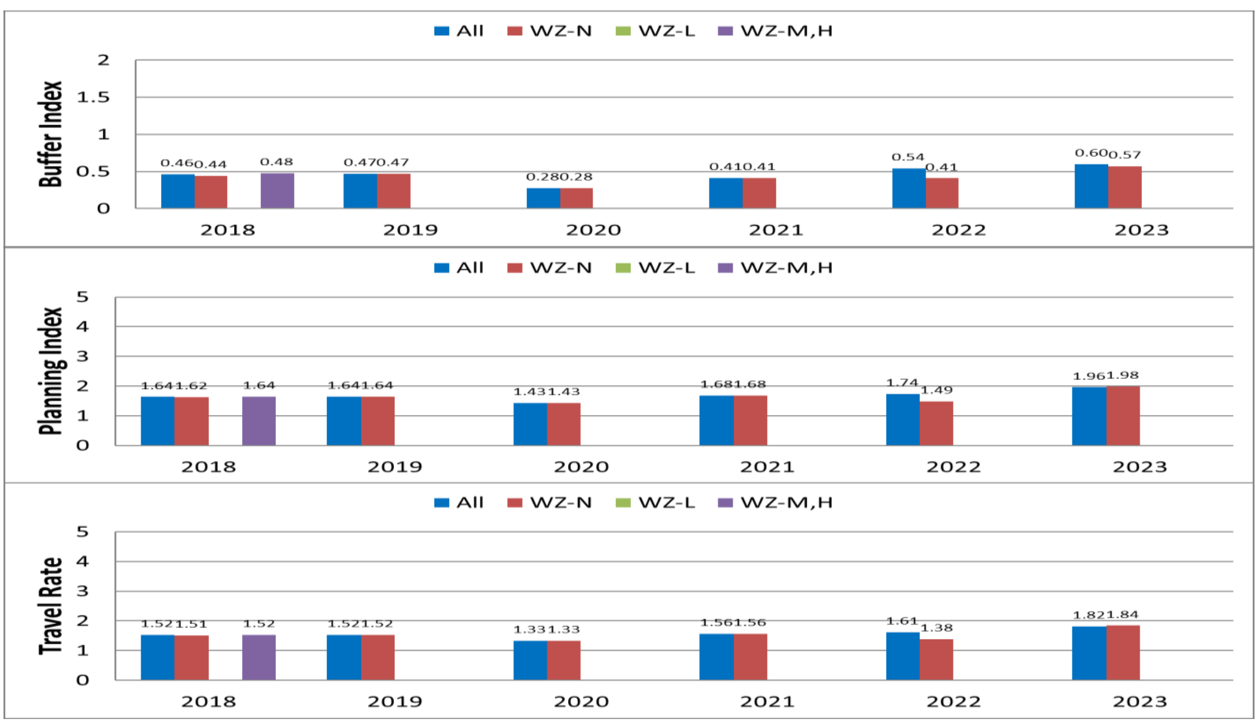
Yearly Variations - *Weather Effects*



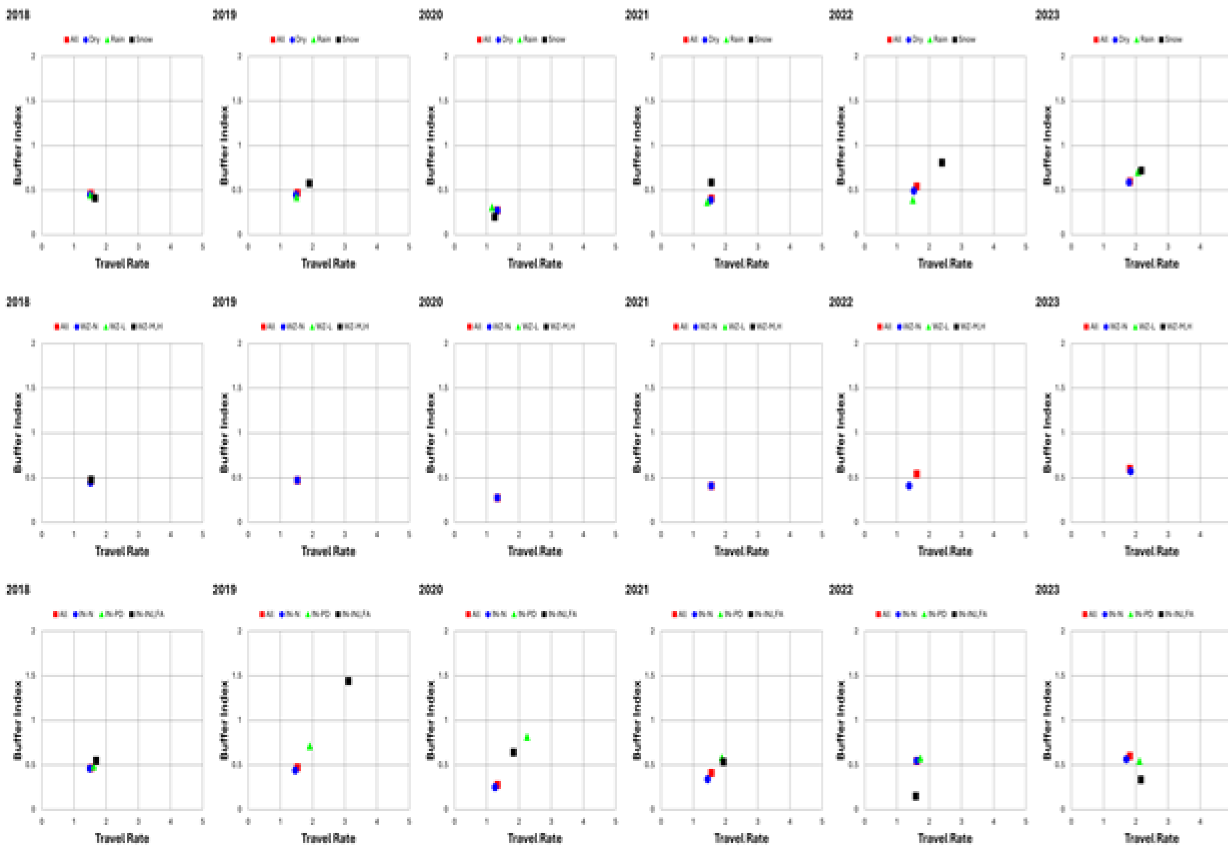
Incident Effects



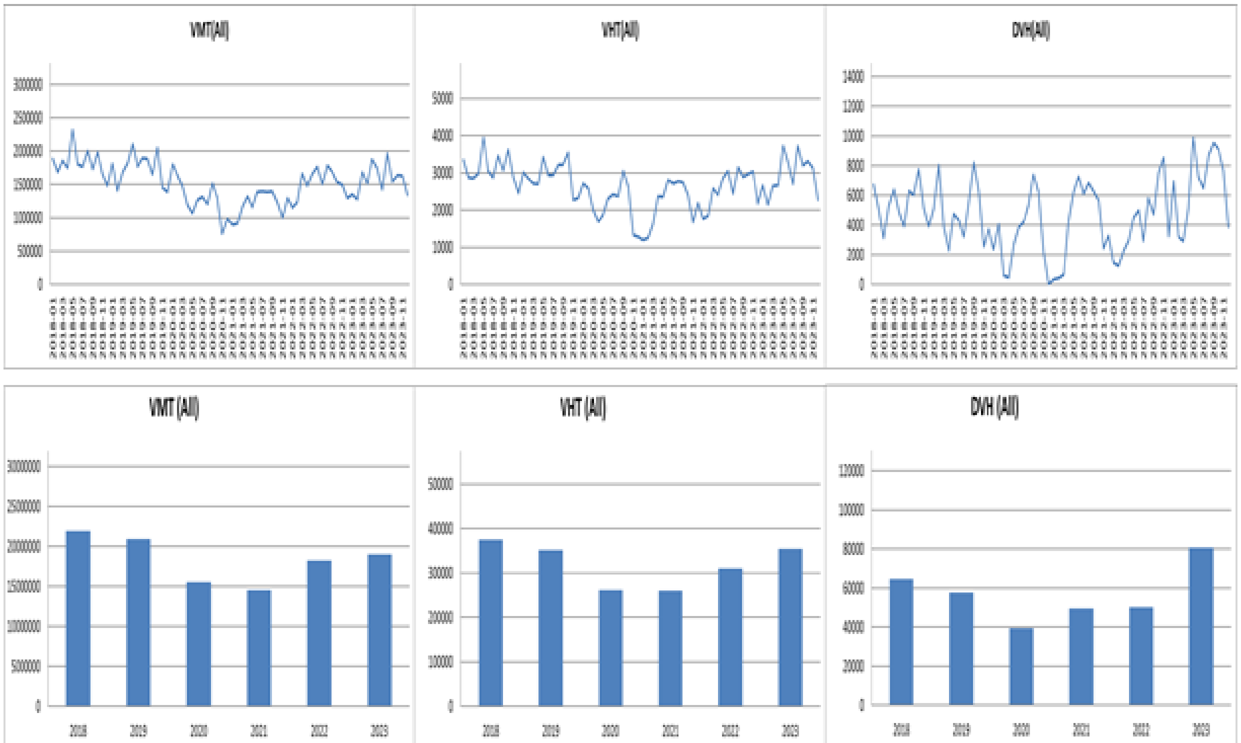
Work-Zone Effects



Yearly Variations of Buffer Index - Travel Rate Relationships

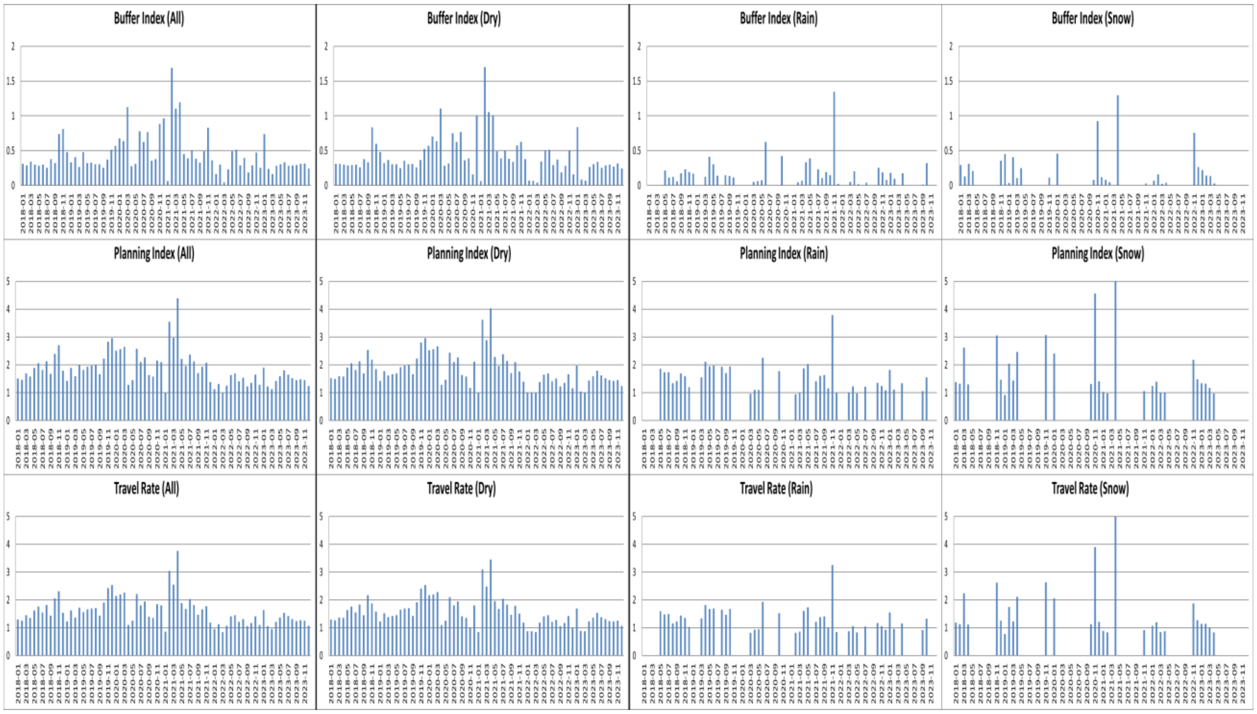


Variations of Traffic-Flow Measures

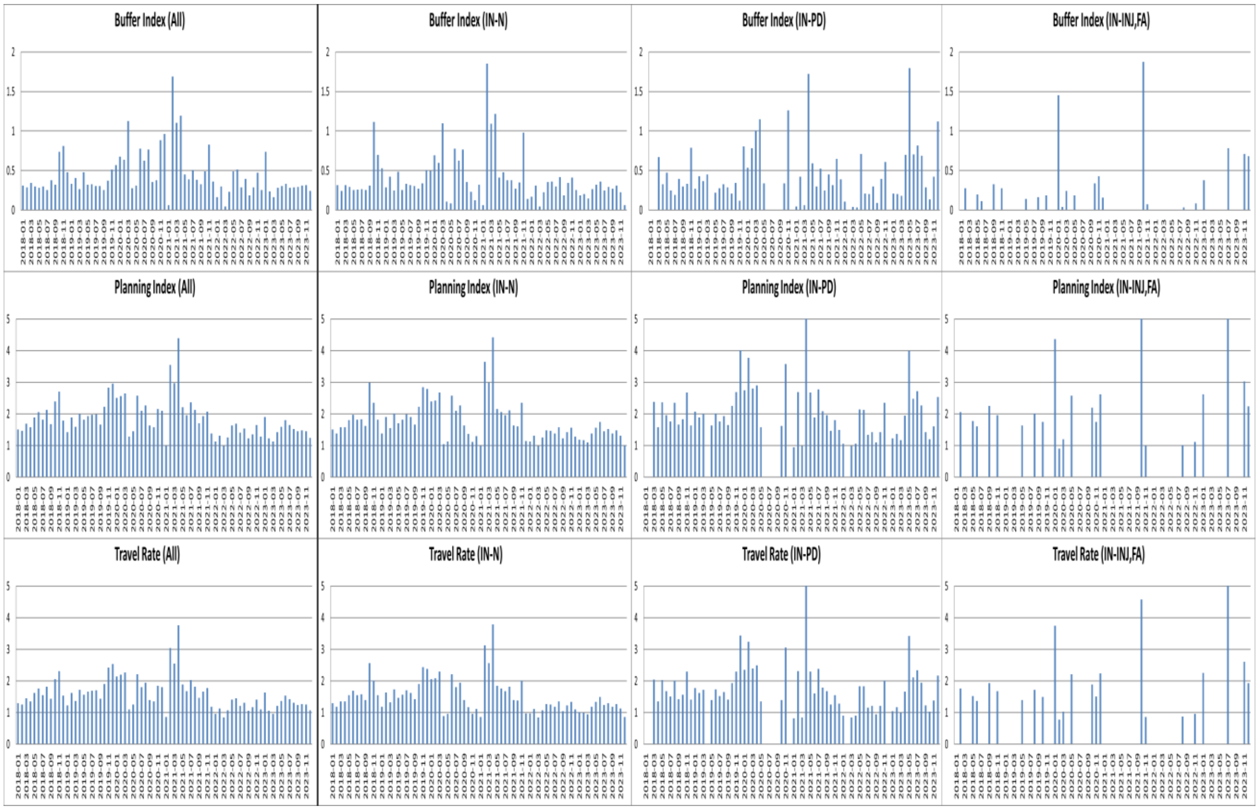

VMT(All)
VHT(All)
DVH(All)
VMT (All)
VHT (All)
DVH (All)
2018
2019
2020
2021
2022
2023

ii) I-94 Corridor A - WB I-494 to Rogers for Afternoon Peak Periods

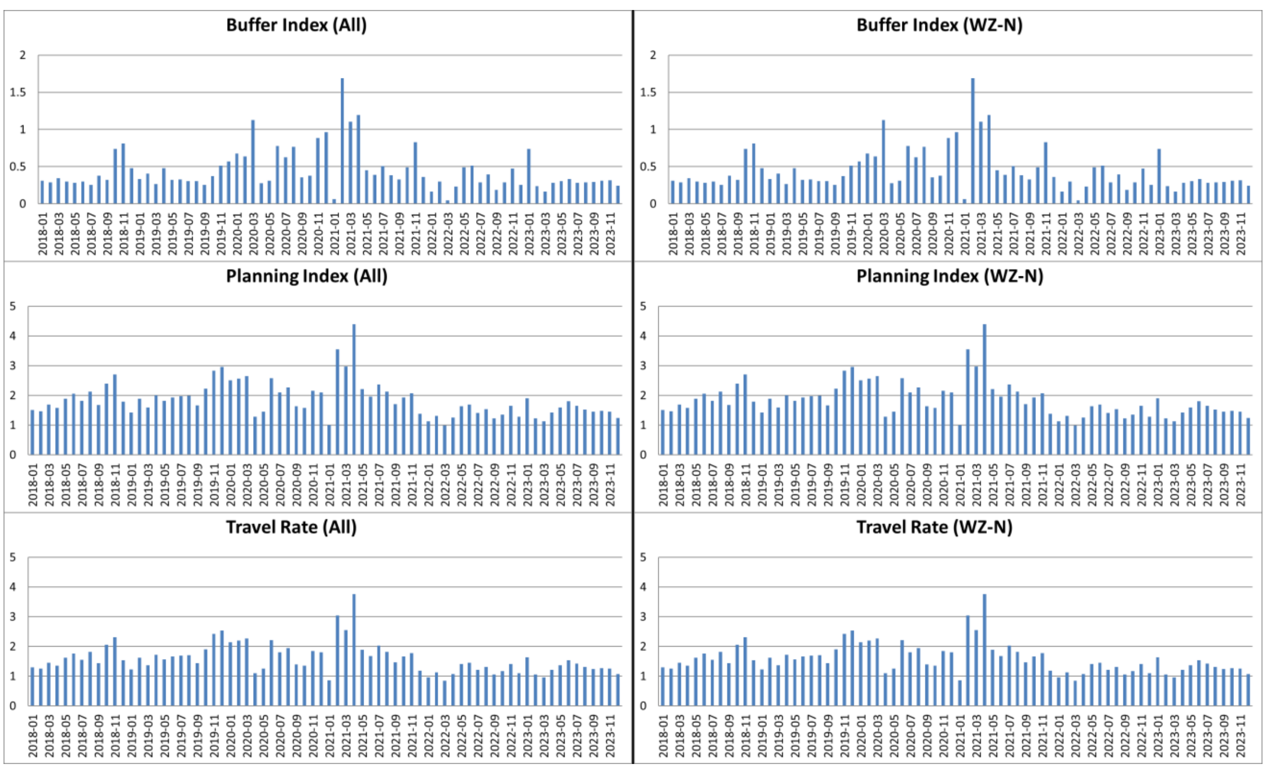
Effects of Weather conditions on Travel-Time Reliability



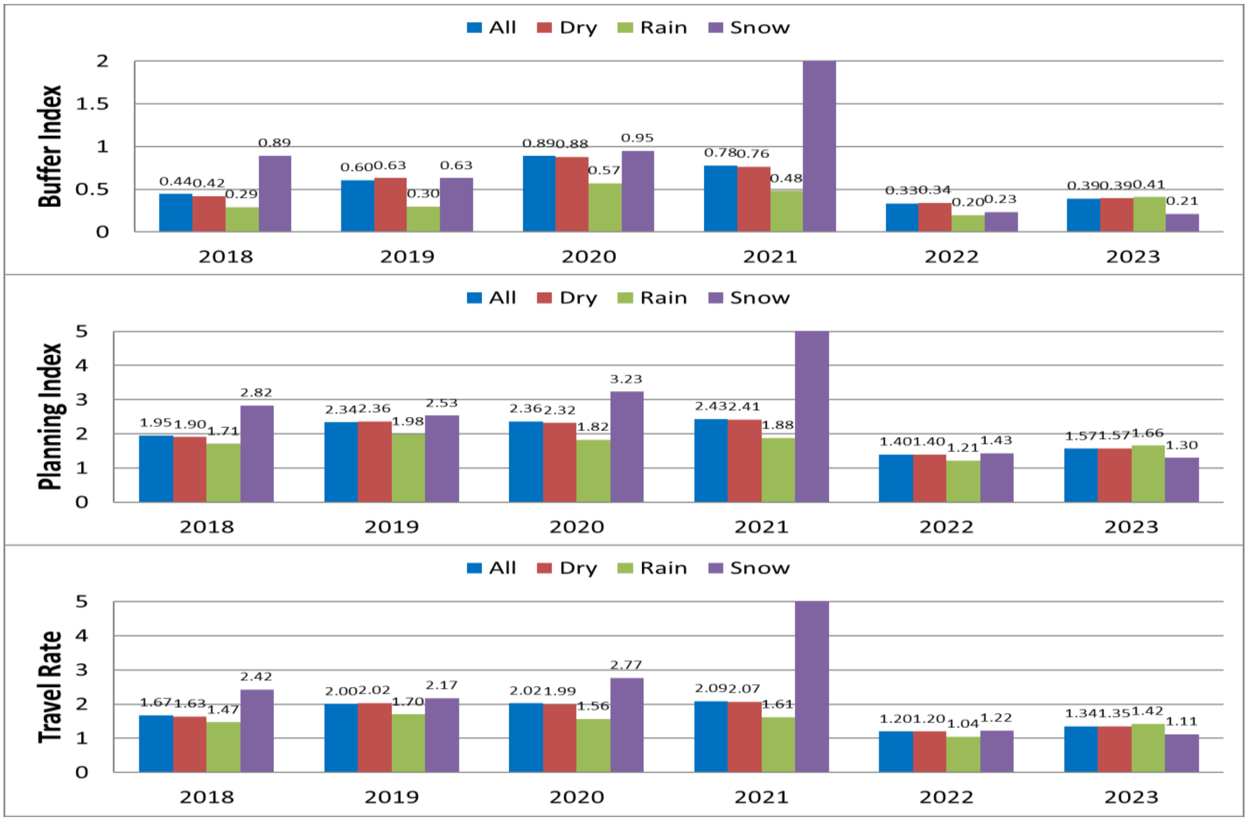
Effects of Incidents



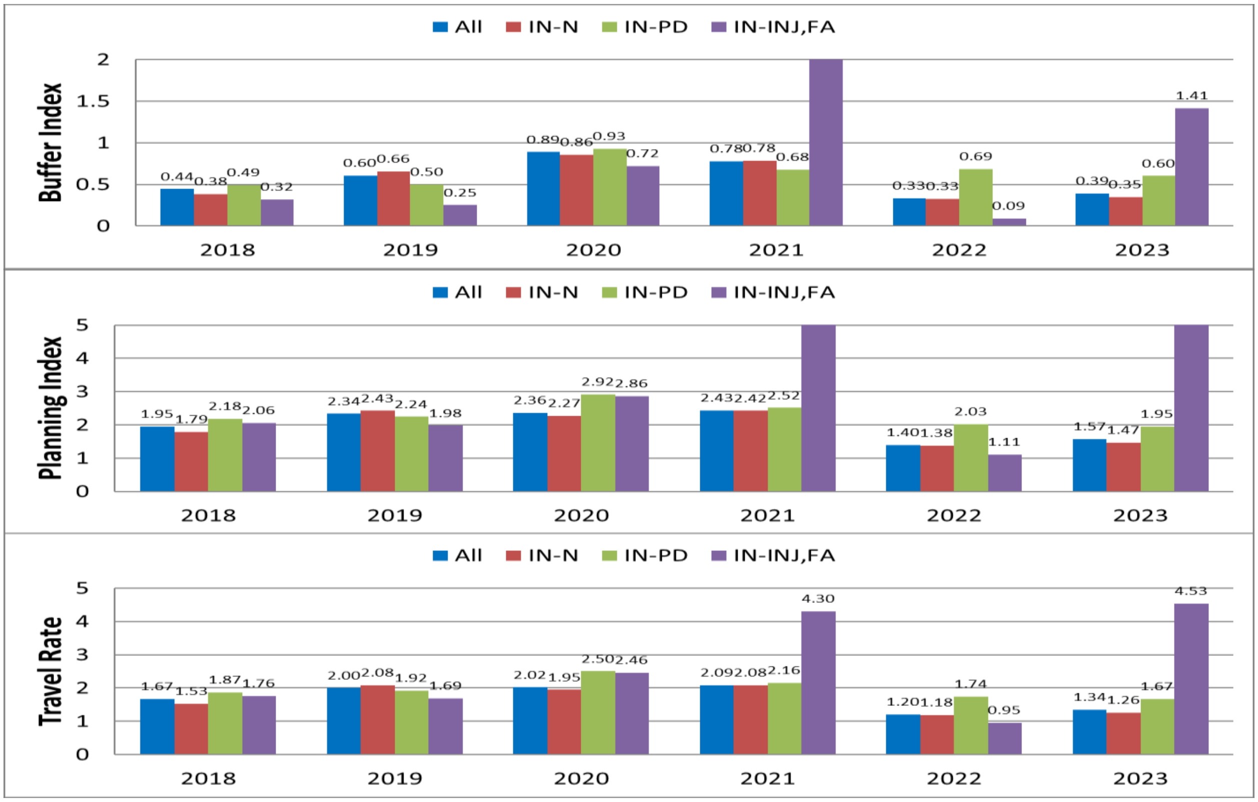
Effects of Work Zones



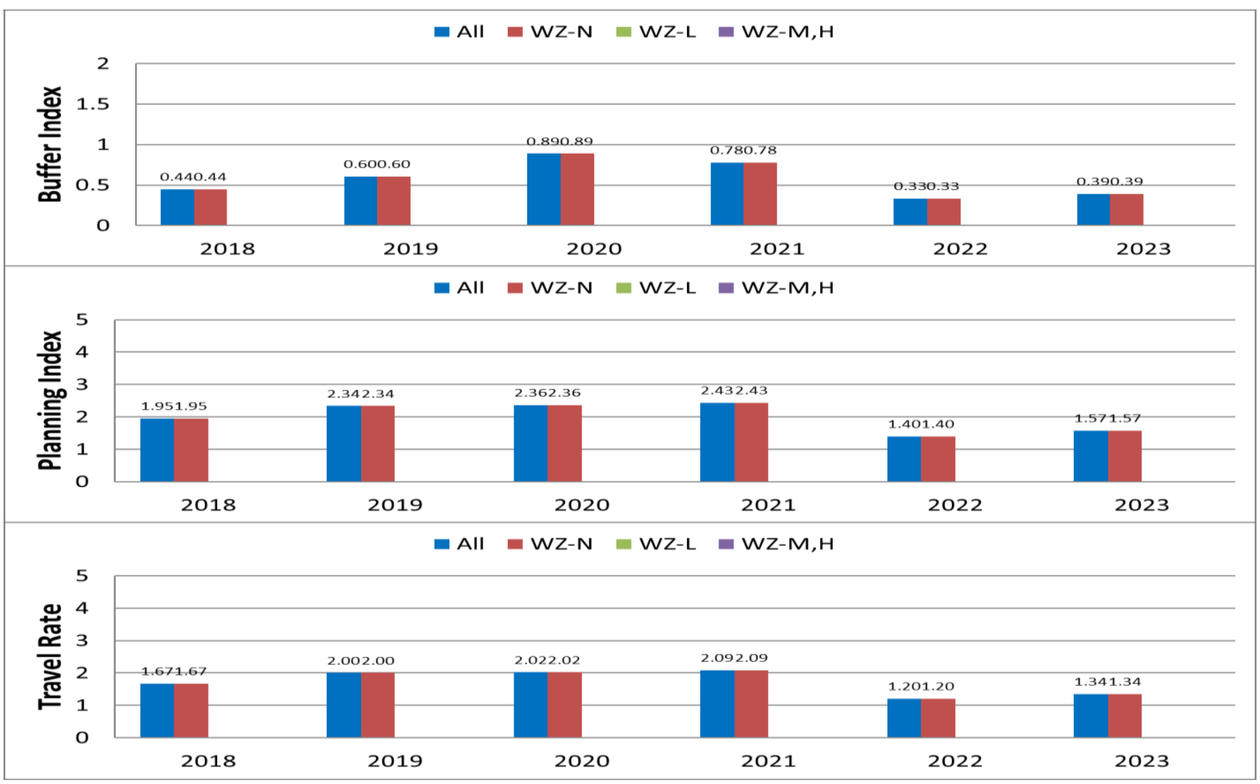
Yearly Variations - *Weather Effects*



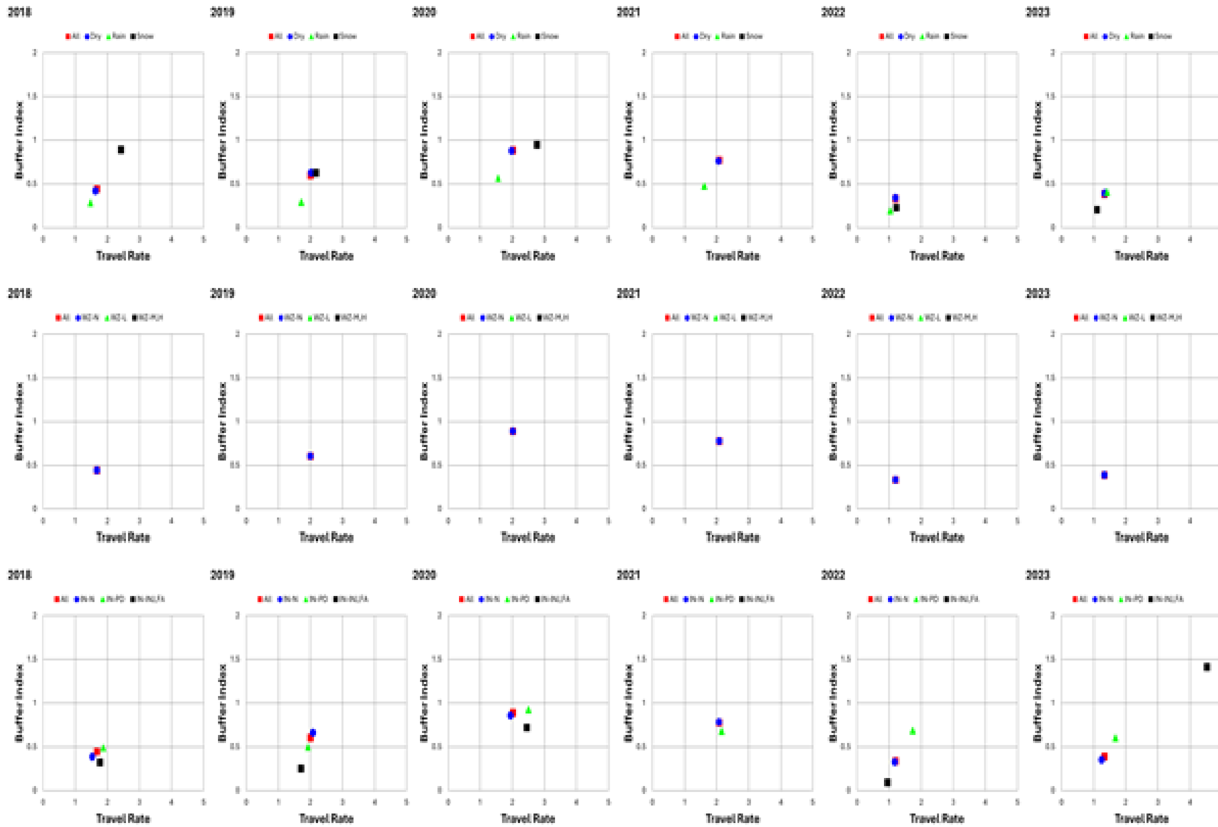
Incident Effects



Work-Zone Effects



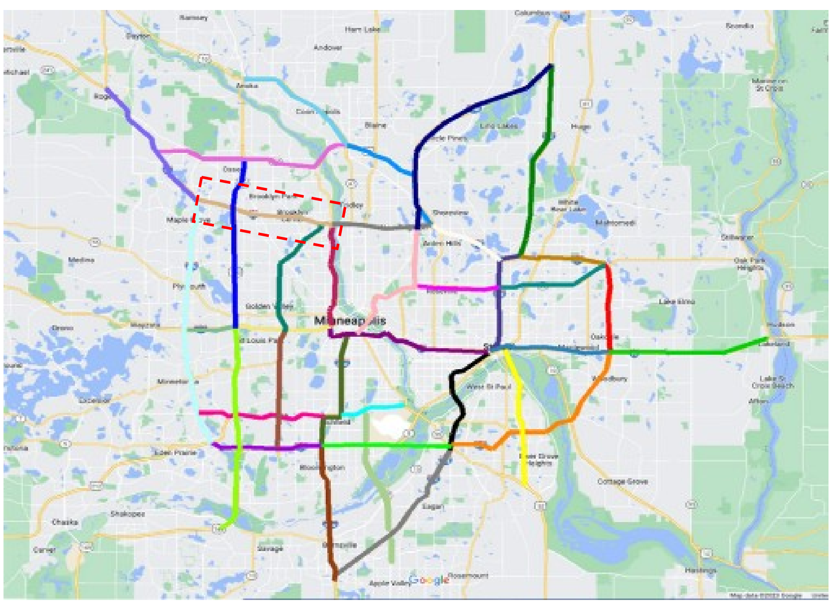
Yearly Variations of Buffer Index - Travel Rate Relationships



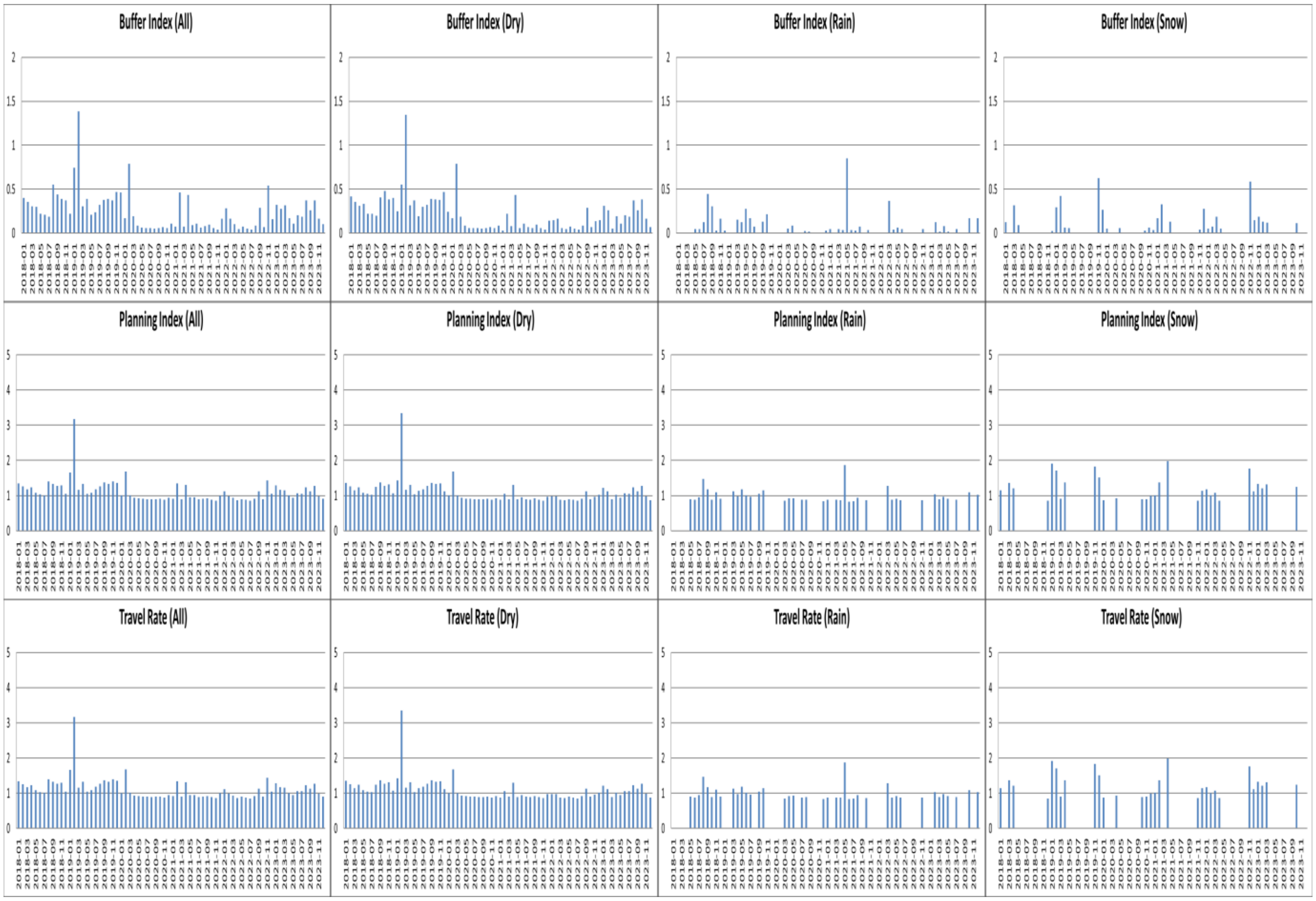
Variations of Traffic-Flow Measures

20) I-94 Corridor B (I494 < -- > TH252)

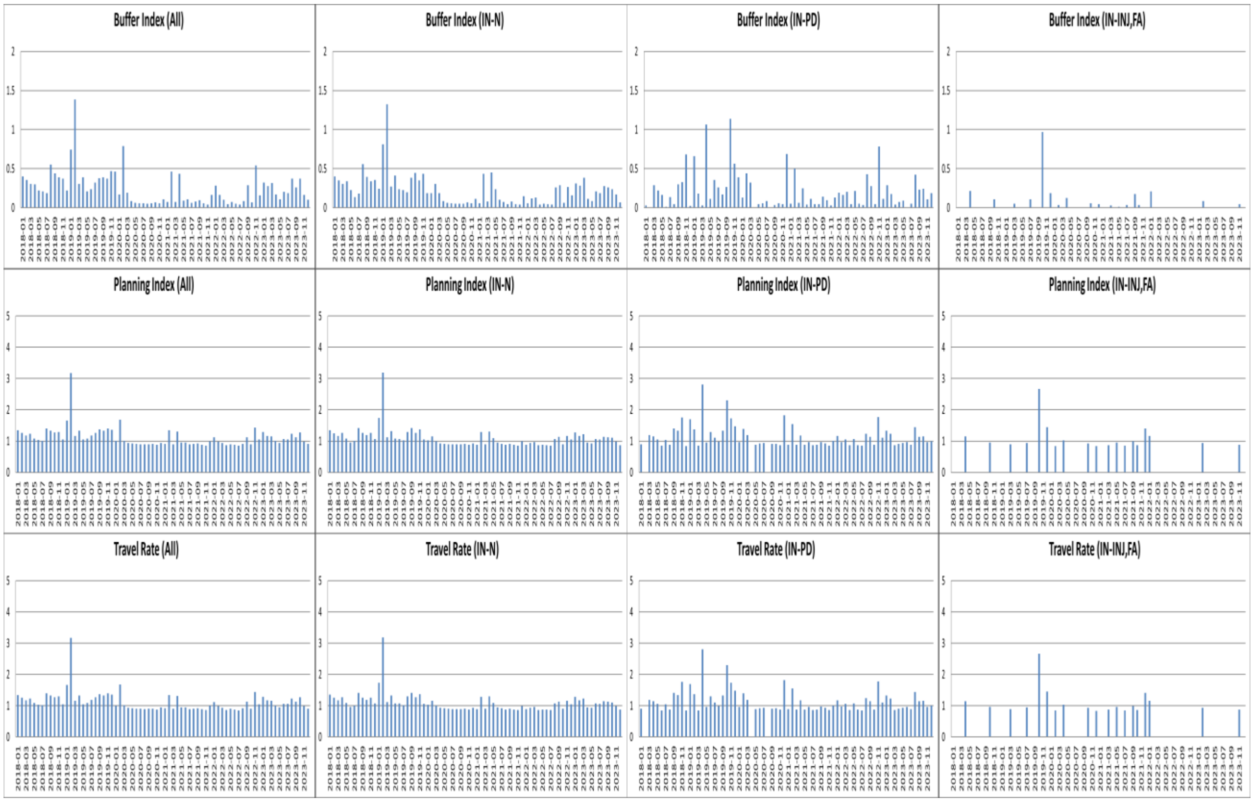
i) I-94 Corridor B -- EB -I-494 to TH252 for Morning Peak Periods



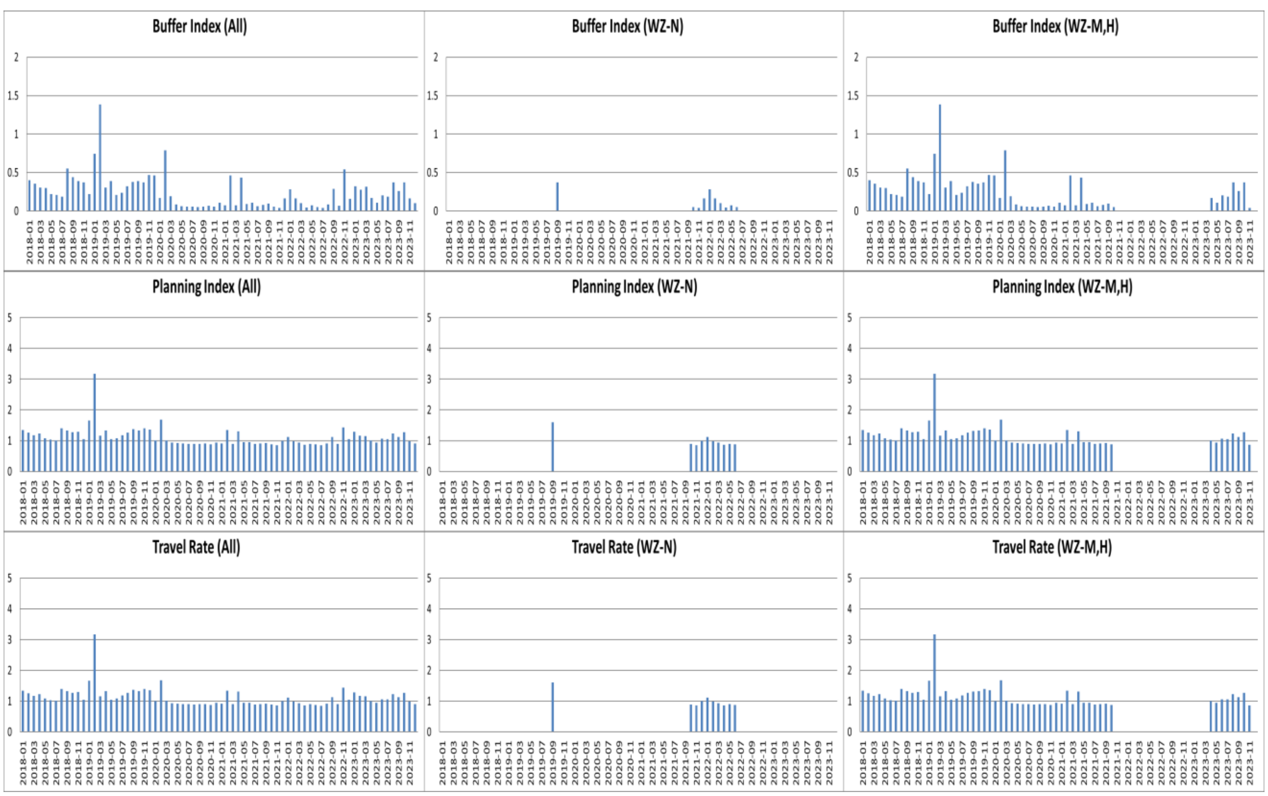
Effects of Weather conditions on Travel-Time Reliability



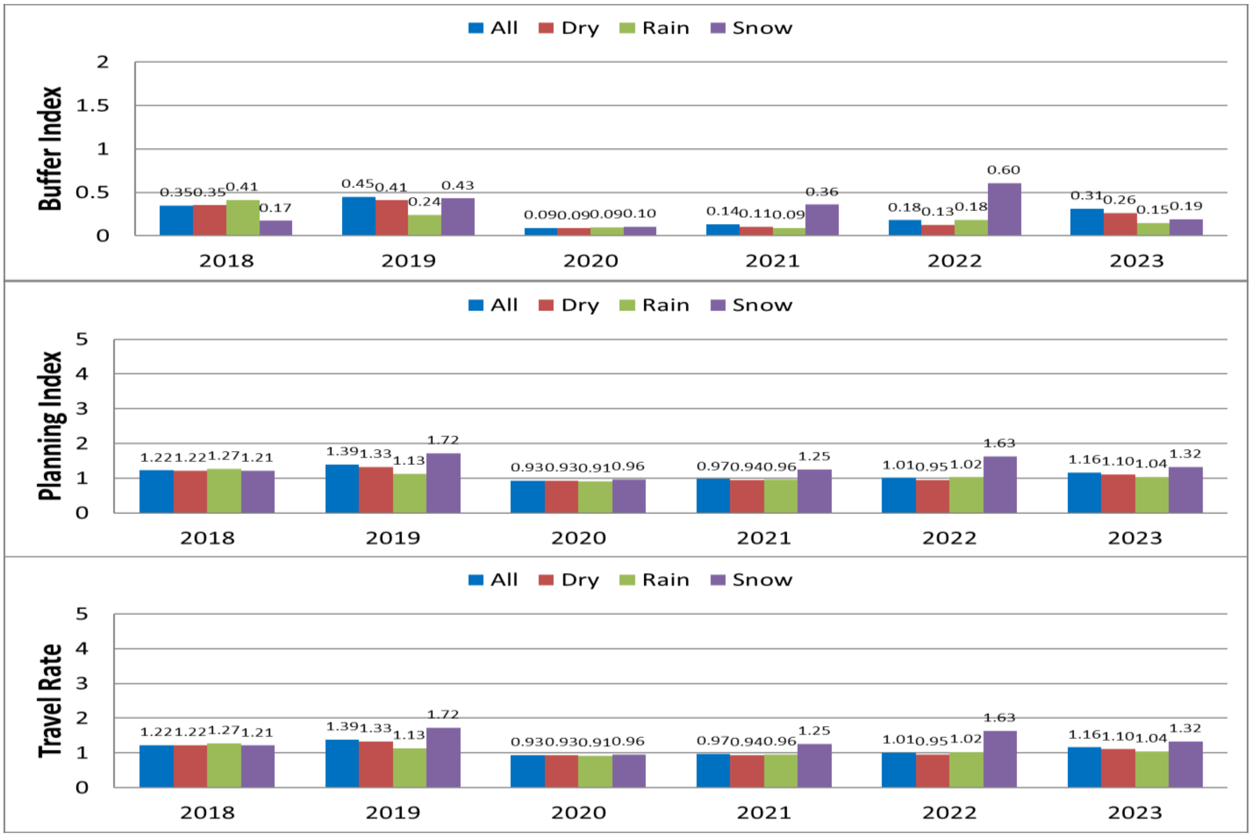
Effects of Incidents



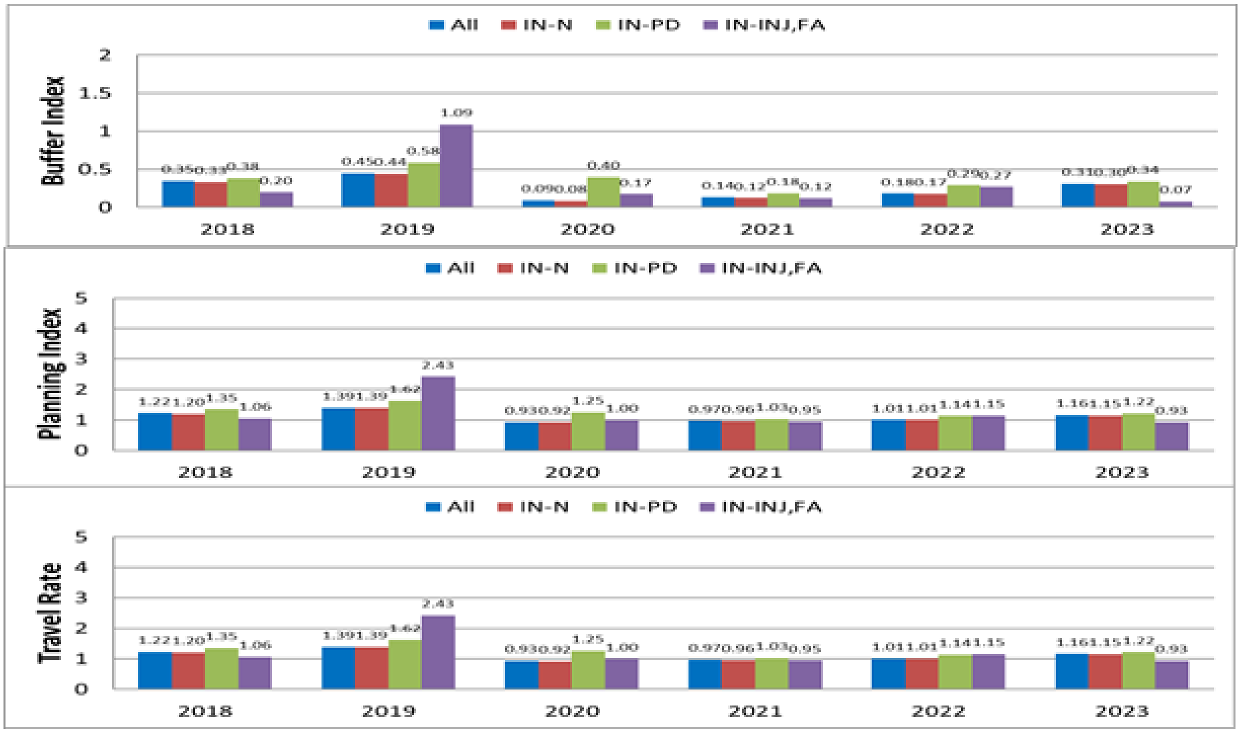
Effects of Work Zones



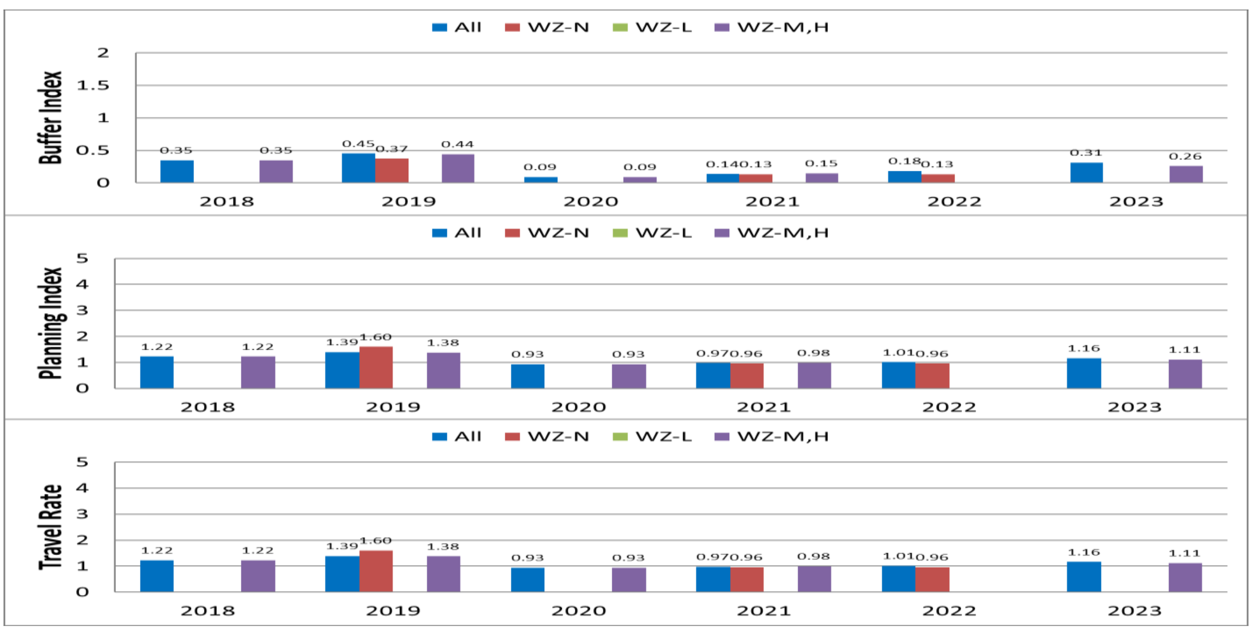
Yearly Variations - *Weather Effects*



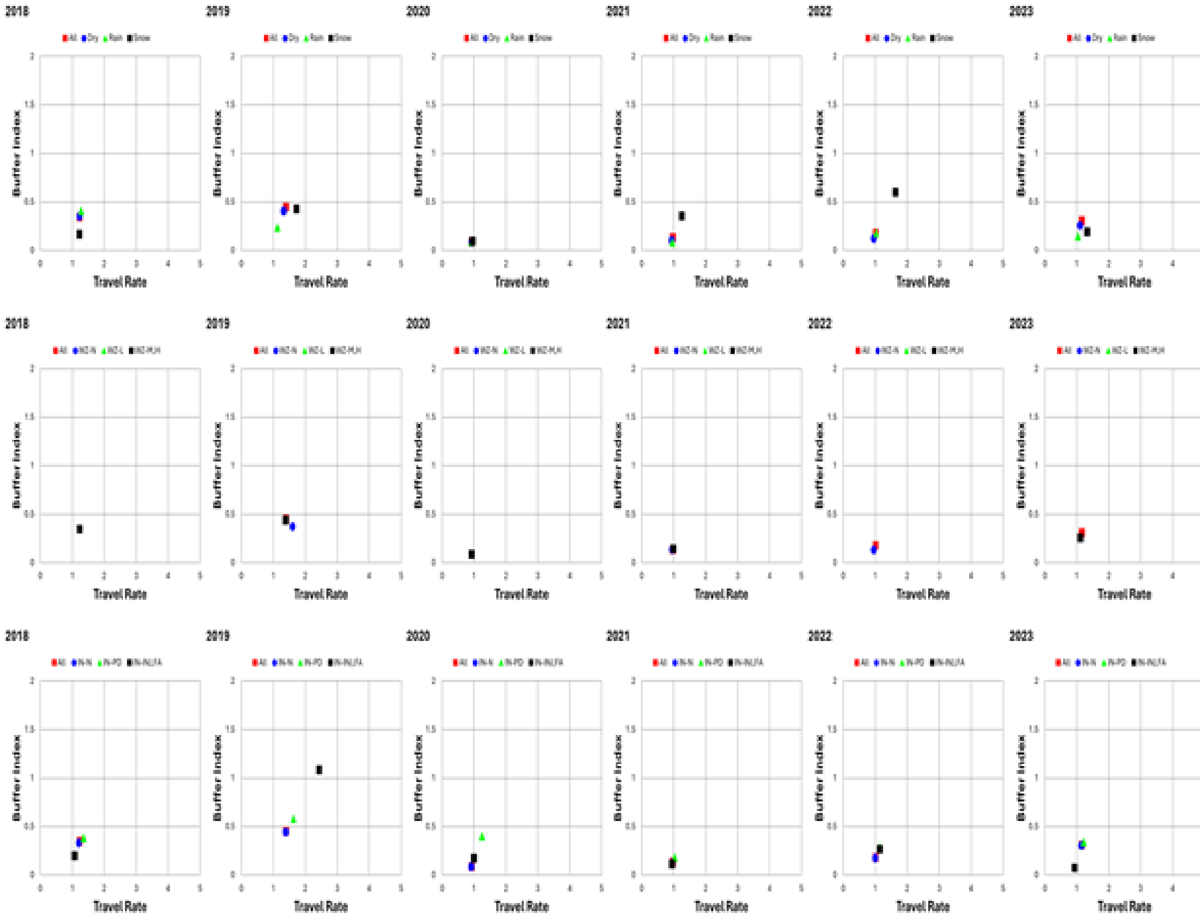
Incident Effects



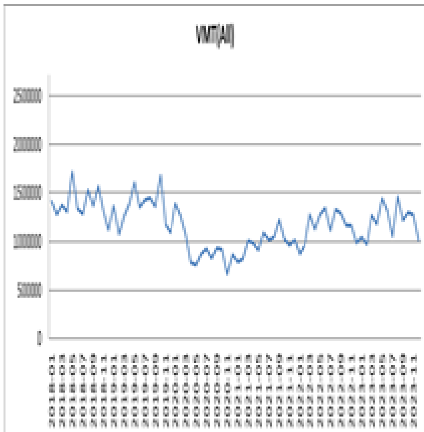
Work-Zone Effects

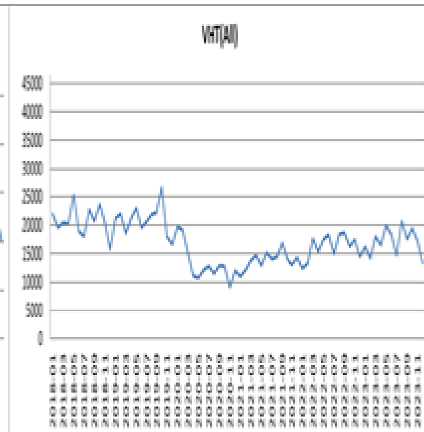


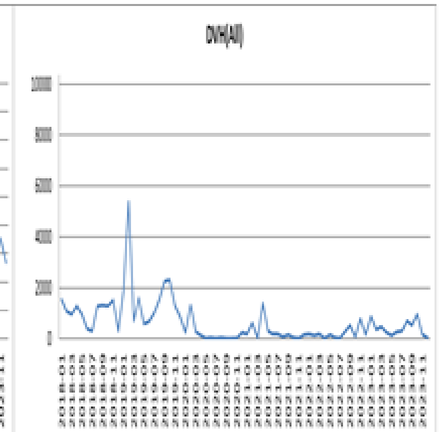
Yearly Variations of Buffer Index - Travel Rate Relationships

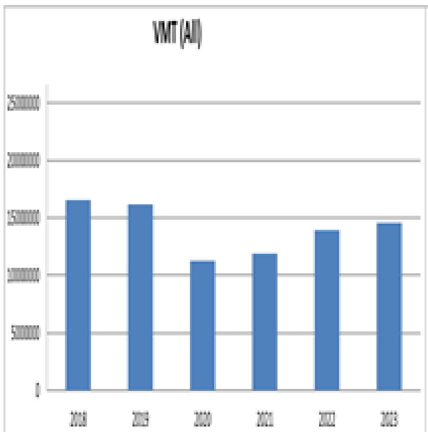


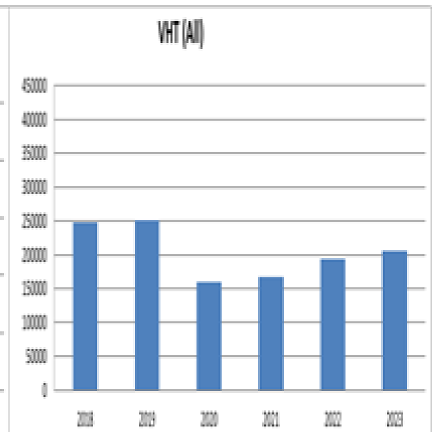
Variations of Traffic-Flow Measures

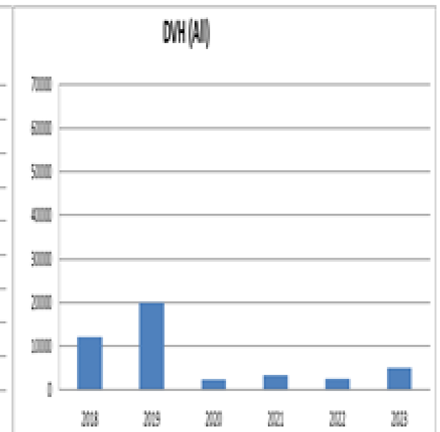

VMT(All)


VHT(All)


DVH(All)

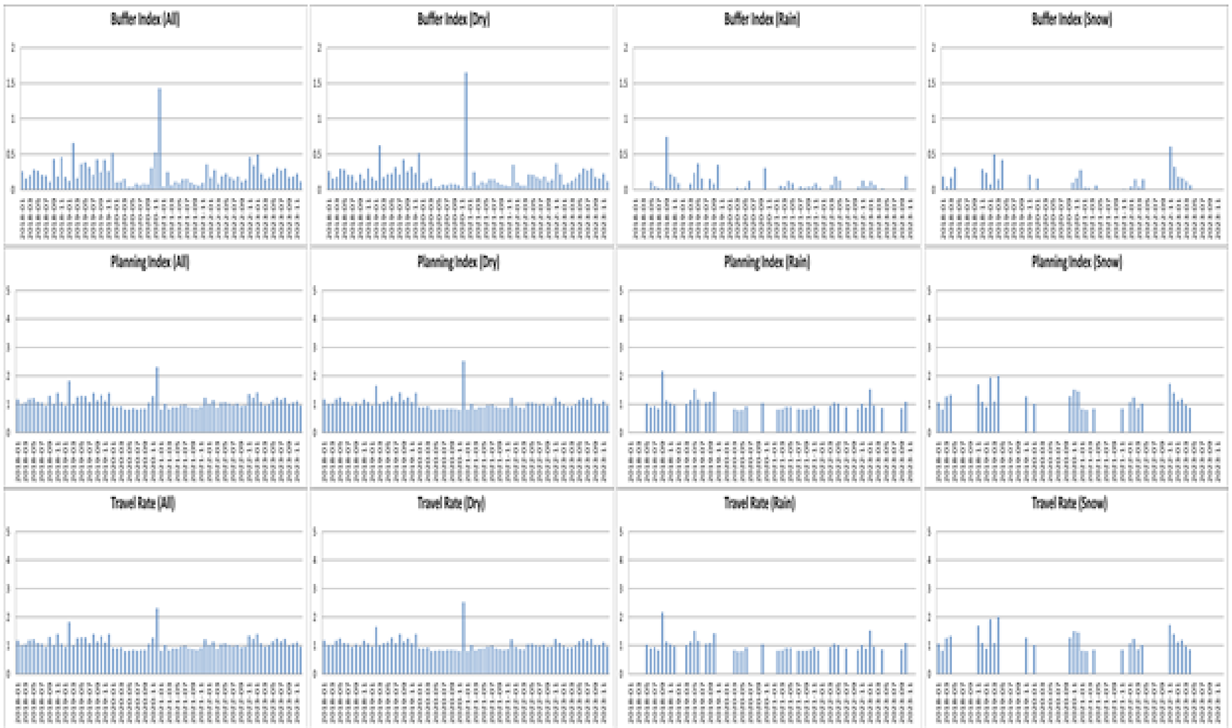

VMT (All)
2018
2019
2020
2021
2022
2023


VHT (All)
2018
2019
2020
2021
2022
2023

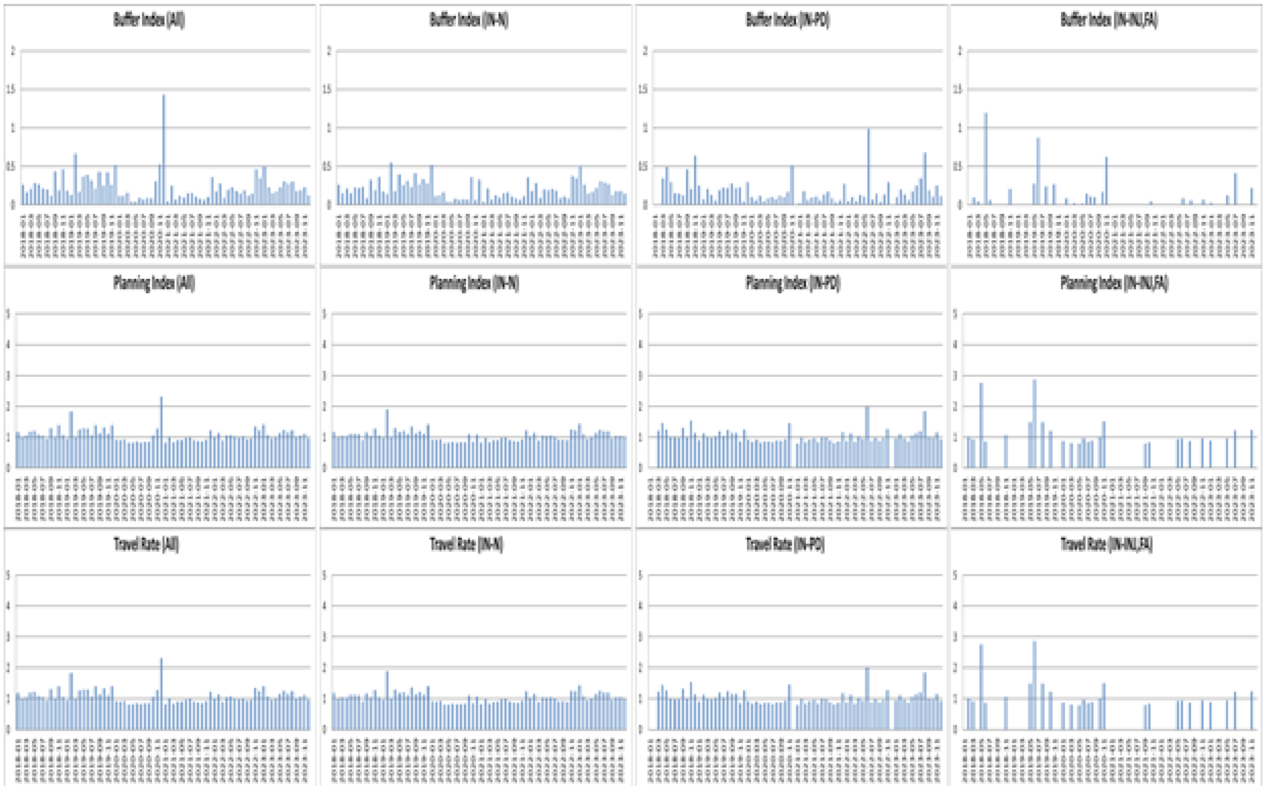

DVH (All)
2018
2019
2020
2021
2022
2023

ii) I-94 Corridor B -- WB TH252 to I494 for Afternoon Peak Periods

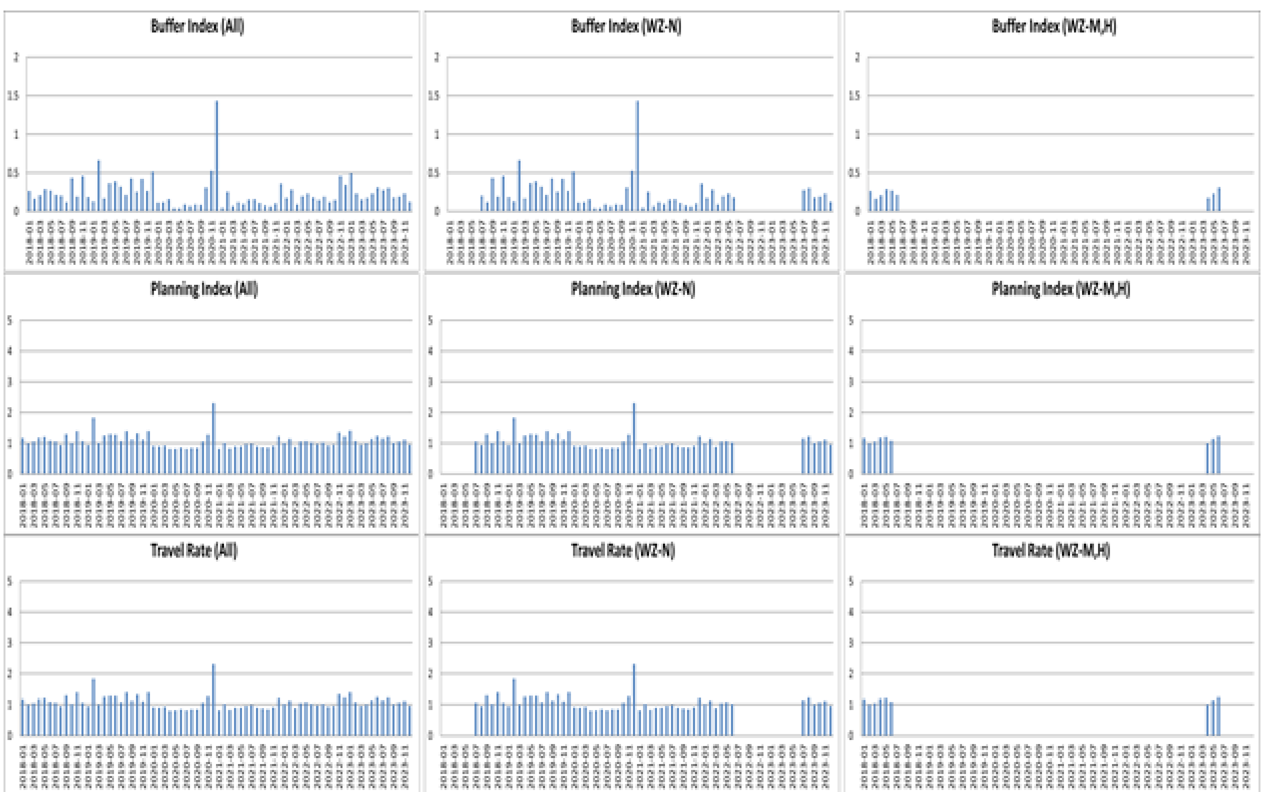
Effects of Weather conditions on Travel-Time Reliability



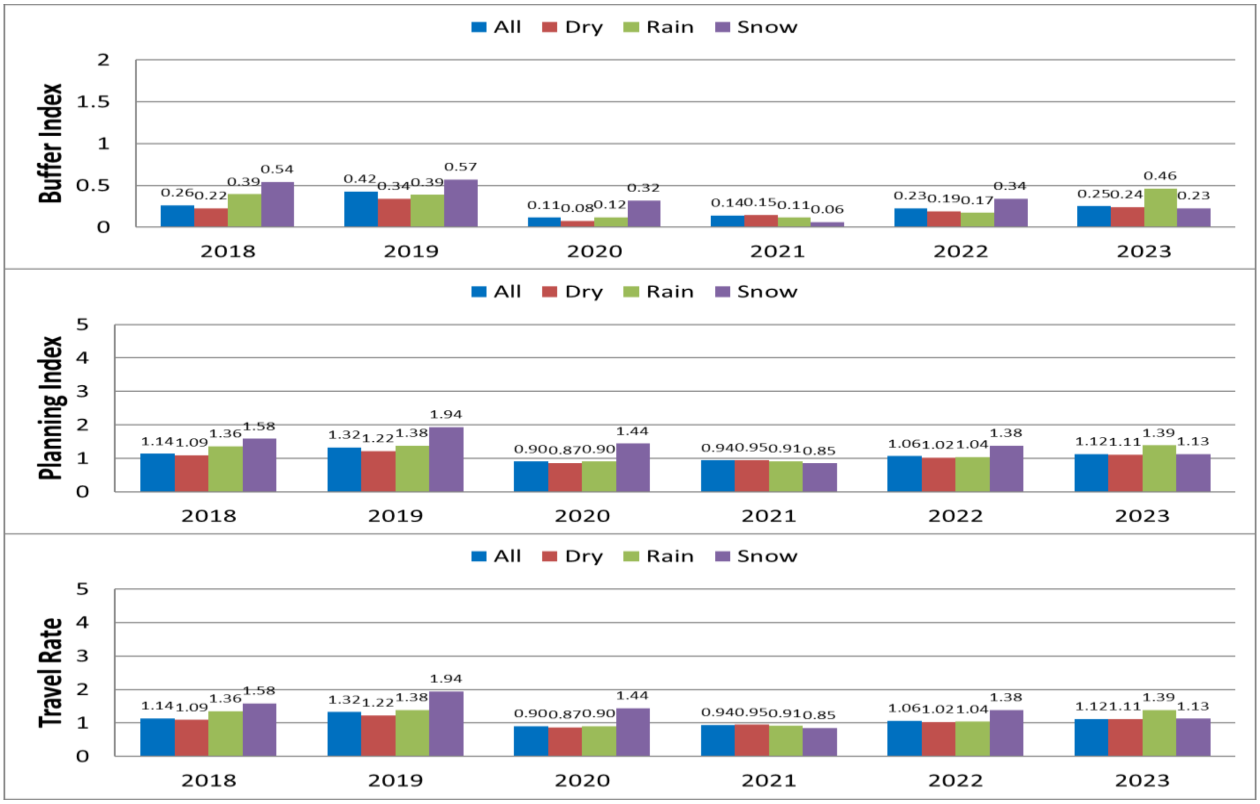
Effects of Incidents



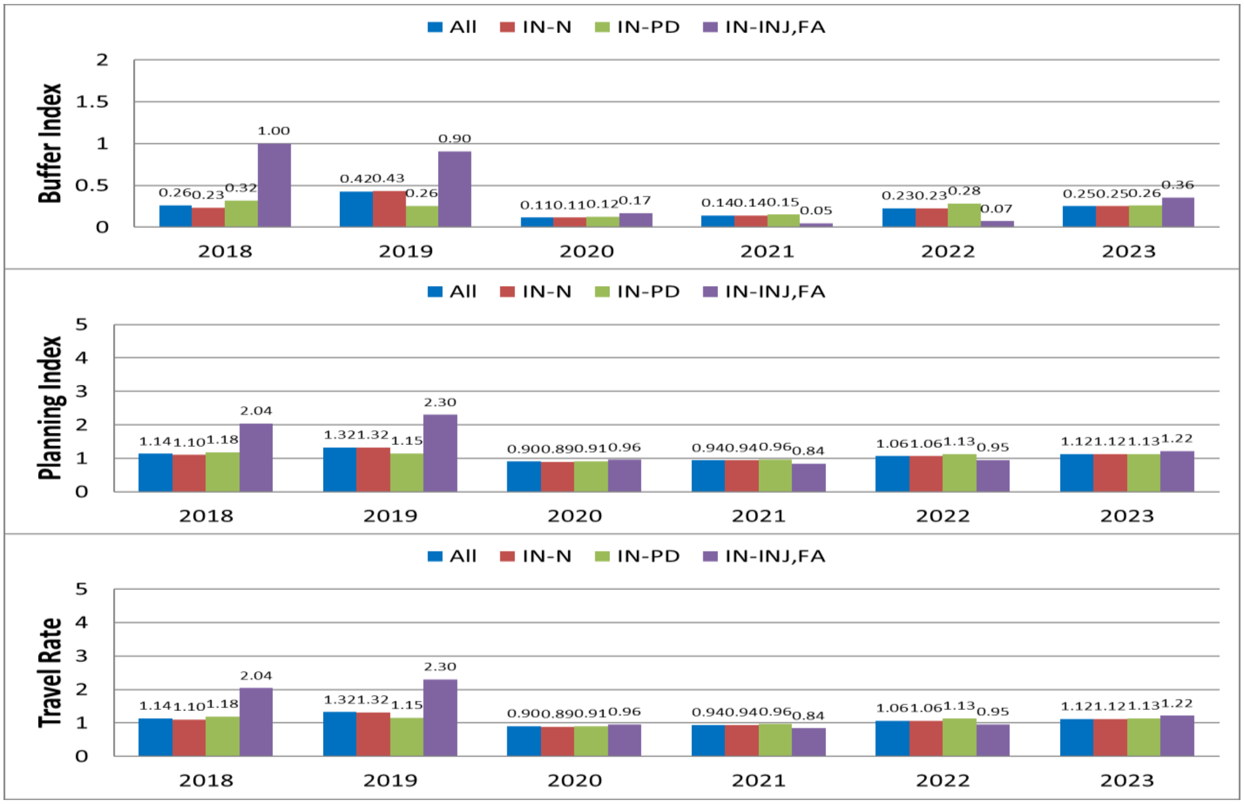
Effects of Work Zones



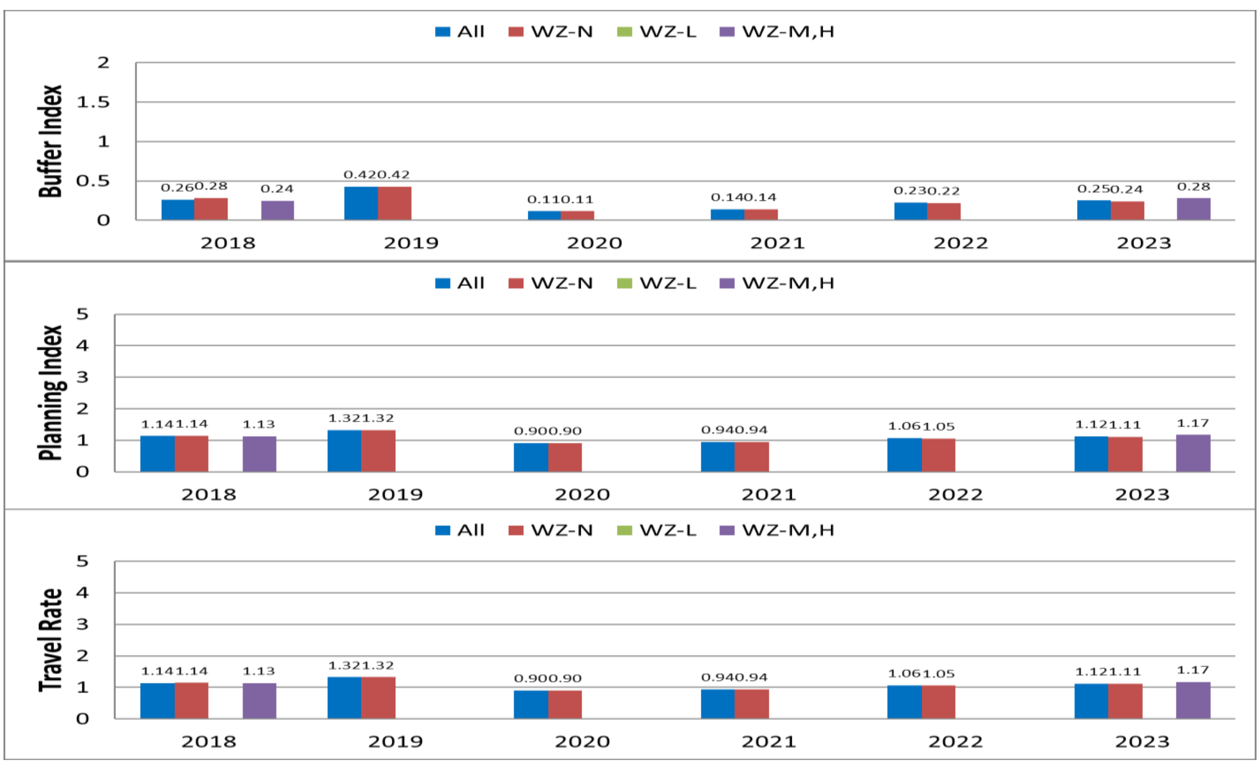
Yearly Variations - *Weather Effects*



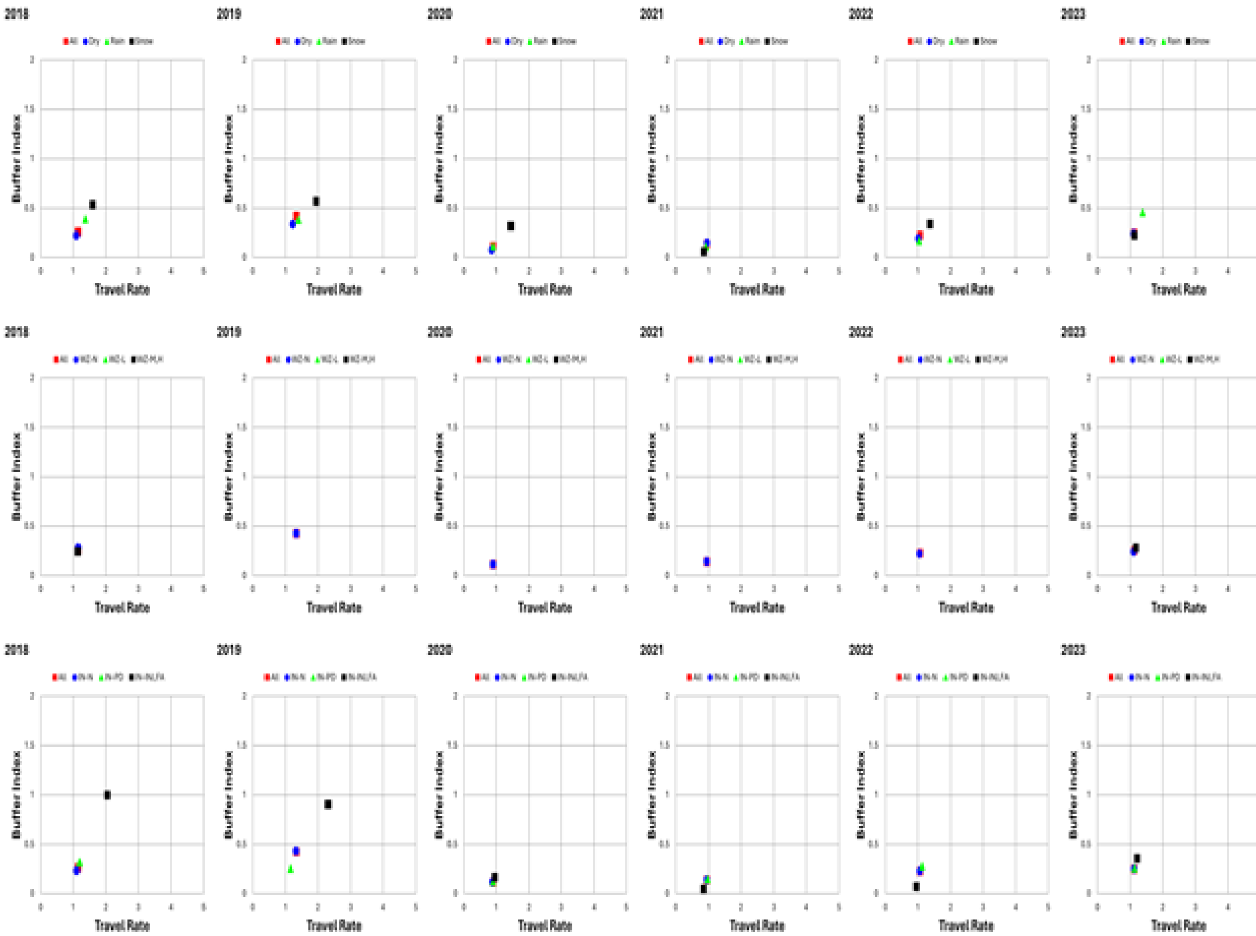
Incident Effects



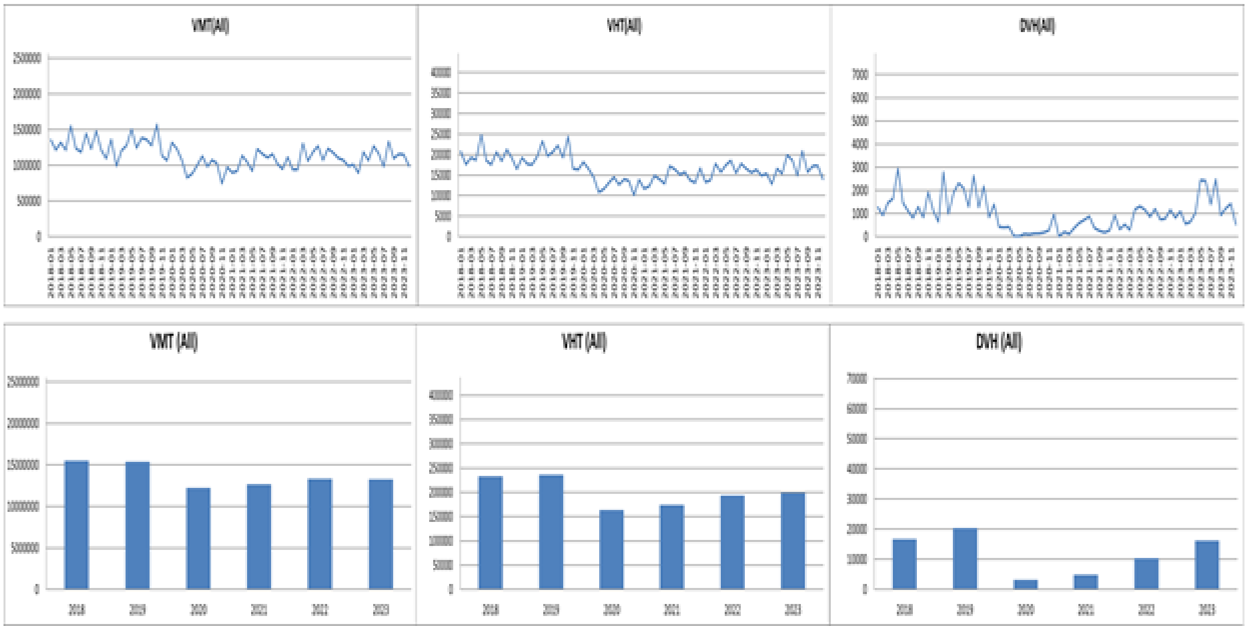
Work-Zone Effects



Yearly Variations of Buffer Index - Travel Rate Relationships

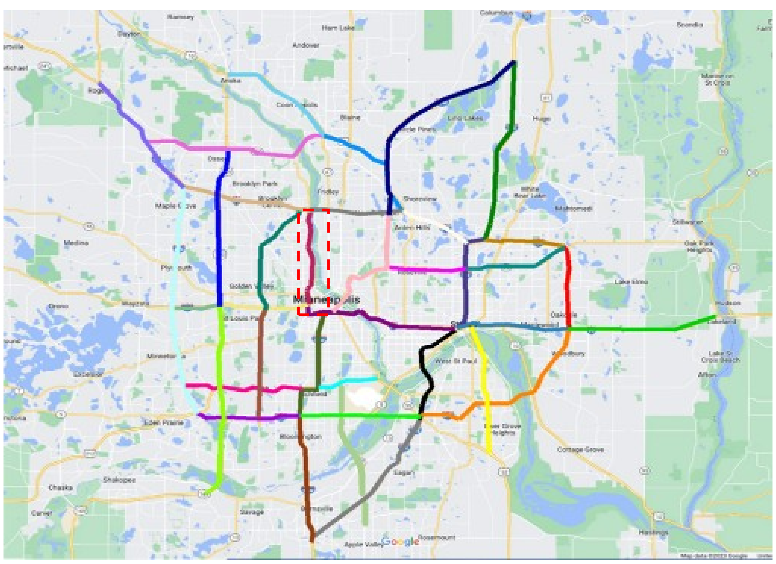


Variations of Traffic-Flow Measures

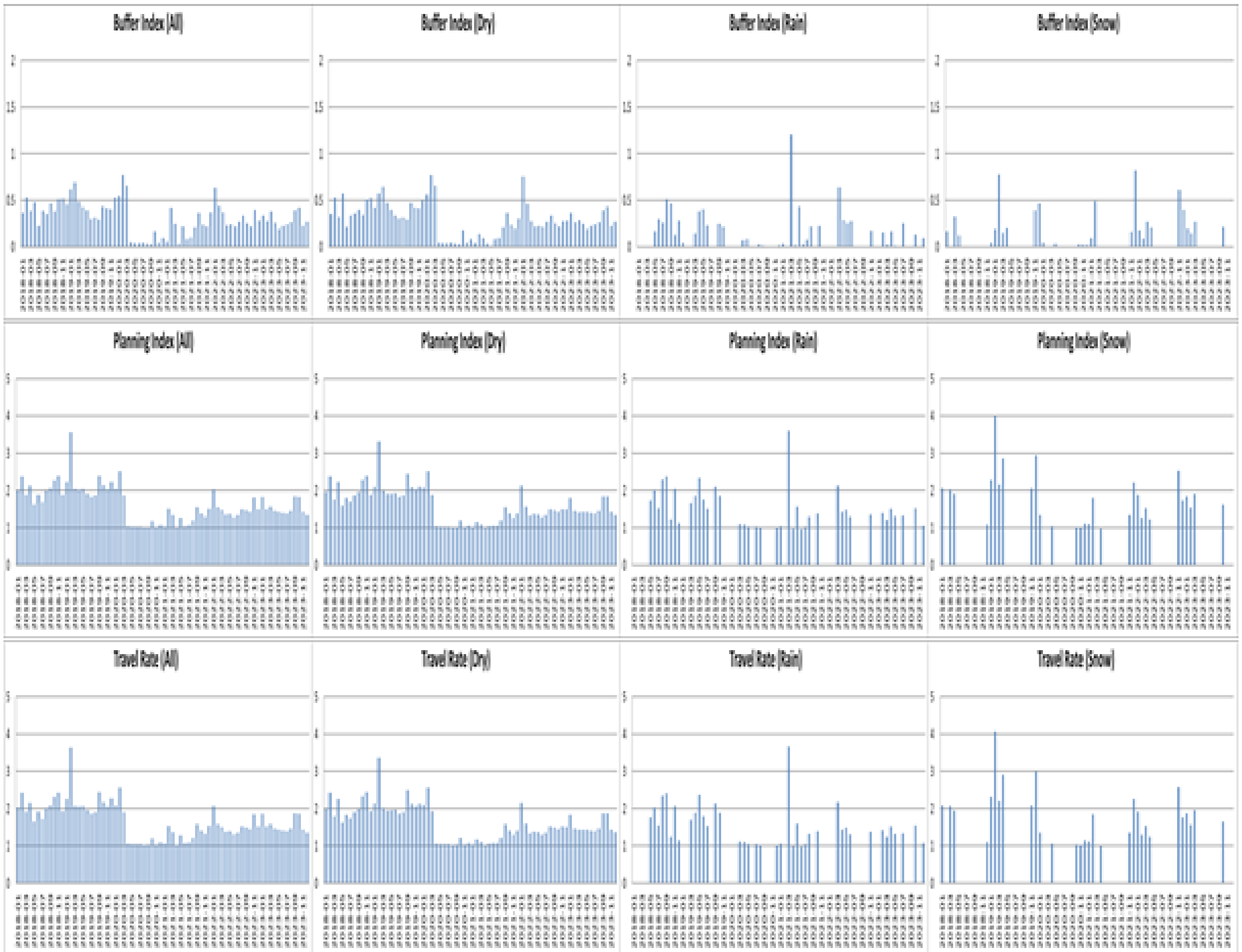


21) I-94 Corridor C (TH252 < -- > MPLS)

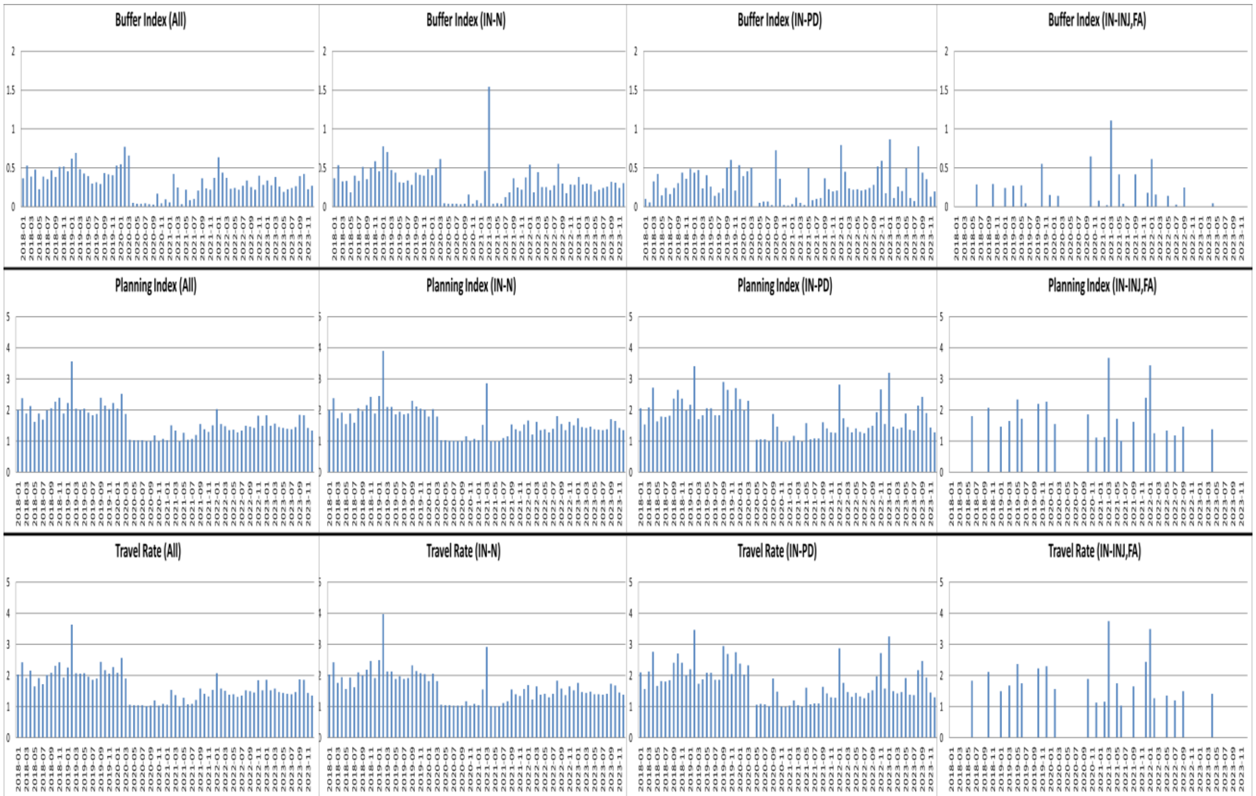
i) I-94 Corridor C -- EB TH252 to Minneapolis DT for Morning Peak Periods



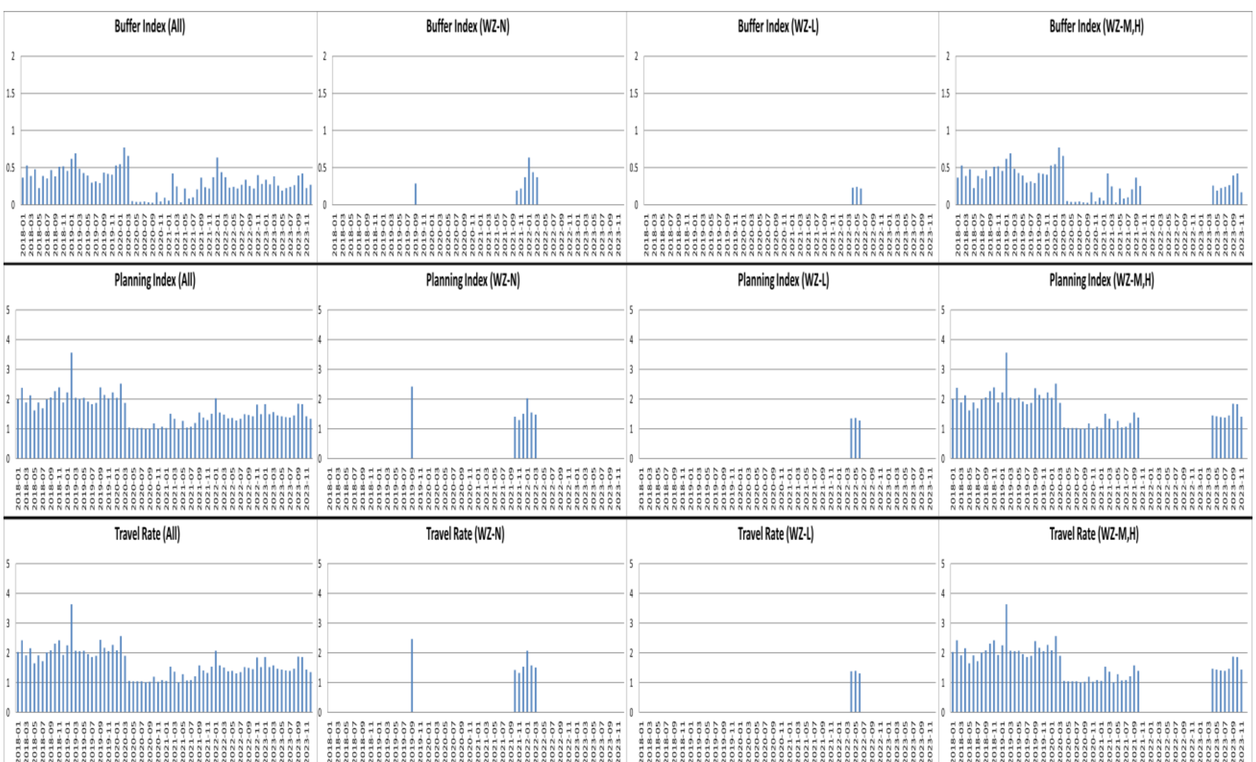
Effects of Weather conditions on Travel-Time Reliability



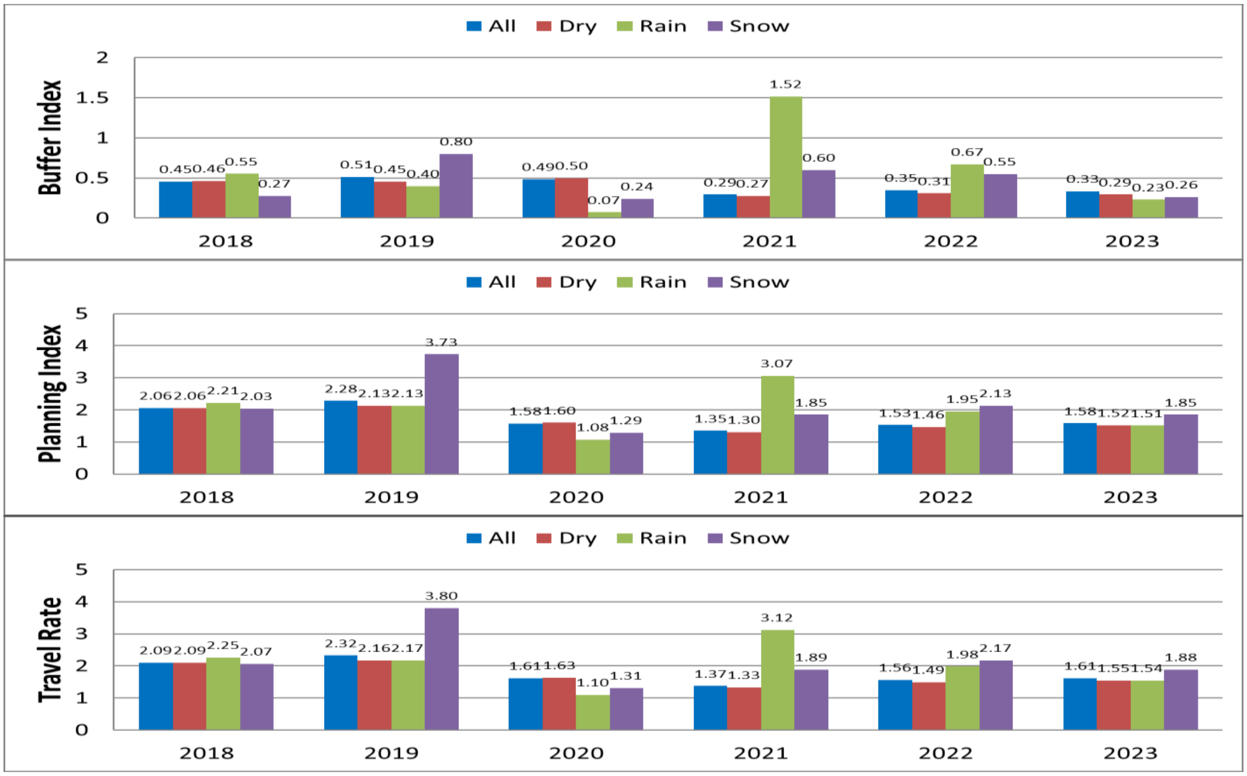
Effects of Incidents



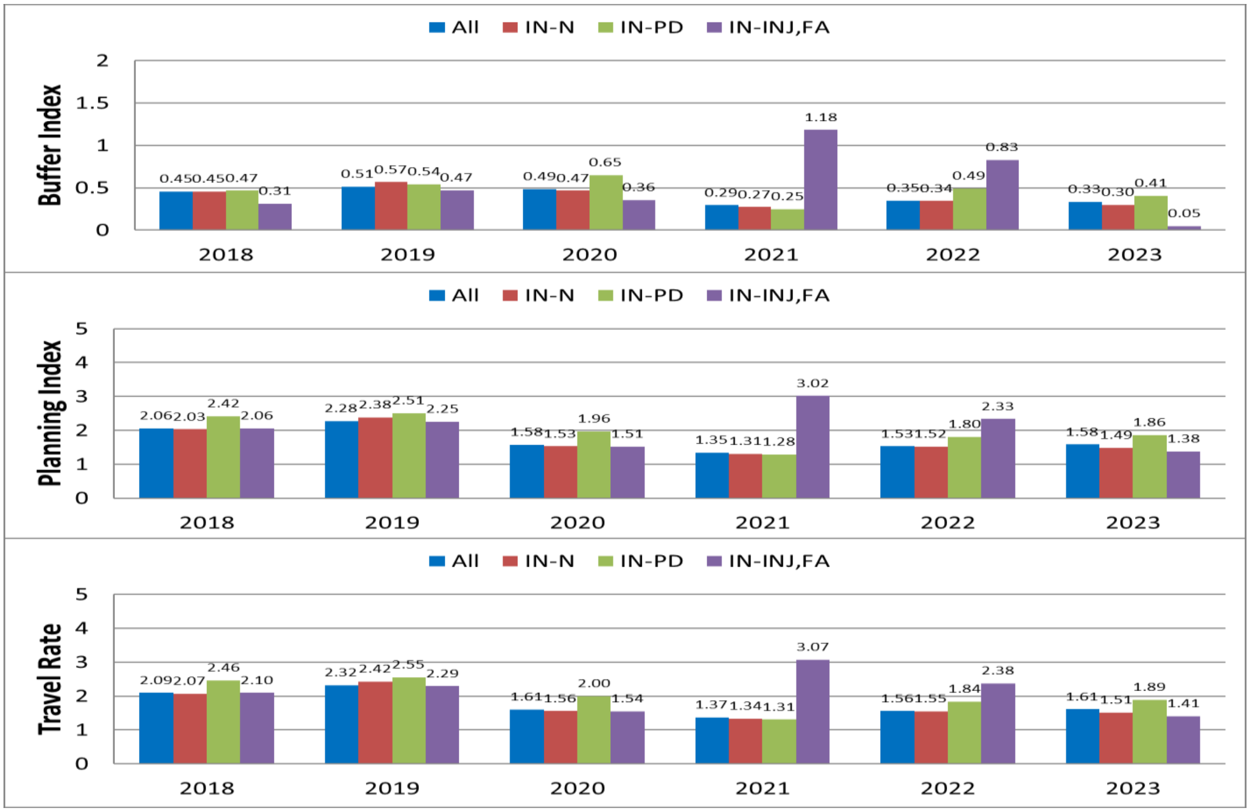
Effects of Work Zones



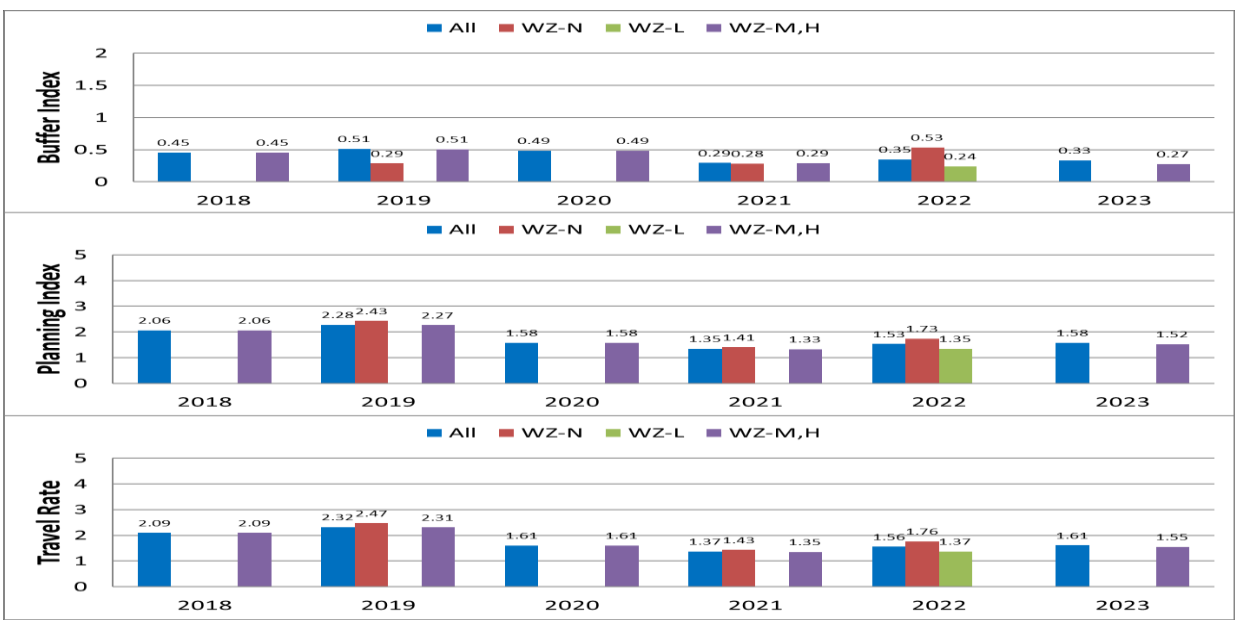
Yearly Variations - *Weather Effects*



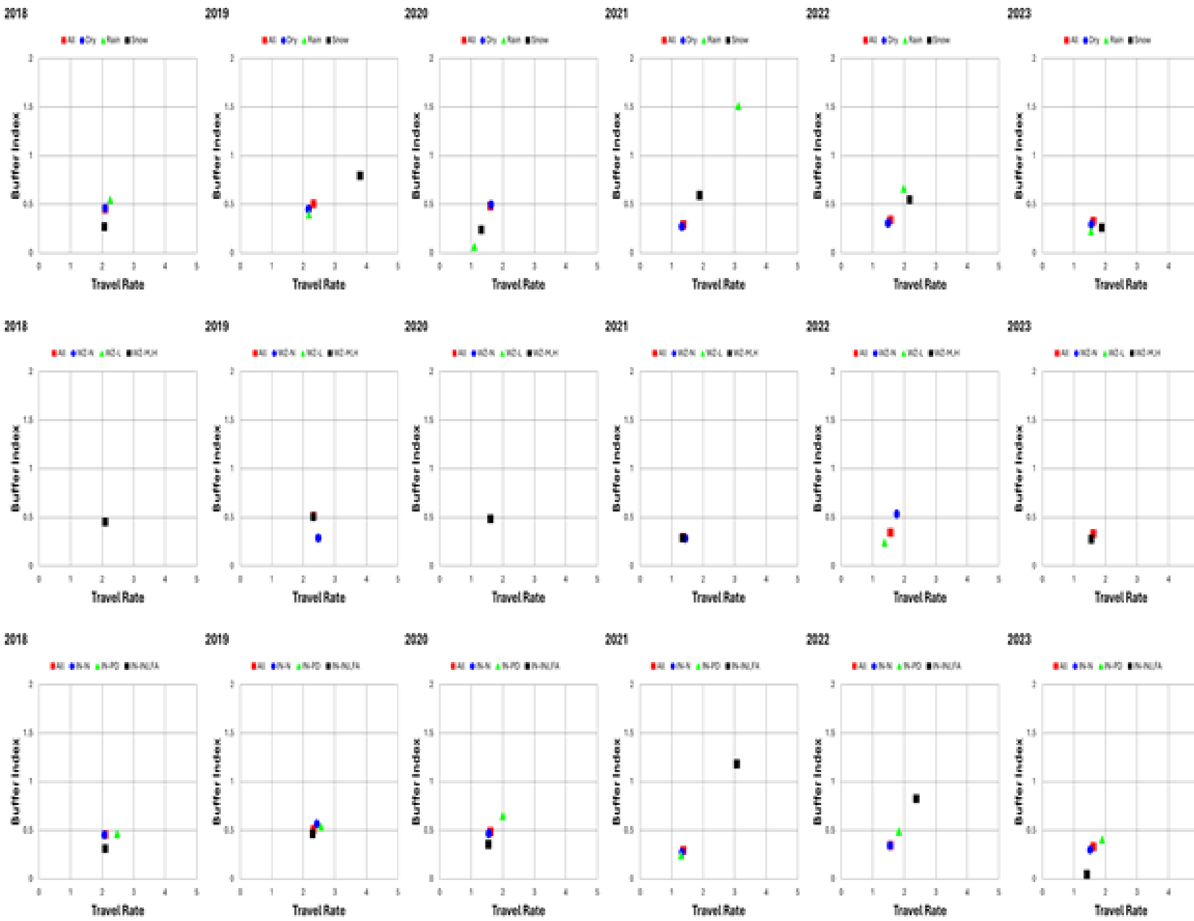
Incident Effects



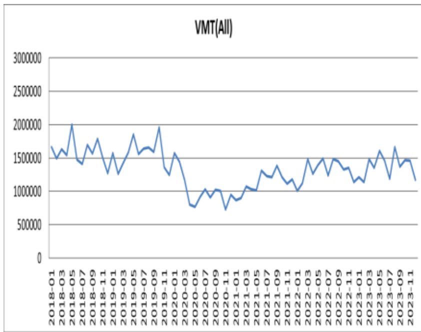
Work-Zone Effects



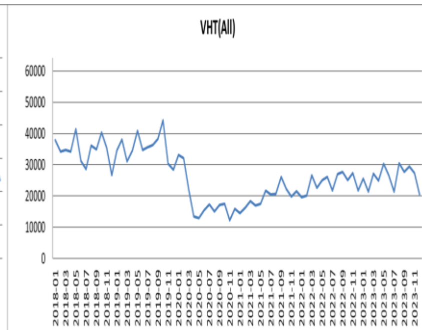
Yearly Variations of Buffer Index - Travel Rate Relationships



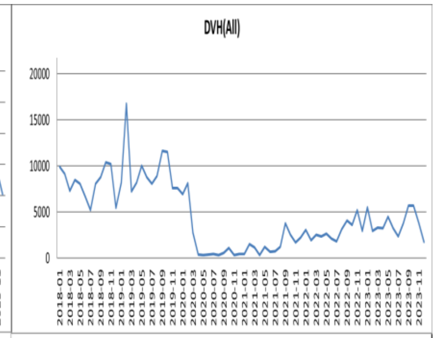
Variations of Traffic-Flow Measures



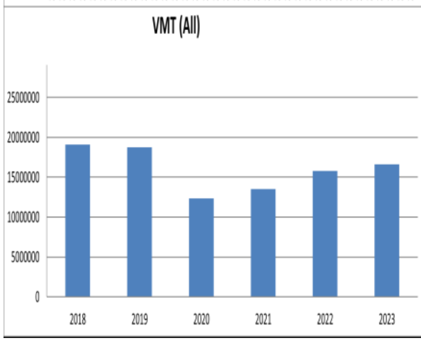
VMT(All)



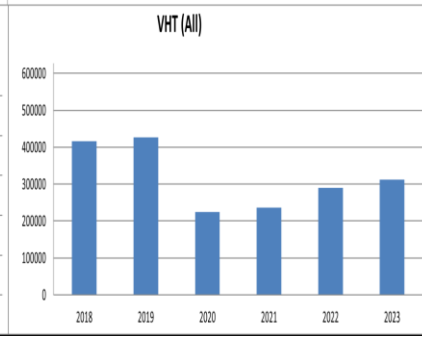
VHT(All)



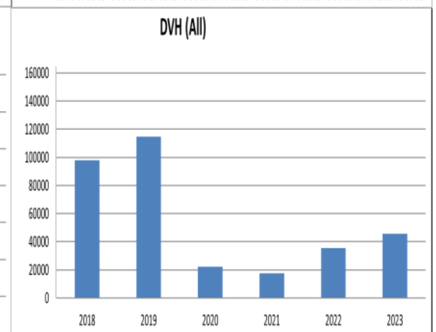
DVH(All)



VMT (All)
2018
2019
2020
2021
2022
2023



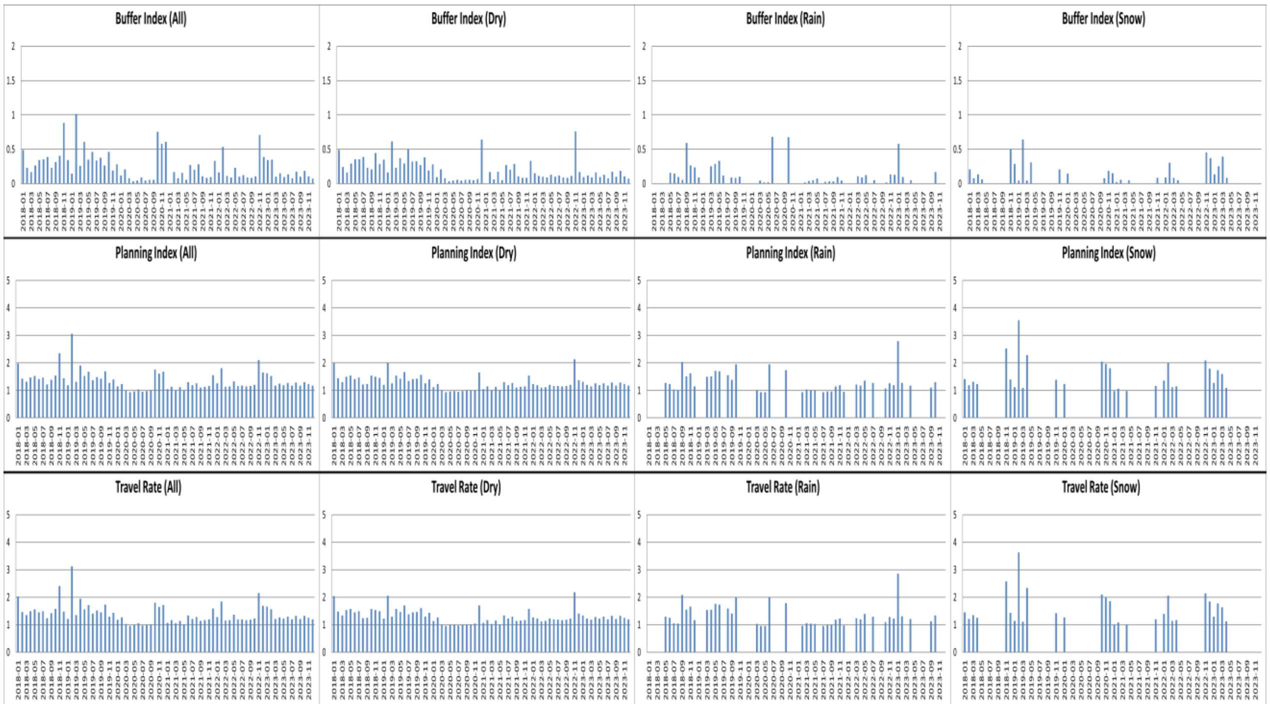
VHT (All)
2018
2019
2020
2021
2022
2023



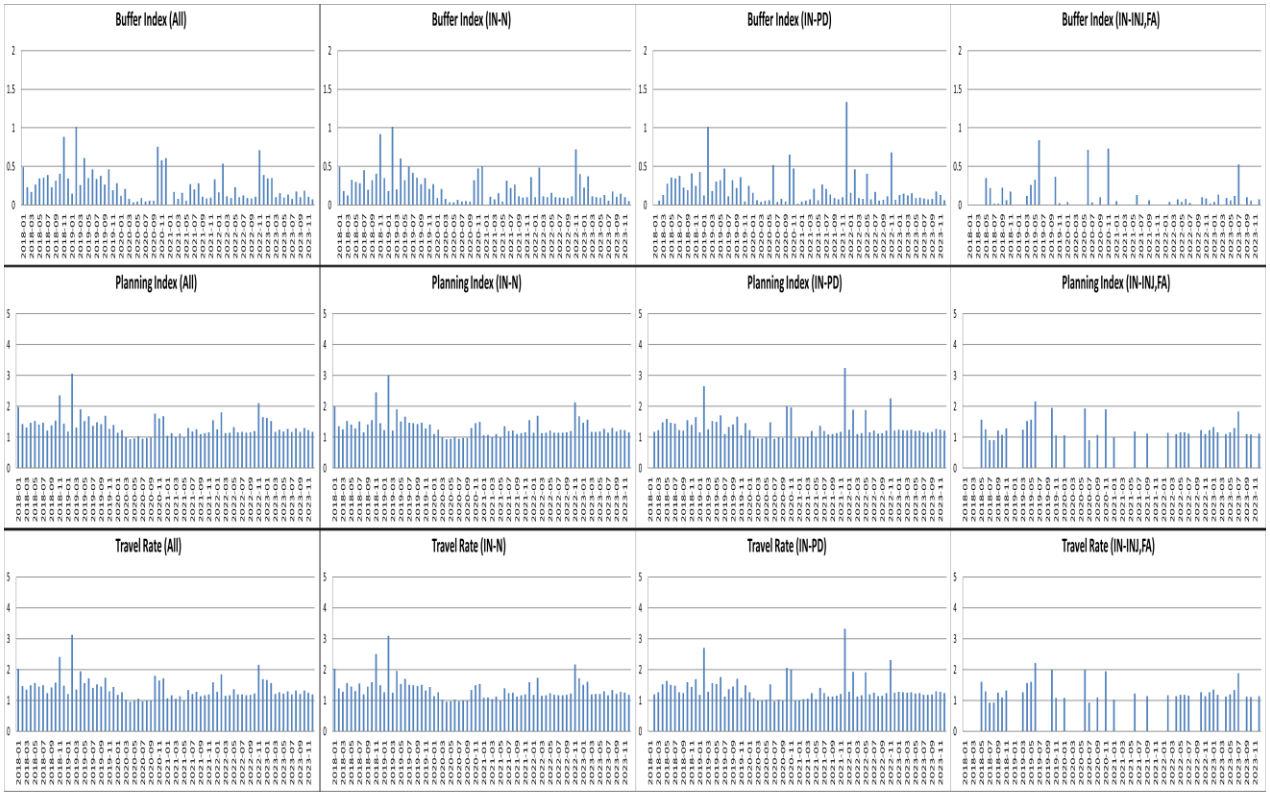
DVH (All)
2018
2019
2020
2021
2022
2023

ii) I-94 Corridor C -- WB MPLS DT to TH252 for Afternoon Peak Periods

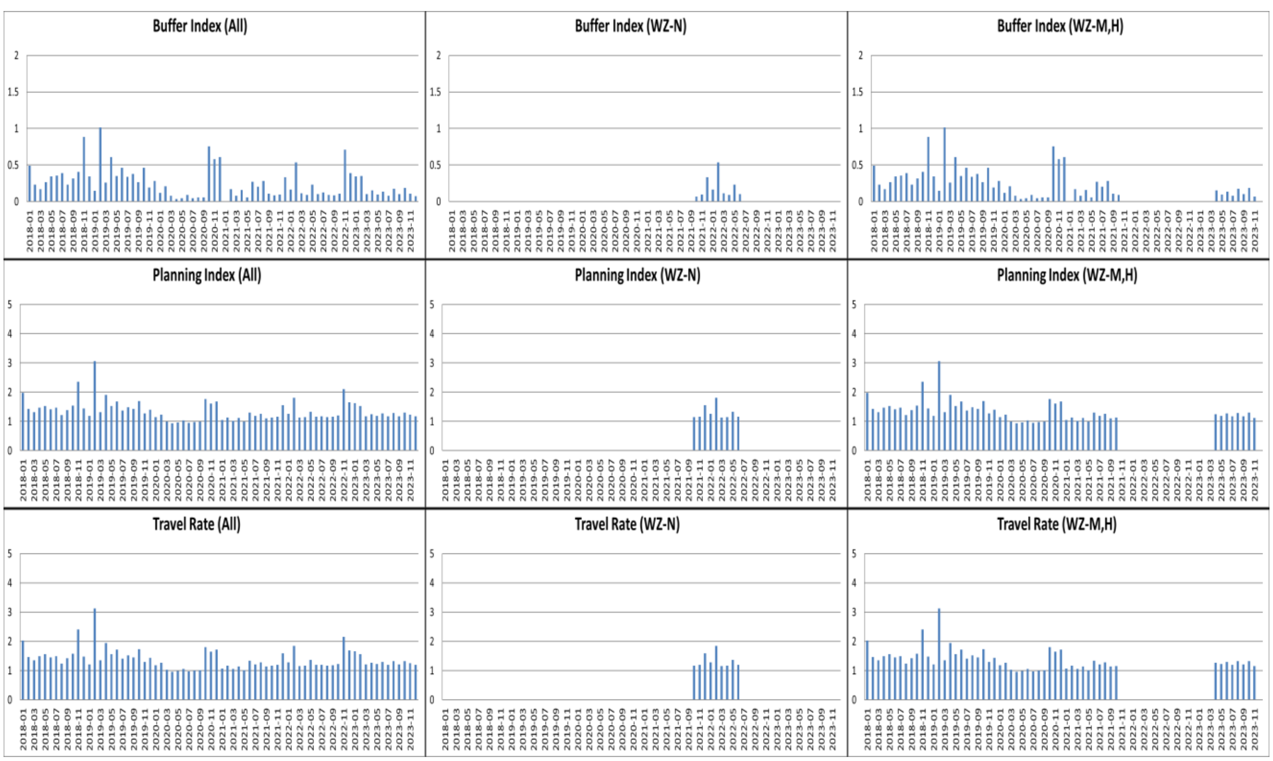
Effects of Weather conditions on Travel-Time Reliability



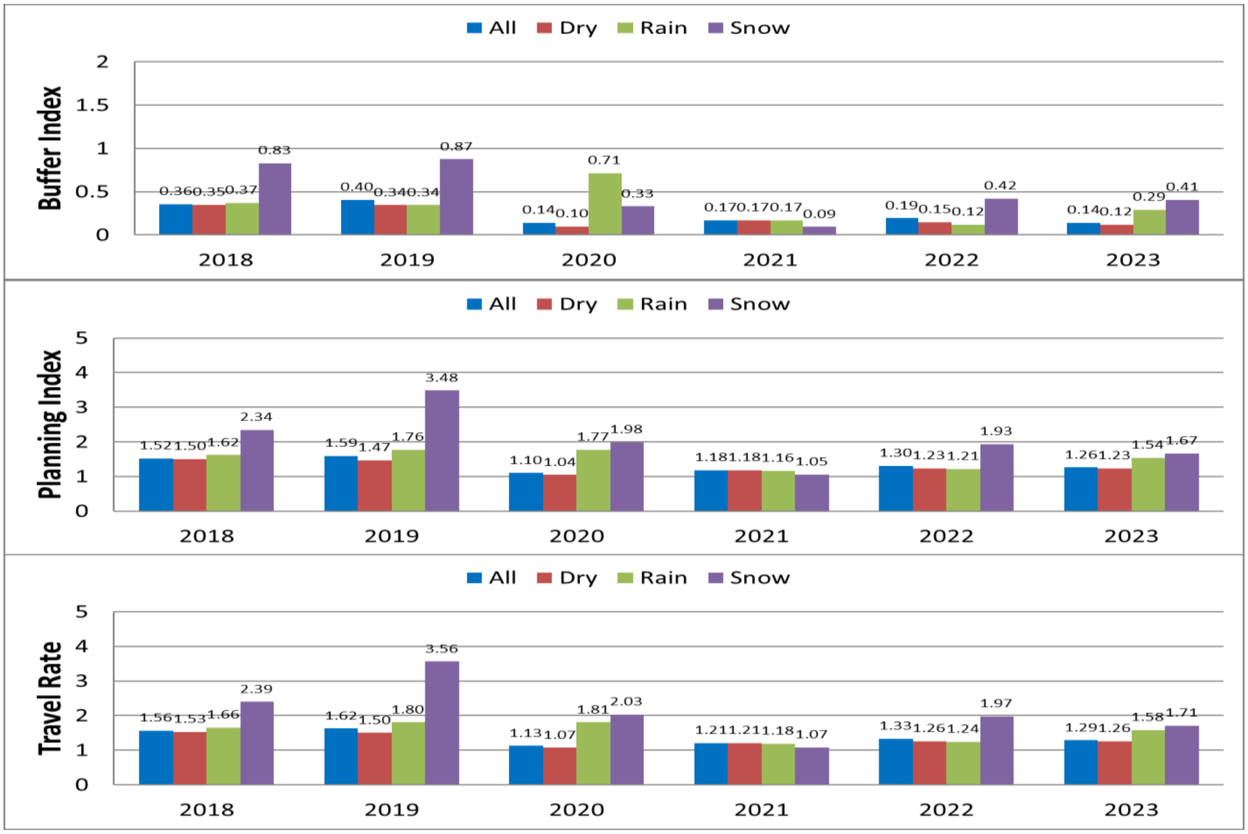
Effects of Incidents



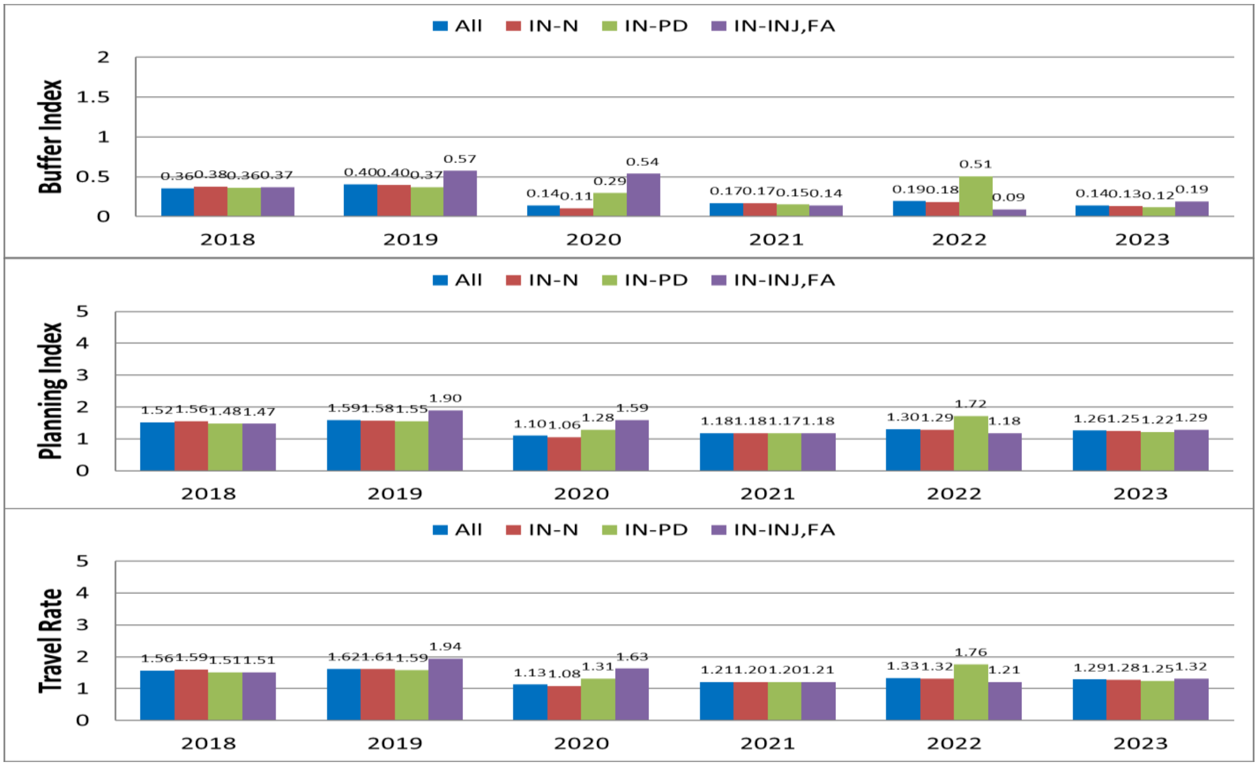
Effects of Work Zones



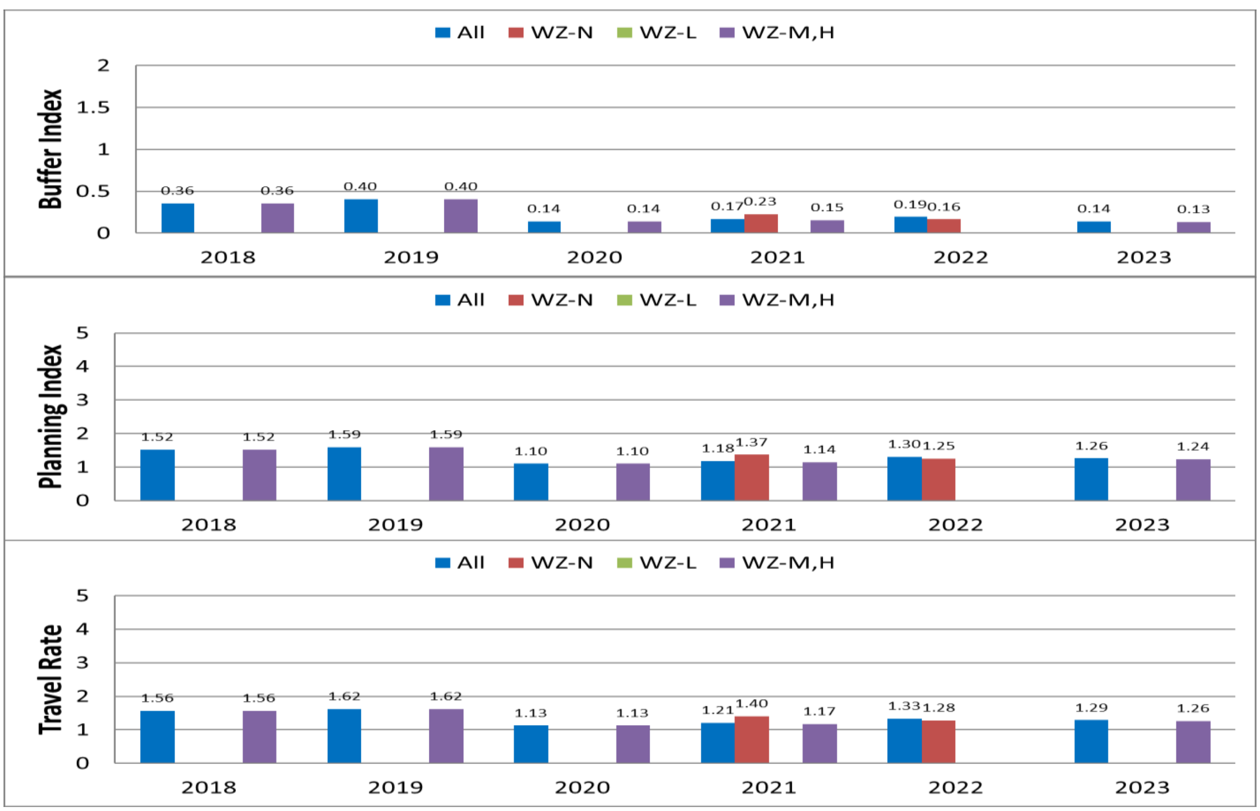
Yearly Variations - *Weather Effects*



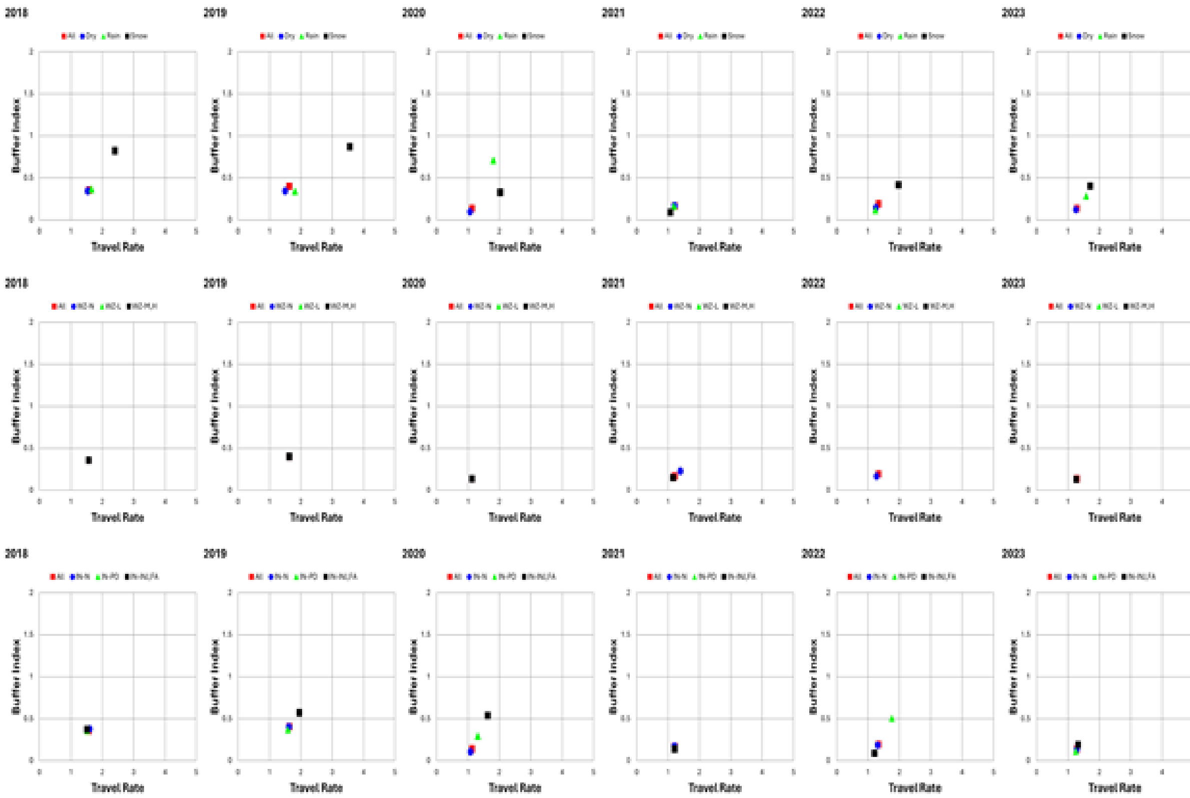
Incident Effects



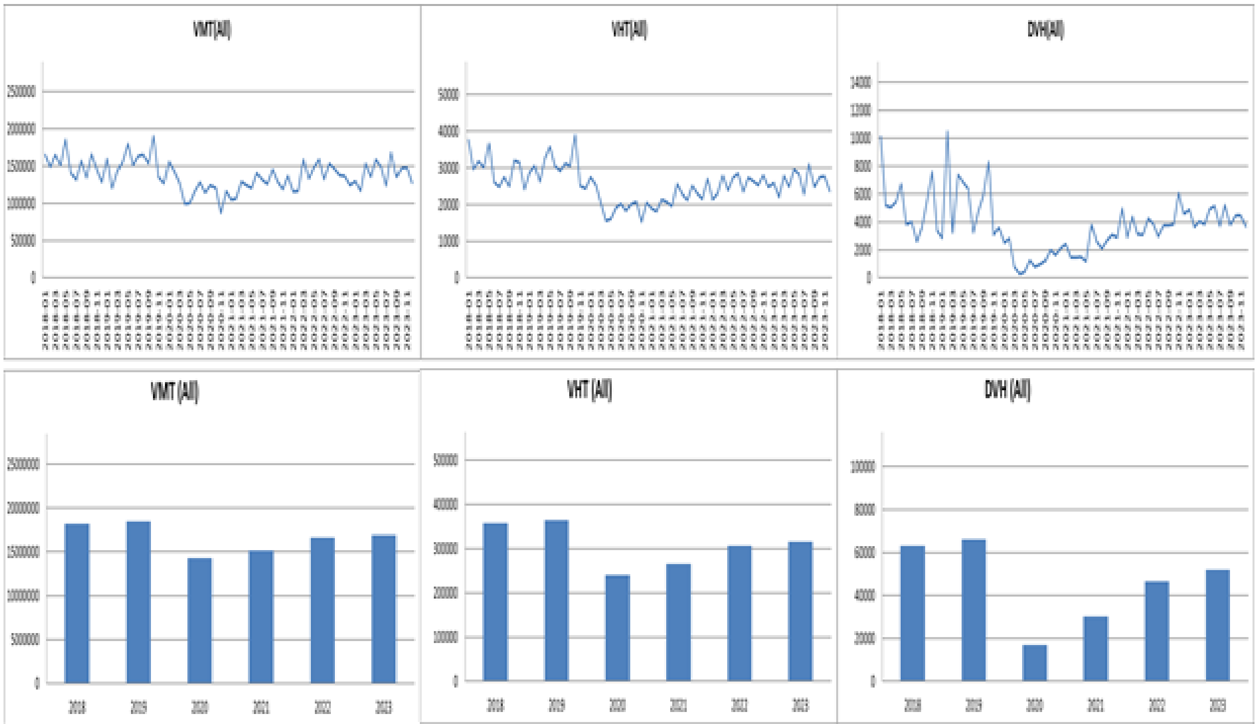
Work-Zone Effects



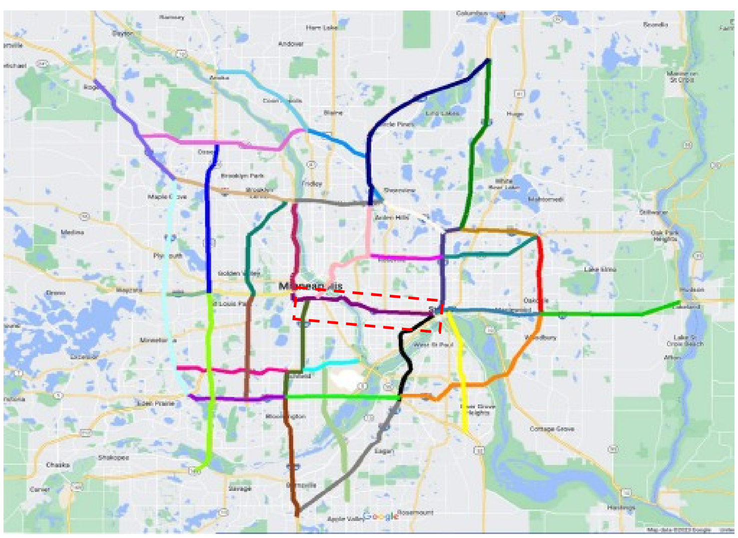
Yearly Variations of Buffer Index - Travel Rate Relationships



Variations of Traffic-Flow Measures

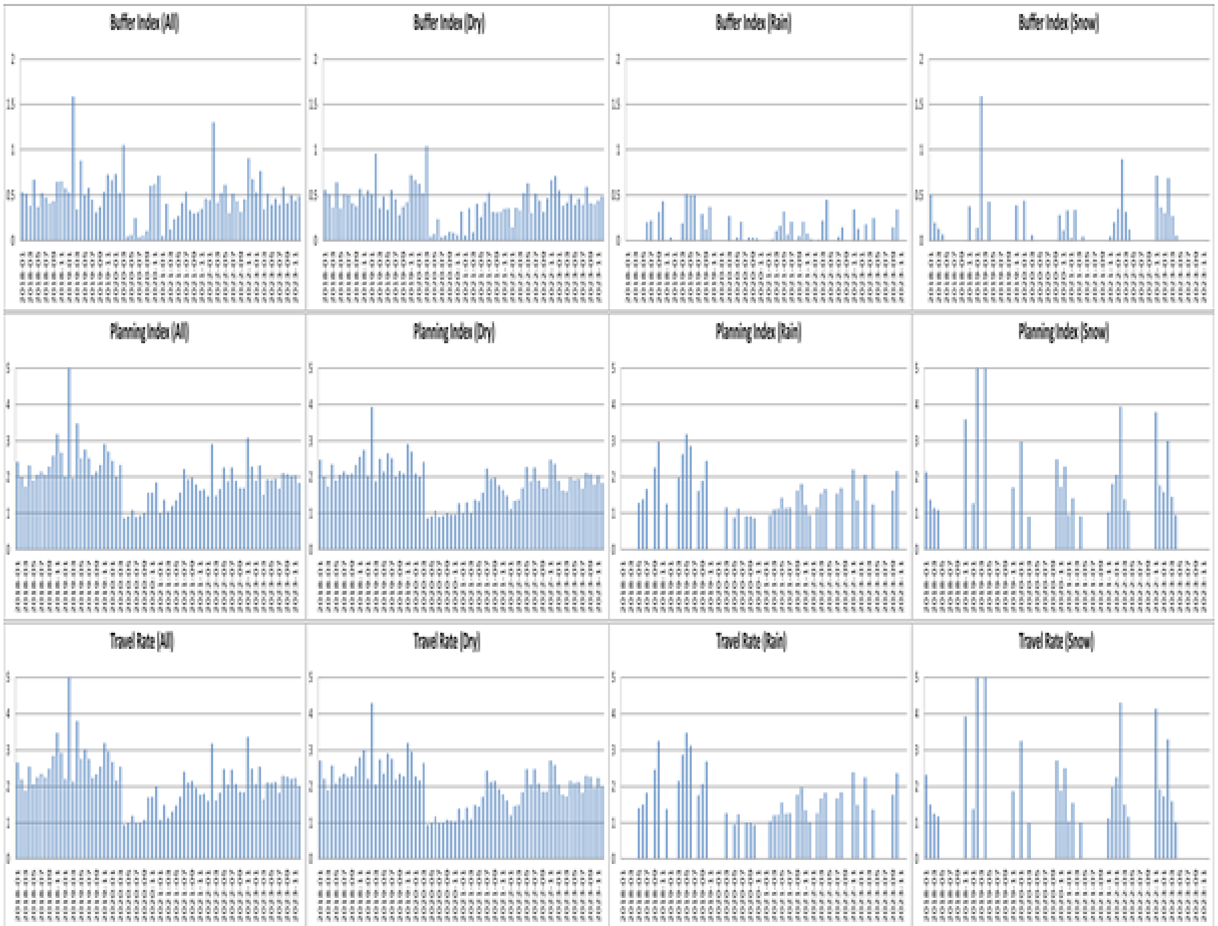


22) I-94 Corridor D (MPLS < – > STPL)



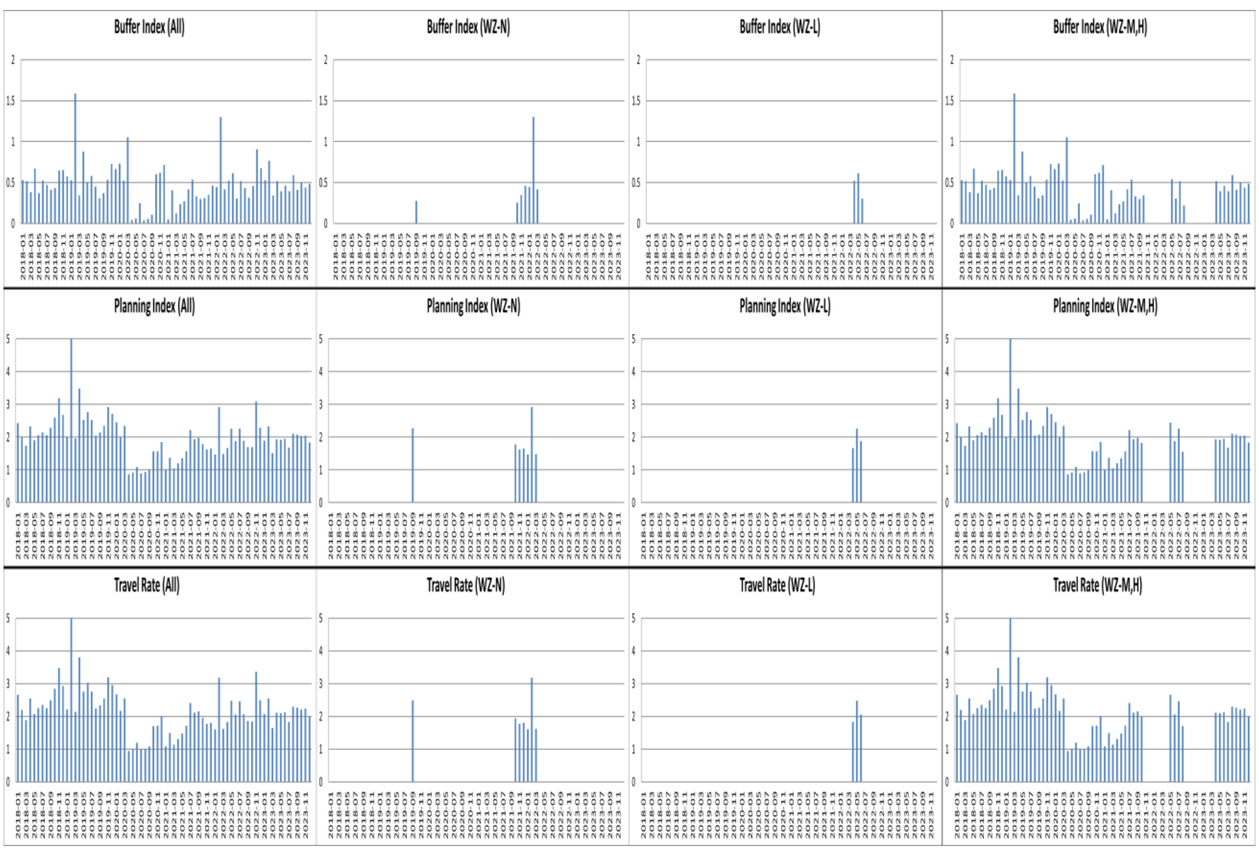
i) I-94 Corridor D -- EB MPLS to STPL for Afternoon Peak Periods

Effects of Weather conditions on Travel-Time Reliability

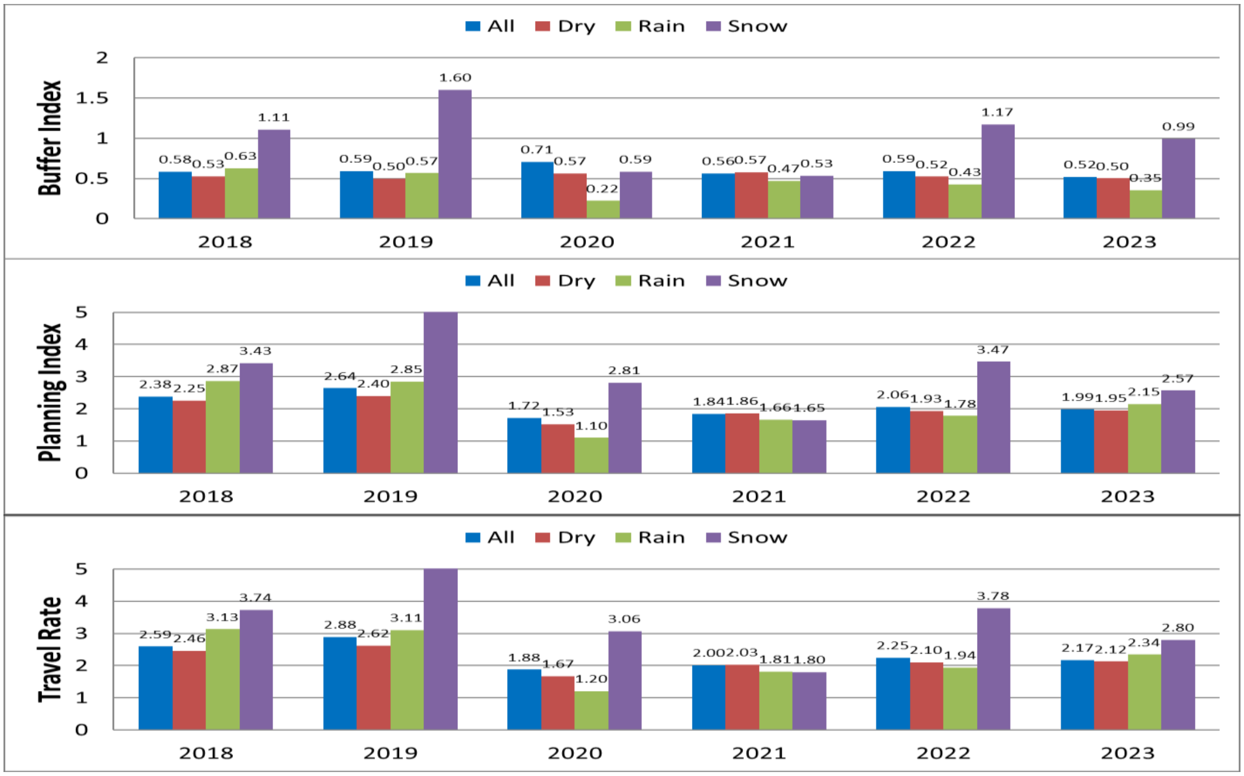


Effects of Incidents

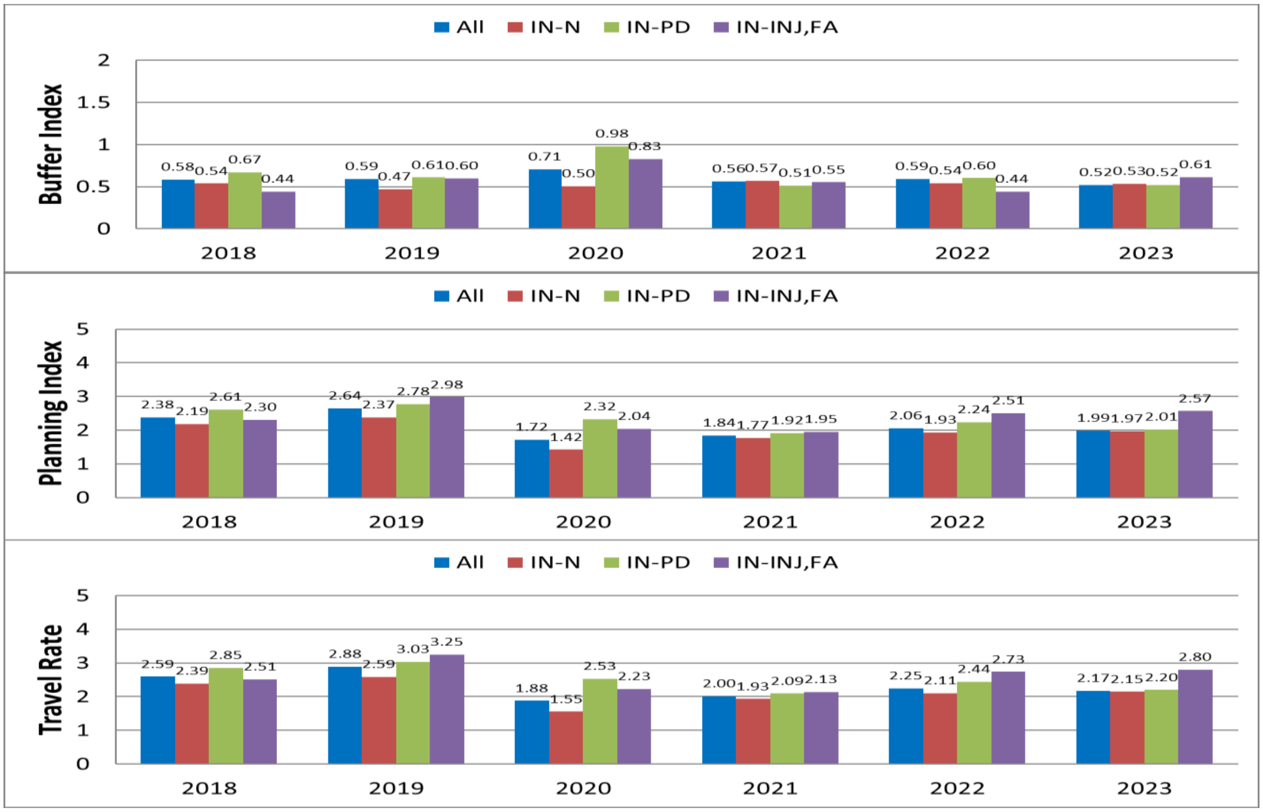
Effects of Work Zones



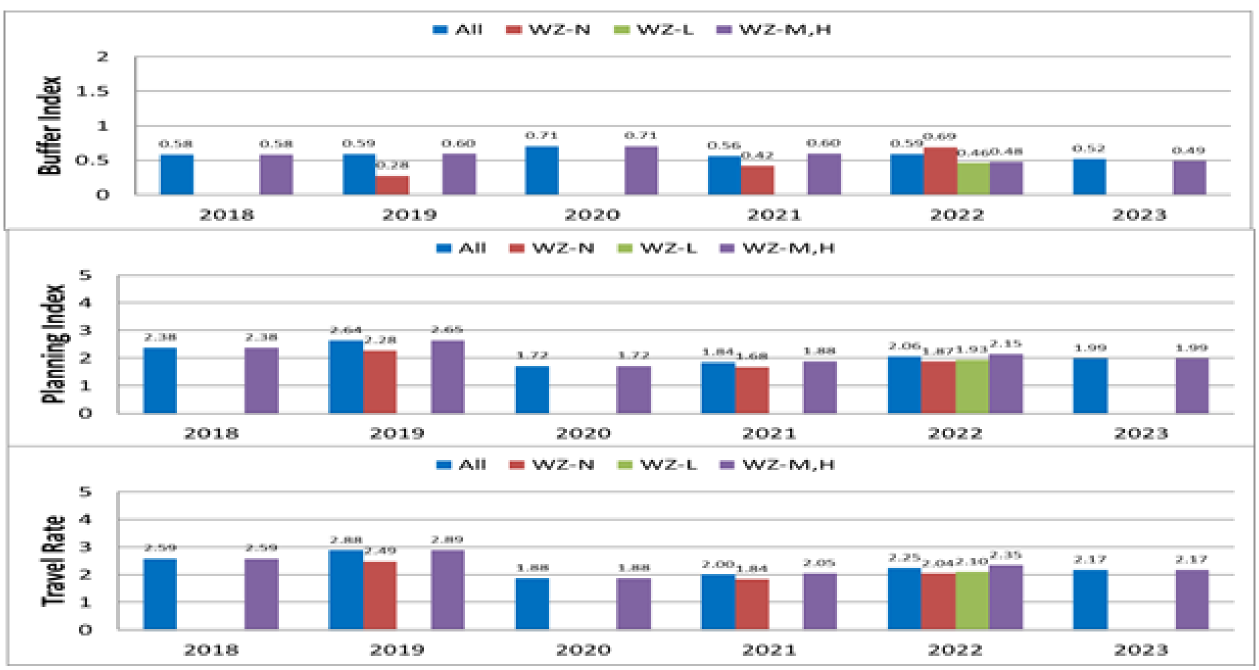
Yearly Variations - *Weather Effects*



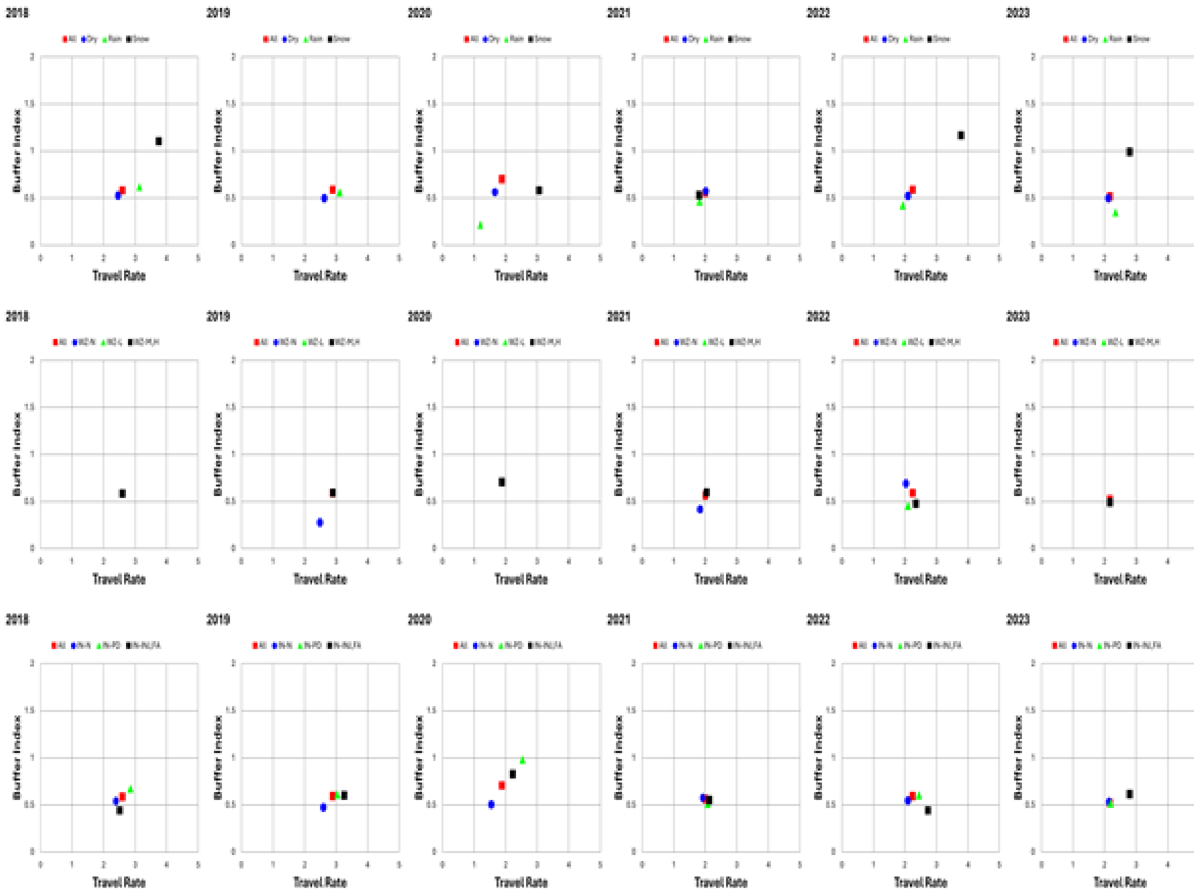
Incident Effects



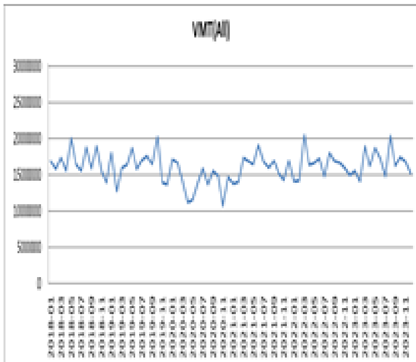
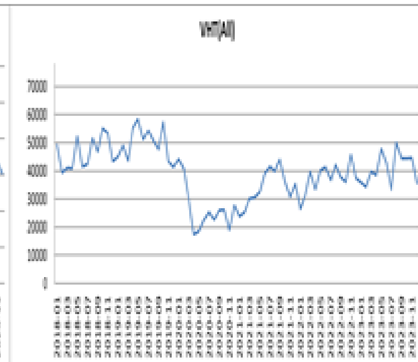
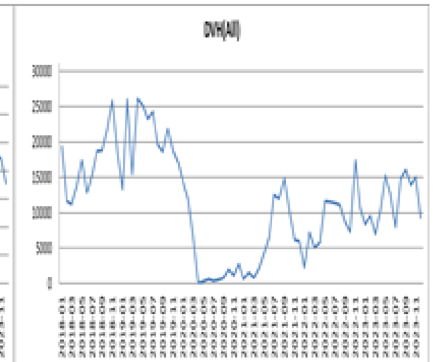
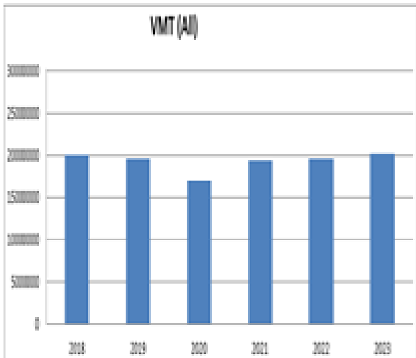
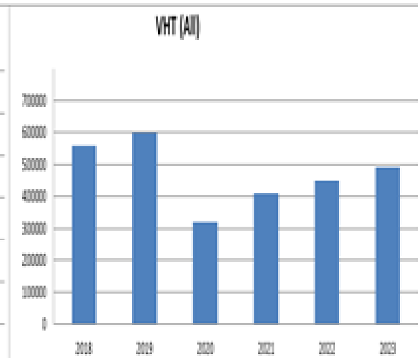
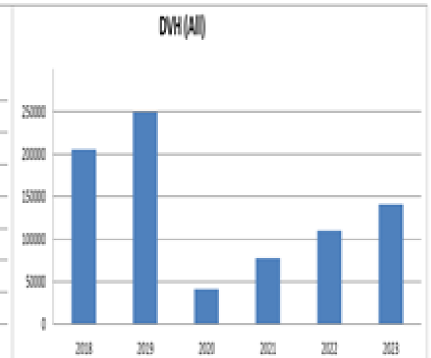
Work-Zone Effects



Yearly Variations of Buffer Index - Travel Rate Relationships

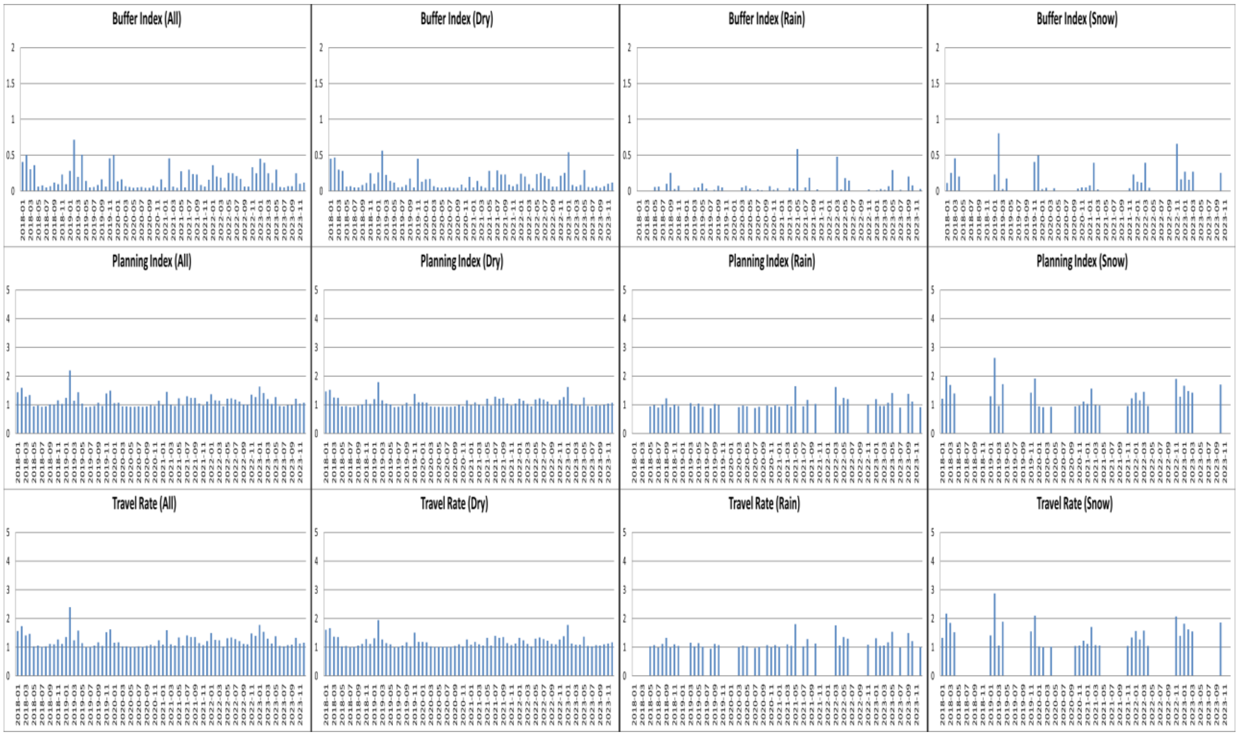


Variations of Traffic-Flow Measures

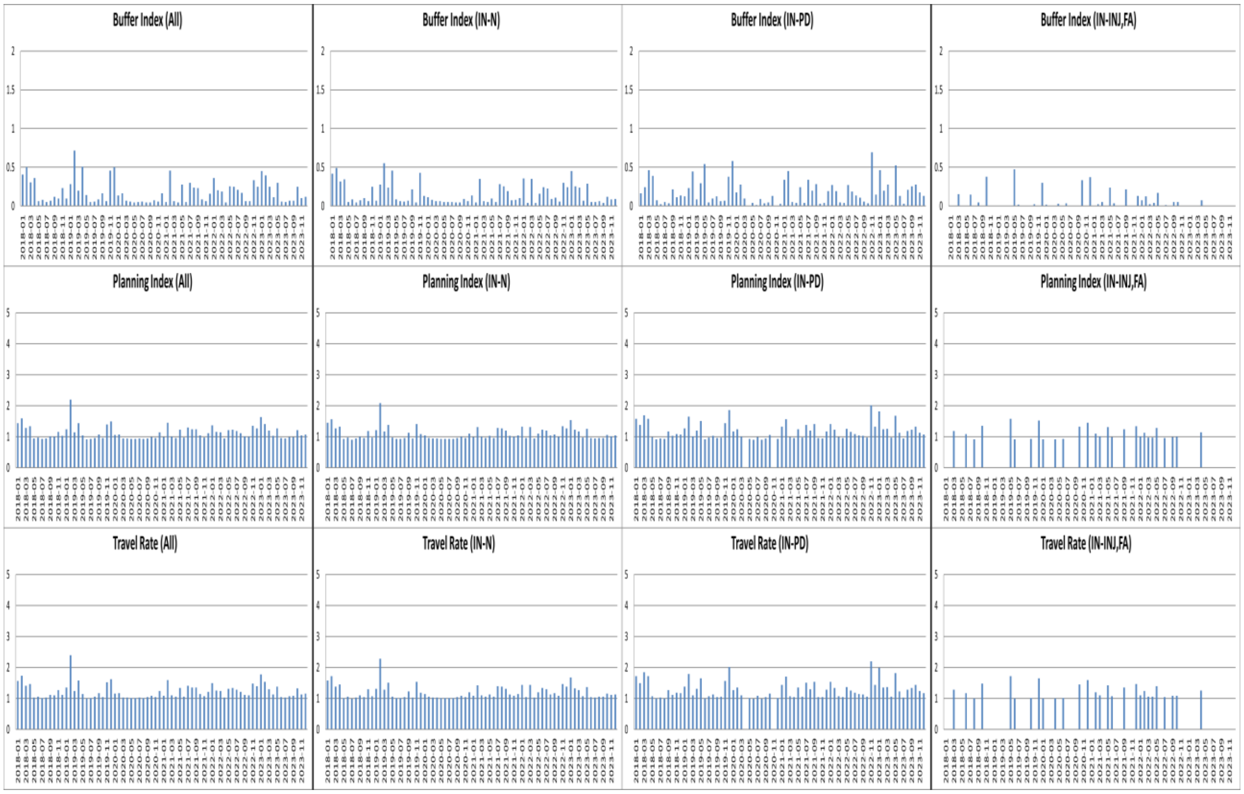

VMT(All)

VHT(All)

DVH(All)

VMT (All)
2018
2019
2020
2021
2022
2023

VHT (All)
2018
2019
2020
2021
2022
2023

DVH (All)
2018
2019
2020
2021
2022
2023

ii) I-94 Corridor D-- EB MPLS to STPL for Morning Peak Periods

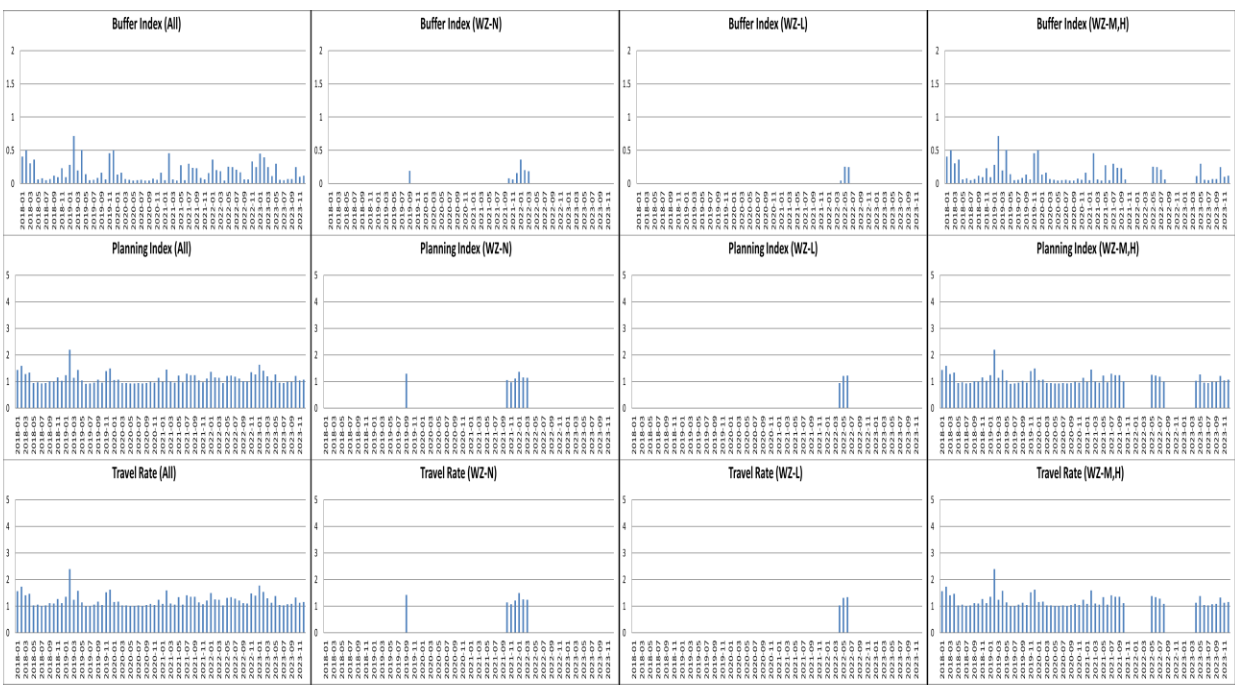
Effects of Weather conditions on Travel-Time Reliability



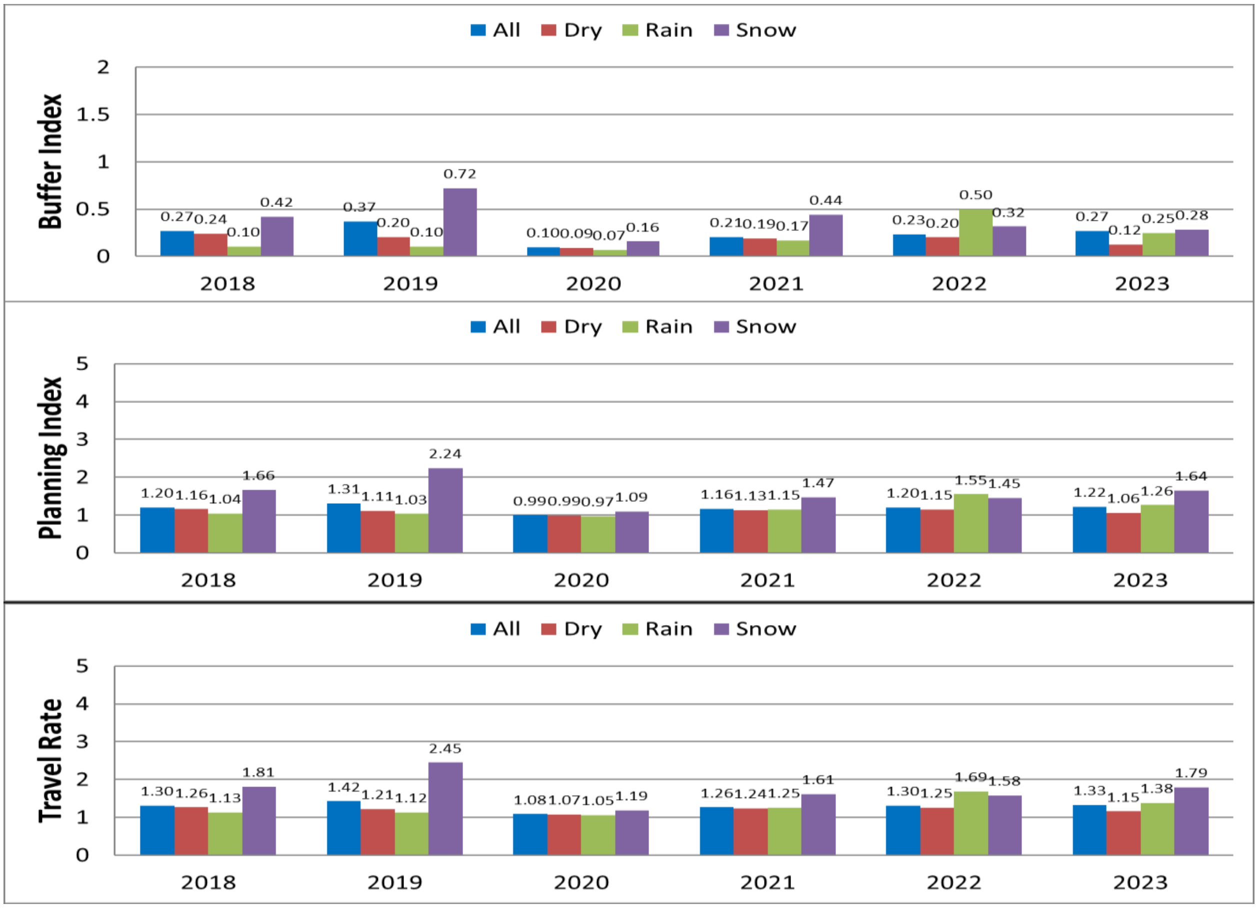
Effects of Incidents



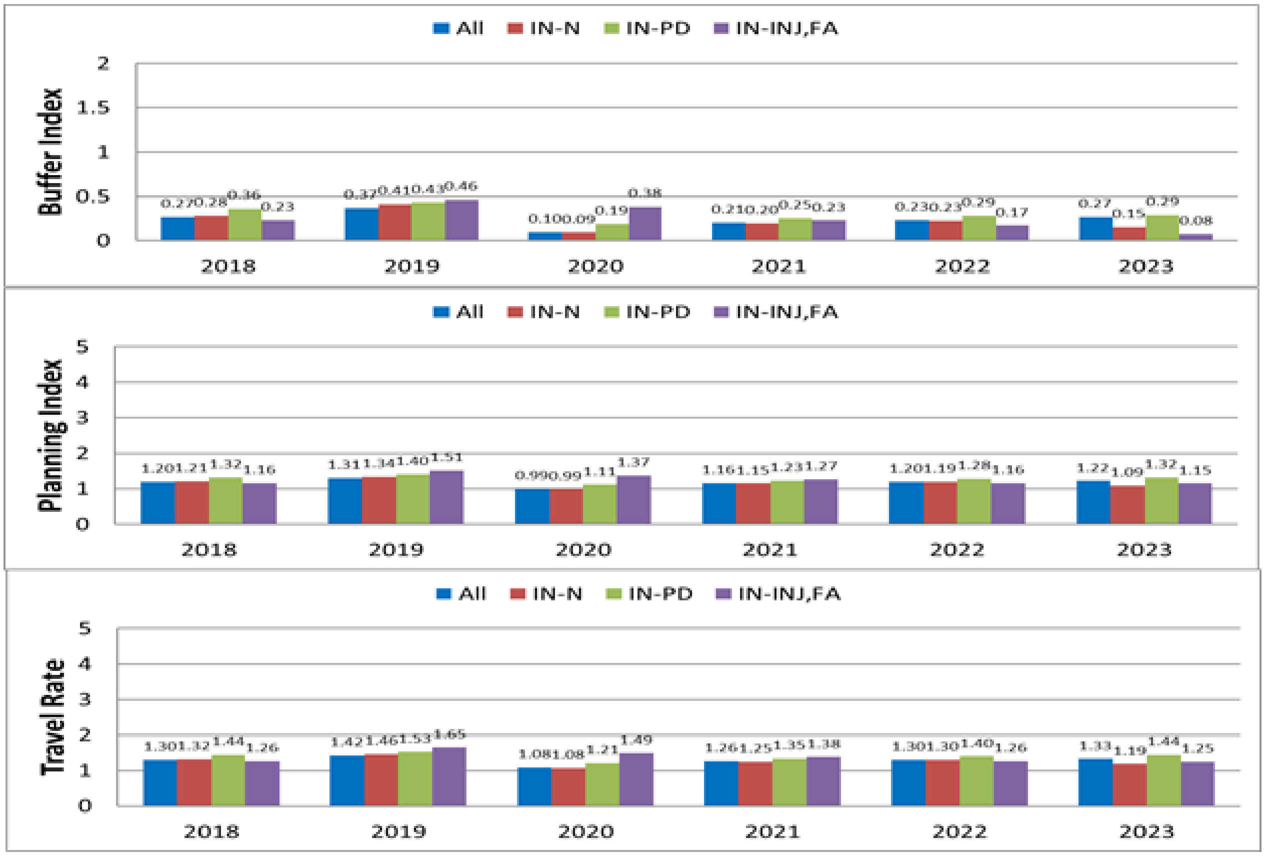
Effects of Work Zones



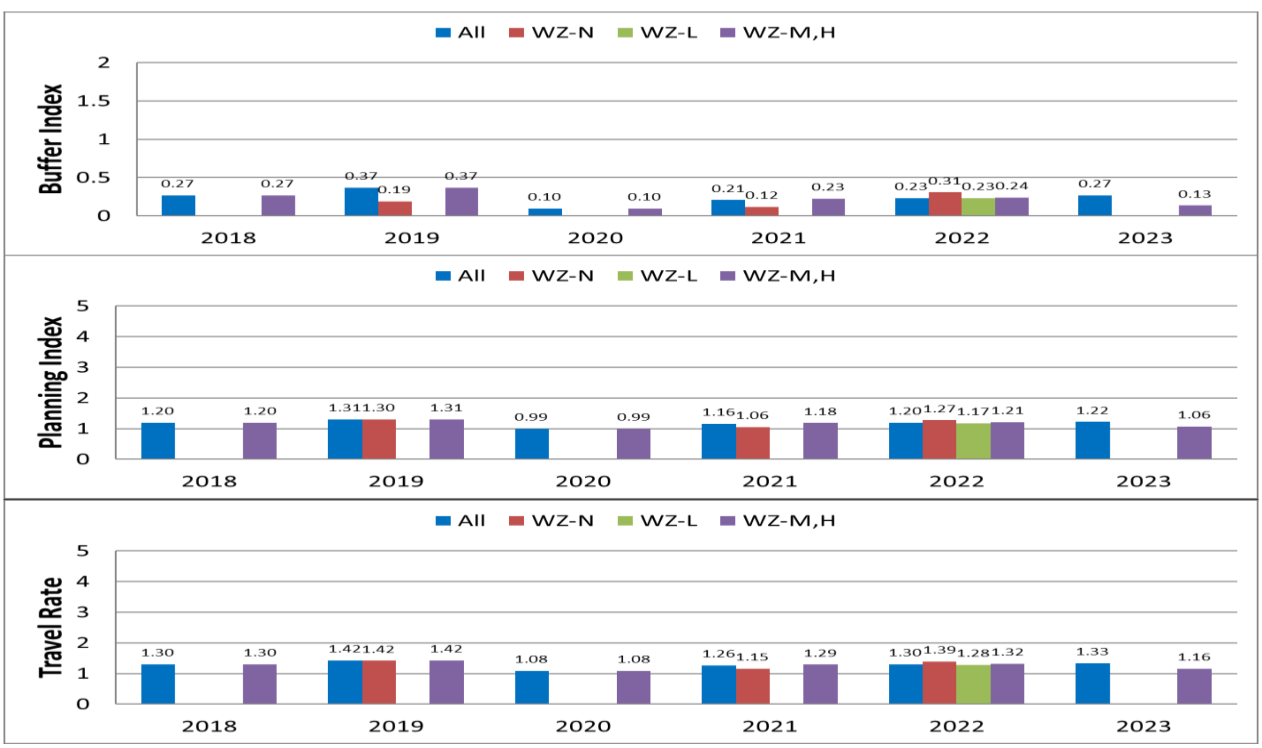
Yearly Variations - *Weather Effects*



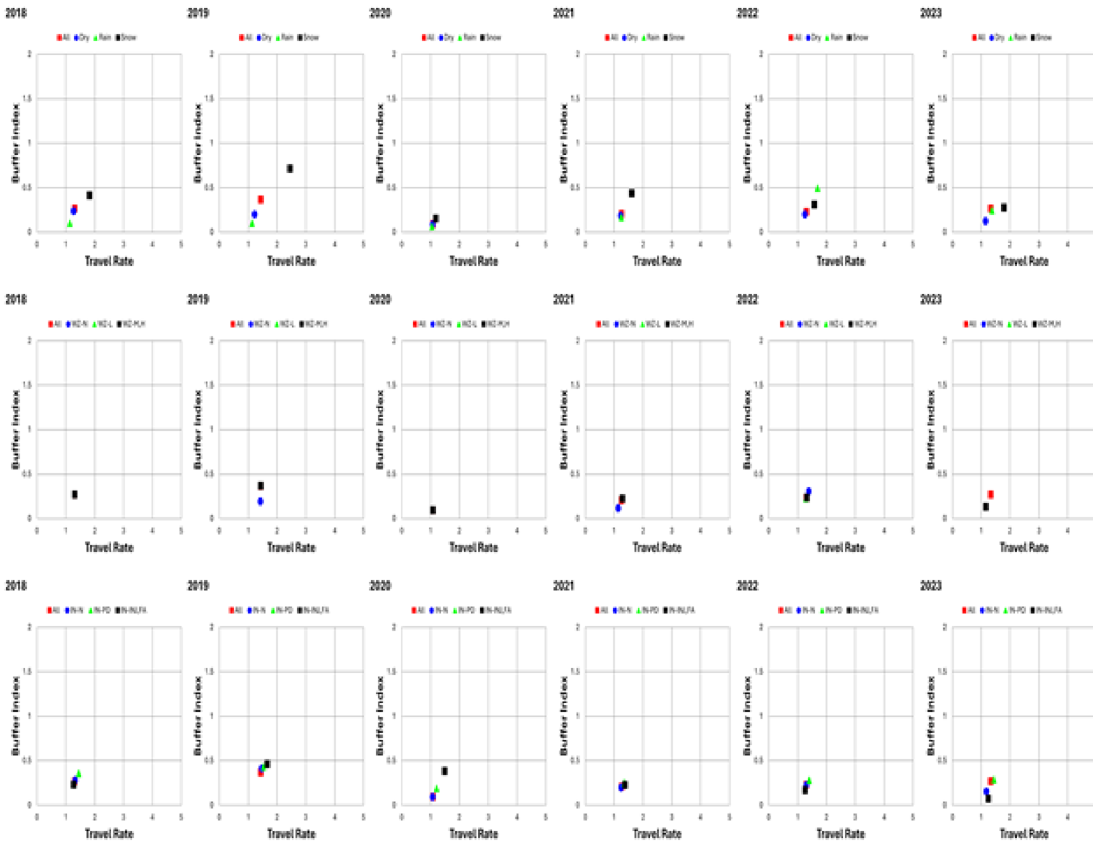
Incident Effects



Work-Zone Effects



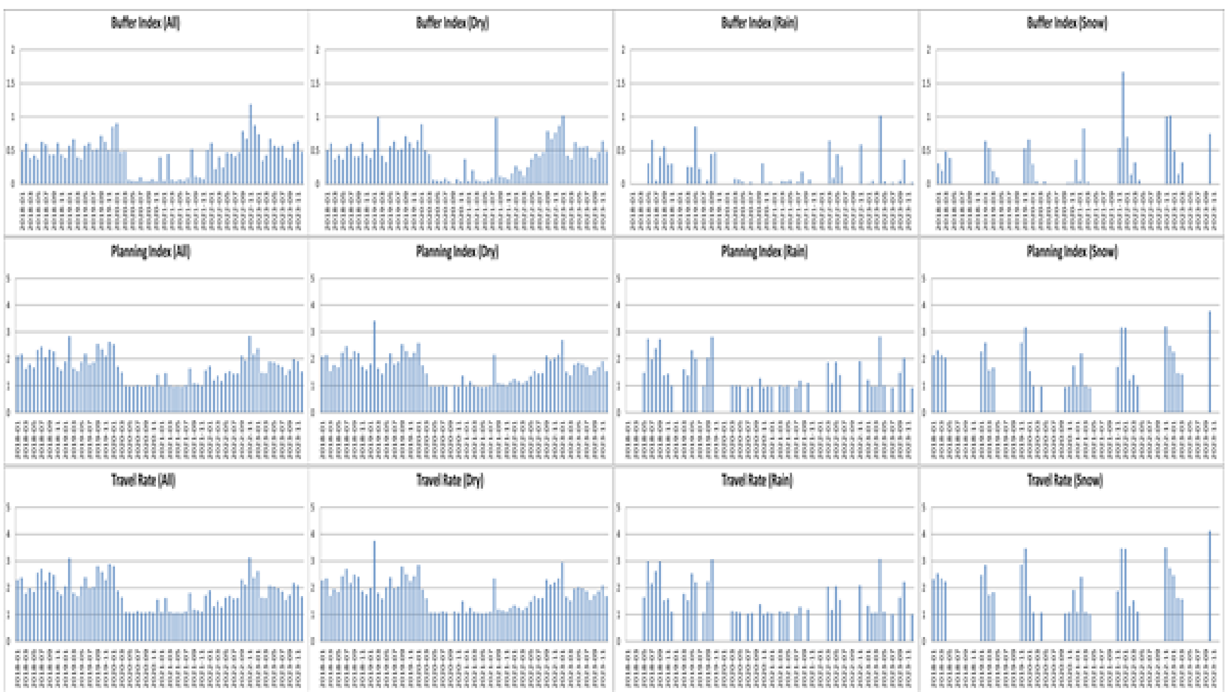
Yearly Variations of Buffer Index - Travel Rate Relationships



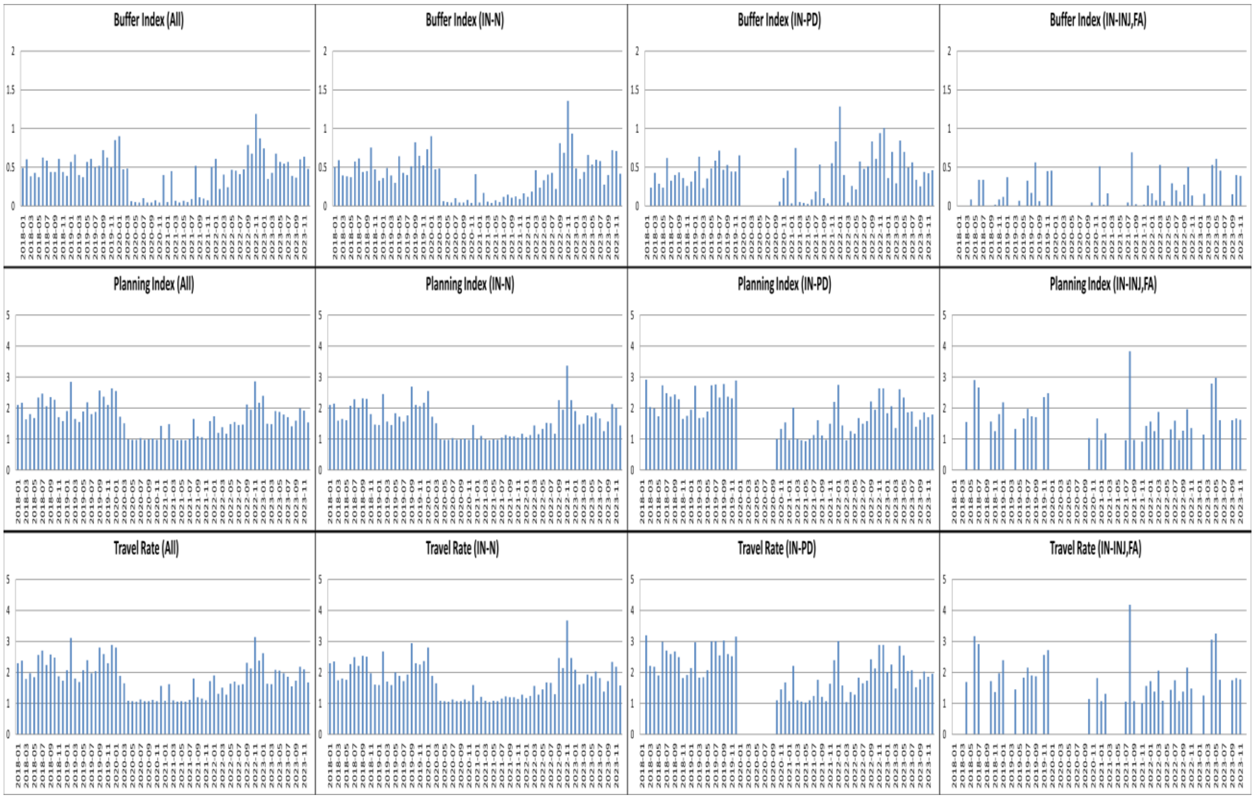
Variations of Traffic-Flow Measures

iii) I-94 Corridor D -- WB STPL to MPLS for Morning Peak Periods

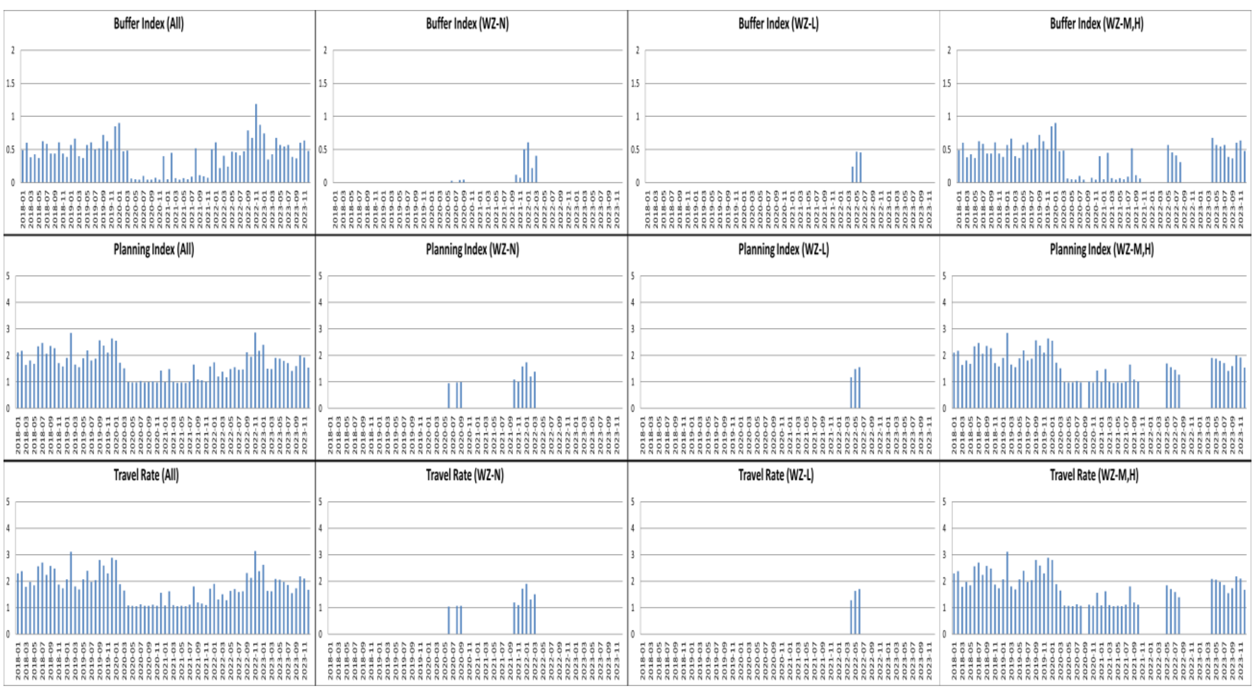
Effects of Weather conditions on Travel-Time Reliability



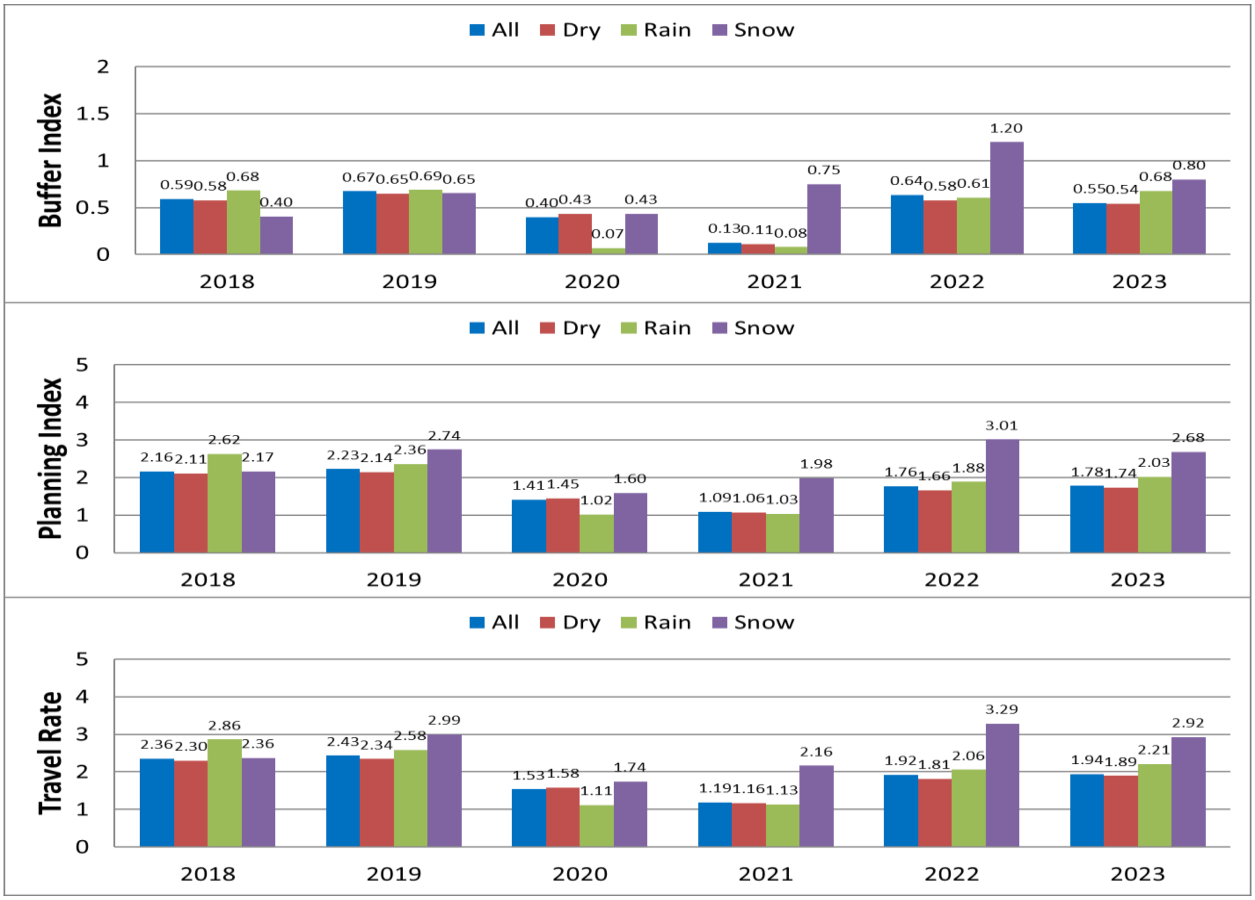
Effects of Incidents



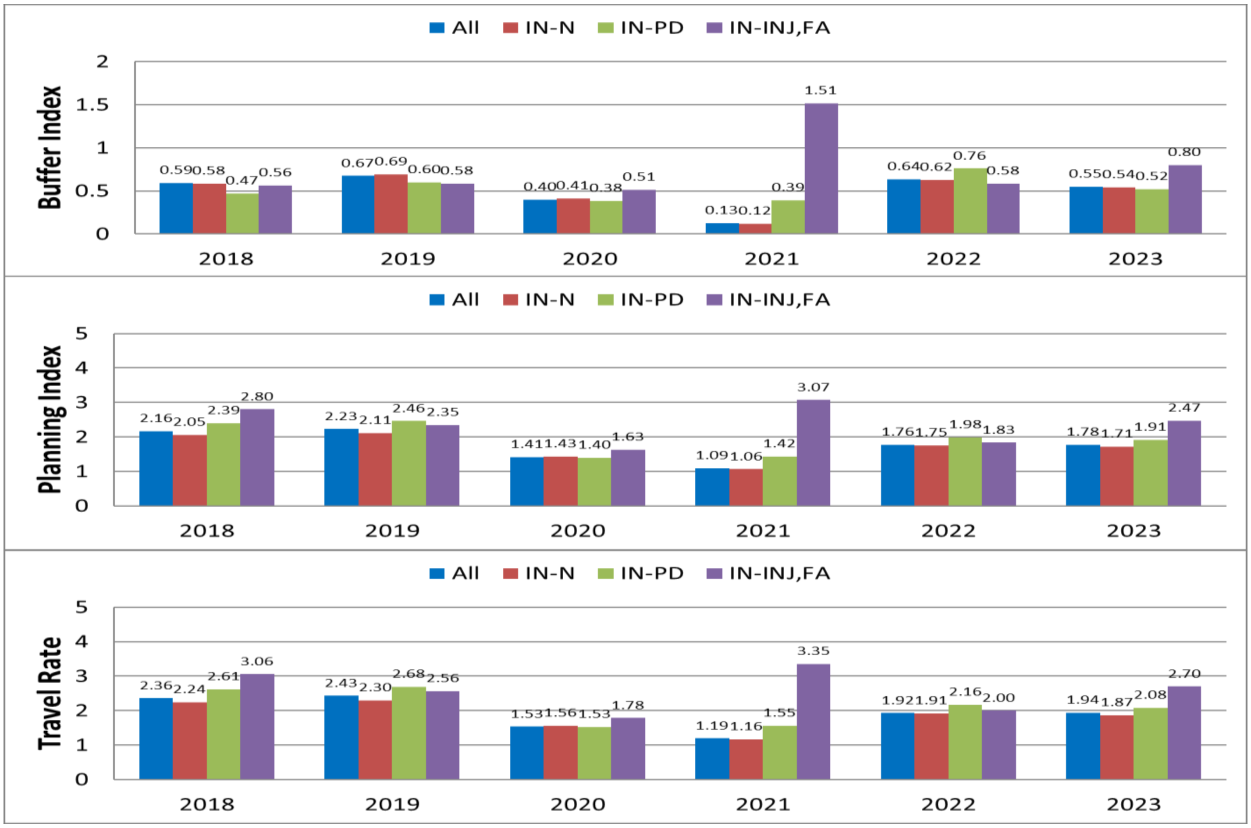
Effects of Work Zones



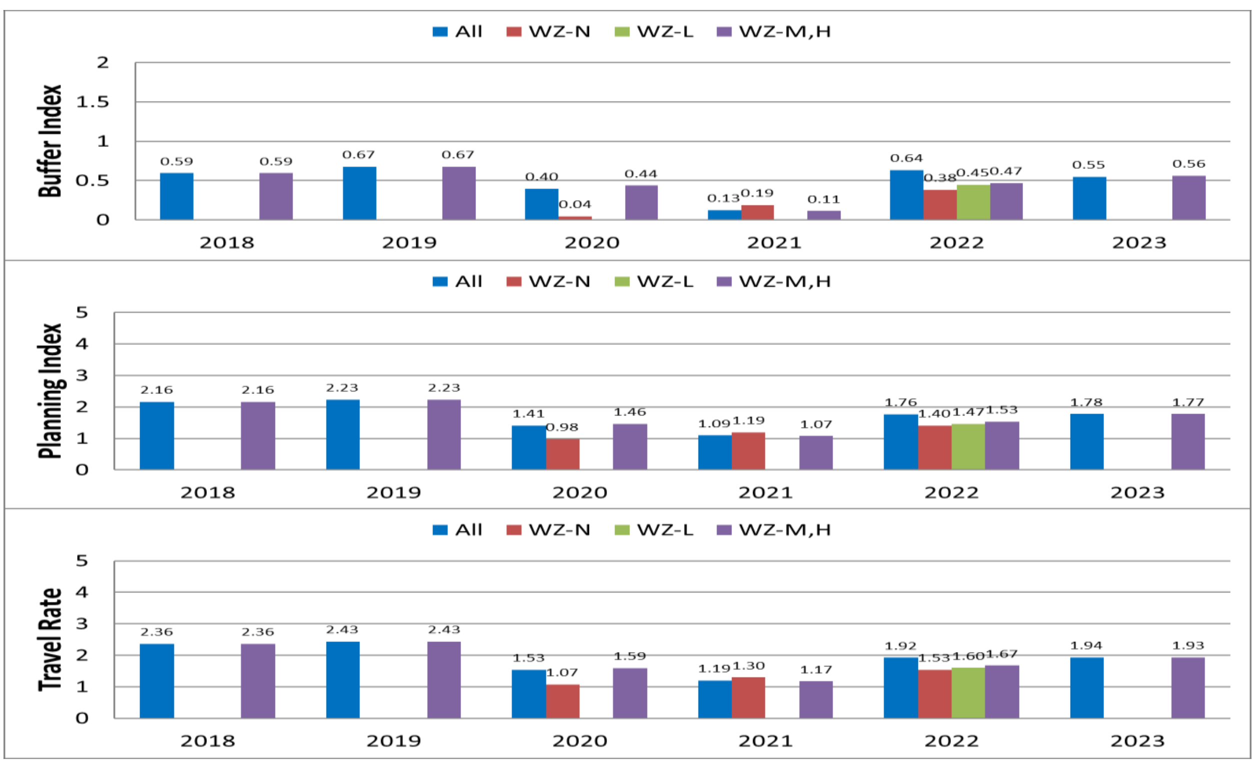
Yearly Variations - *Weather Effects*



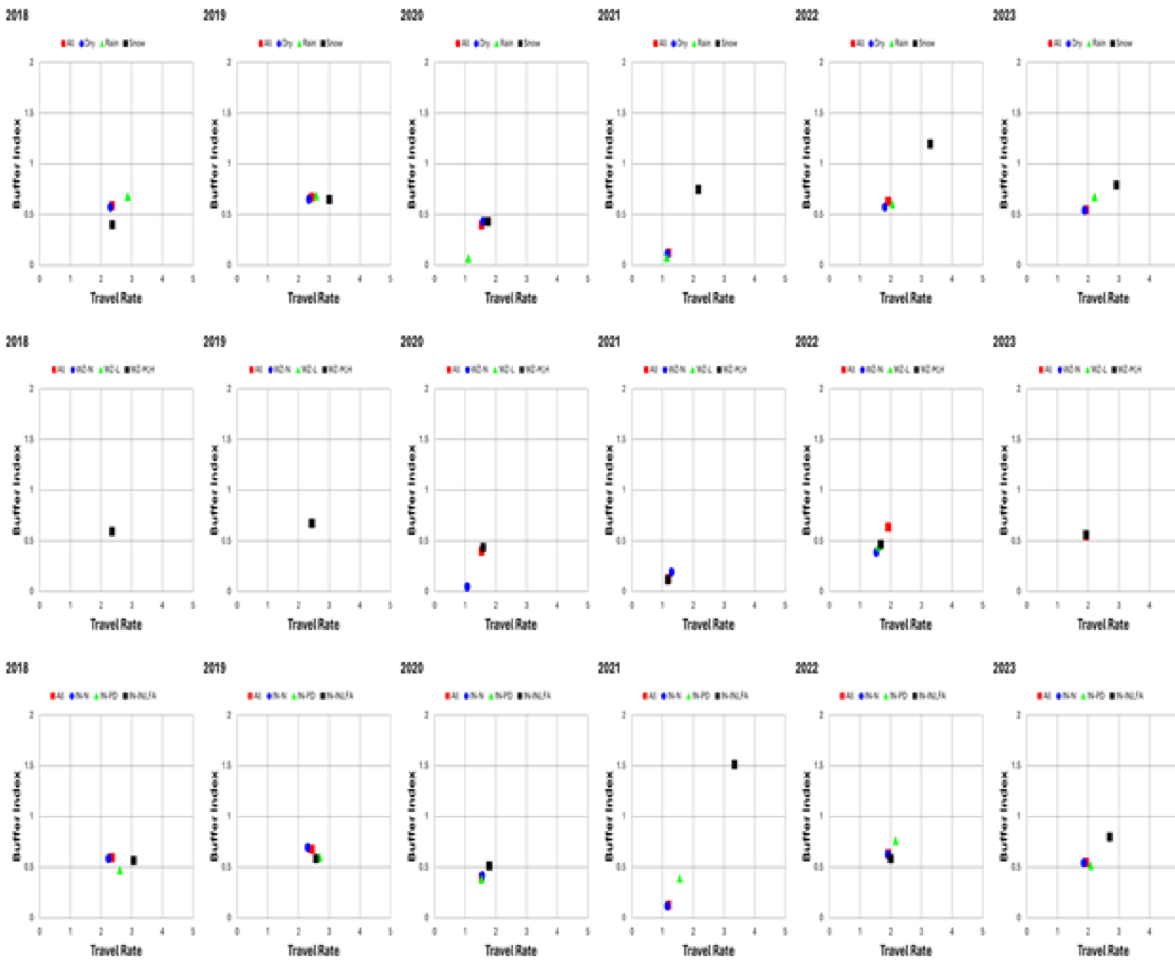
Incident Effects



Work-Zone Effects



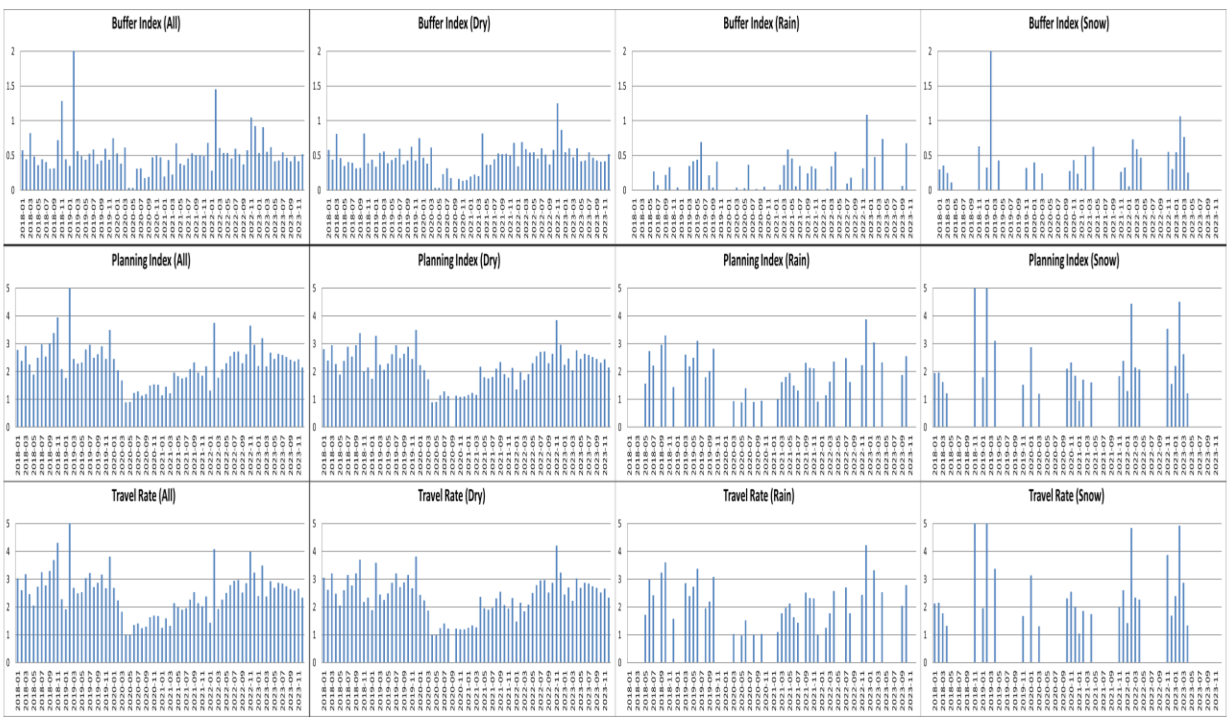
Yearly Variations of Buffer Index - Travel Rate Relationships



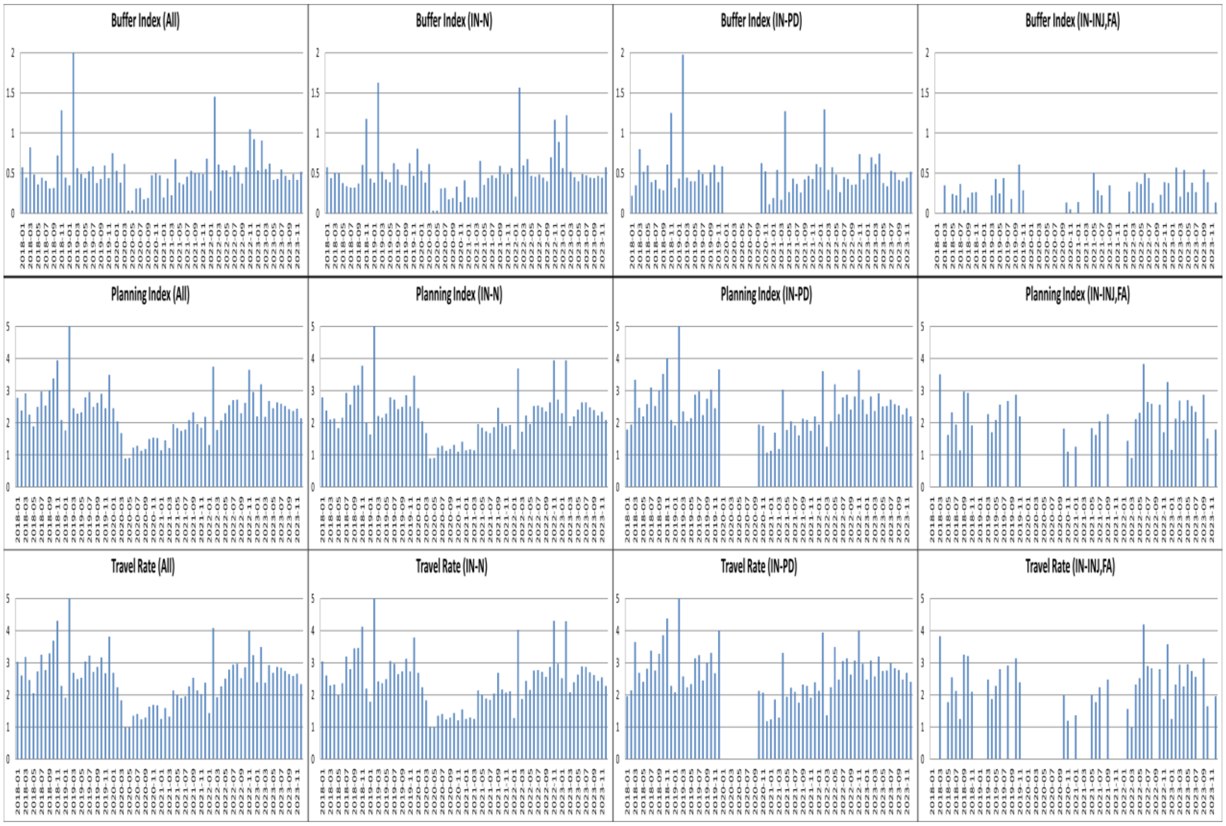
Variations of Traffic-Flow Measures

iv) I-94 Corridor D -- WB STPL to MPLS to Afternoon Peak Periods

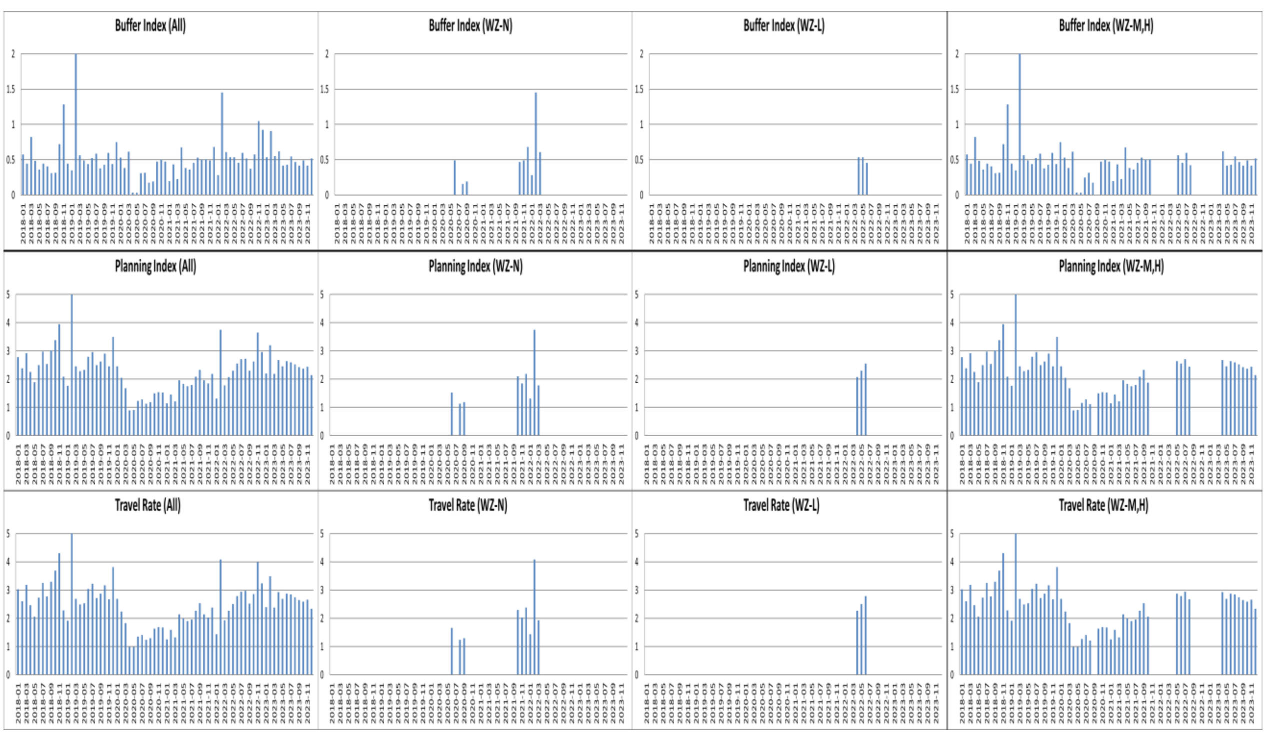
Effects of Weather conditions on Travel-Time Reliability



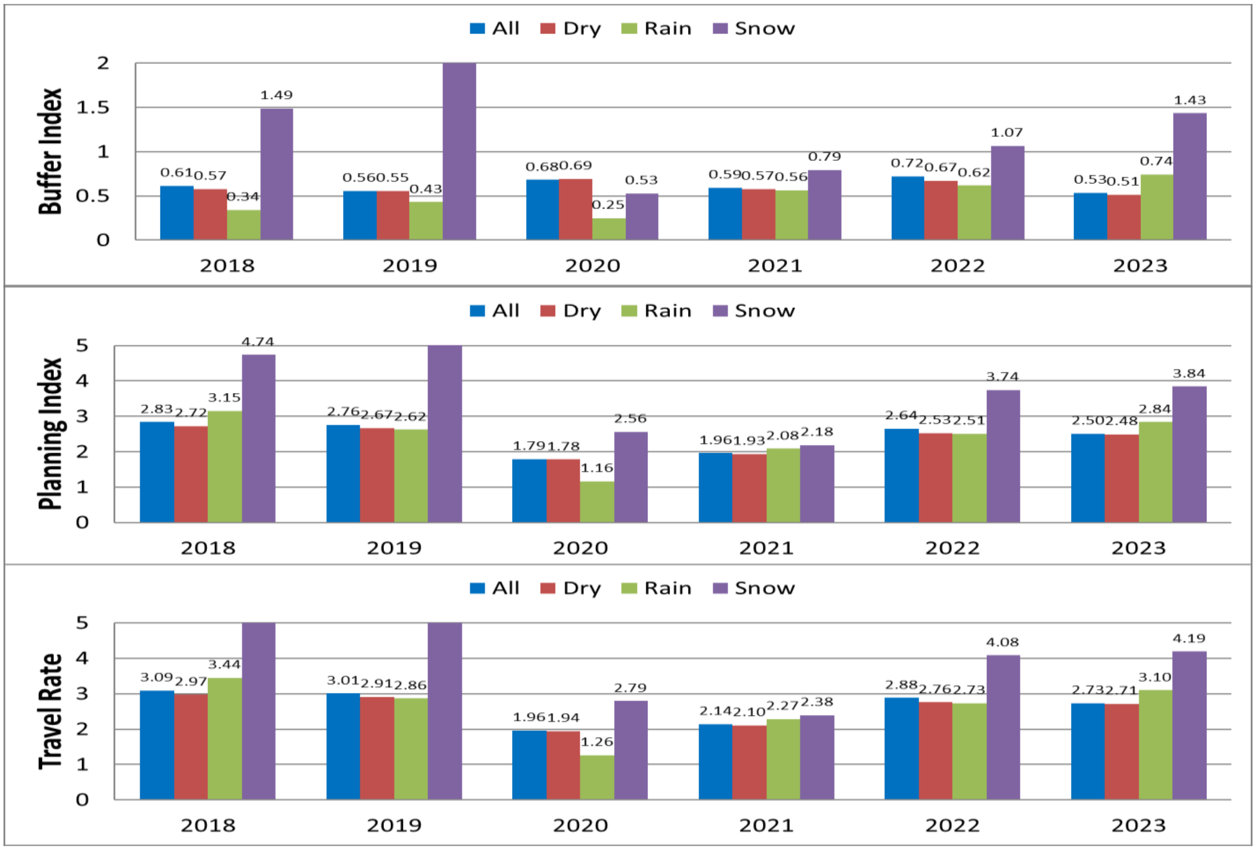
Effects of Incidents



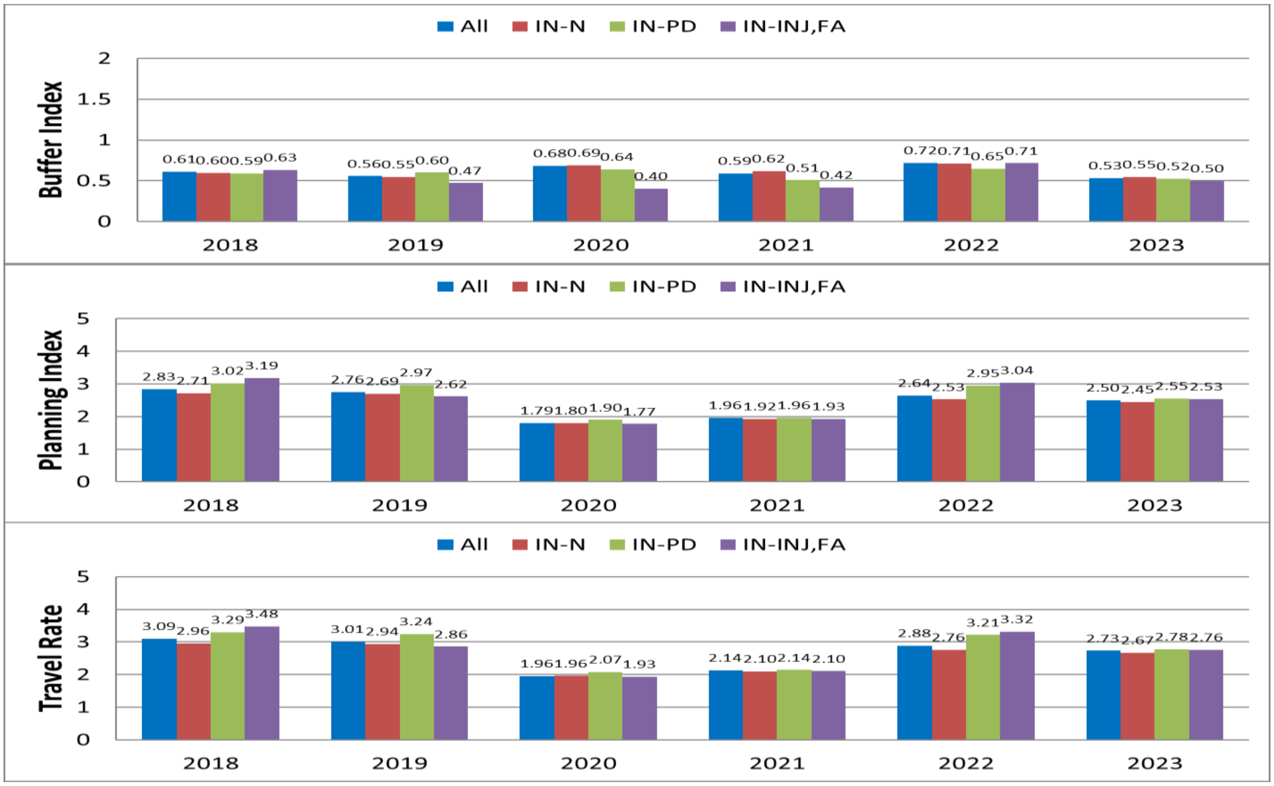
Effects of Work Zones



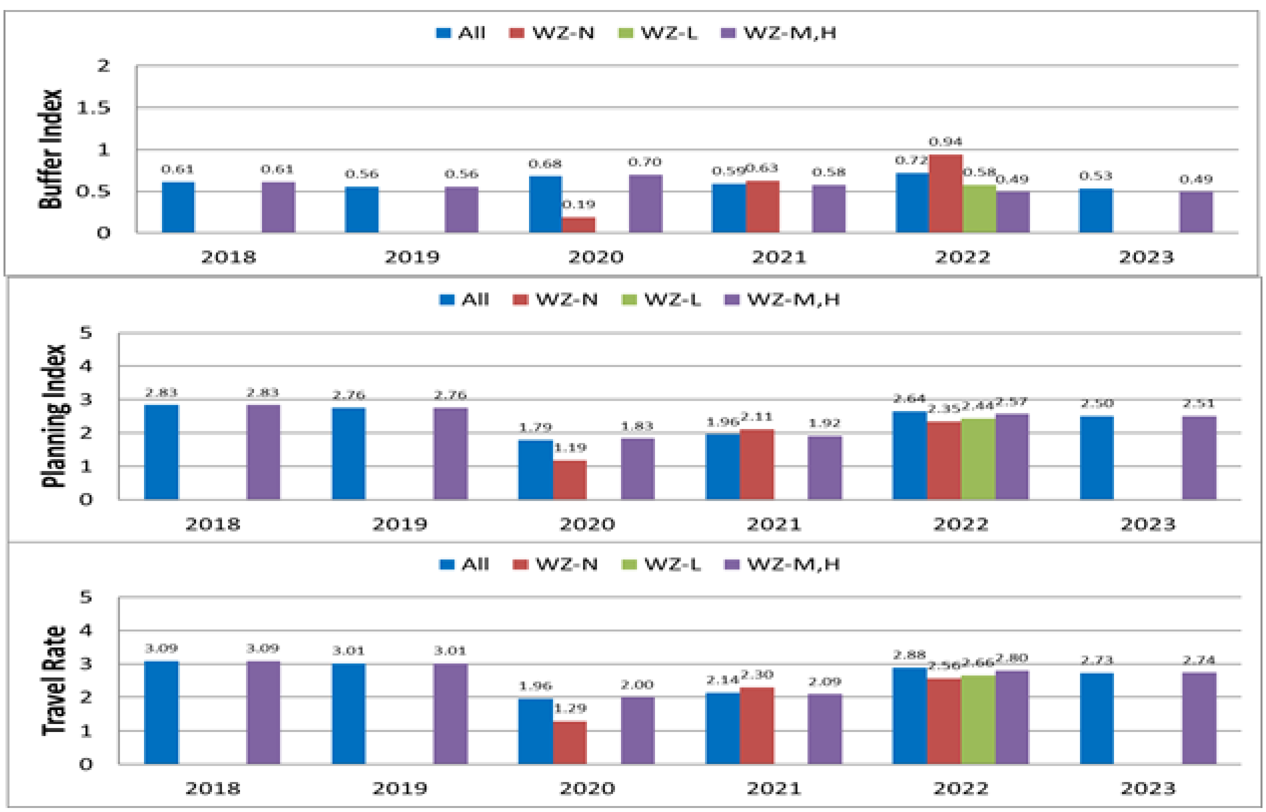
Yearly Variations - *Weather Effects*



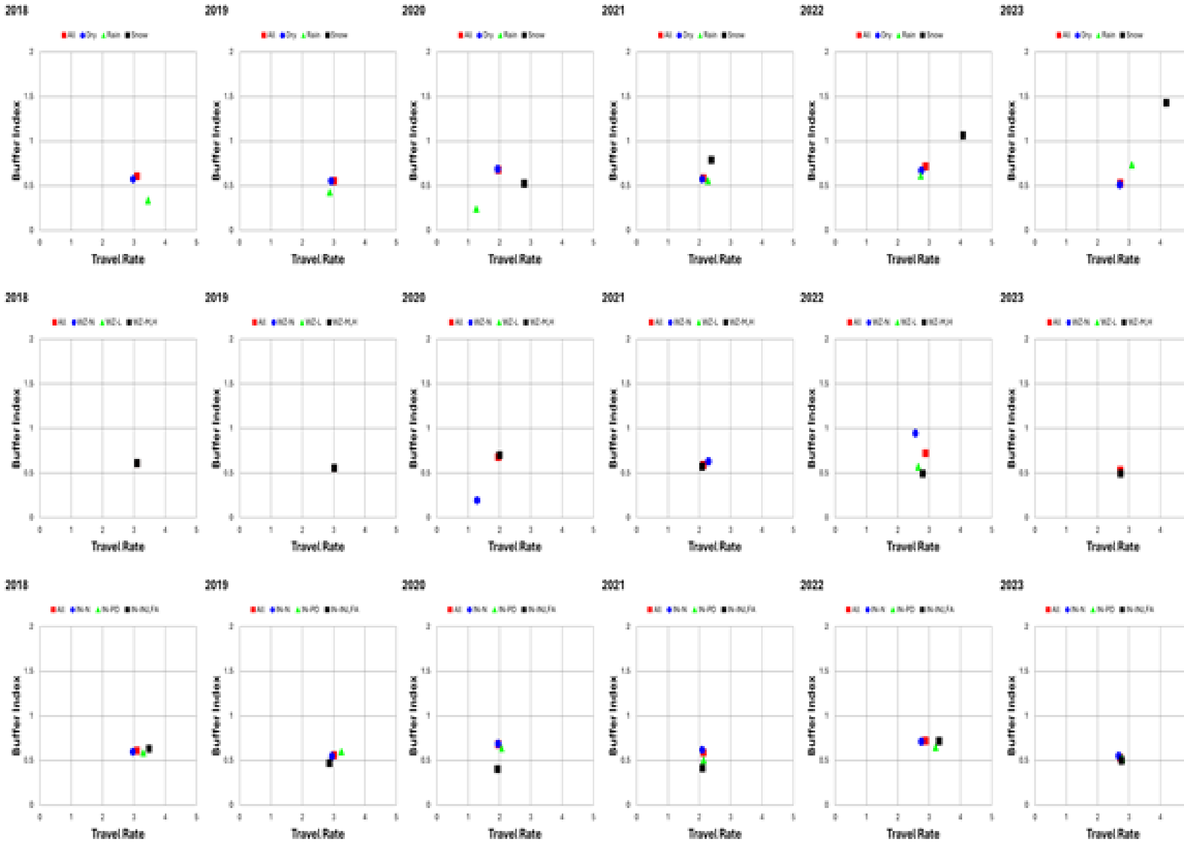
Incident Effects



Work-Zone Effects



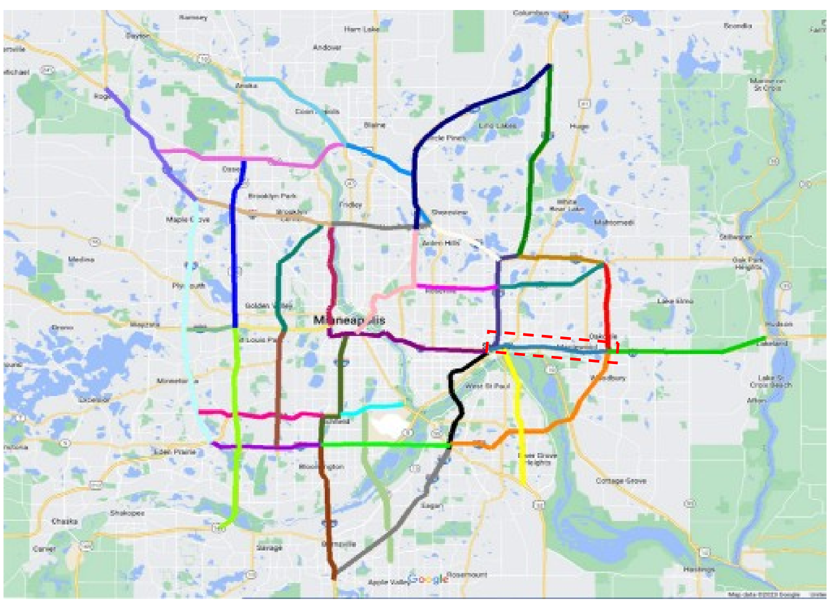
Yearly Variations of Buffer Index - Travel Rate Relationships



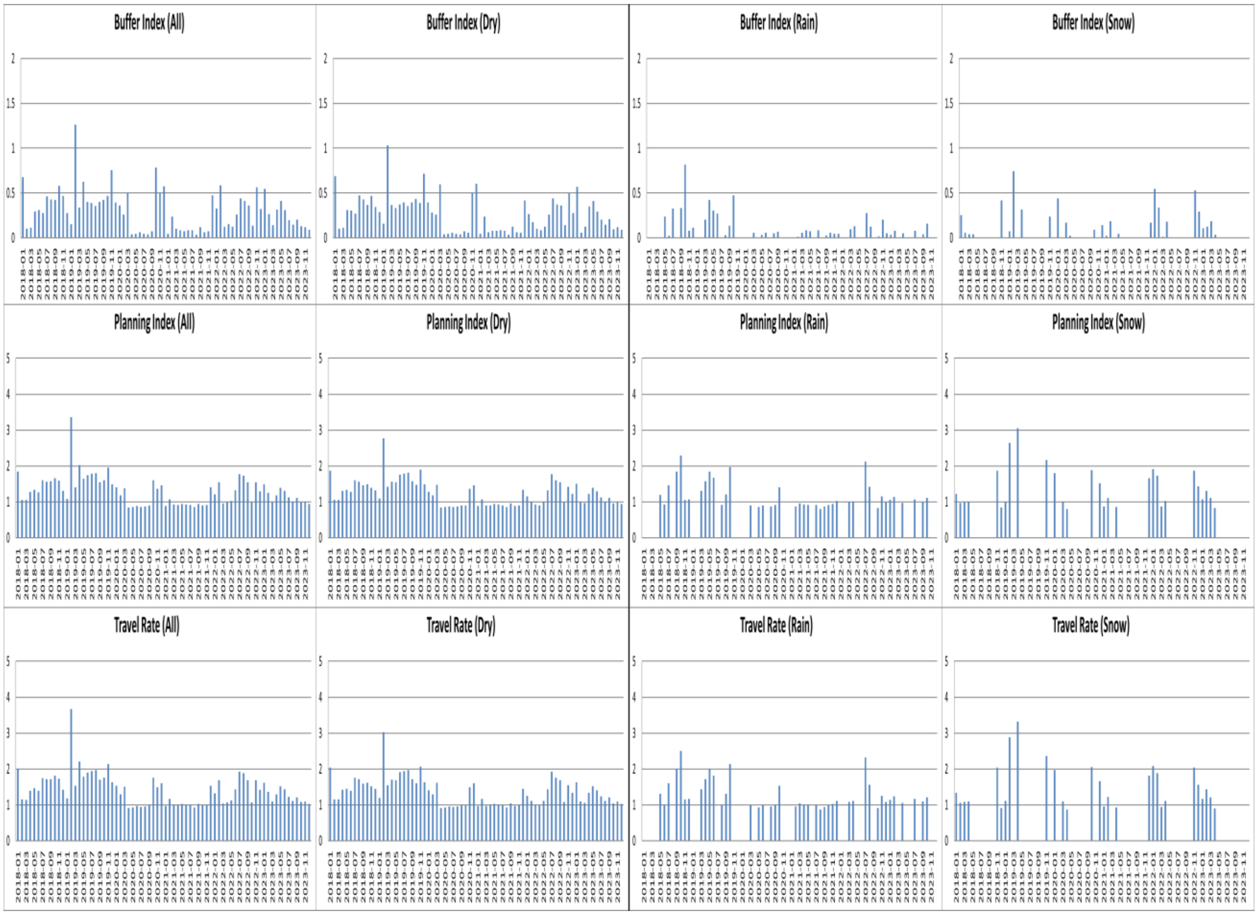
Variations of Traffic-Flow Measures

23) I-94 Corridor E (STPL < -- > I694)

i) I-94 Corridor E -- EB STPL to I694 for Afternoon Peak Periods

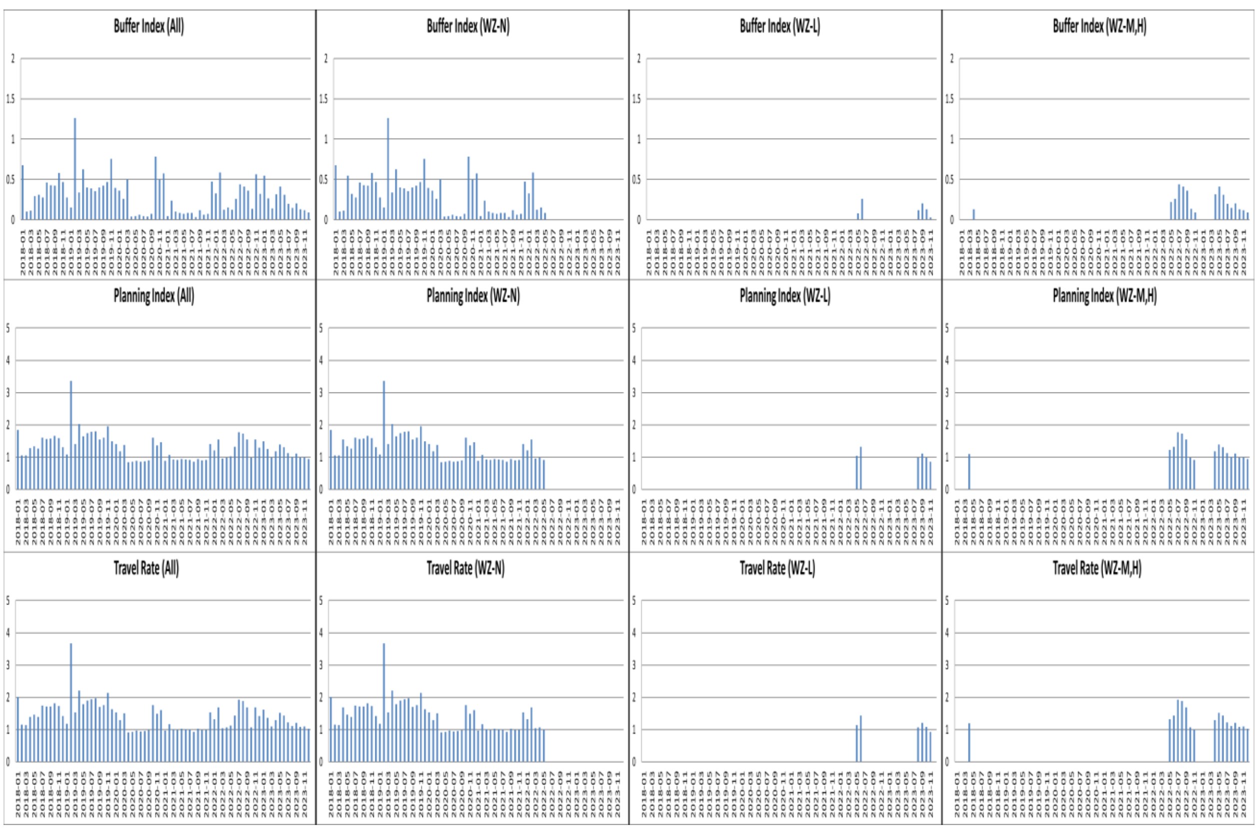


Effects of Weather conditions on Travel-Time Reliability

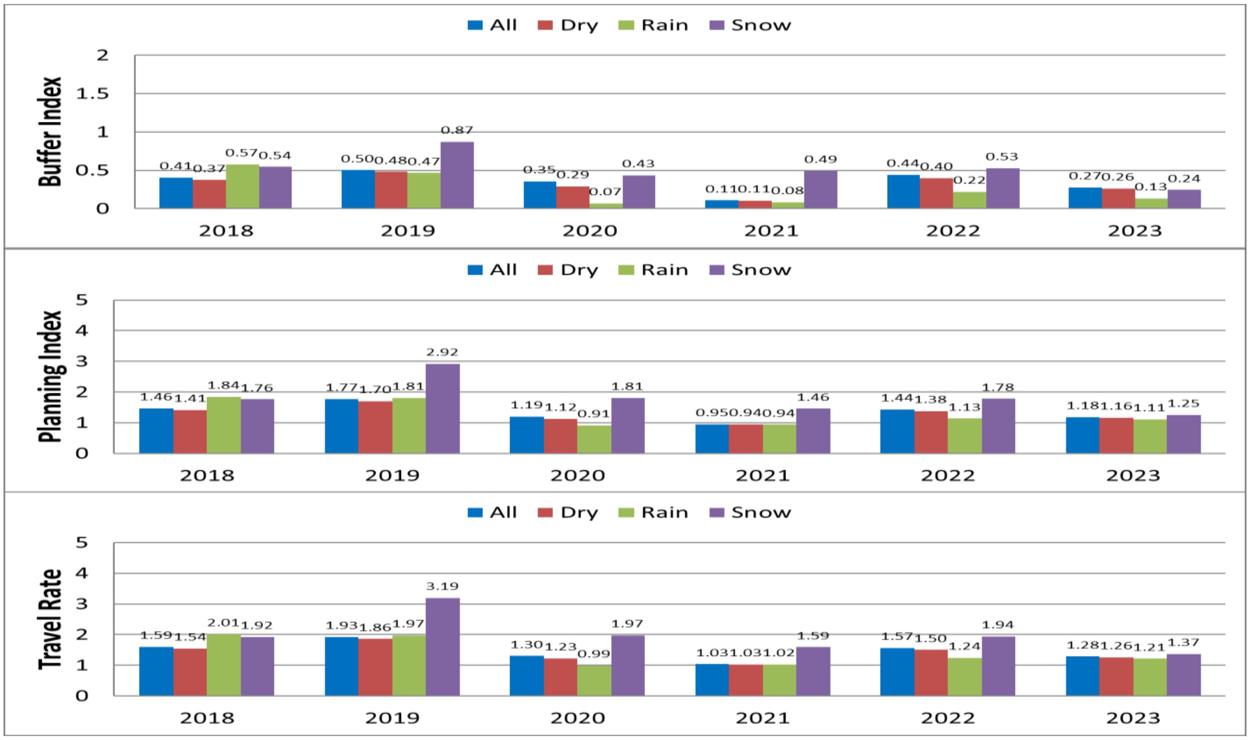


Effects of Incidents

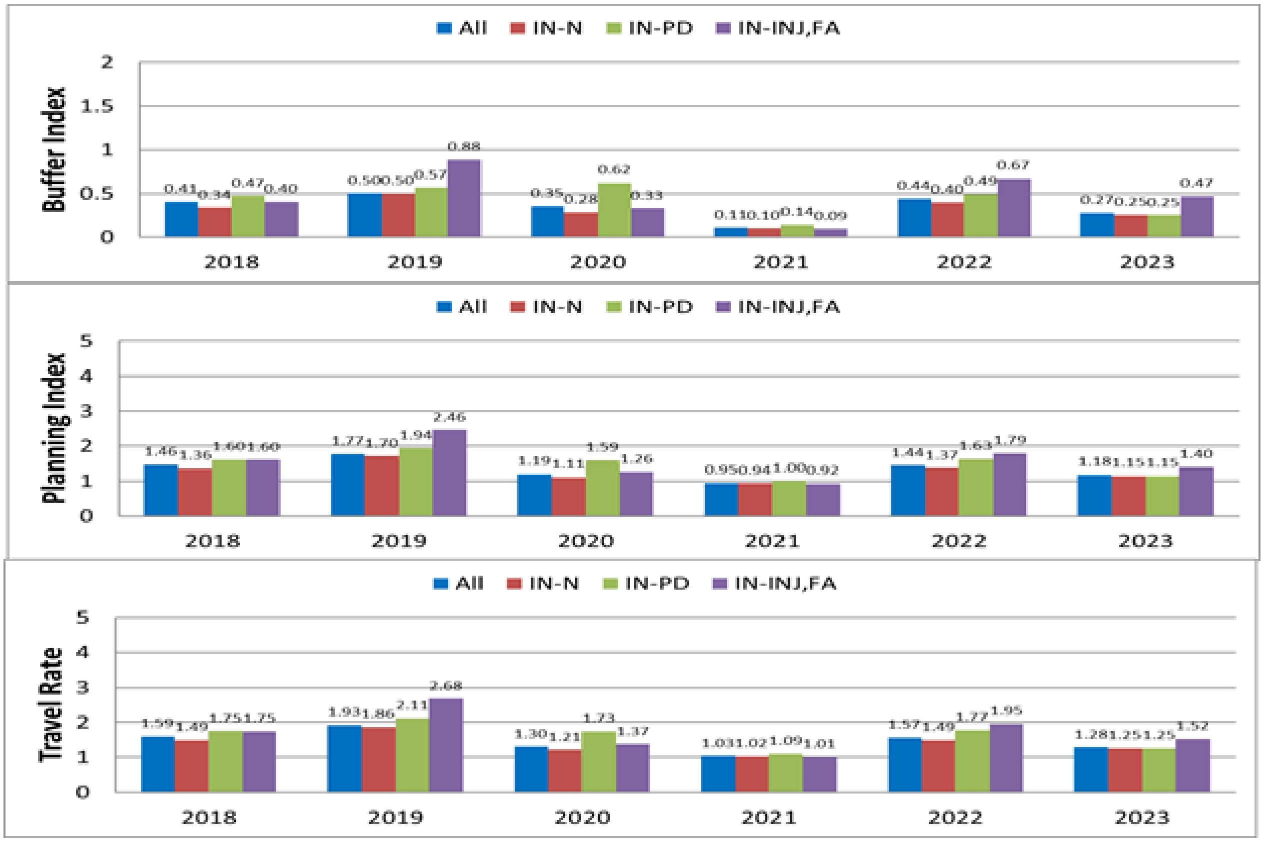
Effects of Work Zones



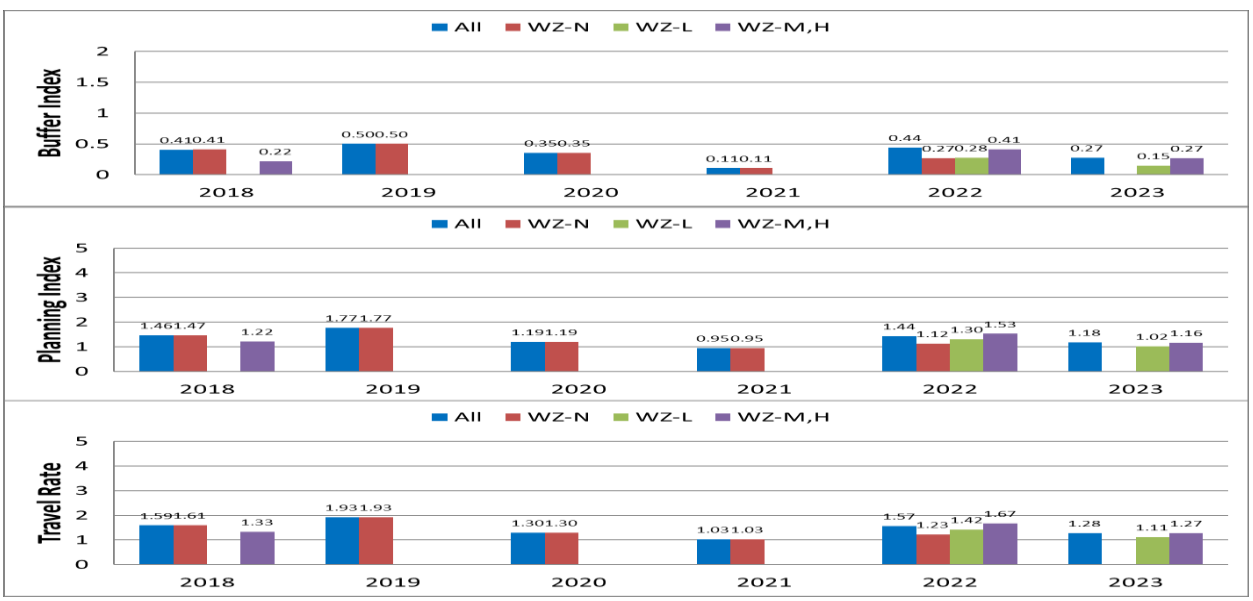
Yearly Variations - *Weather Effects*



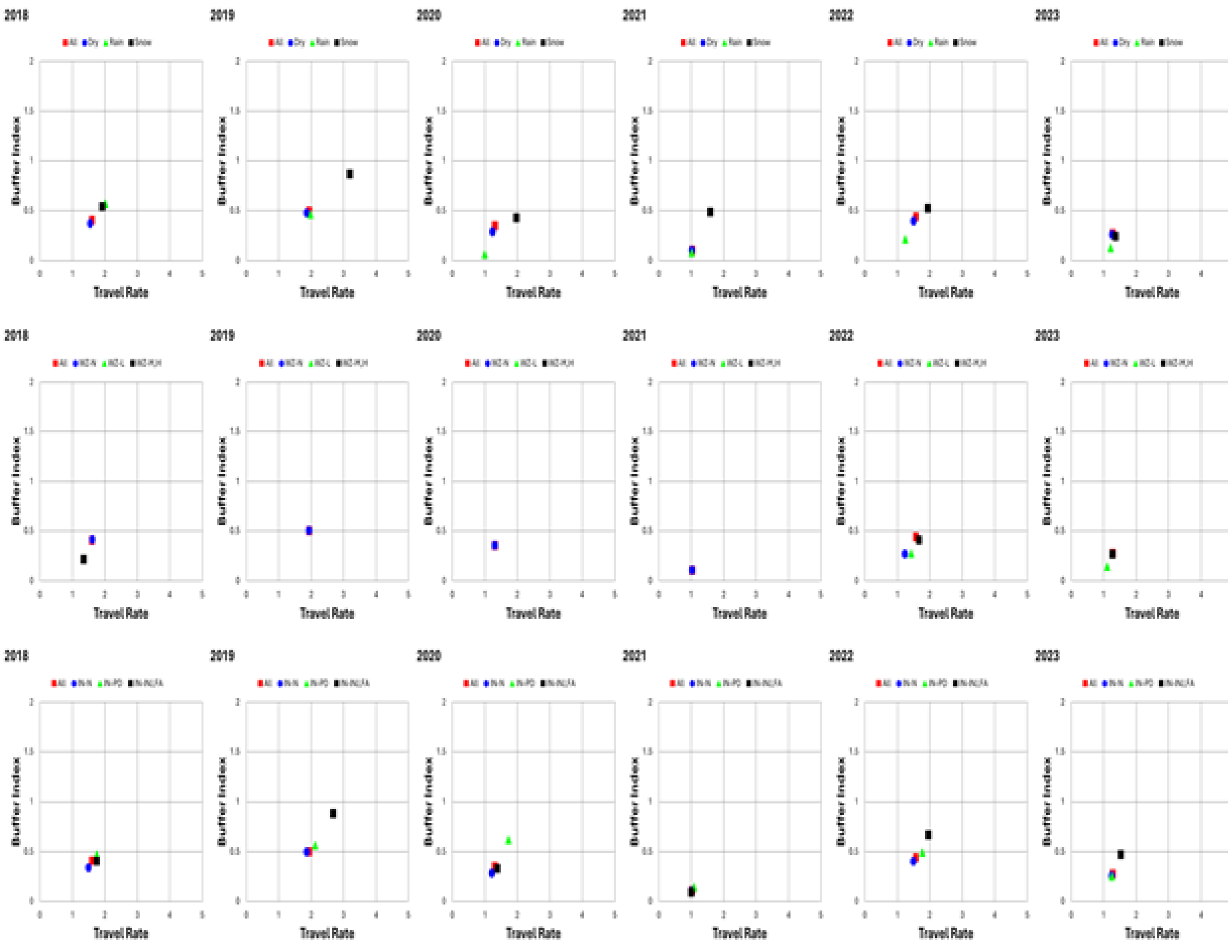
Incident Effects



Work-Zone Effects



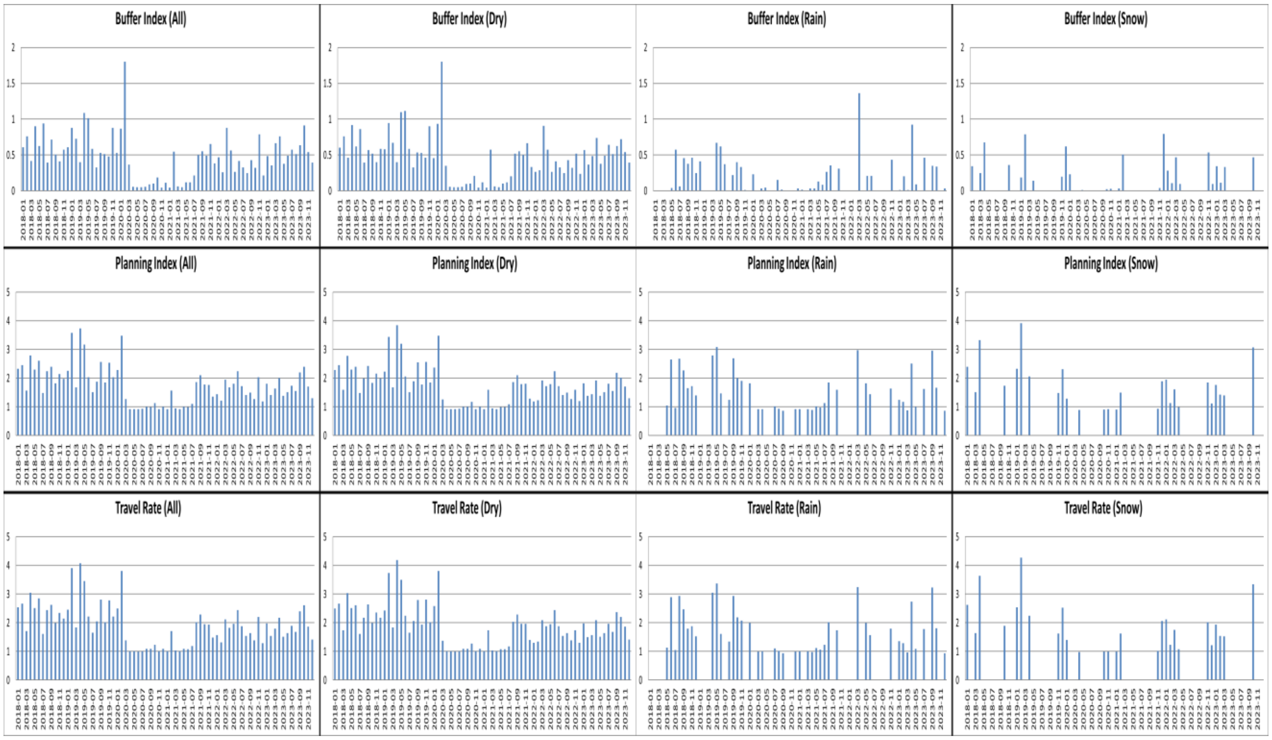
Yearly Variations of Buffer Index - Travel Rate Relationships



Variations of Traffic-Flow Measures

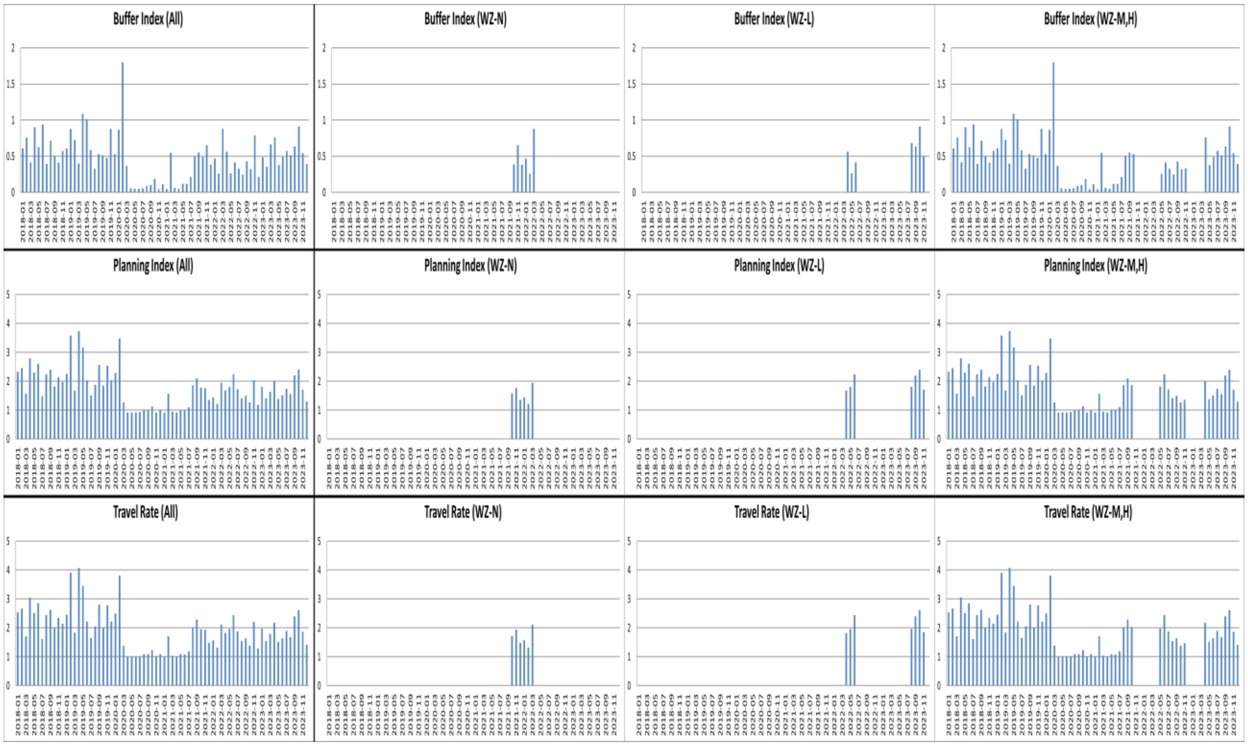
ii) I-94 Corridor E -- WB I694 to STPL for Morning Peak Periods

Effects of Weather conditions on Travel-Time Reliability

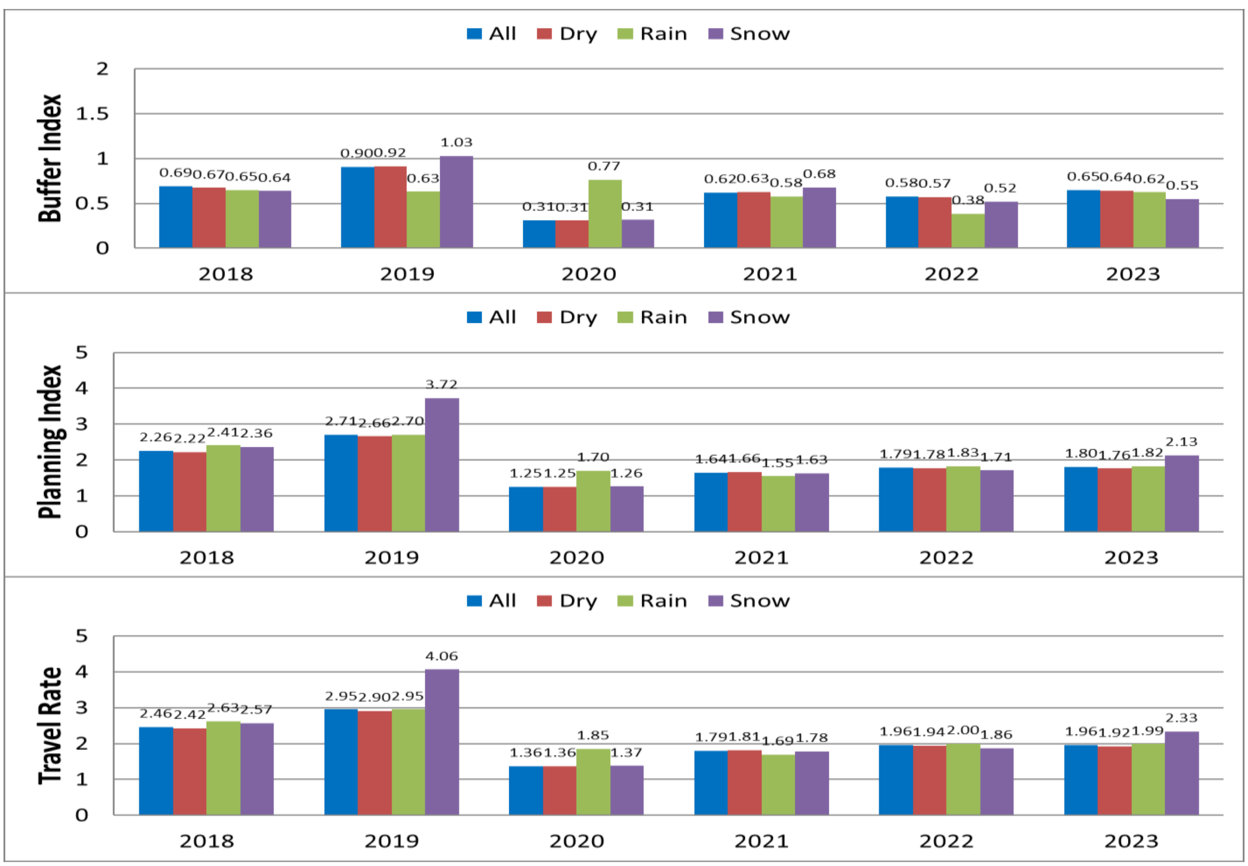


Effects of Incidents

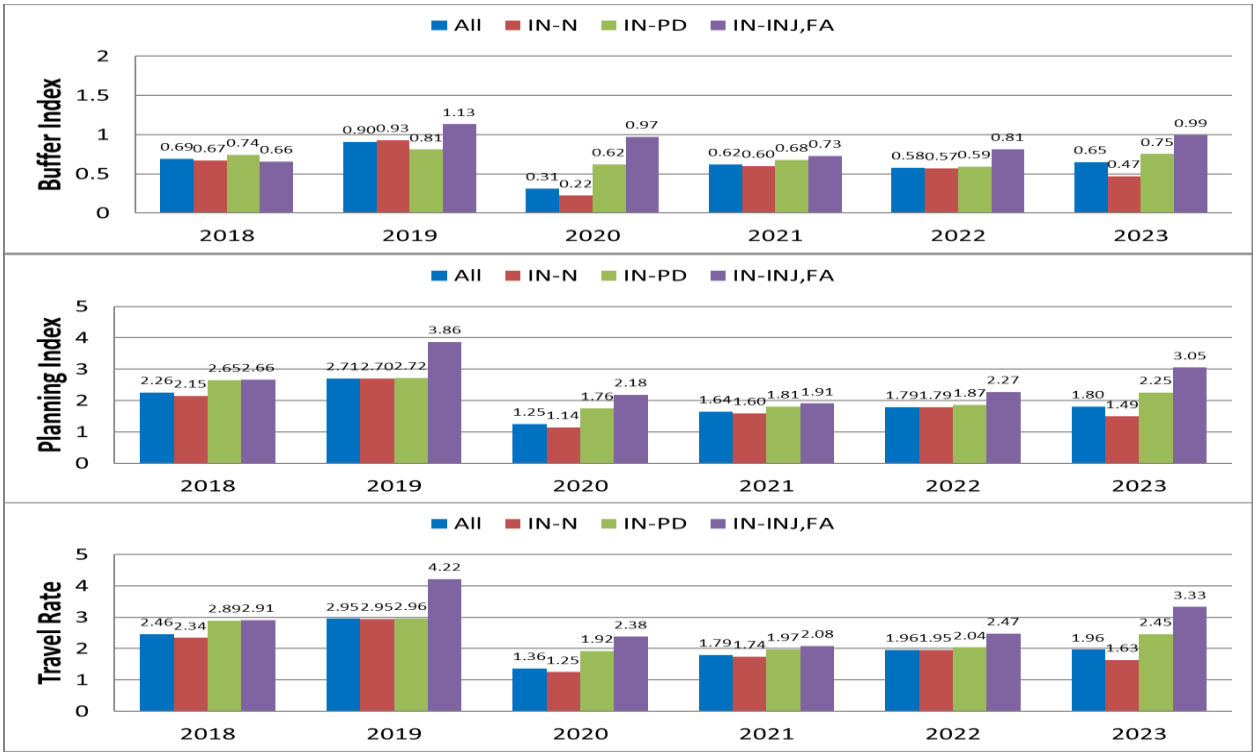
Effects of Work Zones



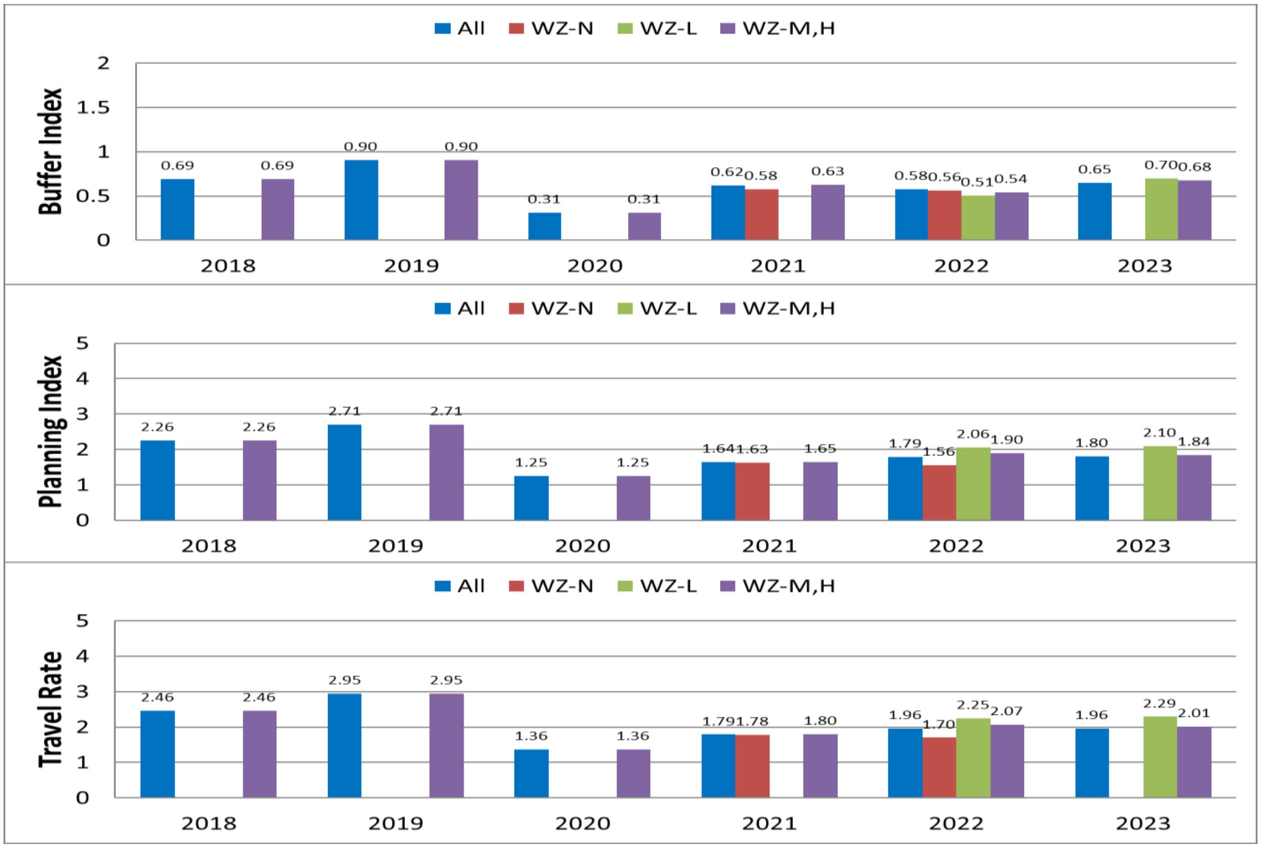
Yearly Variations - *Weather Effects*



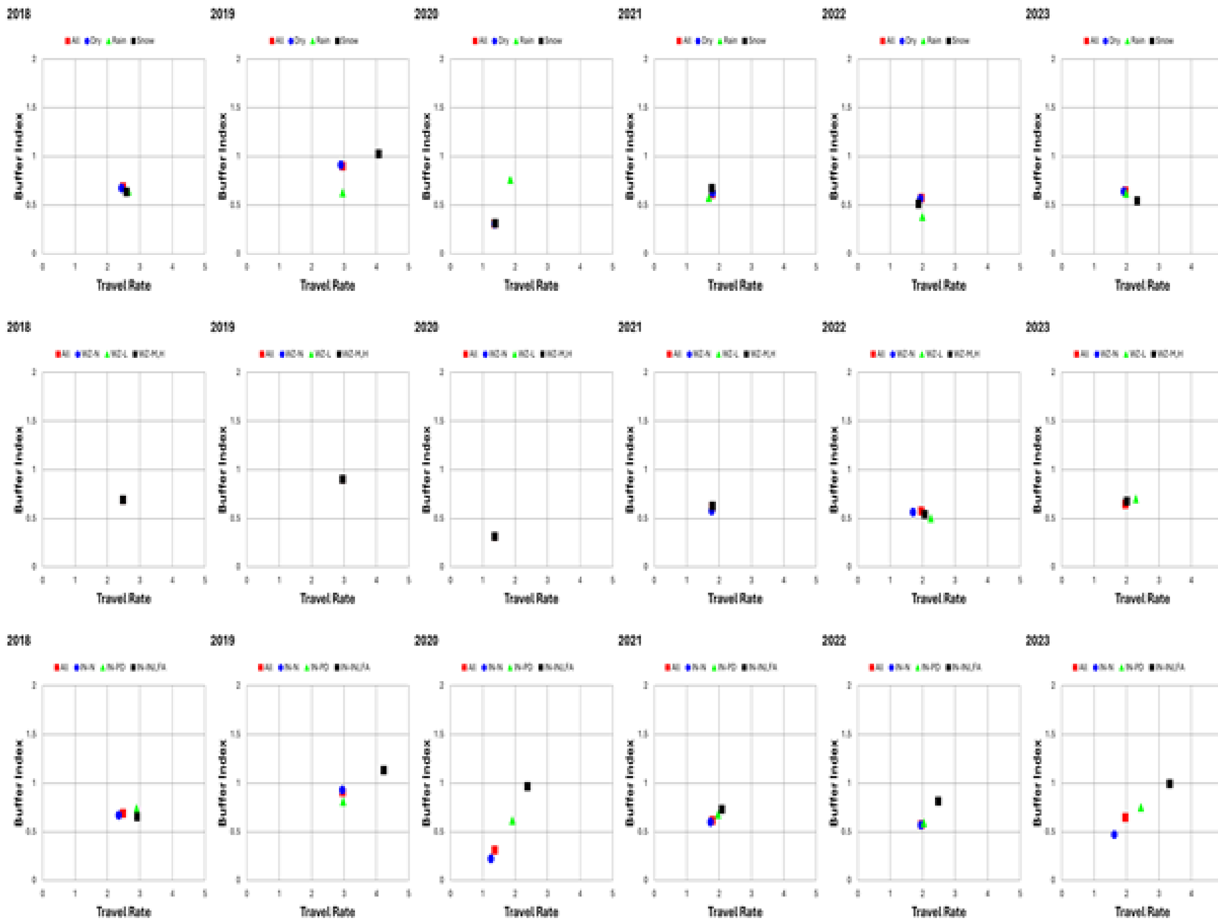
Incident Effects



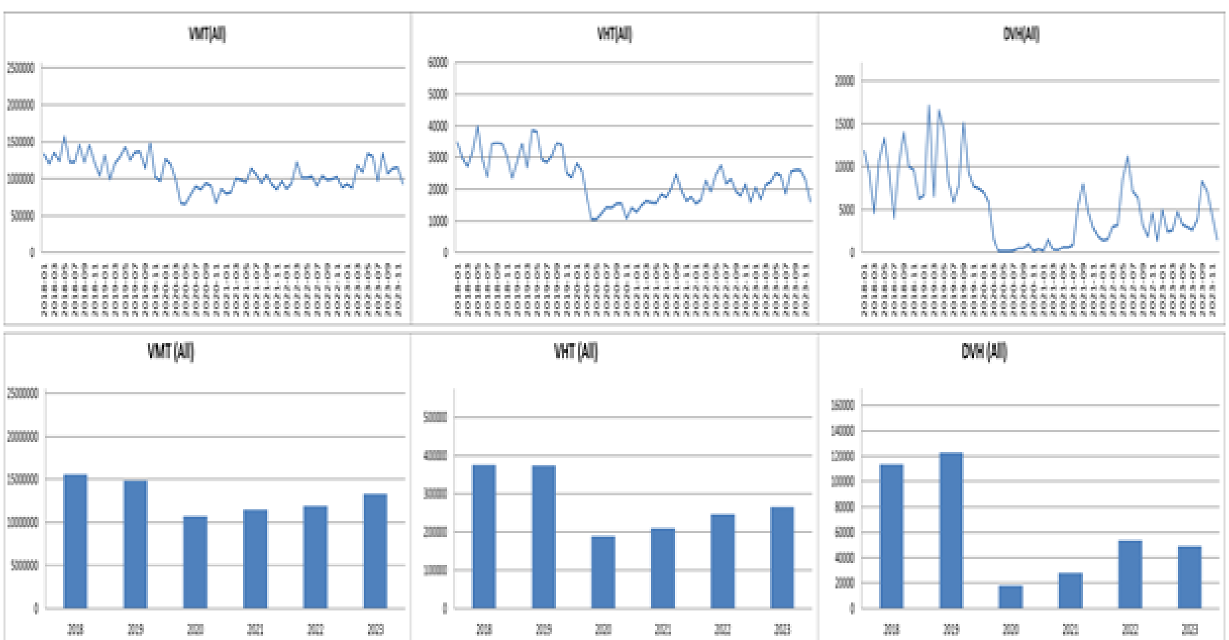
Work-Zone Effects



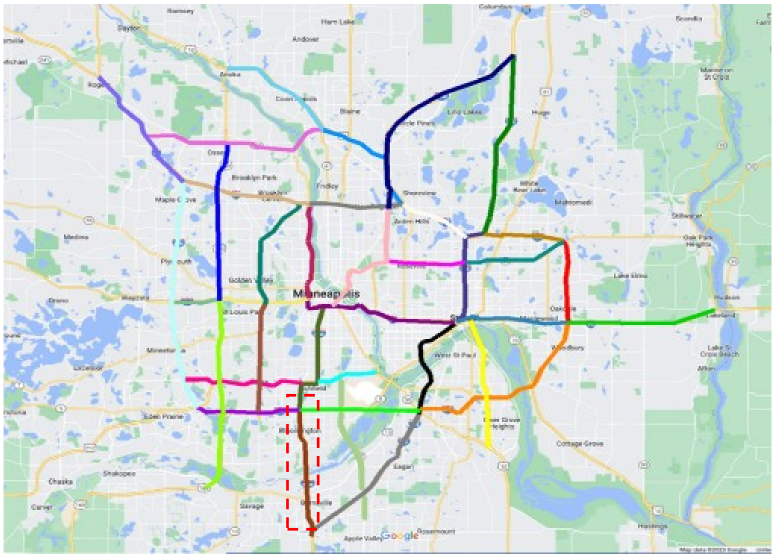
Yearly Variations of Buffer Index - Travel Rate Relationships



Variations of Traffic-Flow Measures

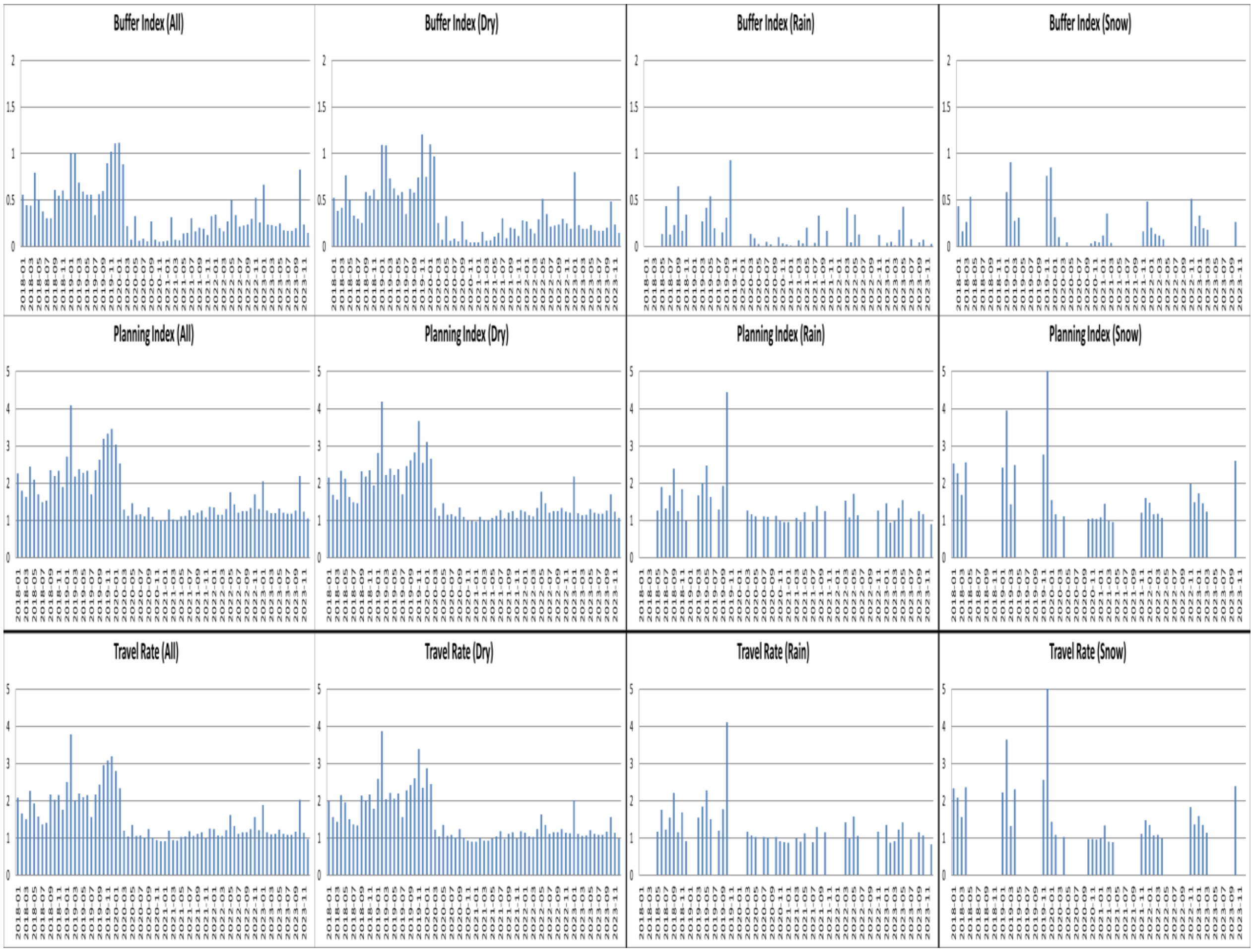


24) I-35W Corridor A (I35 < -- > I494)

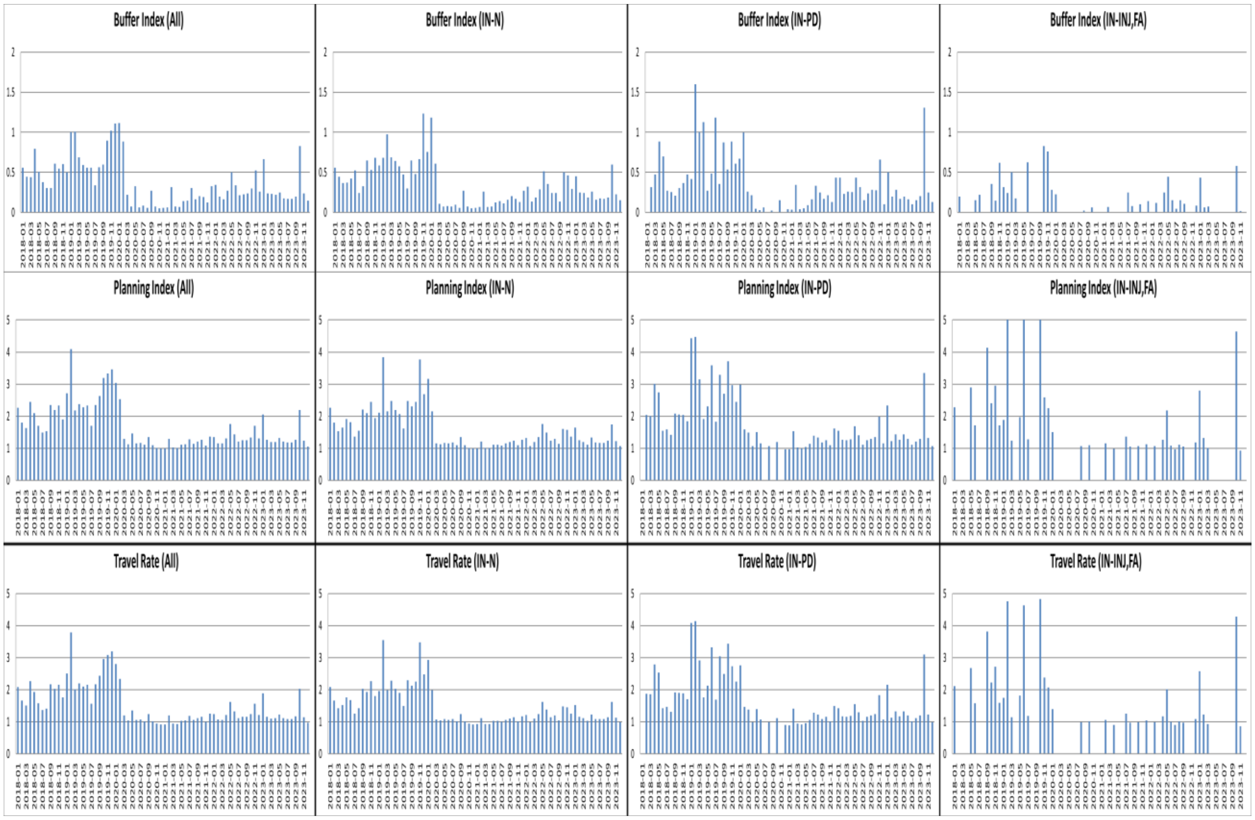


i) I-35W Corridor A -- NB I35 to I494 for Morning Peak Periods

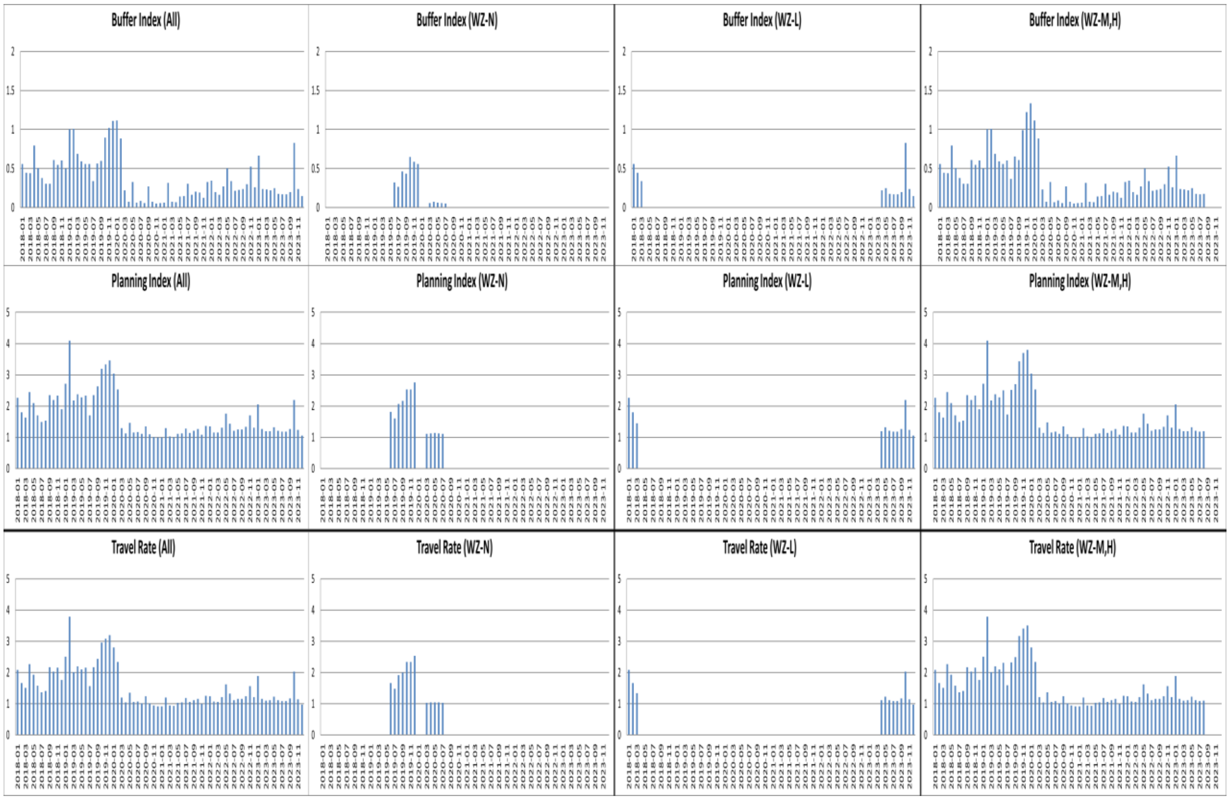
Effects of Weather conditions on Travel-Time Reliability



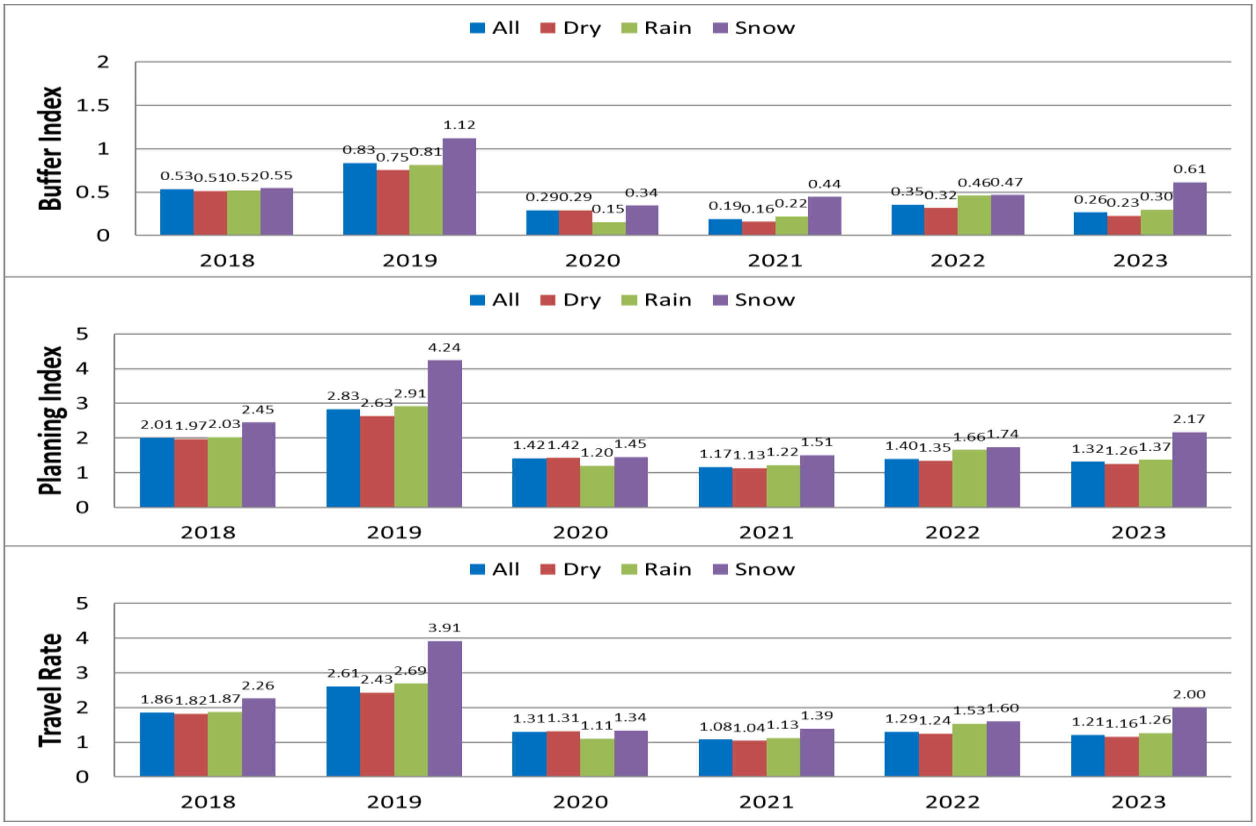
Effects of Incidents



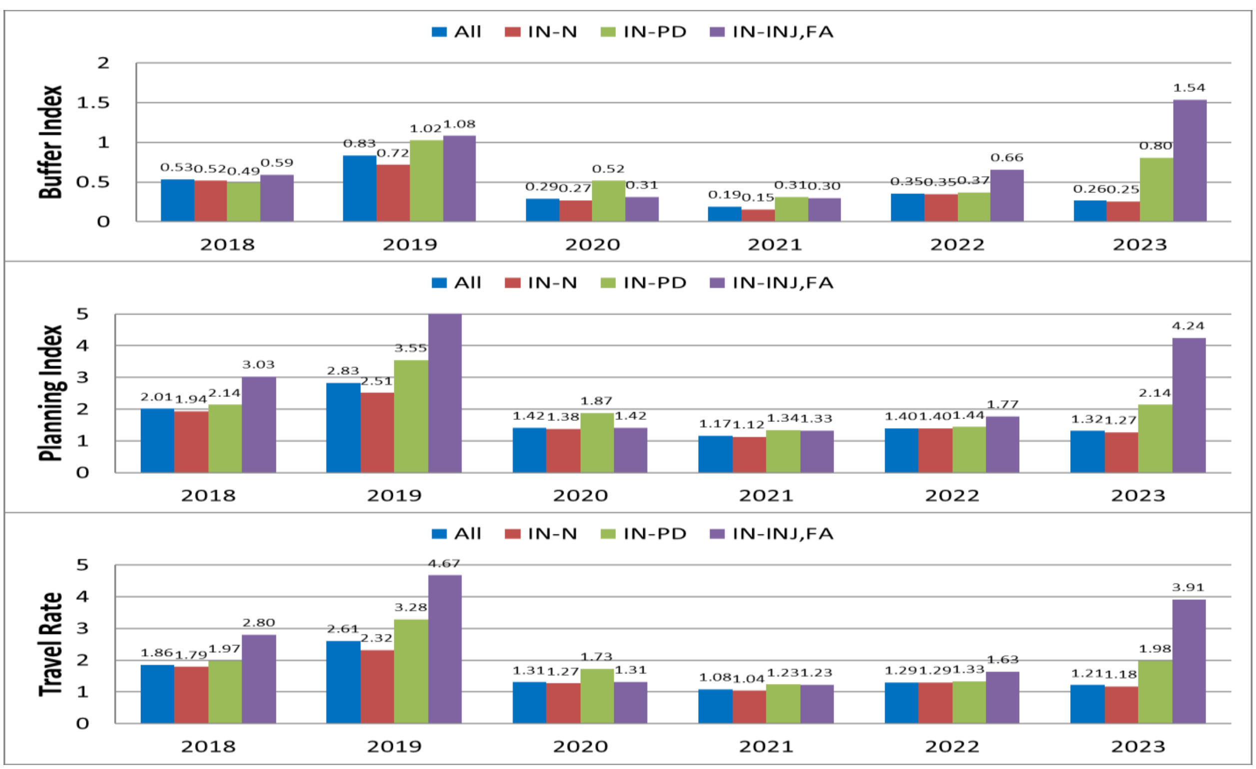
Effects of Work Zones



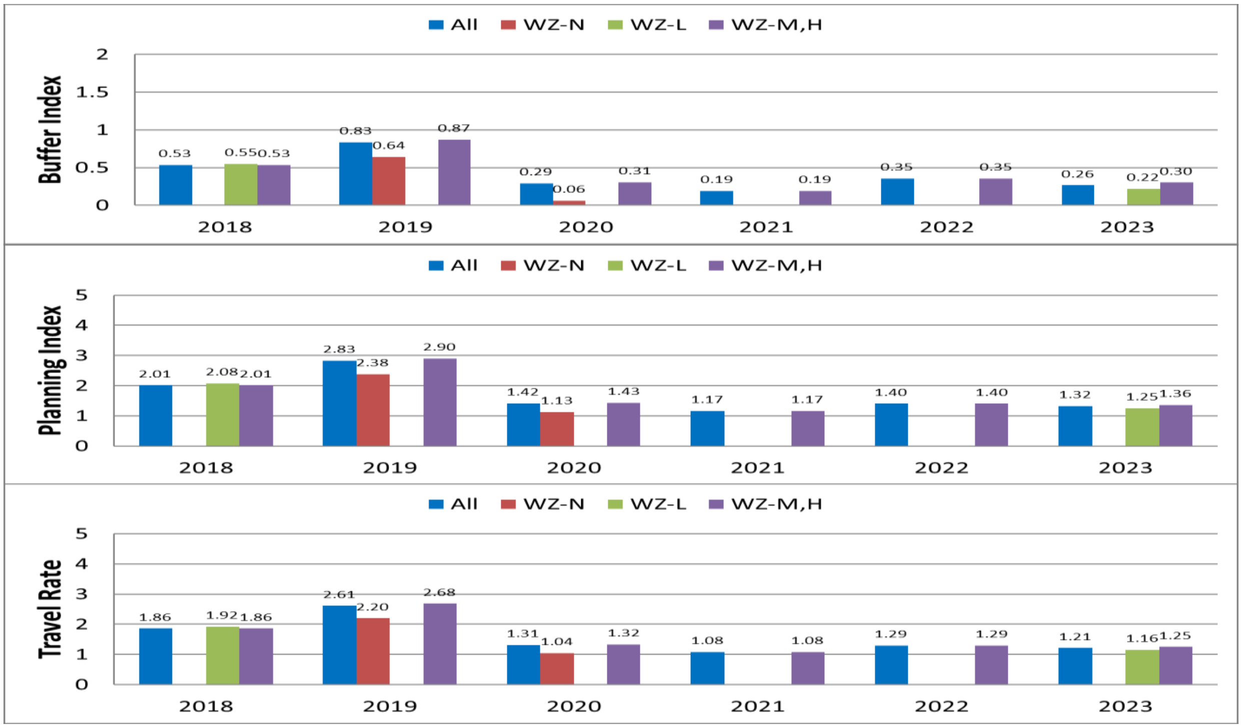
Yearly Variations - ***Weather Effects***



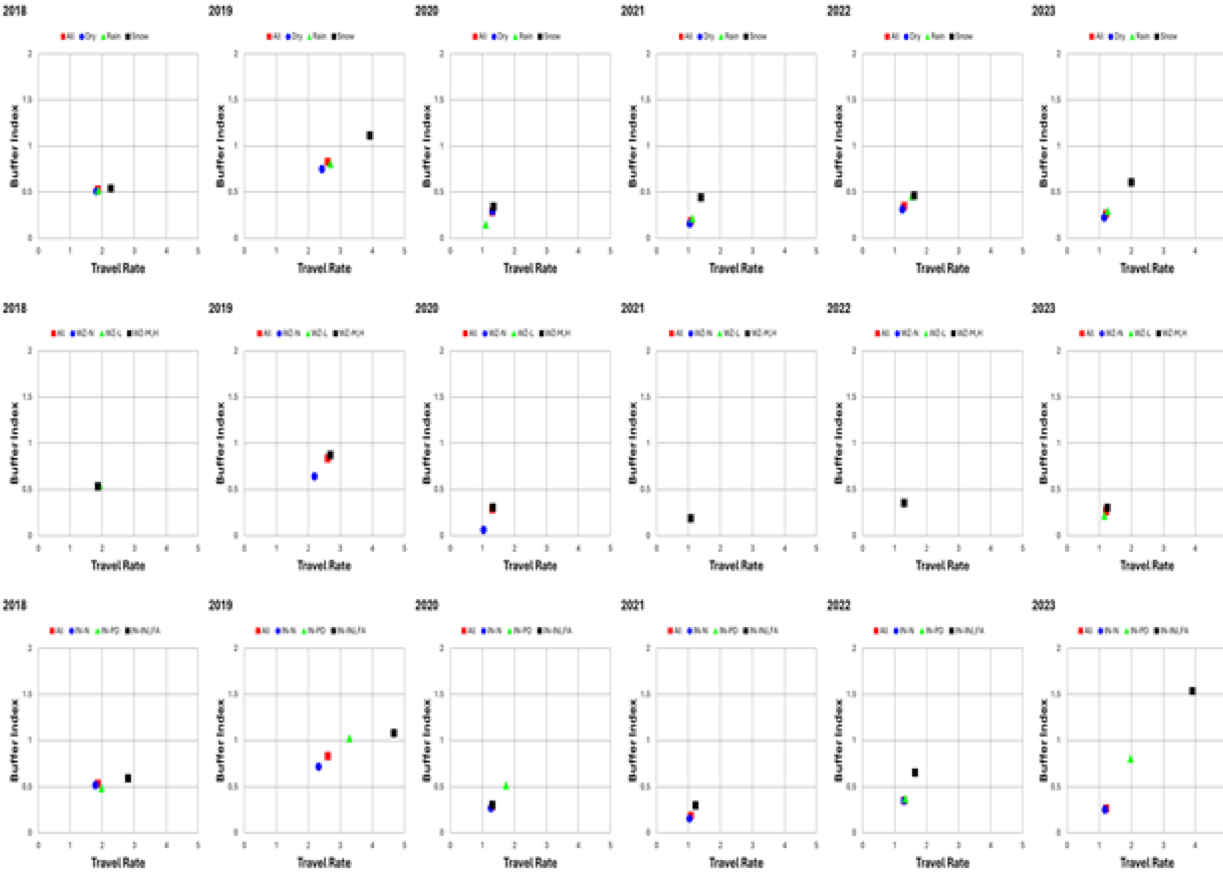
Incident Effects



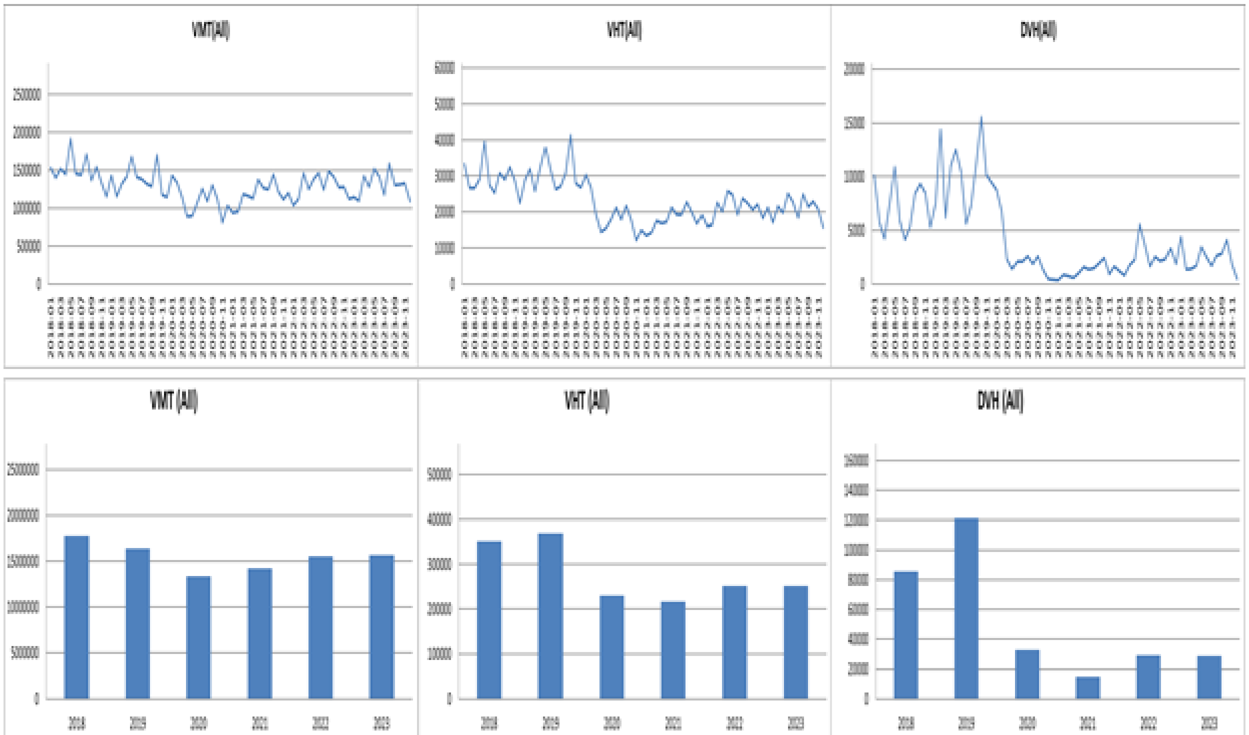
Work-Zone Effects



Yearly Variations of Buffer Index - Travel Rate Relationships



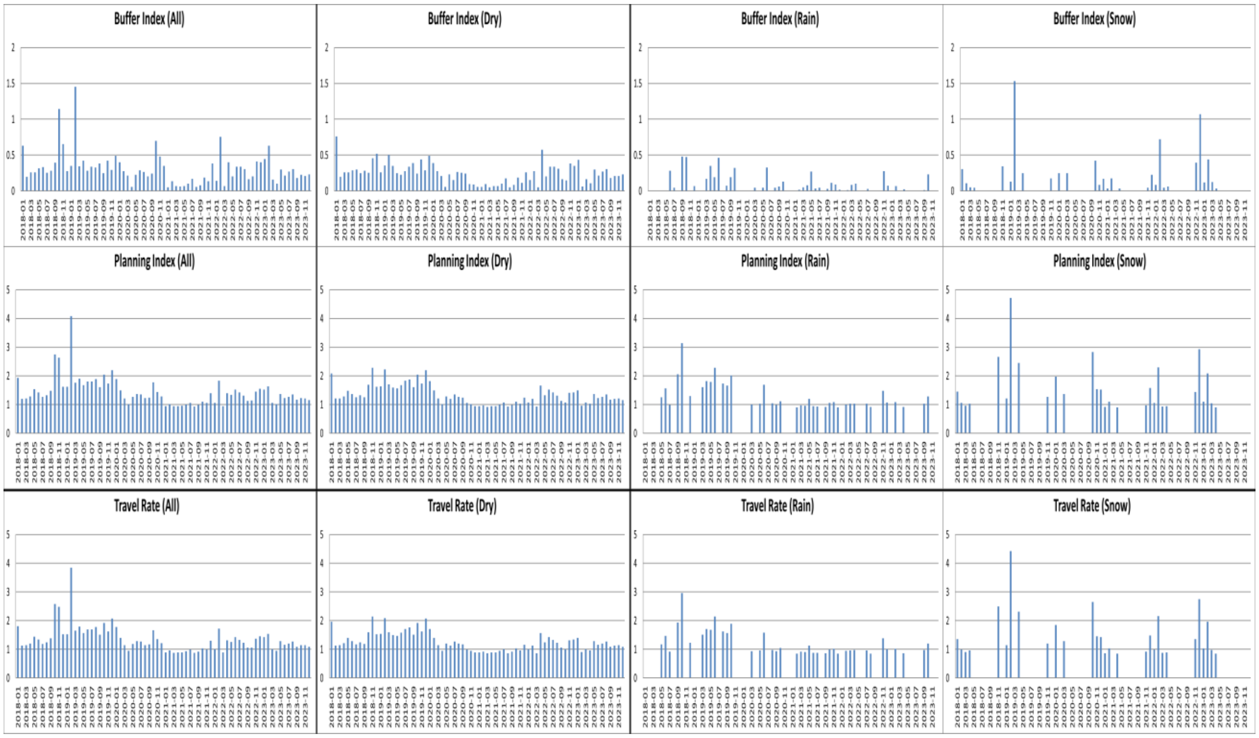
Variations of Traffic-Flow Measures



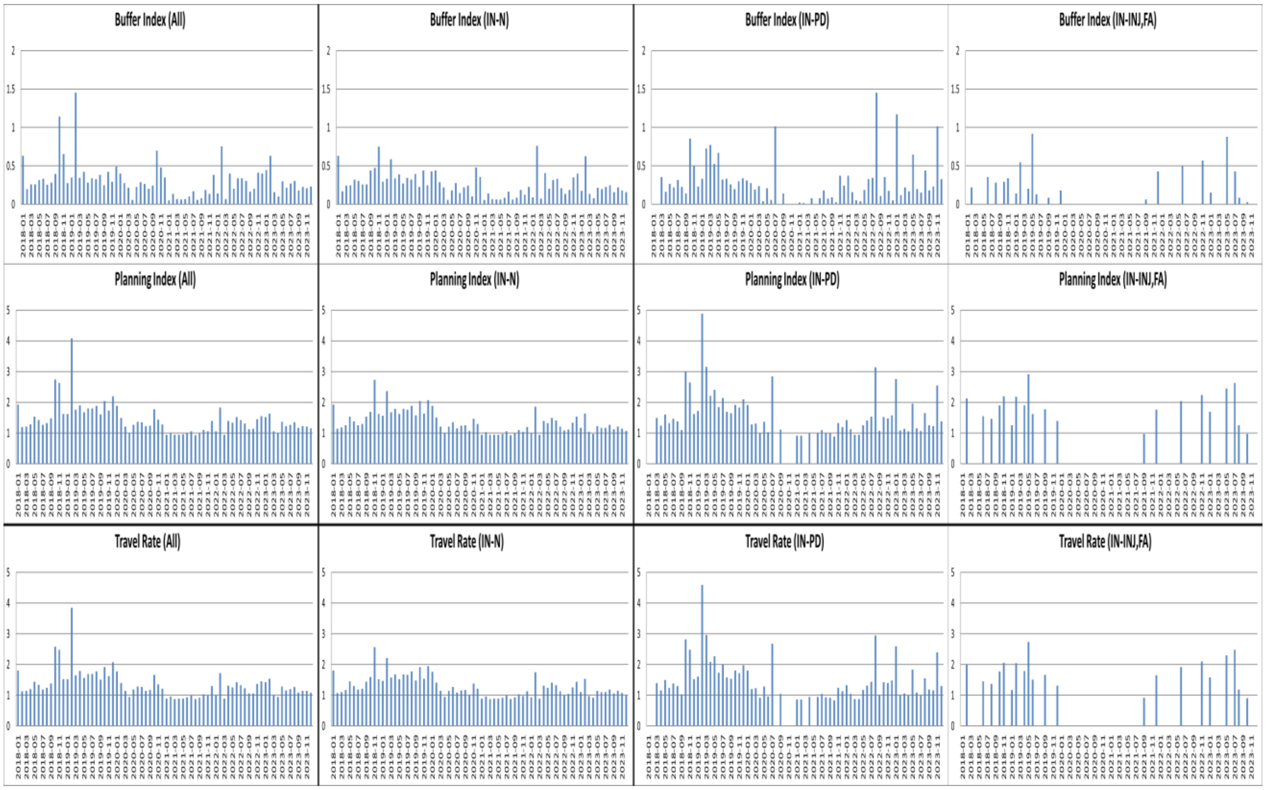
VMT(All)
VHT(All)
DVH(All)
VMT (All)
VHT (All)
DVH (All)
2018
2019
2020
2021
2022
2023

ii) I-35W Corridor A -- SB I494 to I35 for Afternoon Peak Periods

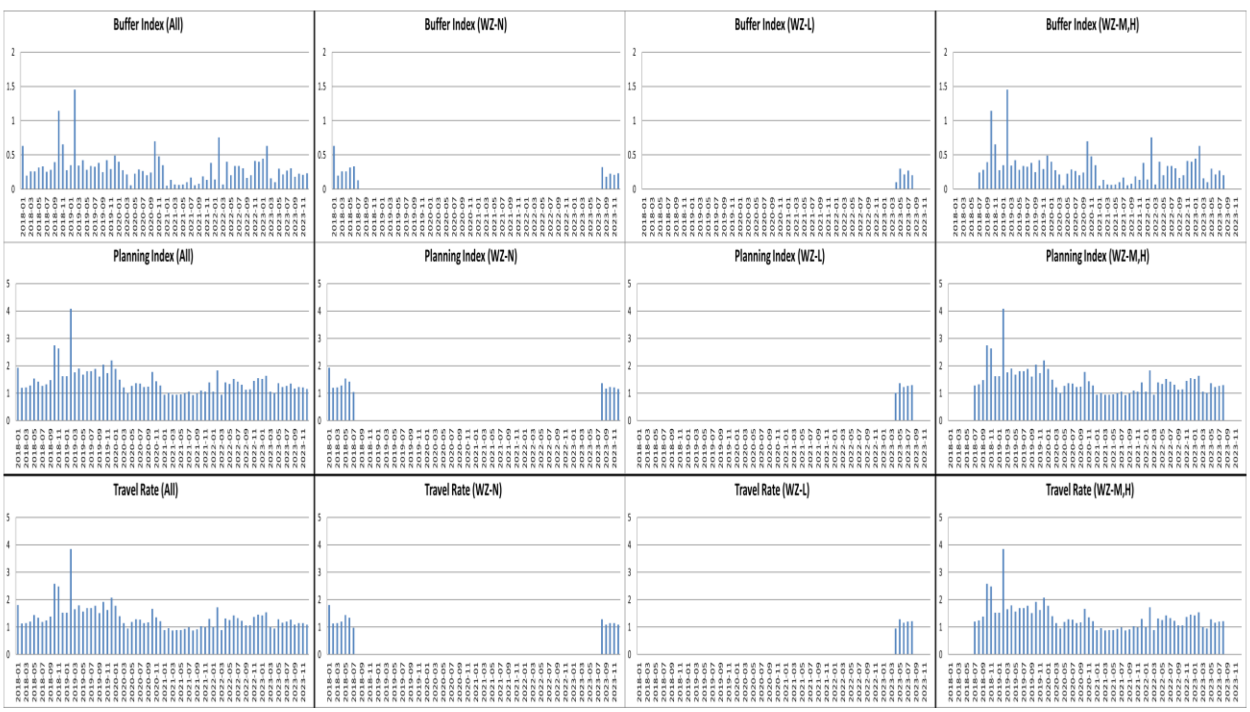
Effects of Weather conditions on Travel-Time Reliability



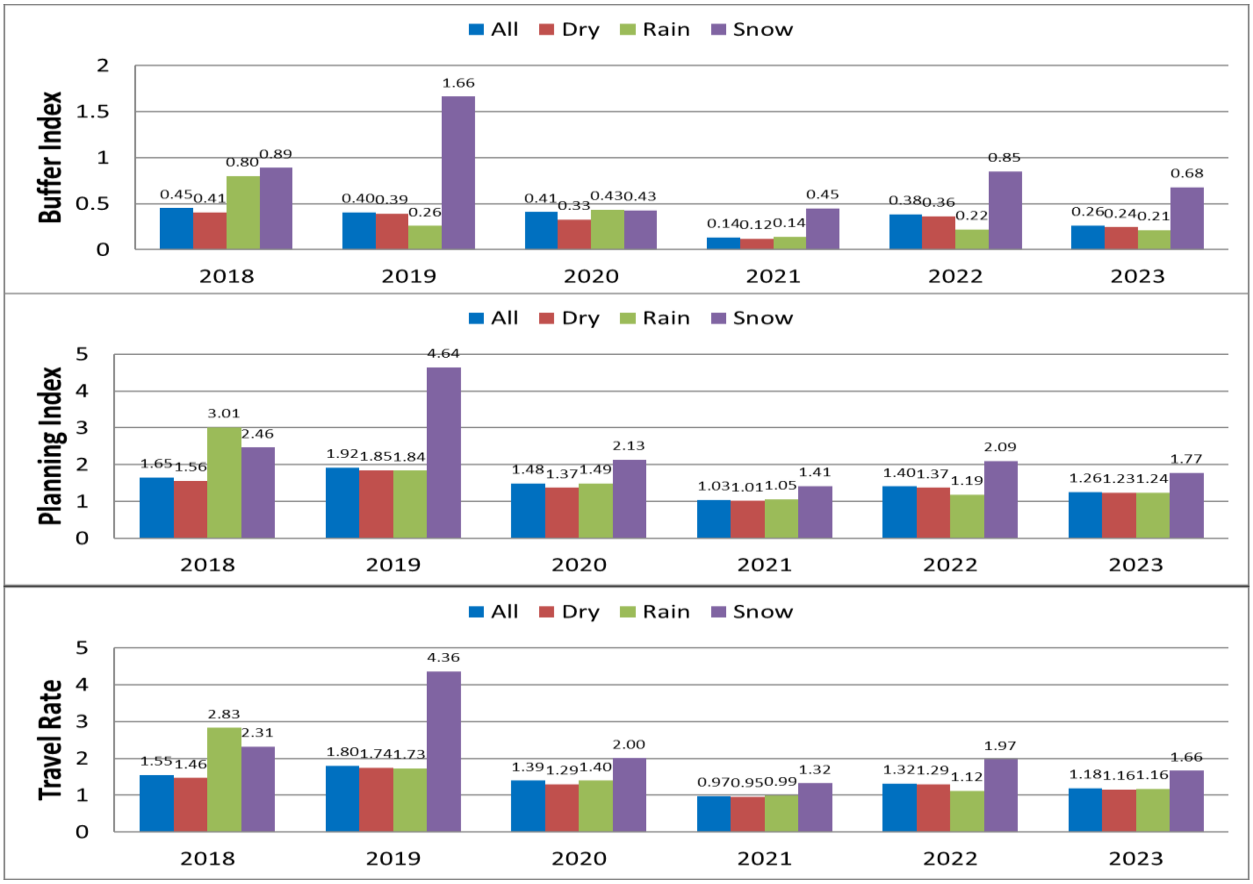
Effects of Incidents



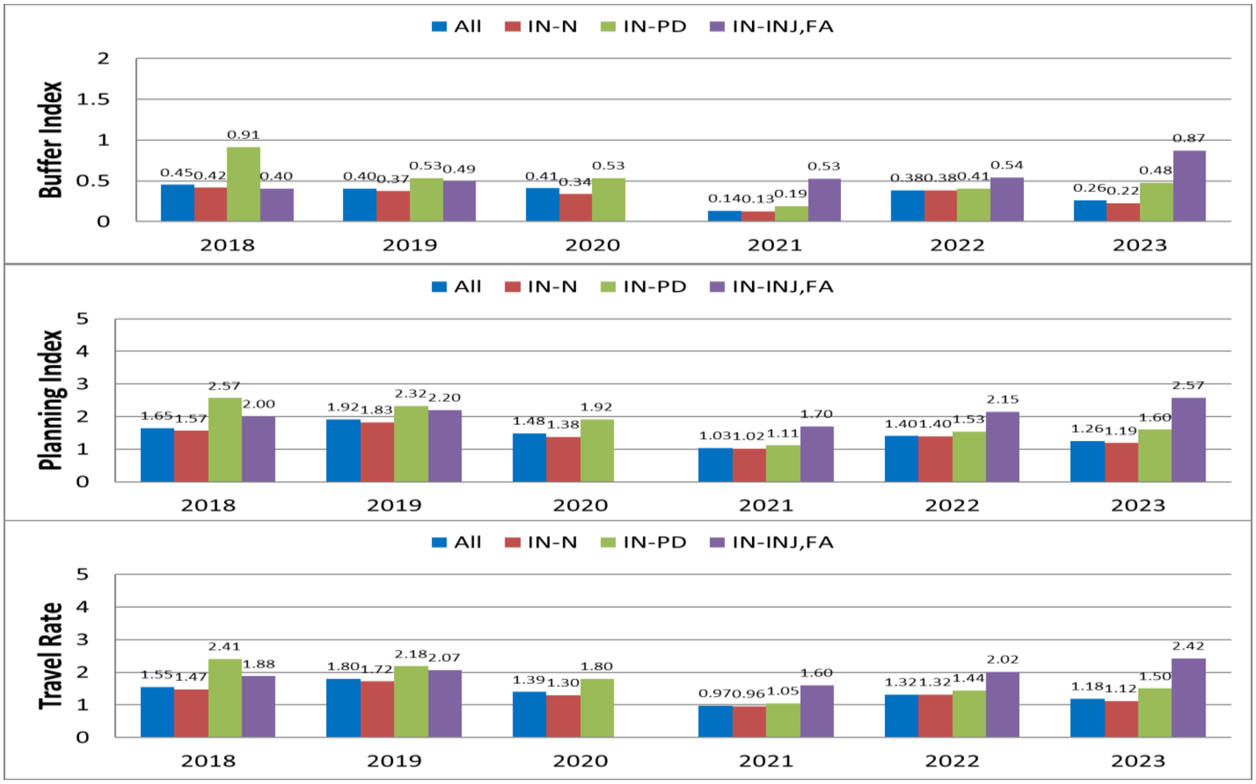
Effects of Work Zones



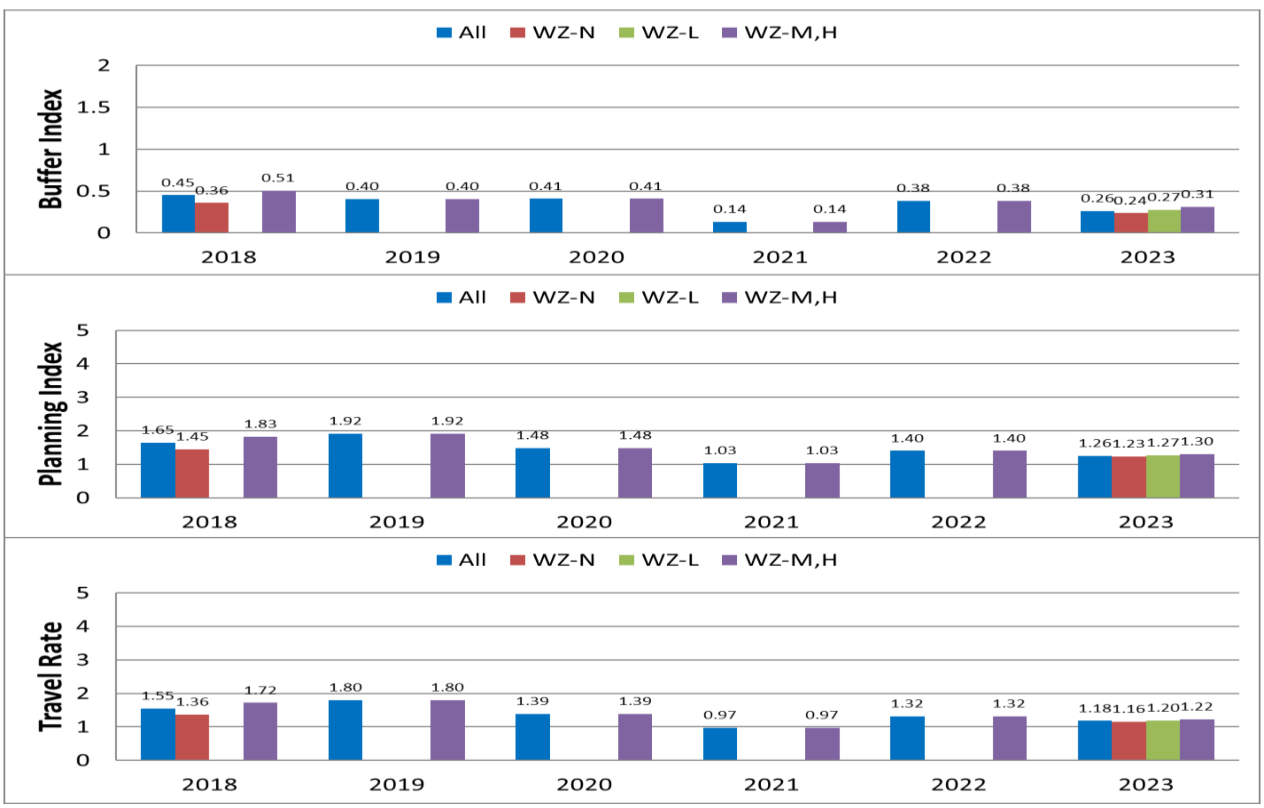
Yearly Variations - *Weather Effects*



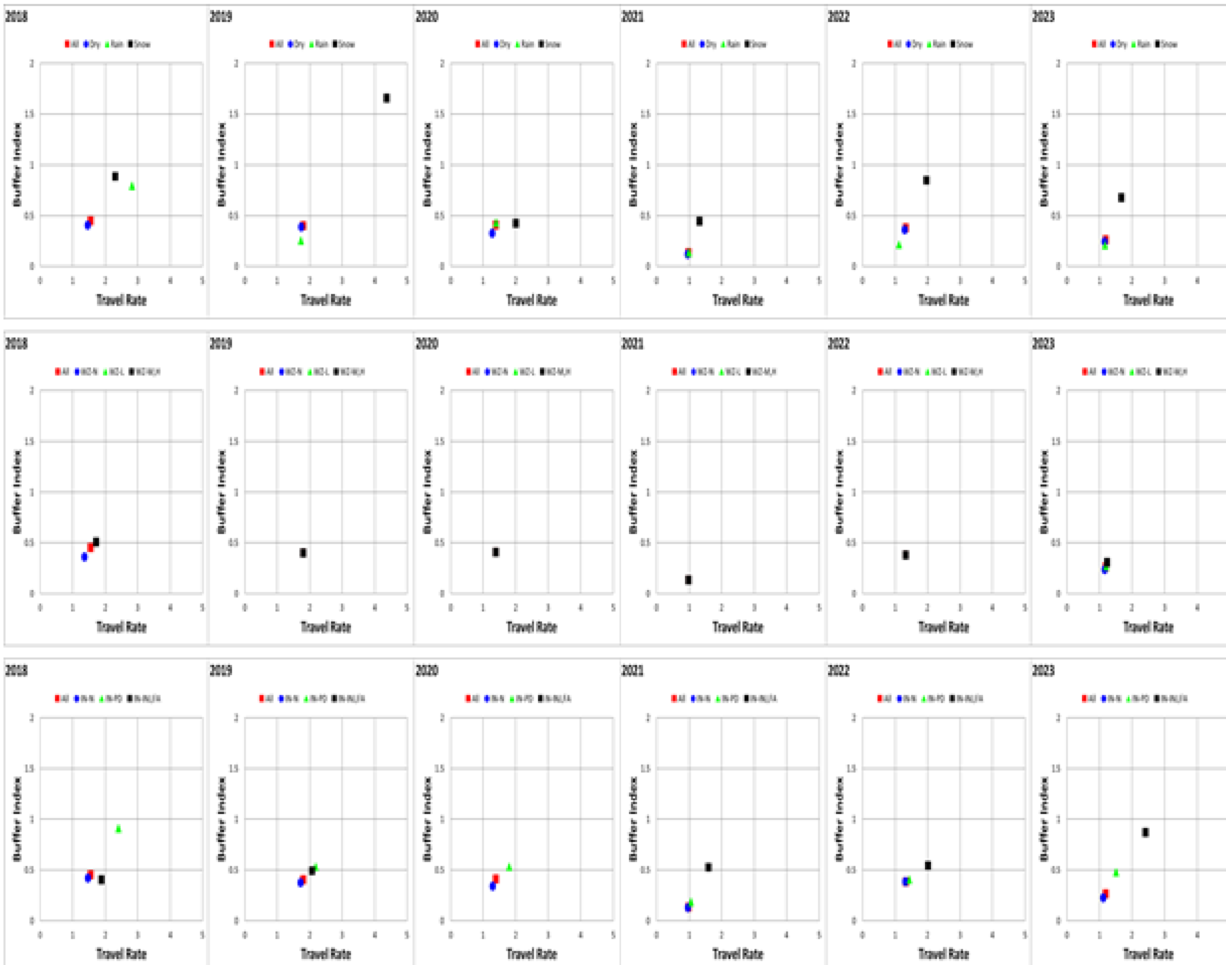
Incident Effects



Work-Zone Effects

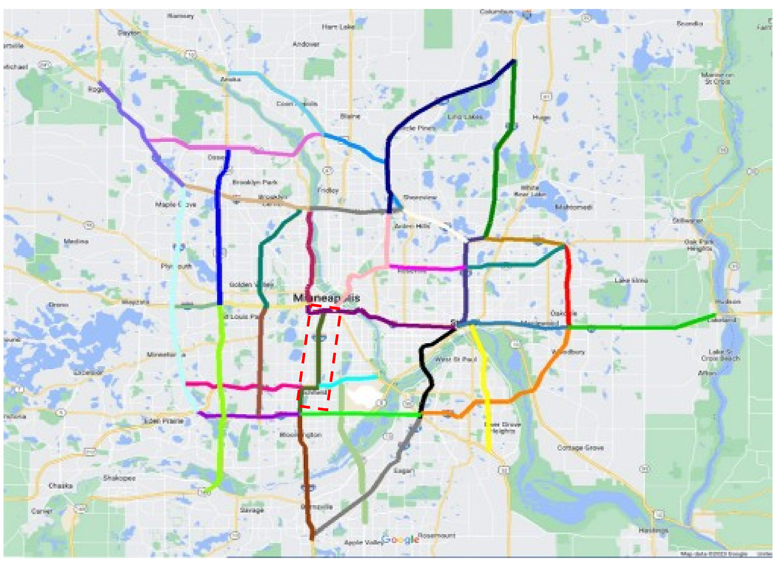


Yearly Variations of Buffer Index - Travel Rate Relationships



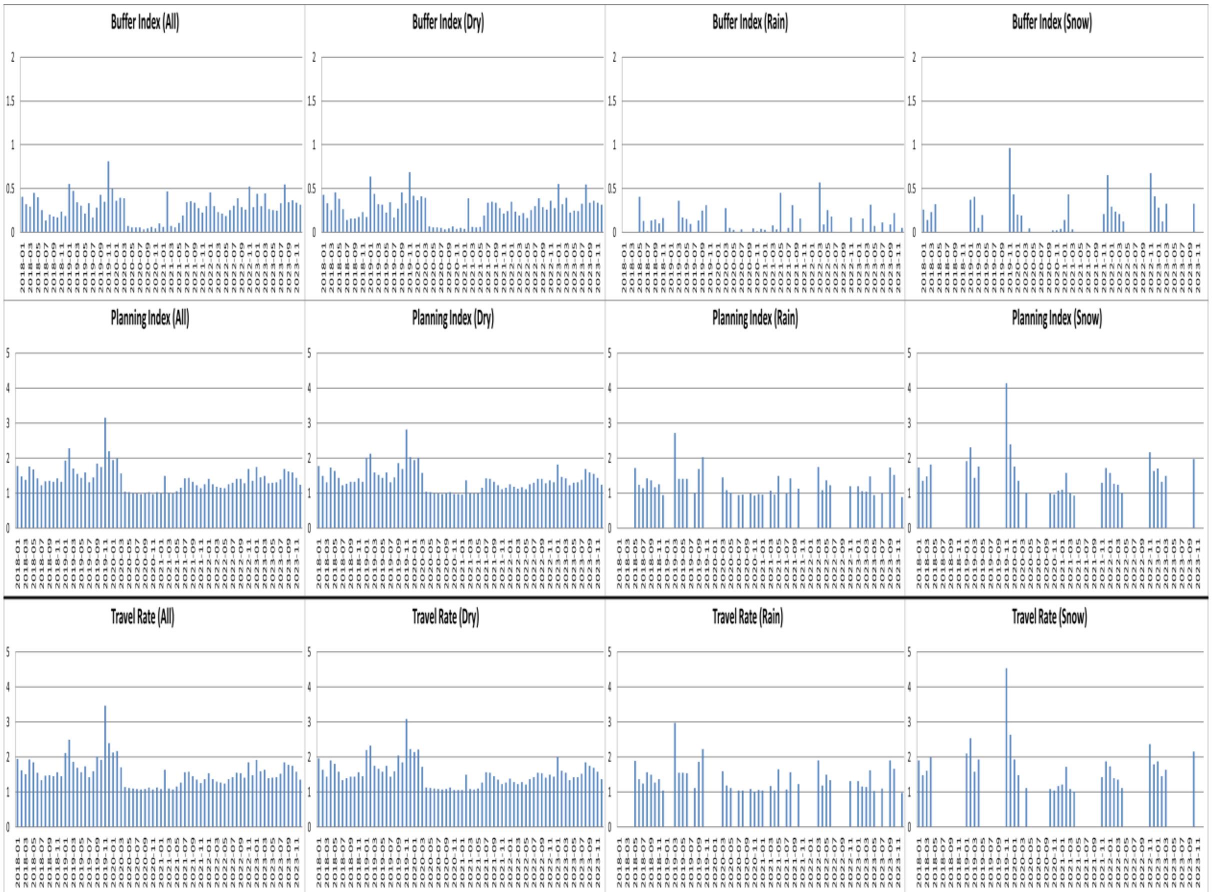
Variations of Traffic-Flow Measures

25) I-35W Corridor B (I494 < -- > MPLS)



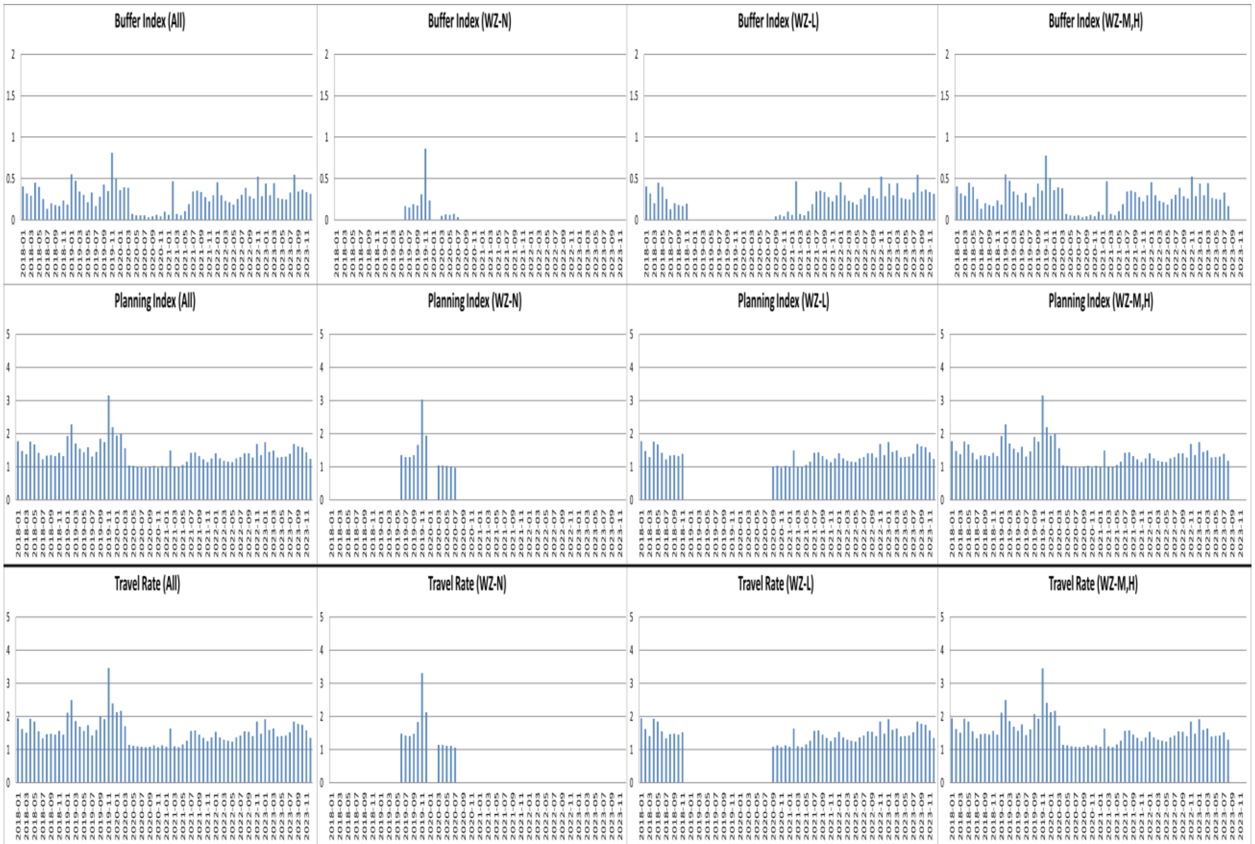
i) I-35W Corridor B -- NB I494 to MPLS for Morning Peak Period

Effects of Weather conditions on Travel-Time Reliability

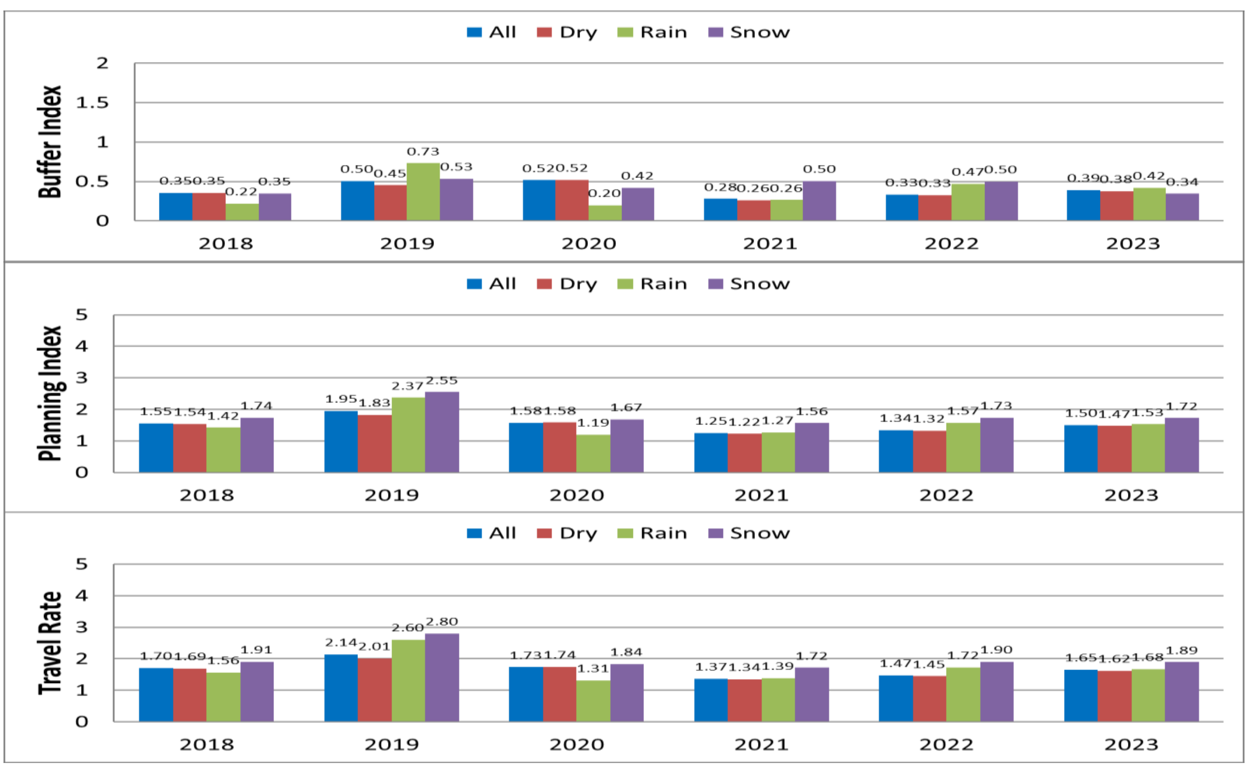


Effects of Incidents

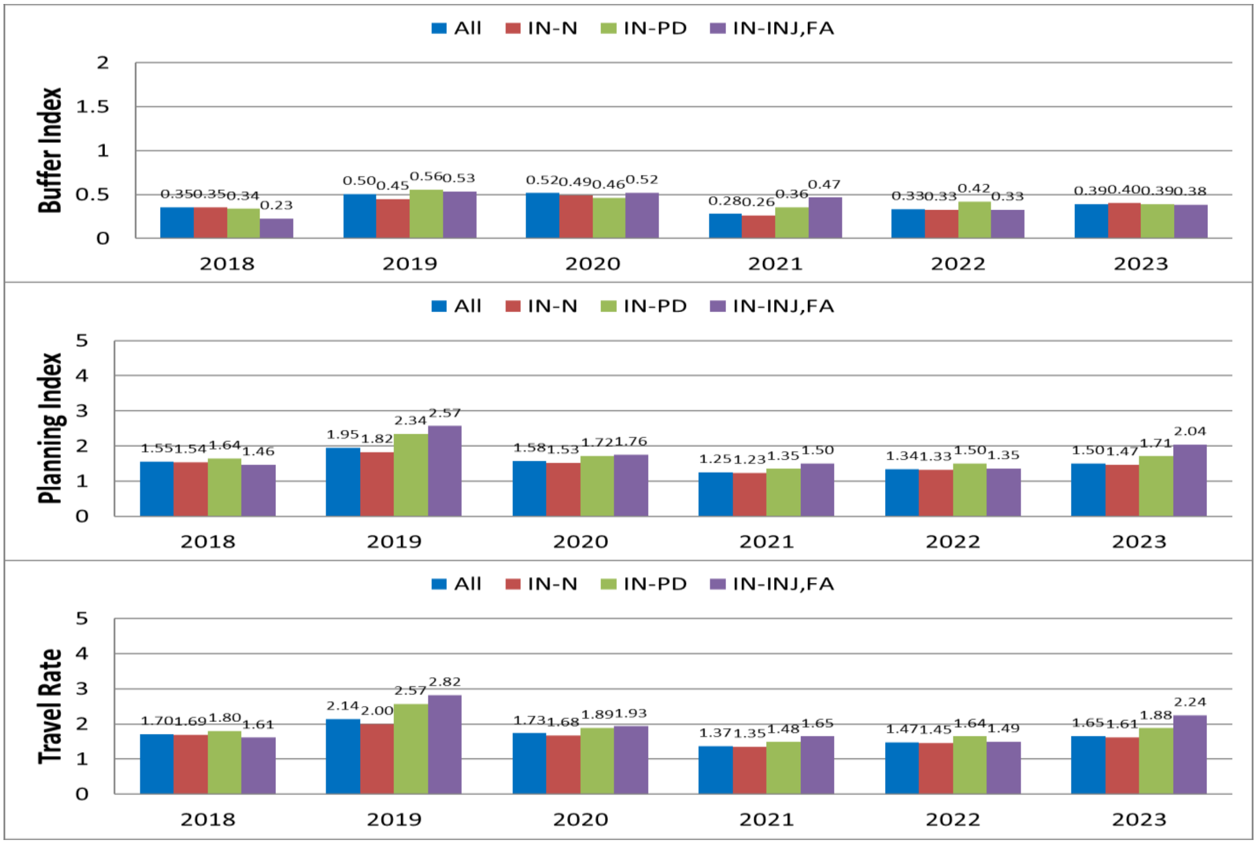
Effects of Work Zones



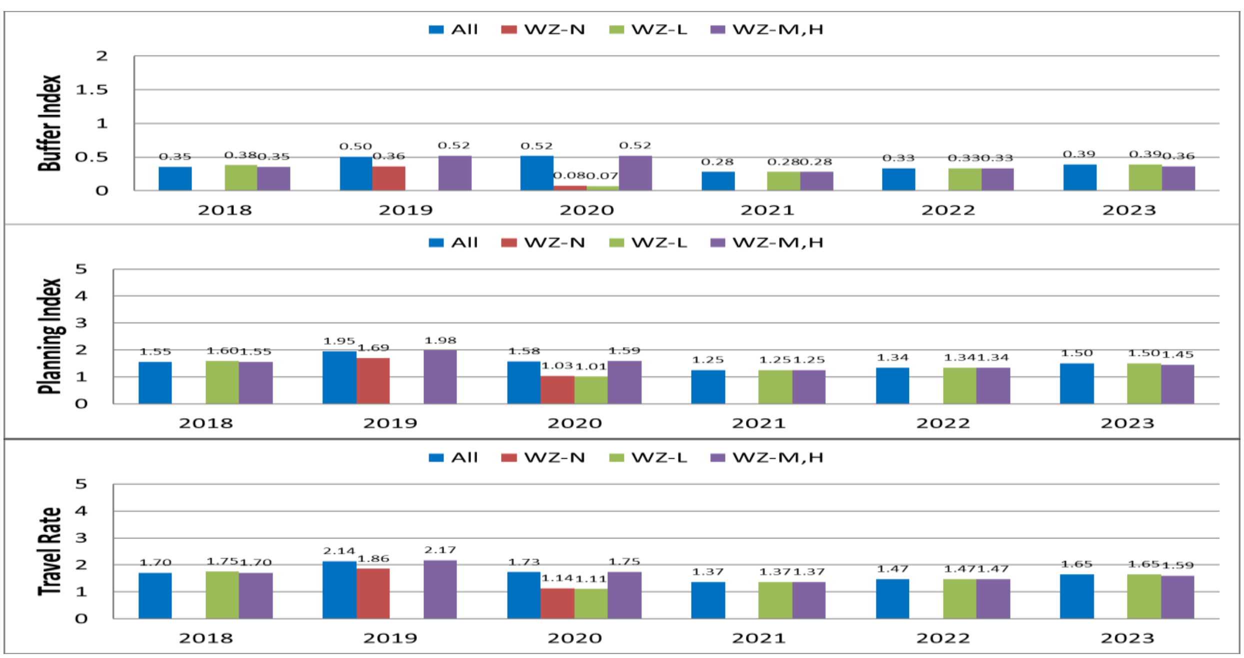
Yearly Variations - *Weather Effects*



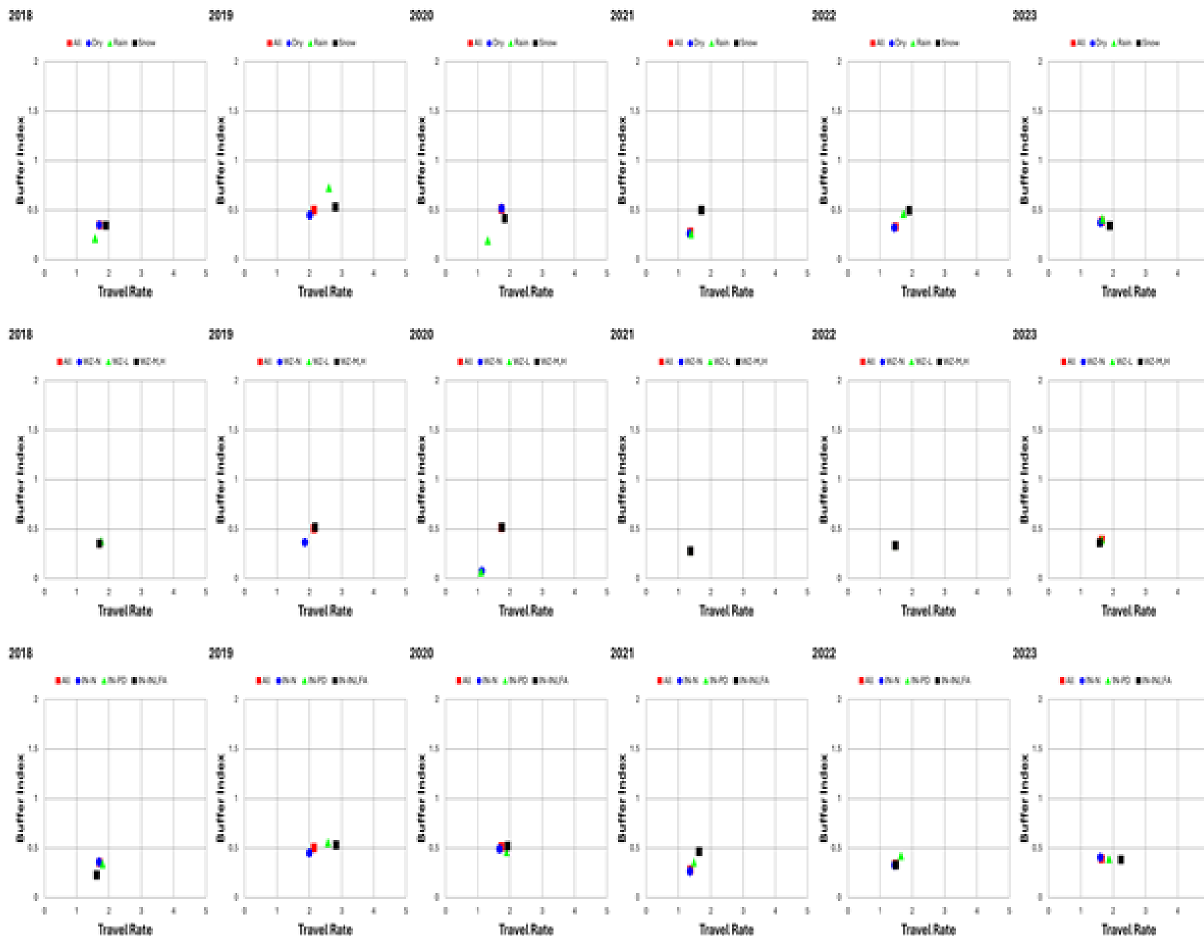
Incident Effects



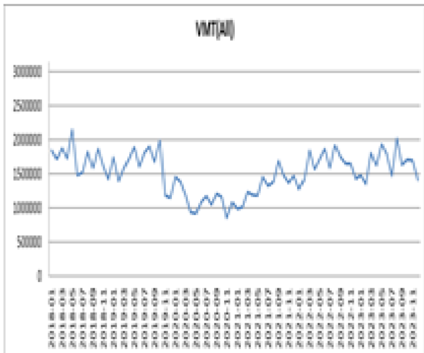
Work-Zone Effects

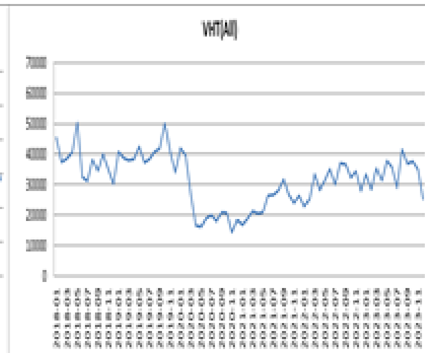


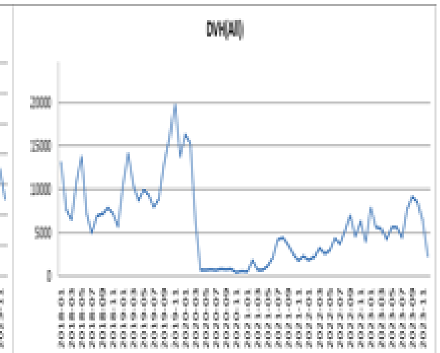
Yearly Variations of Buffer Index - Travel Rate Relationships

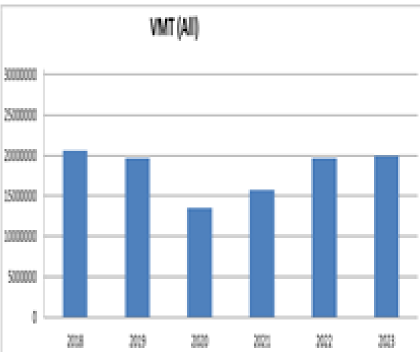


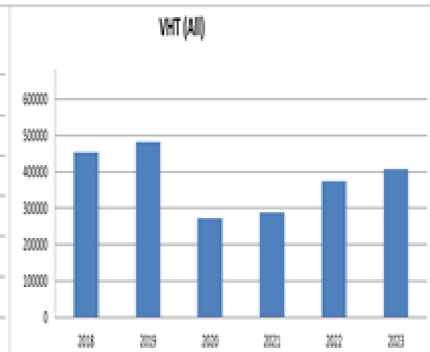
Variations of Traffic-Flow Measures

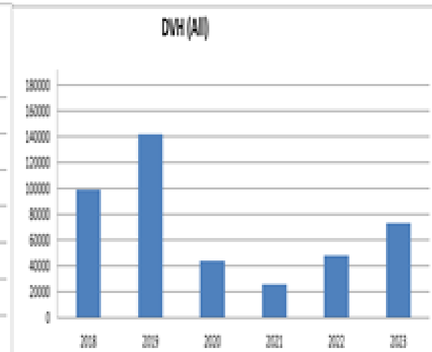

VMT(All)


VHT(All)


DVH(All)

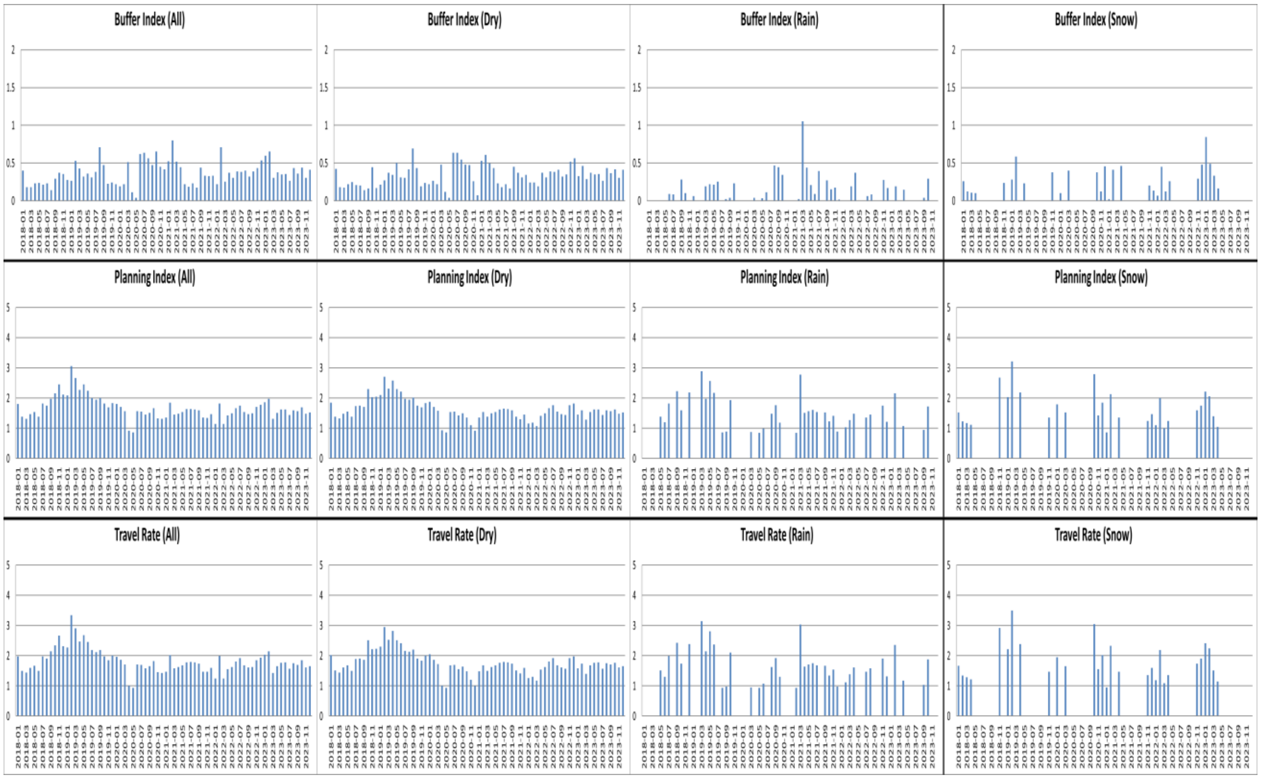

VMT (All)
2018
2019
2020
2021
2022
2023


VHT (All)
2018
2019
2020
2021
2022
2023


DVH (All)
2018
2019
2020
2021
2022
2023

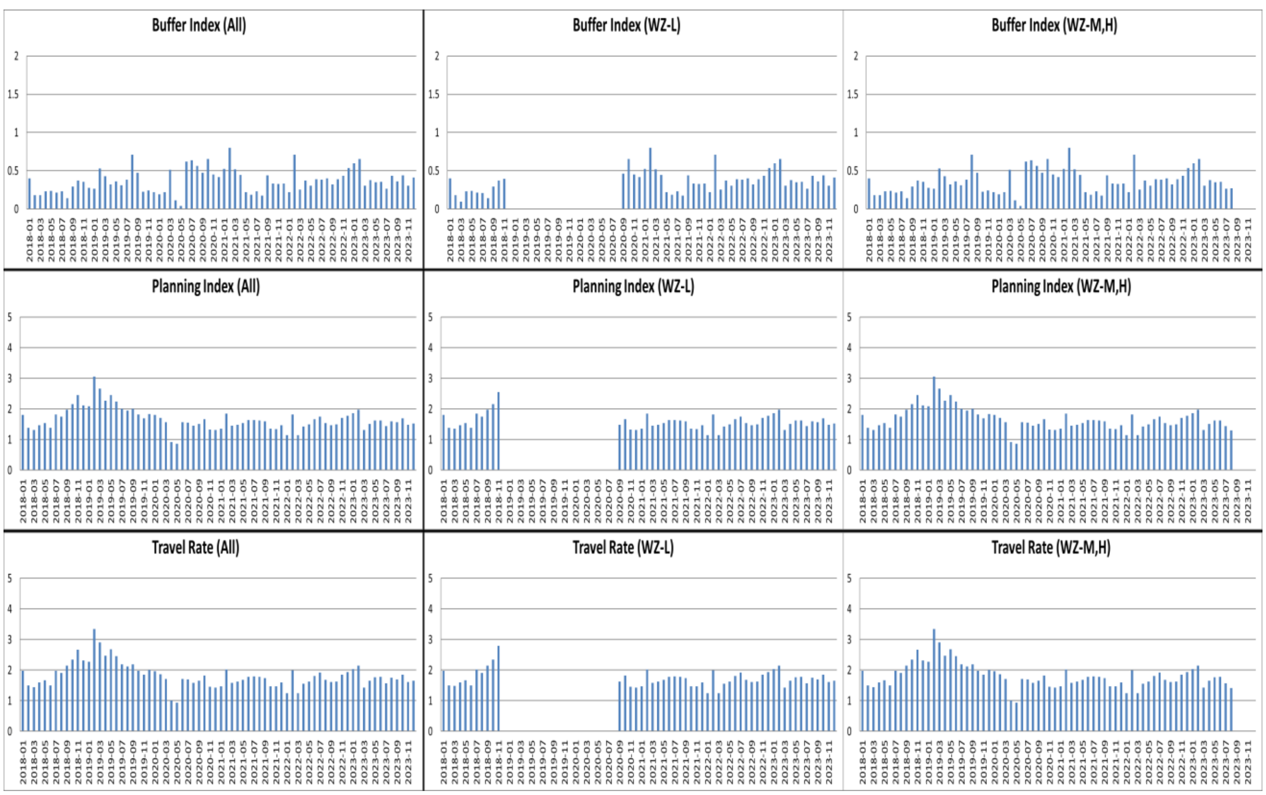
ii) I-35W Corridor B SB Route 1 for L2 - MPLS to I494, Afternoon Peak Periods

Effects of Weather conditions on Travel-Time Reliability

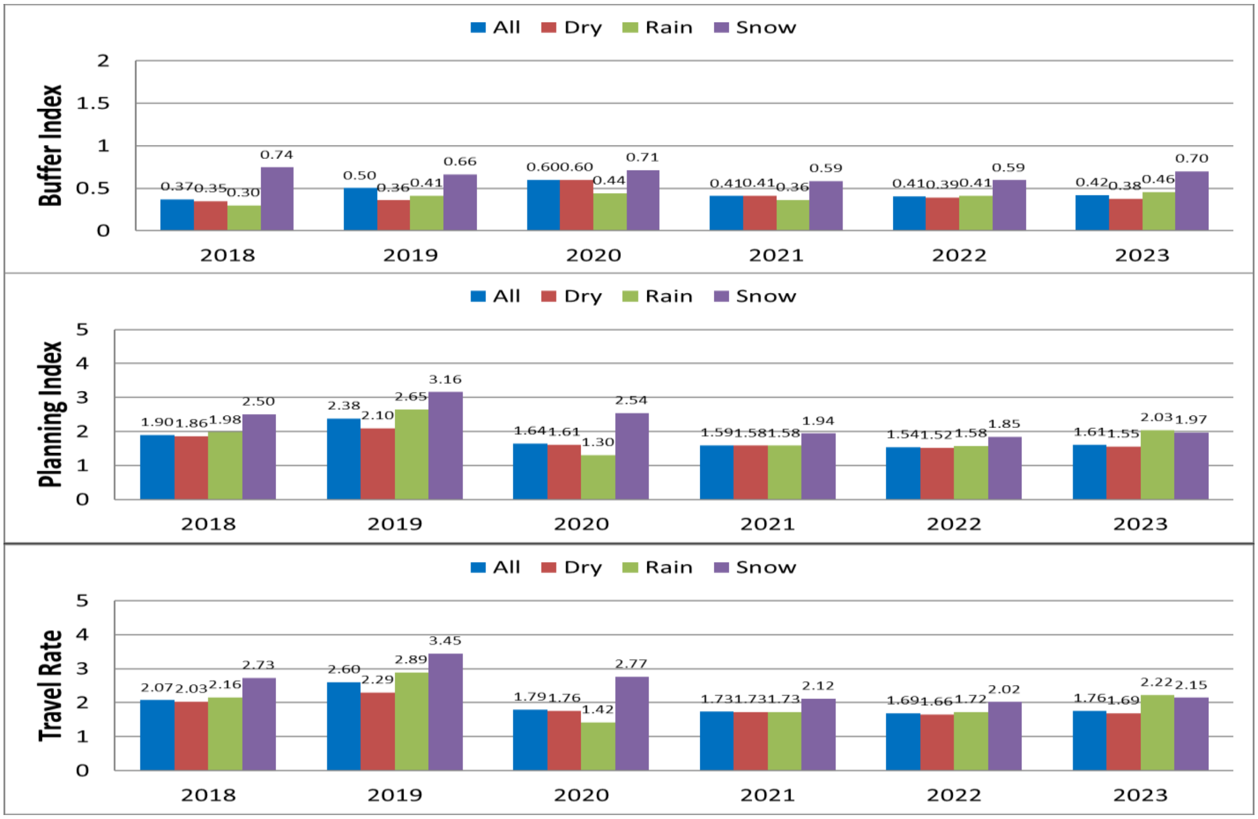


Effects of Incidents

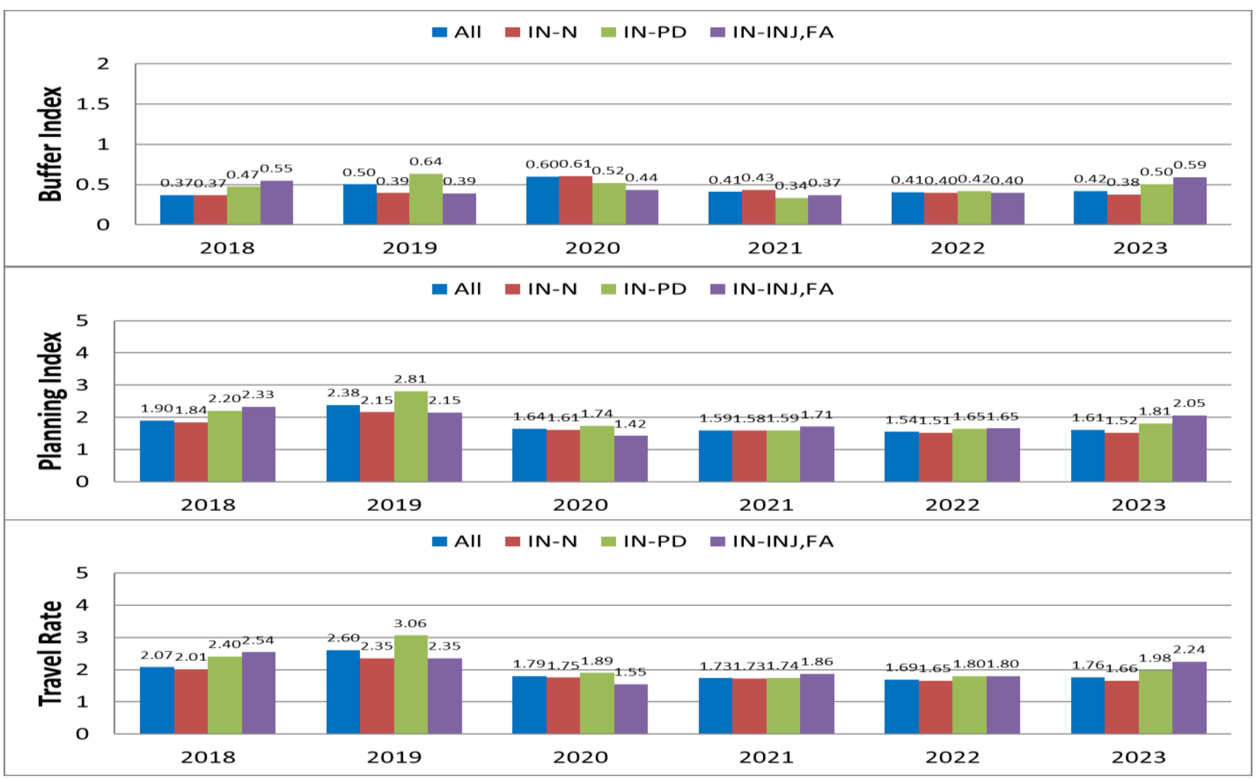
Effects of Work Zones



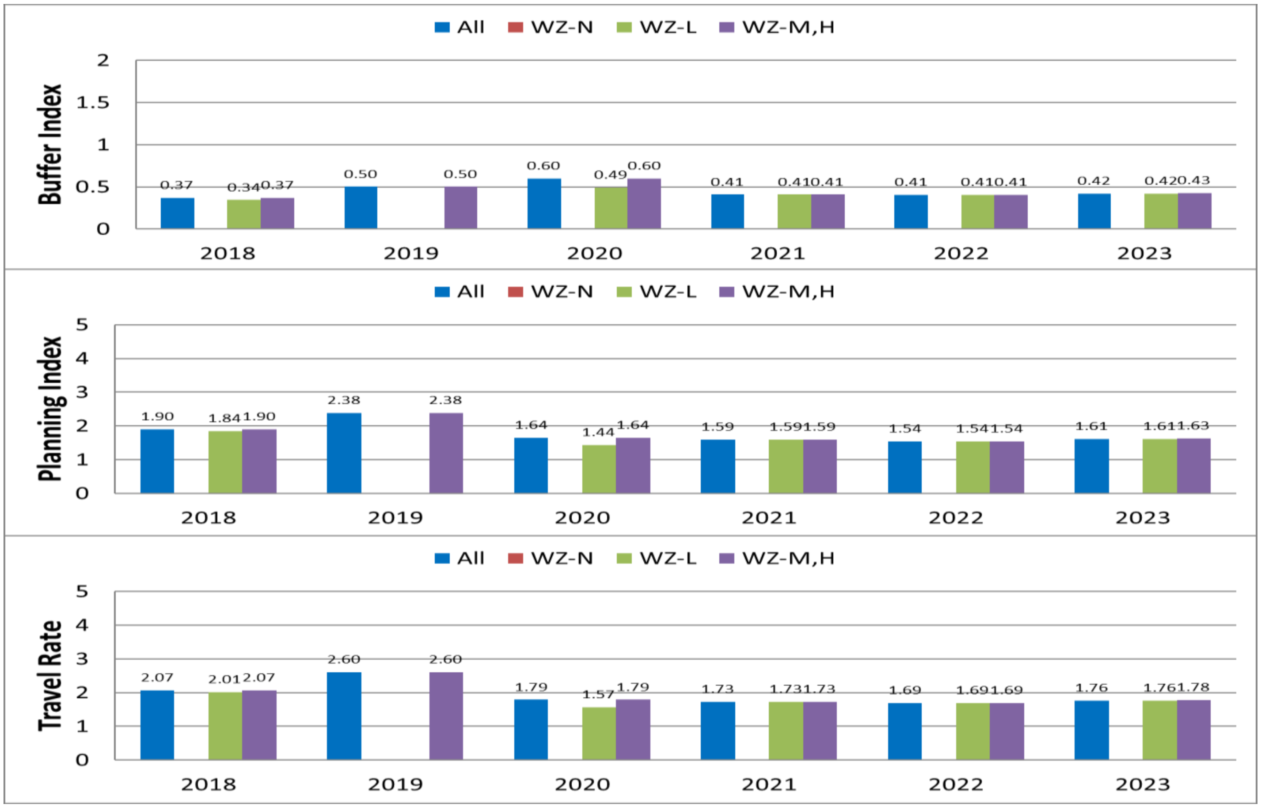
Yearly Variations - *Weather Effects*



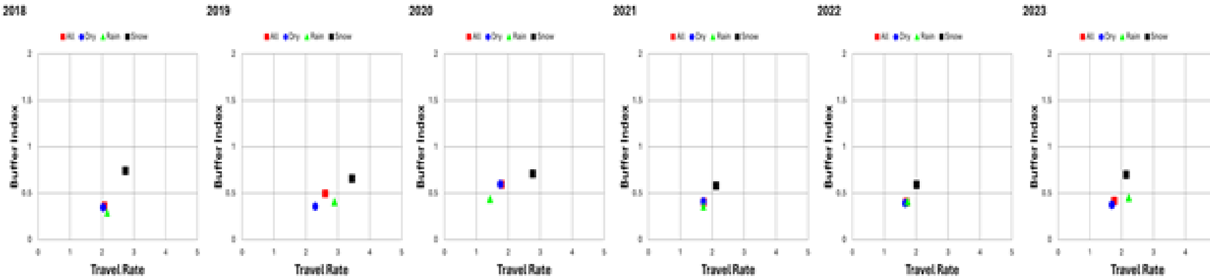
Incident Effects

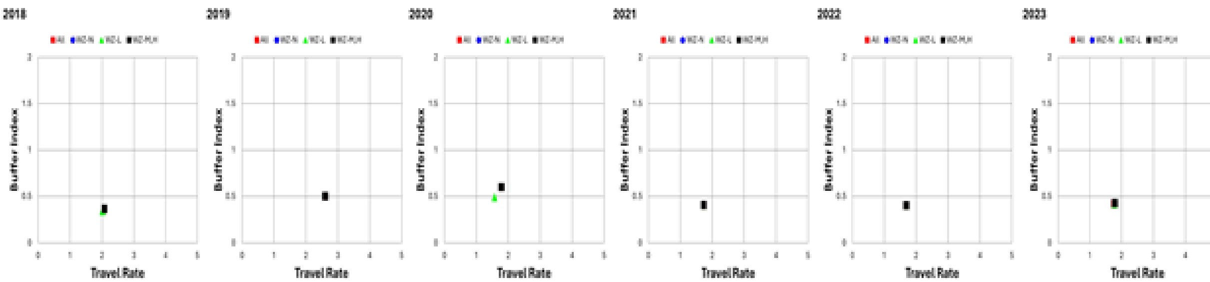


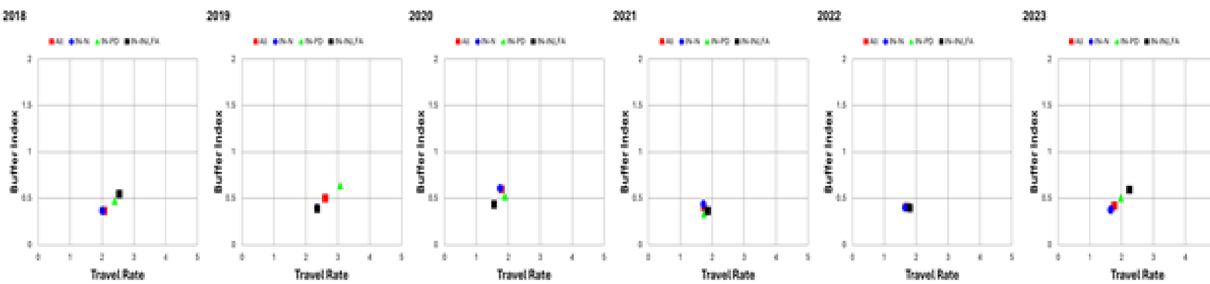
Work-Zone Effects



Yearly Variations of Buffer Index - Travel Rate Relationships

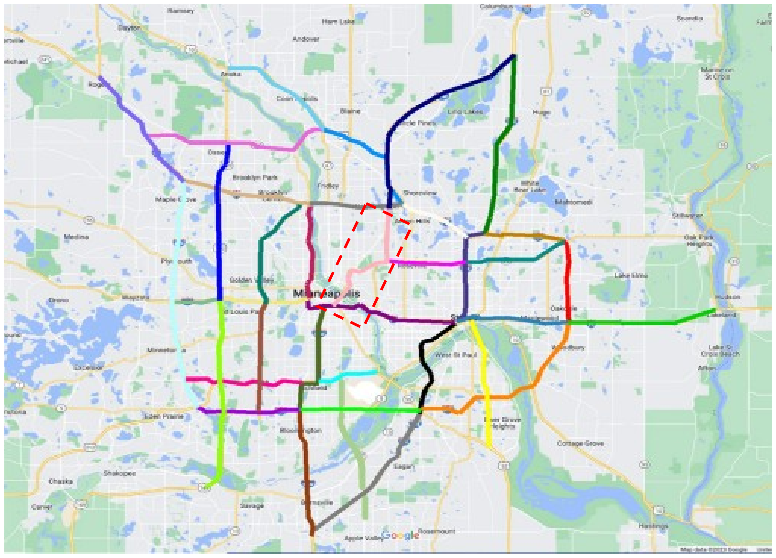






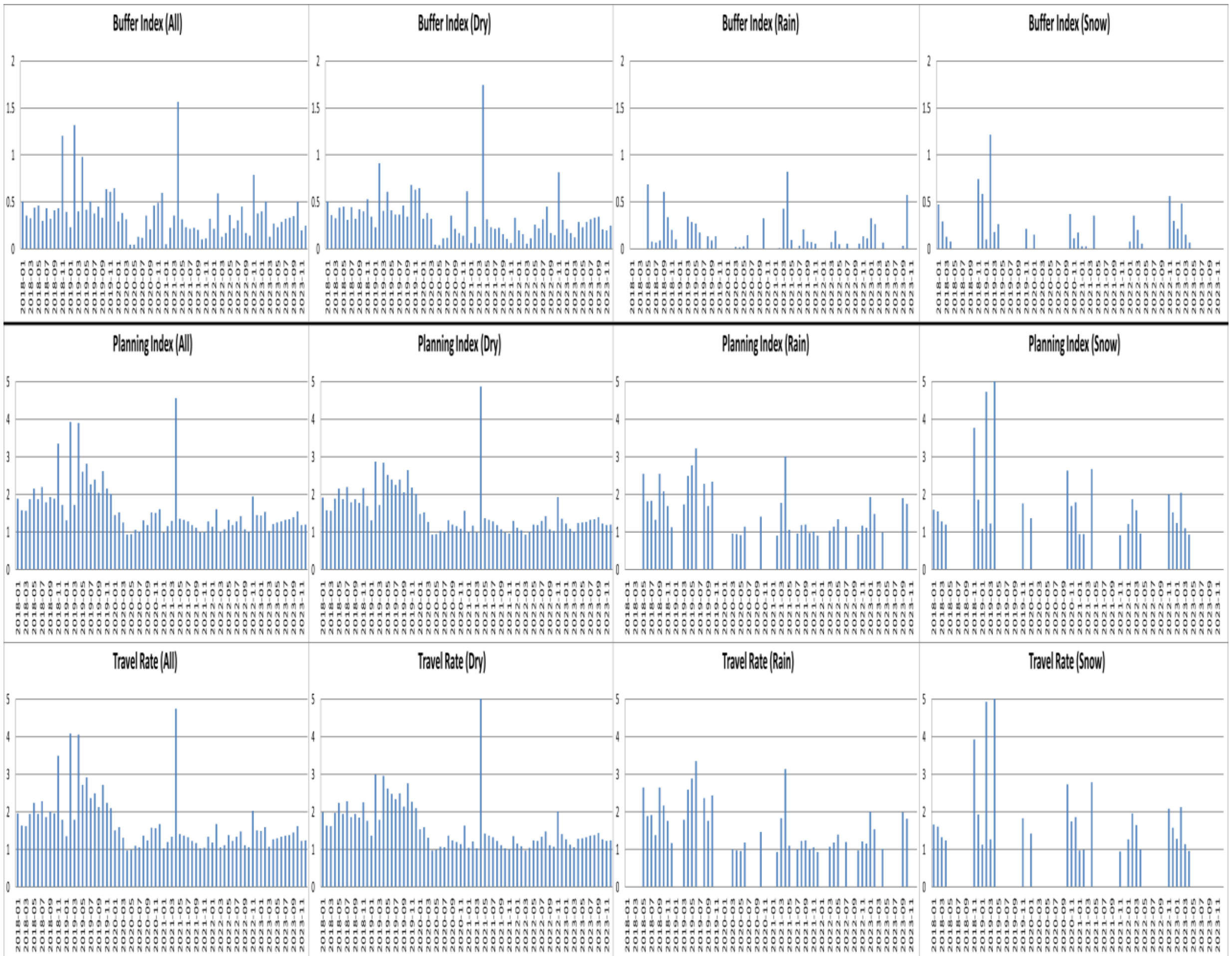
Variations of Traffic-Flow Measures

26) I-35W Corridor C (MPLS < -- > I694)



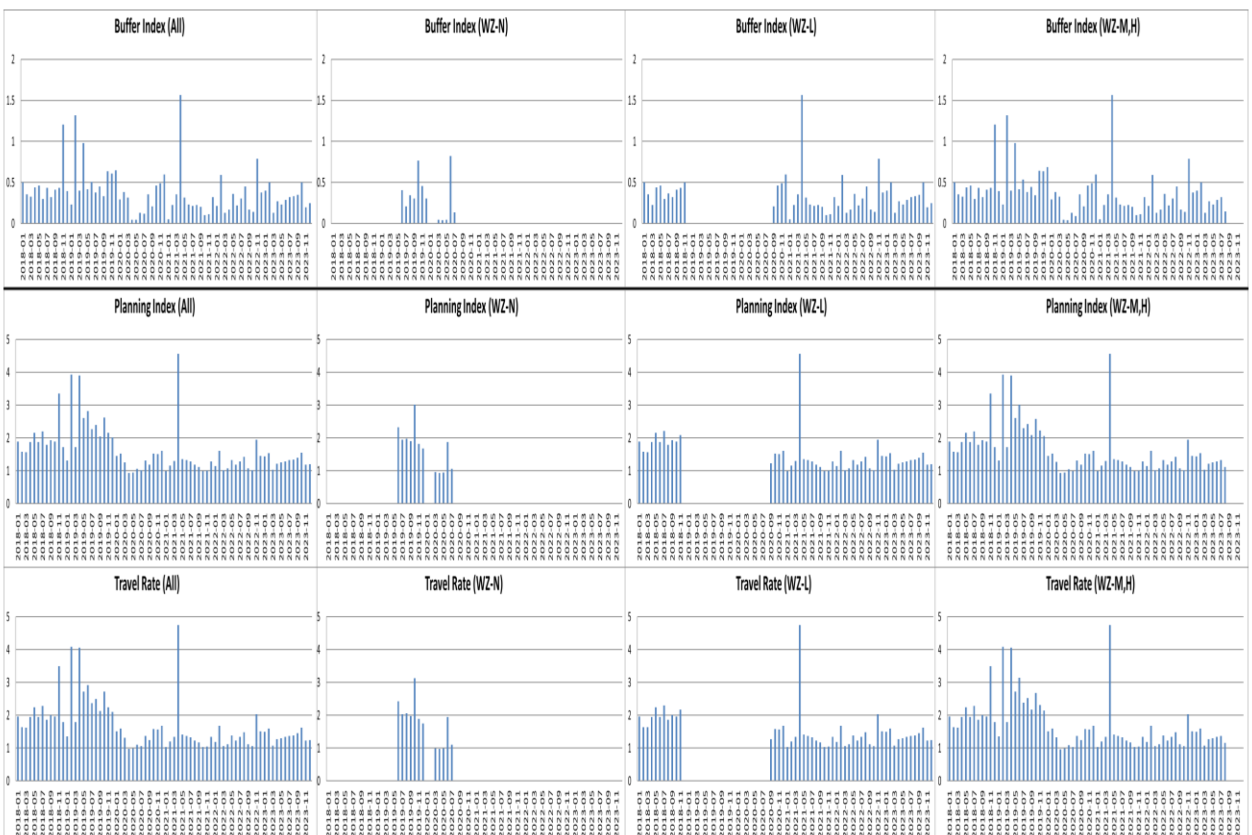
i) I-35W Corridor C -- NB MPLS to I694 for Afternoon Peak Periods

Effects of Weather conditions on Travel-Time Reliability

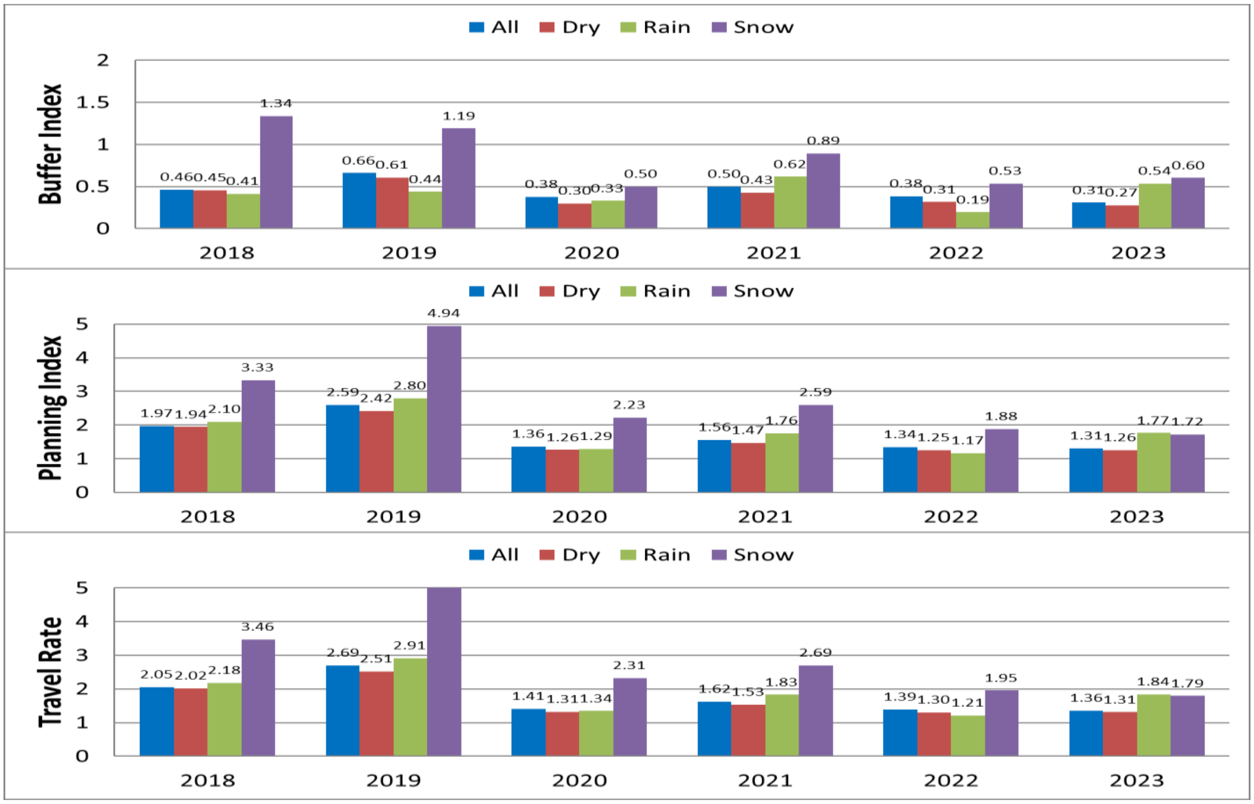


Effects of Incidents

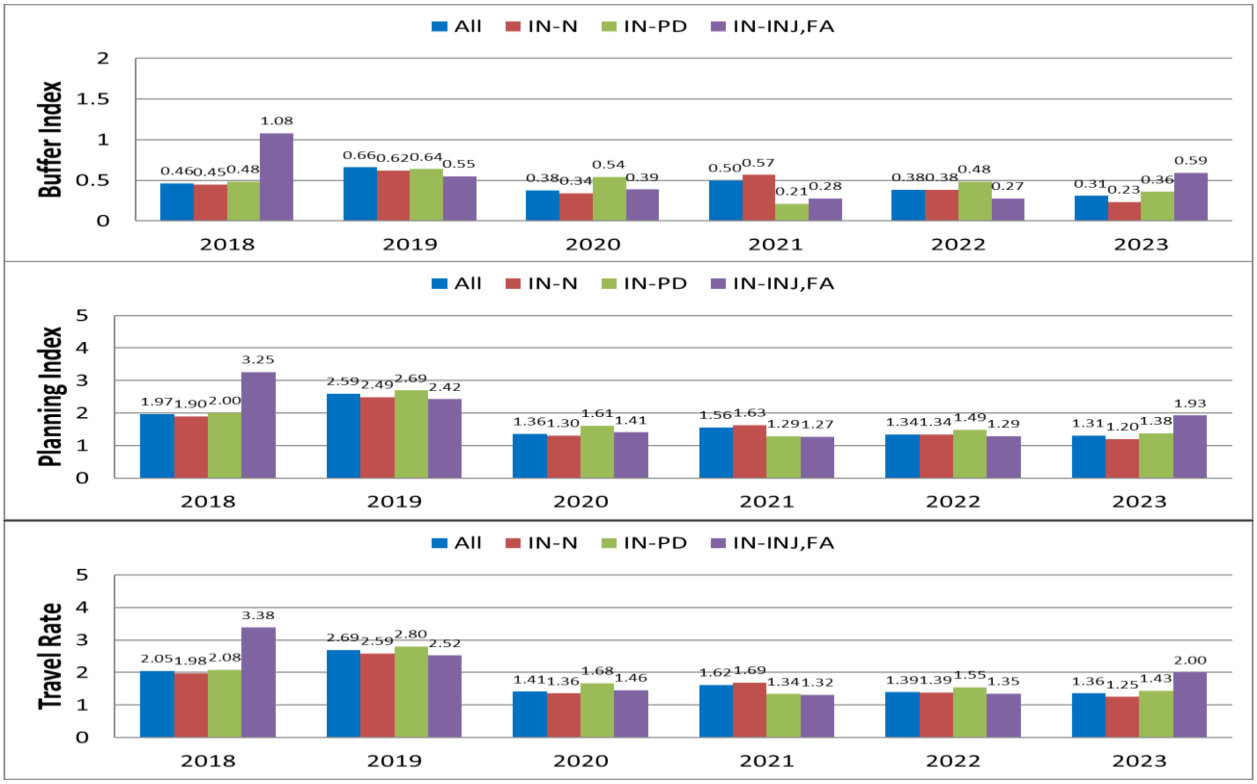
Effects of Work Zones



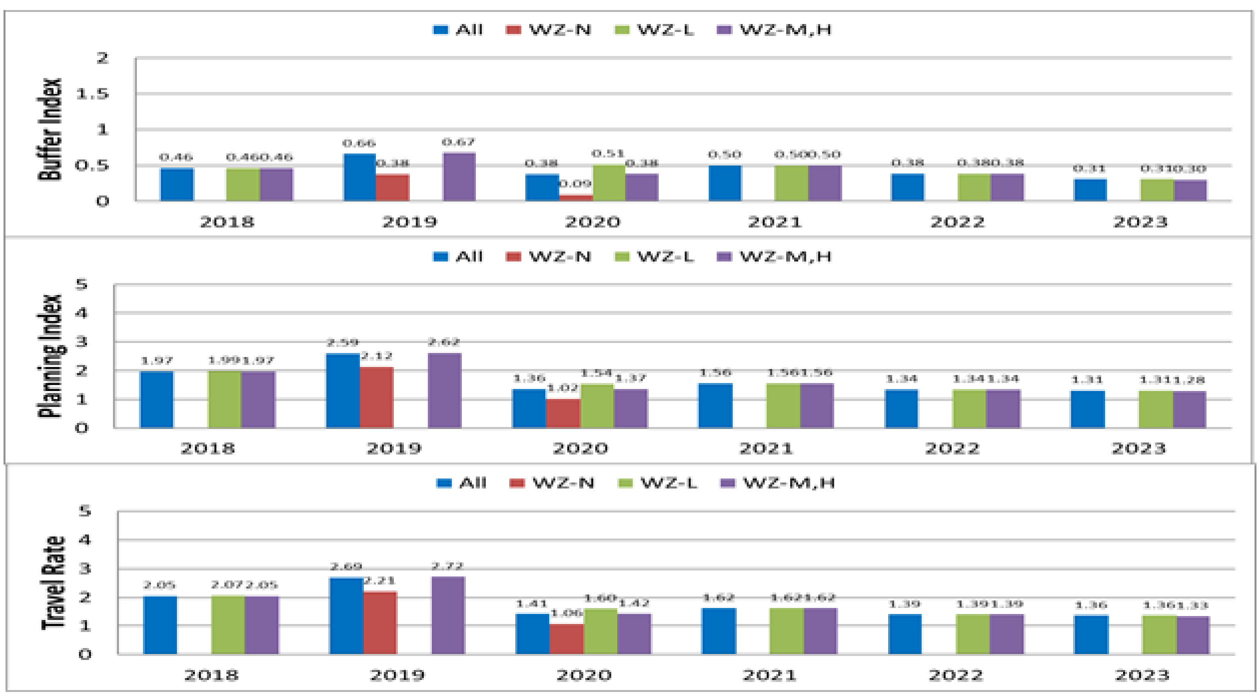
Yearly Variations - *Weather Effects*



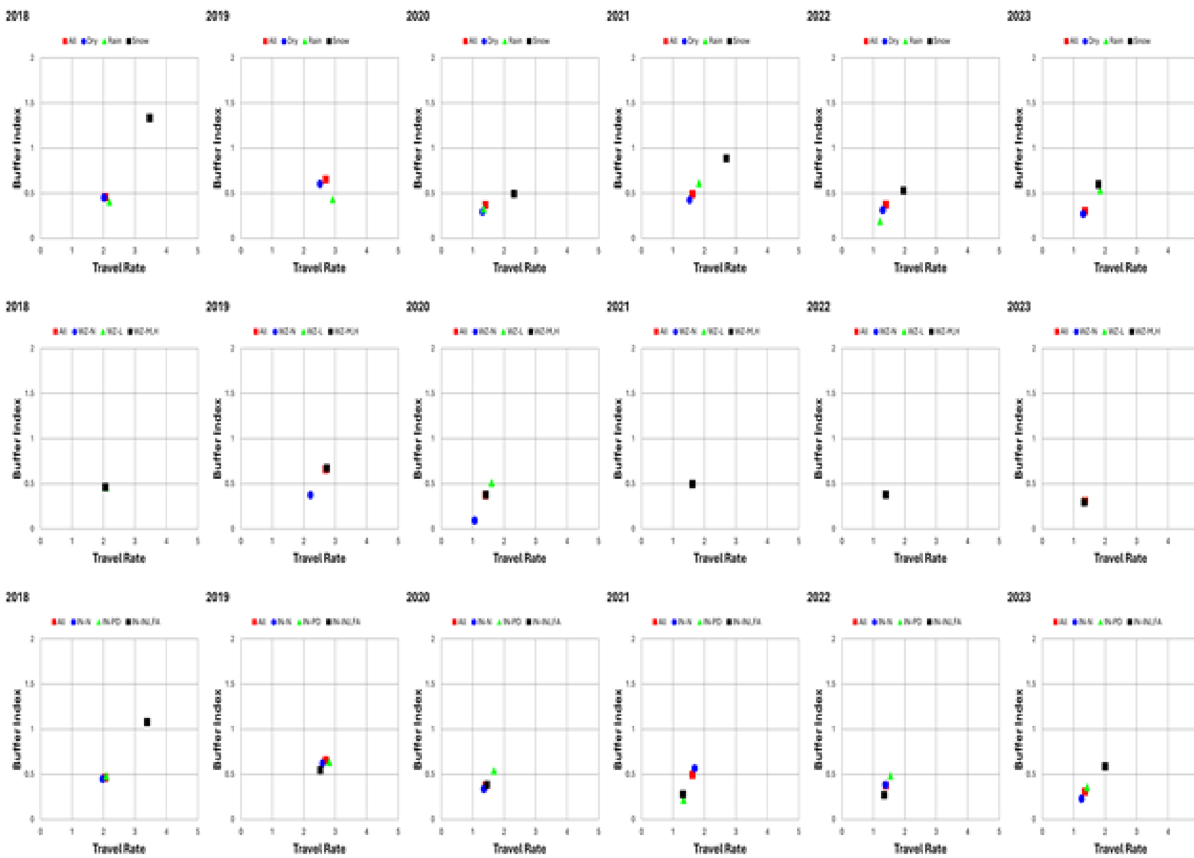
Incident Effects



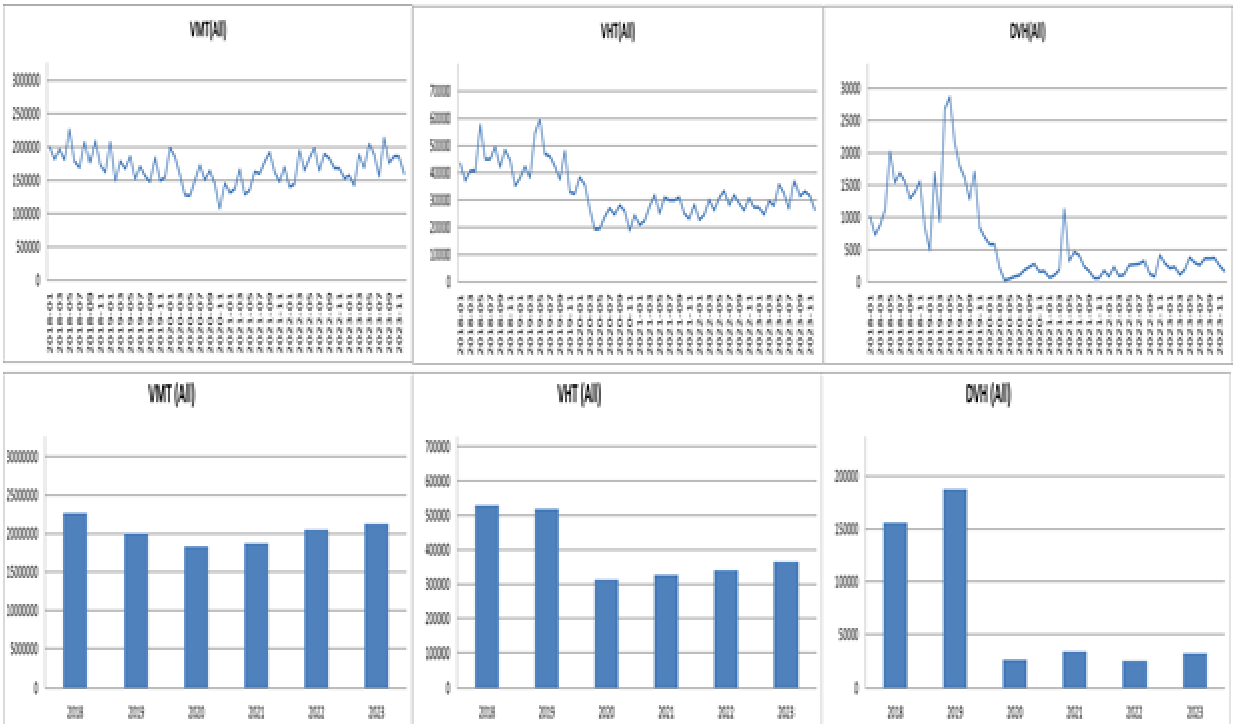
Work-Zone Effects



Yearly Variations of Buffer Index - Travel Rate Relationships

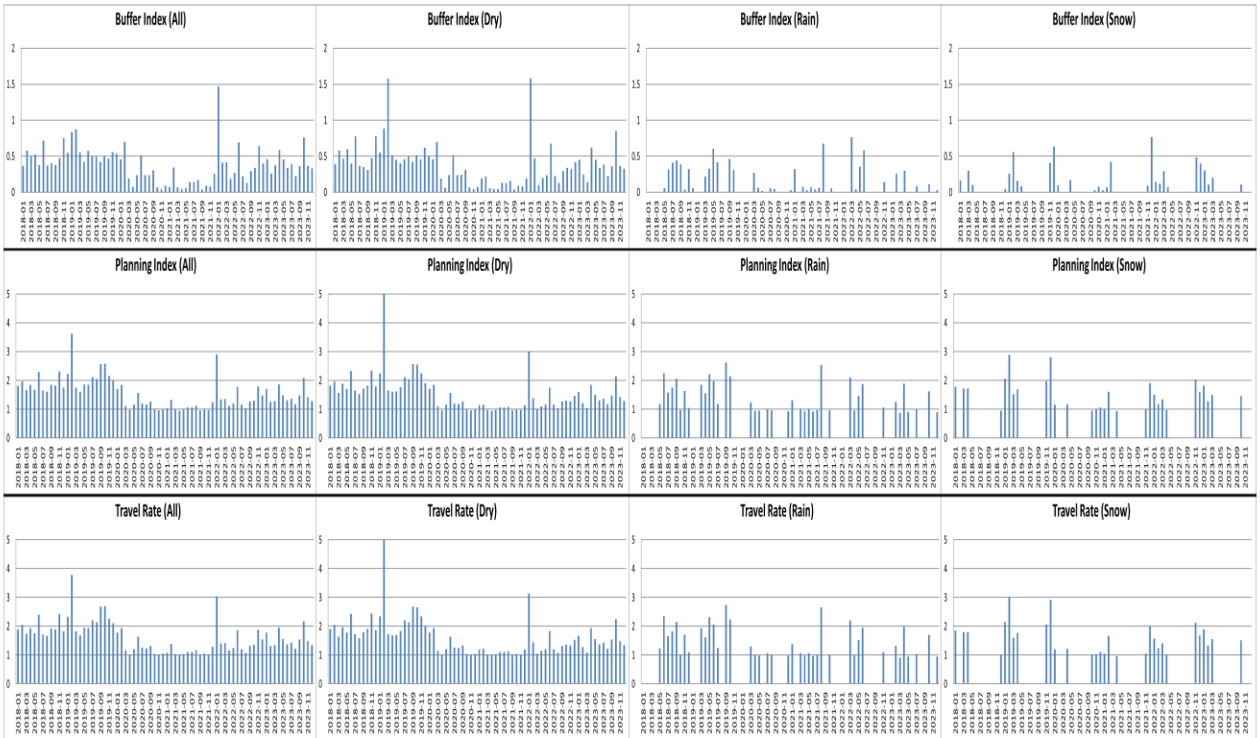


Variations of Traffic-Flow Measures

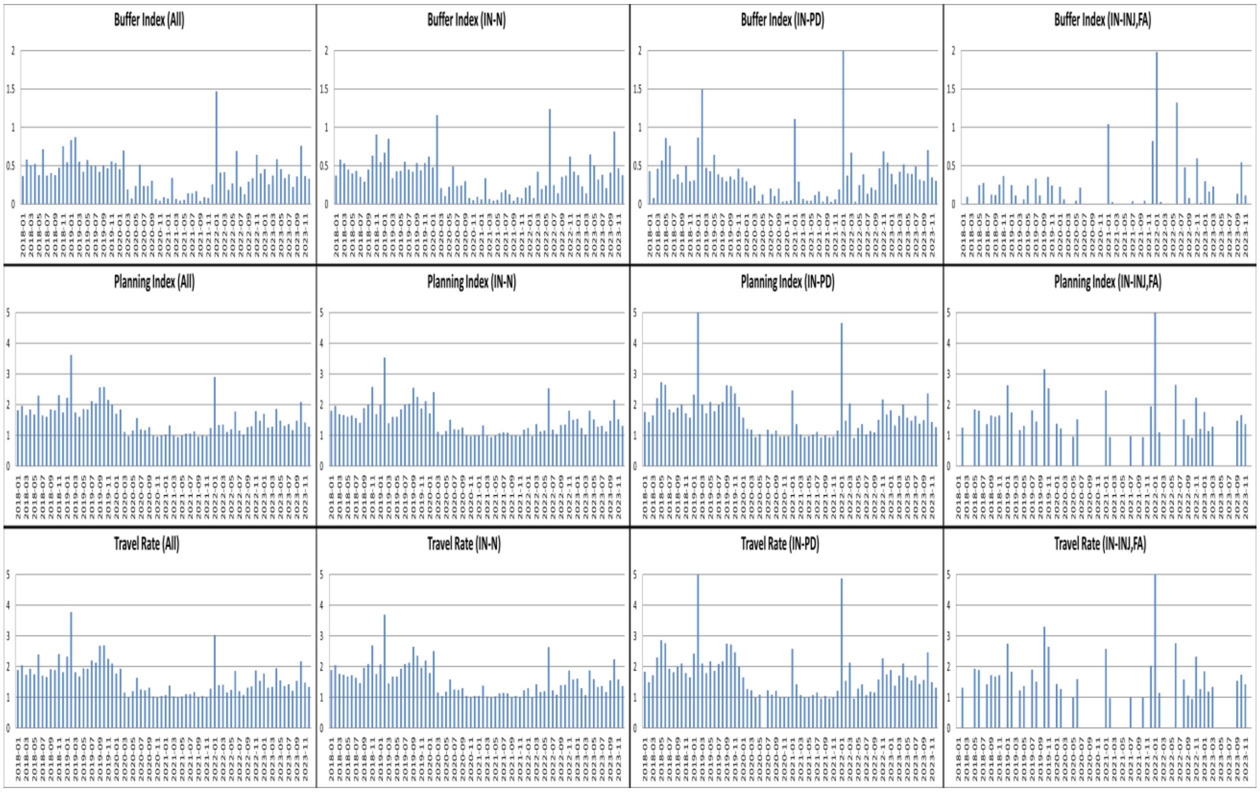

VMT(All)
VHT(All)
DVH(All)
VMT (All)
VHT (All)
DVH (All)

ii) I-35W Corridor C -- SB I694 to MPLS for Morning Peak Periods

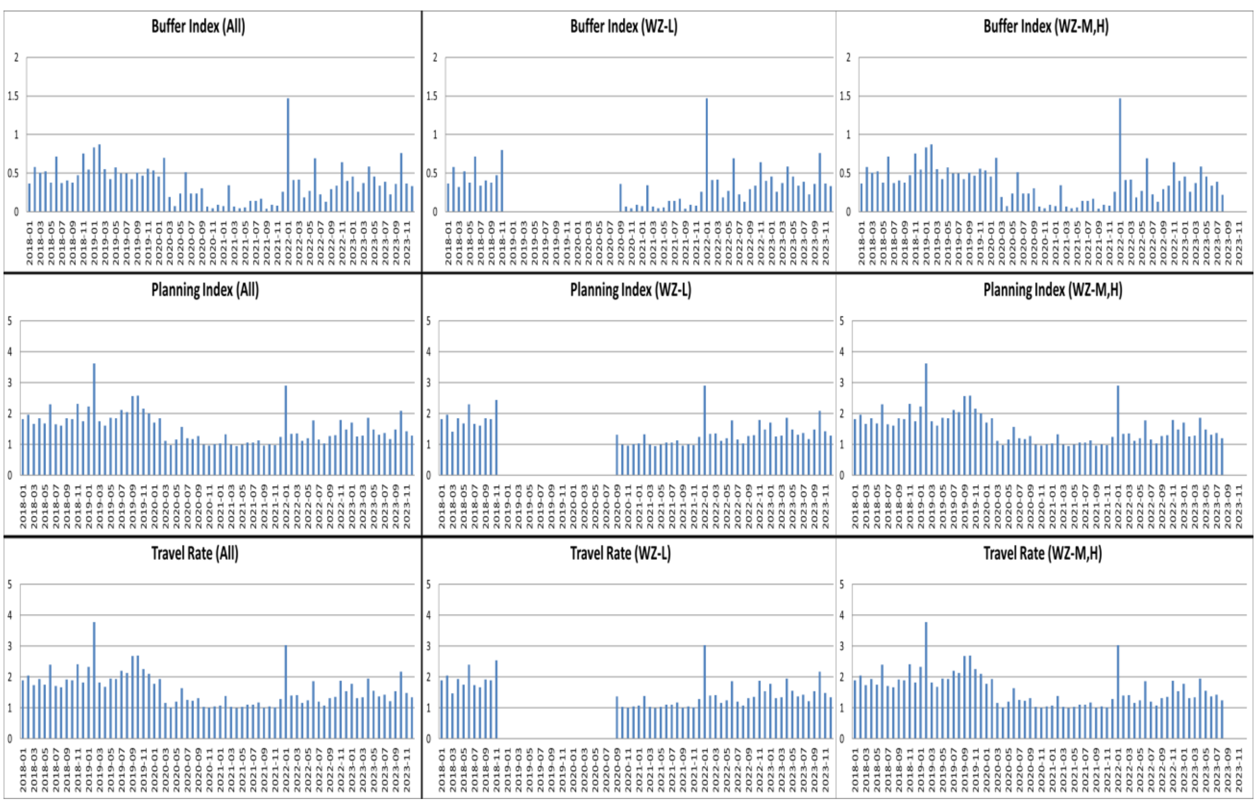
Effects of Weather conditions on Travel-Time Reliability



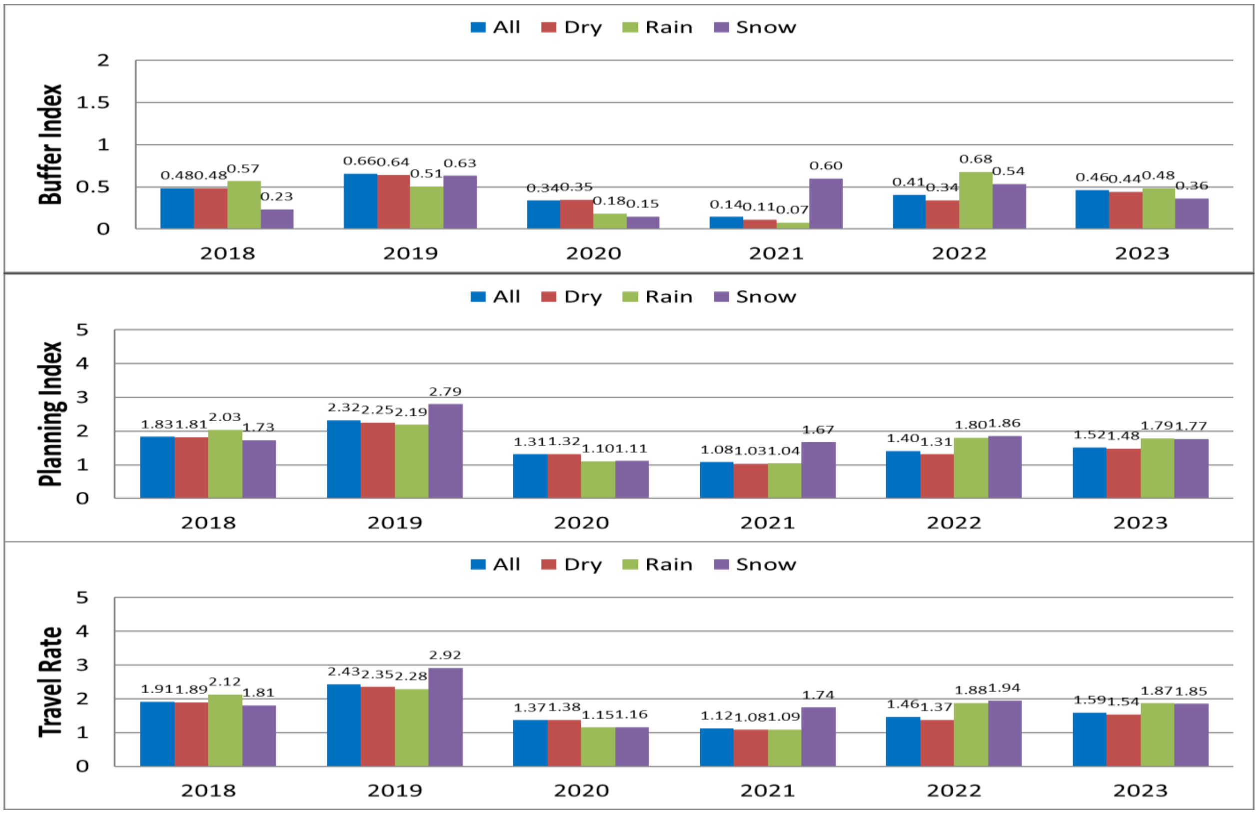
Effects of Incidents



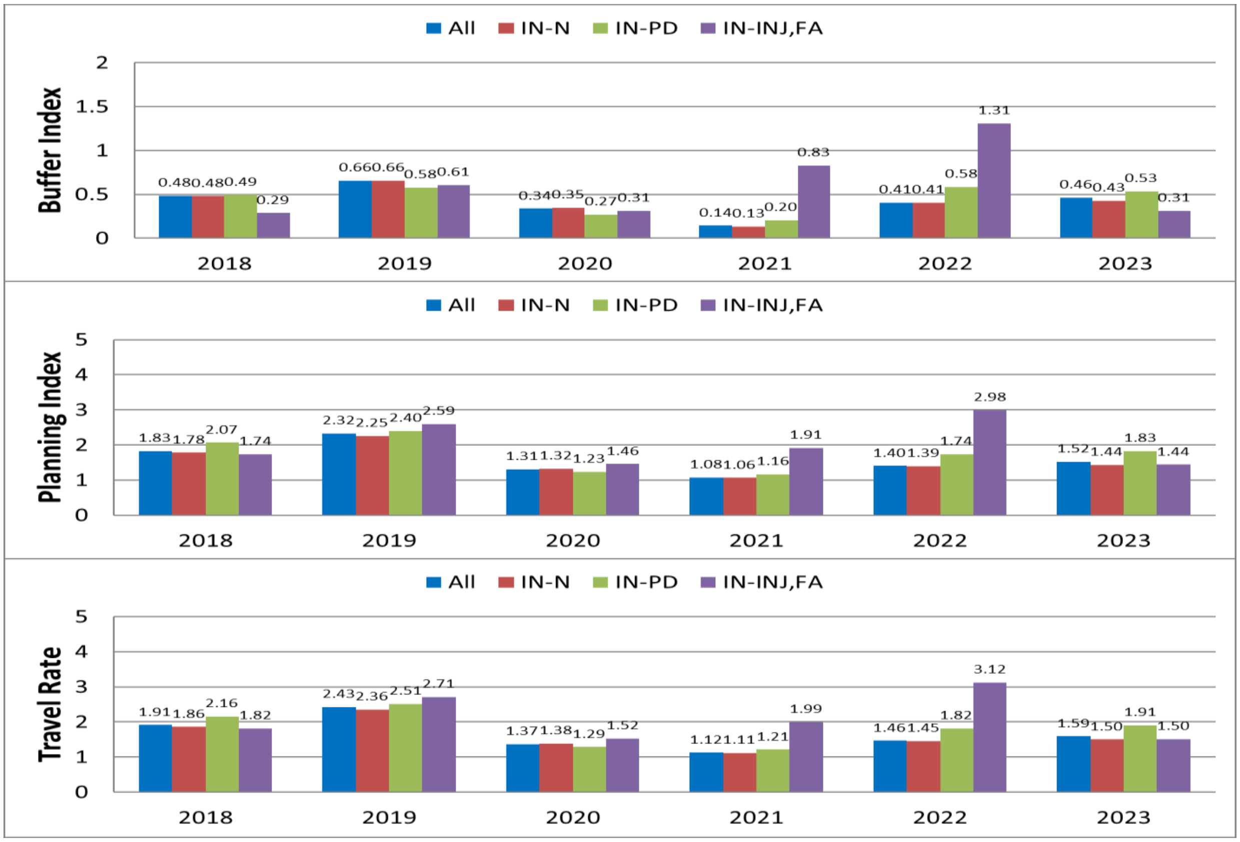
Effects of Work Zones



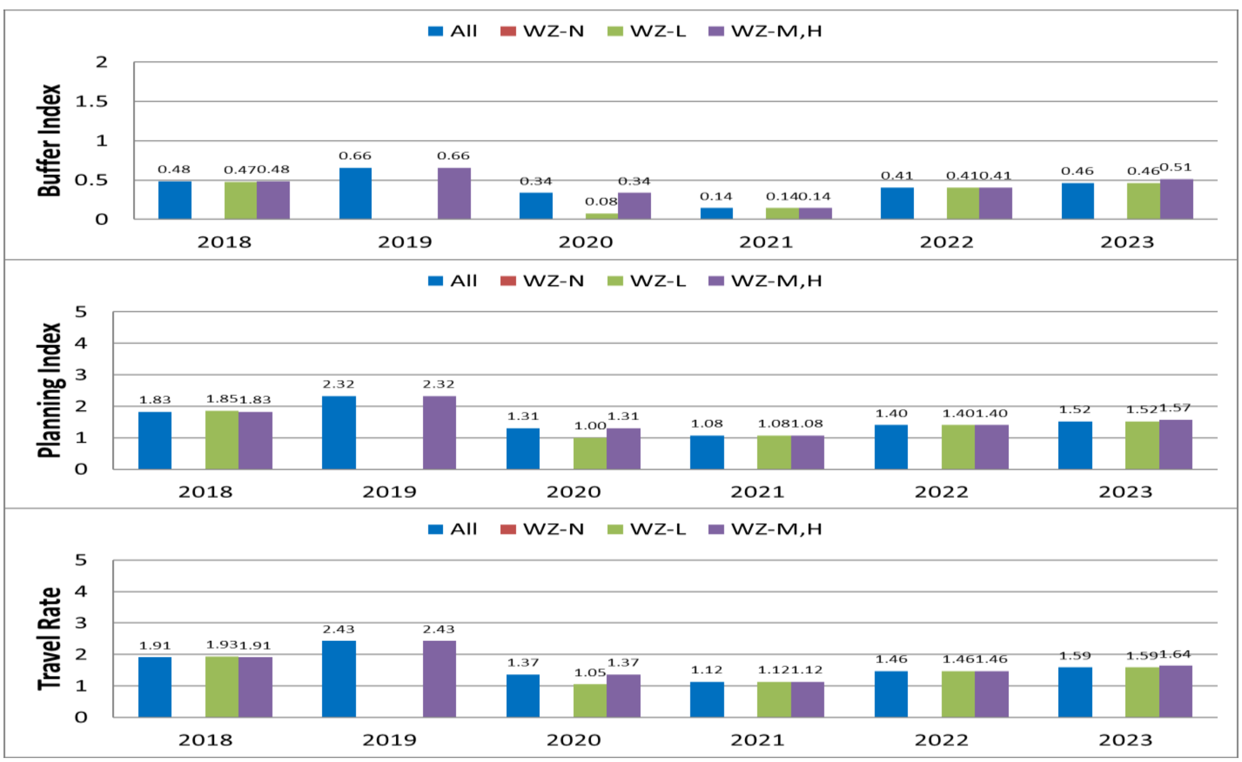
Yearly Variations - *Weather Effects*



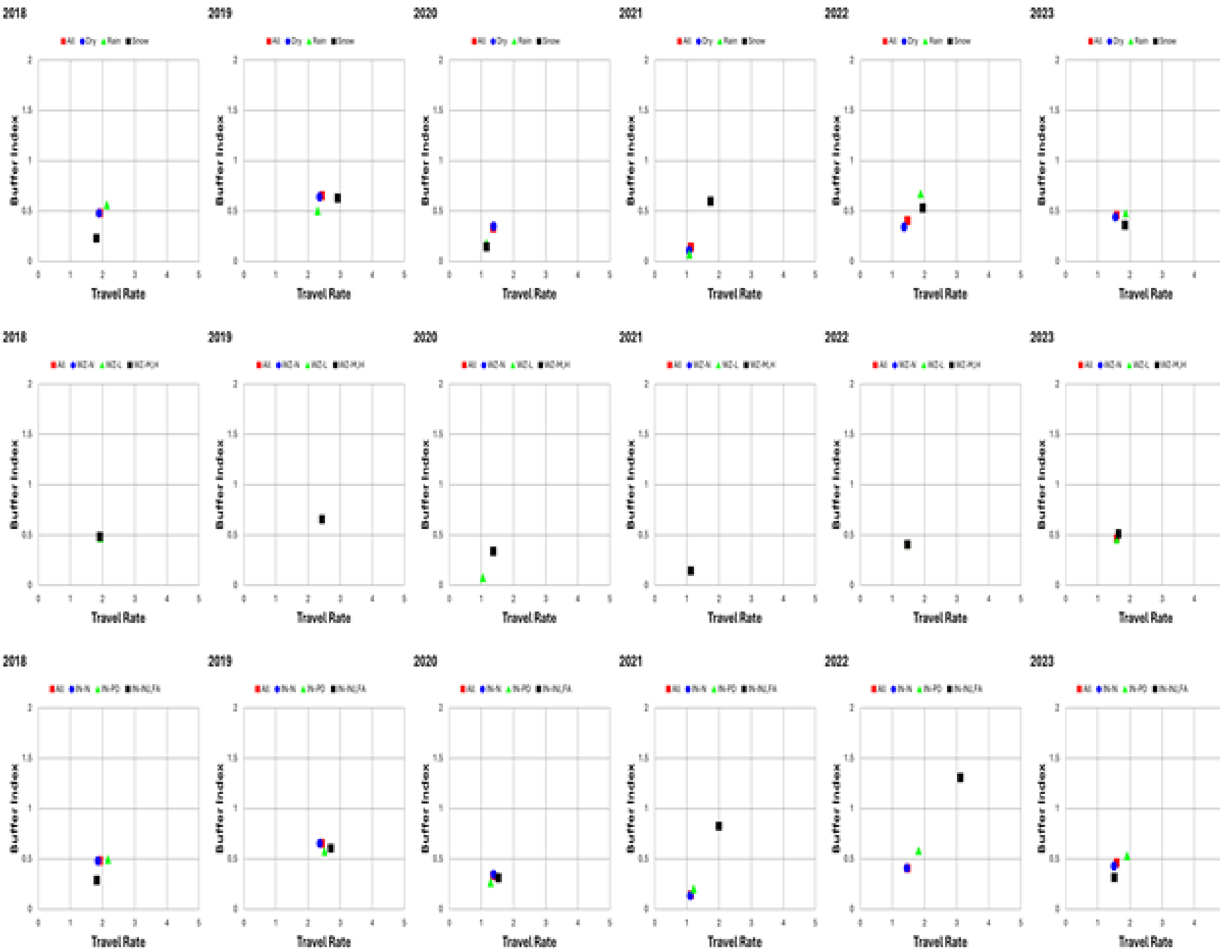
Incident Effects



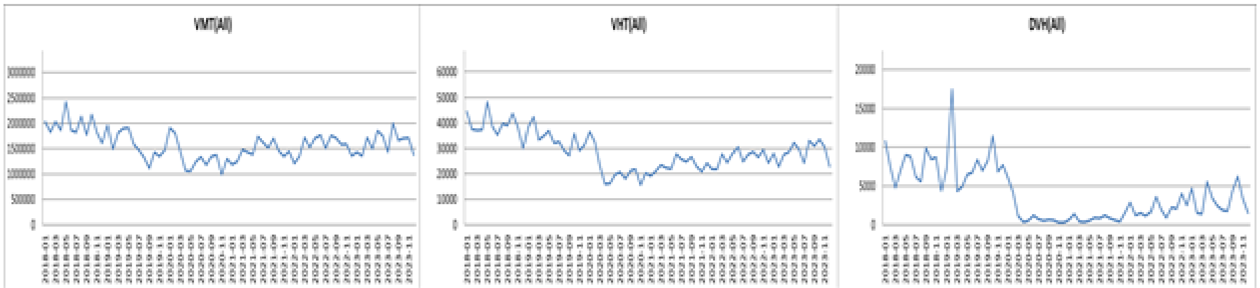
Work-Zone Effects

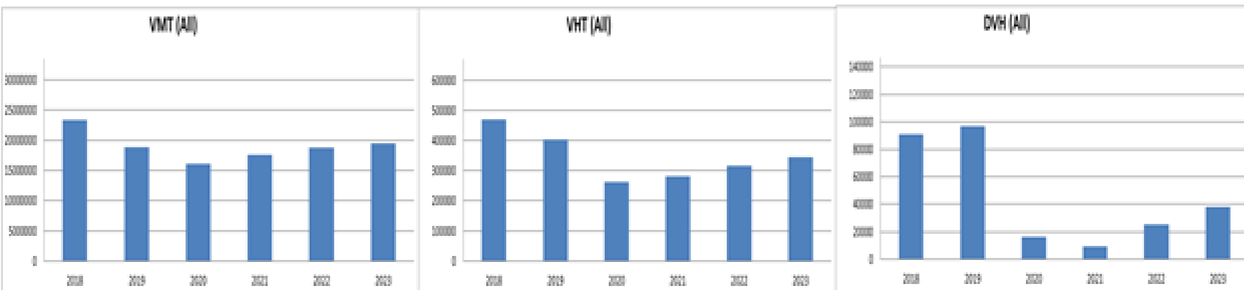


Yearly Variations of Buffer Index - Travel Rate Relationships

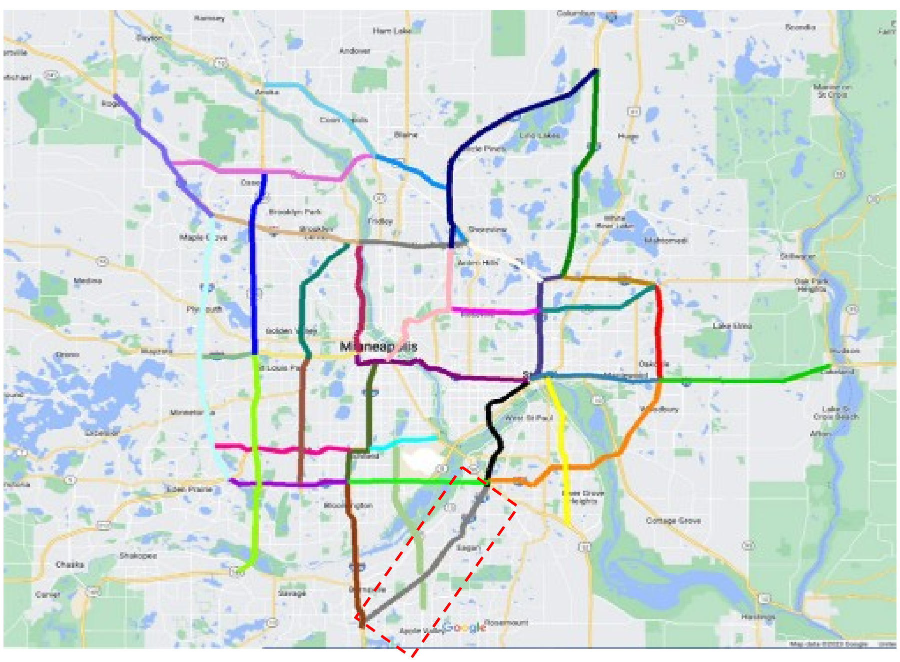


Variations of Traffic-Flow Measures



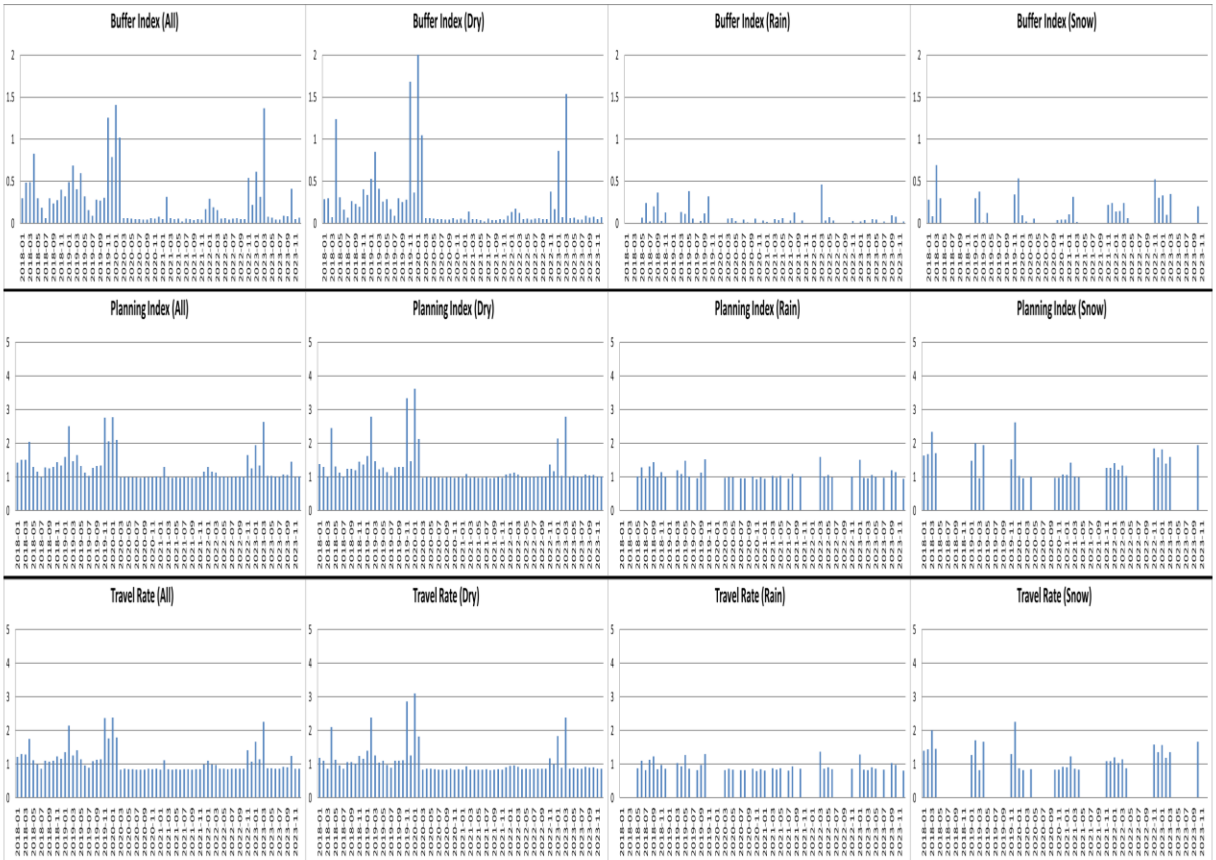


27) I-35E Corridor A (I35 to I494)

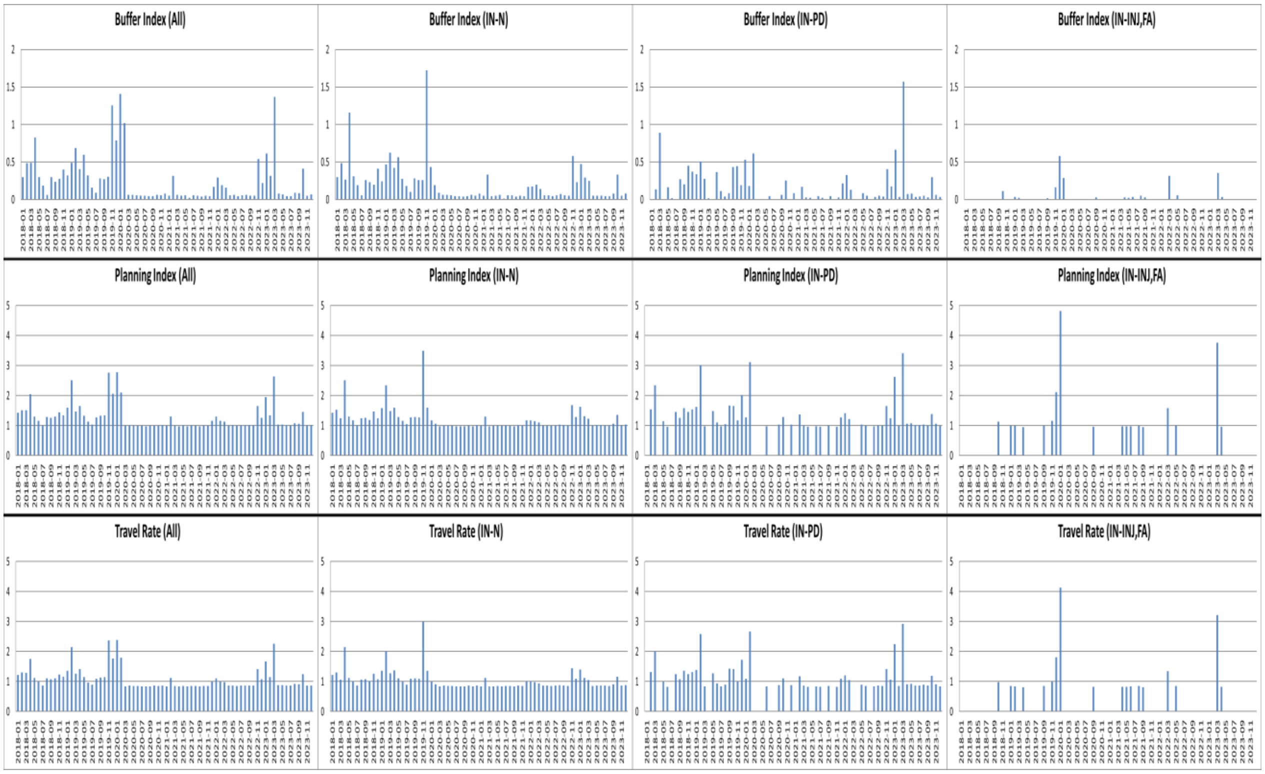


i) I-35E Corridor A -- NB I35 to I494 for Morning Peak Periods

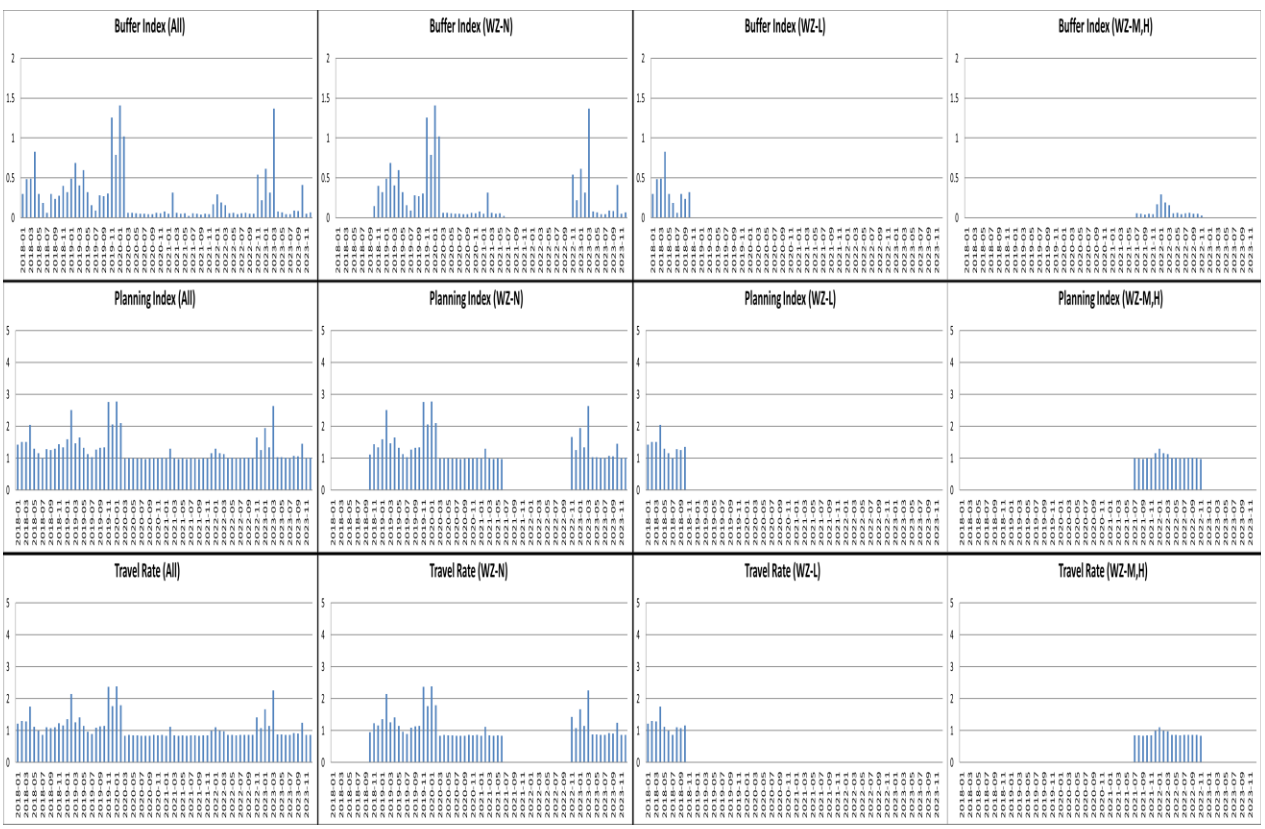
Effects of Weather conditions on Travel-Time Reliability



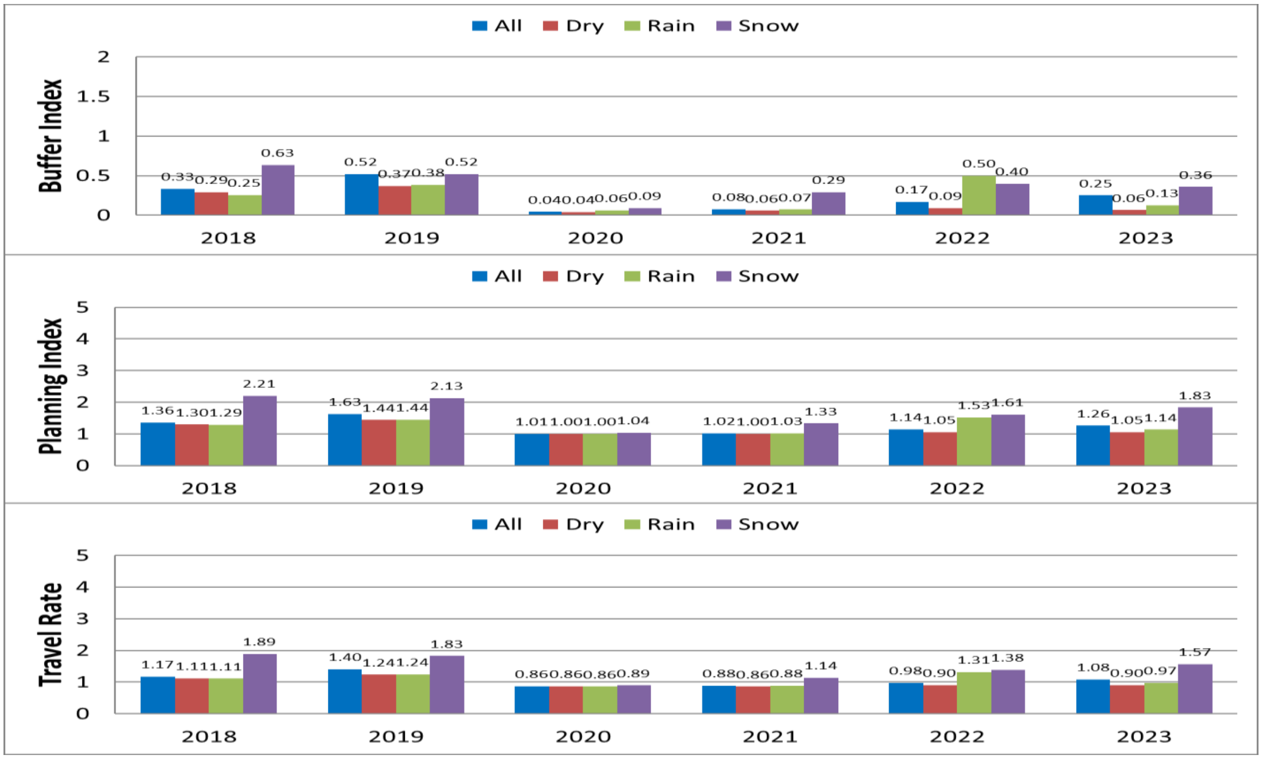
Effects of Incidents



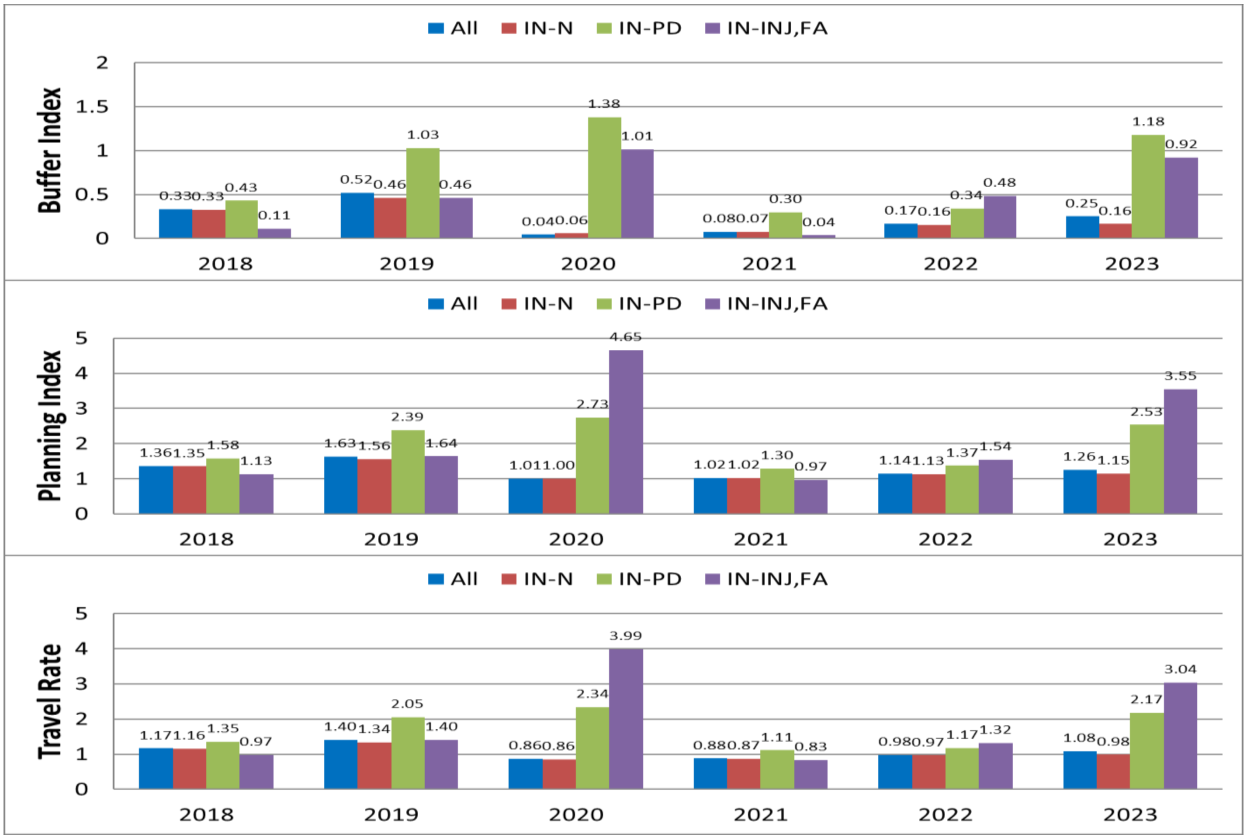
Effects of Work Zones



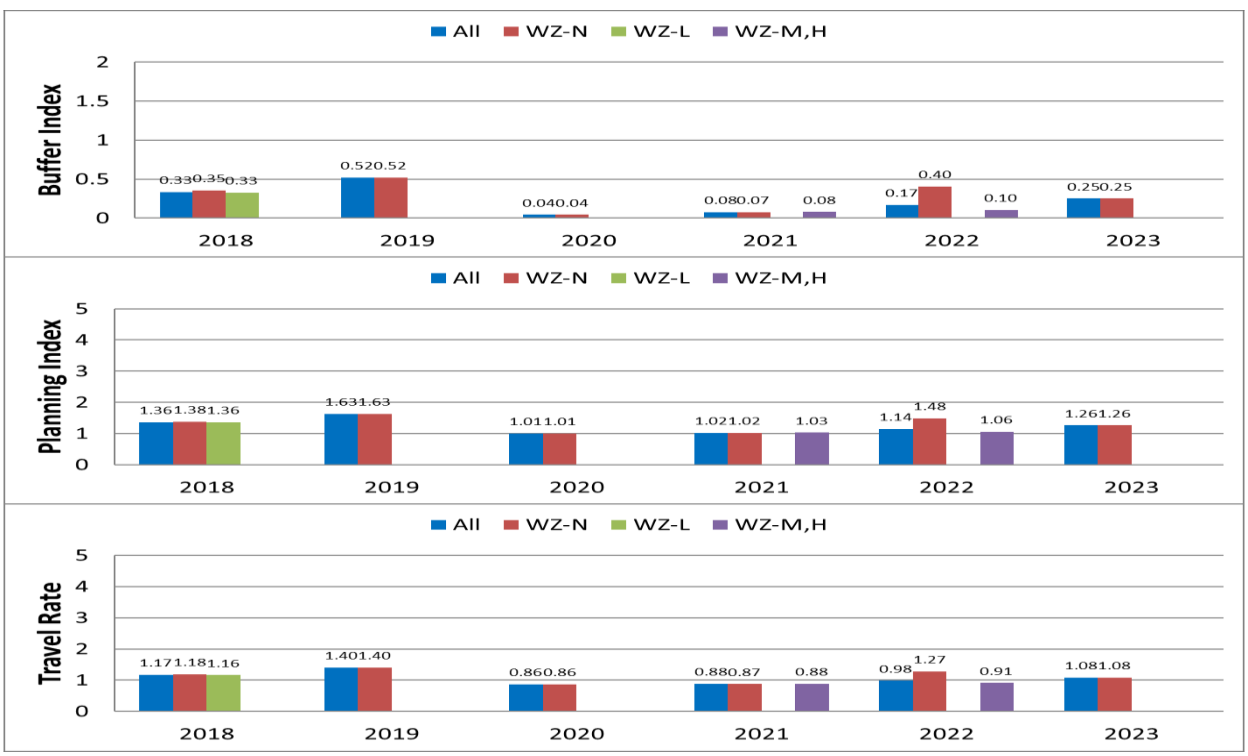
Yearly Variations - *Weather Effects*



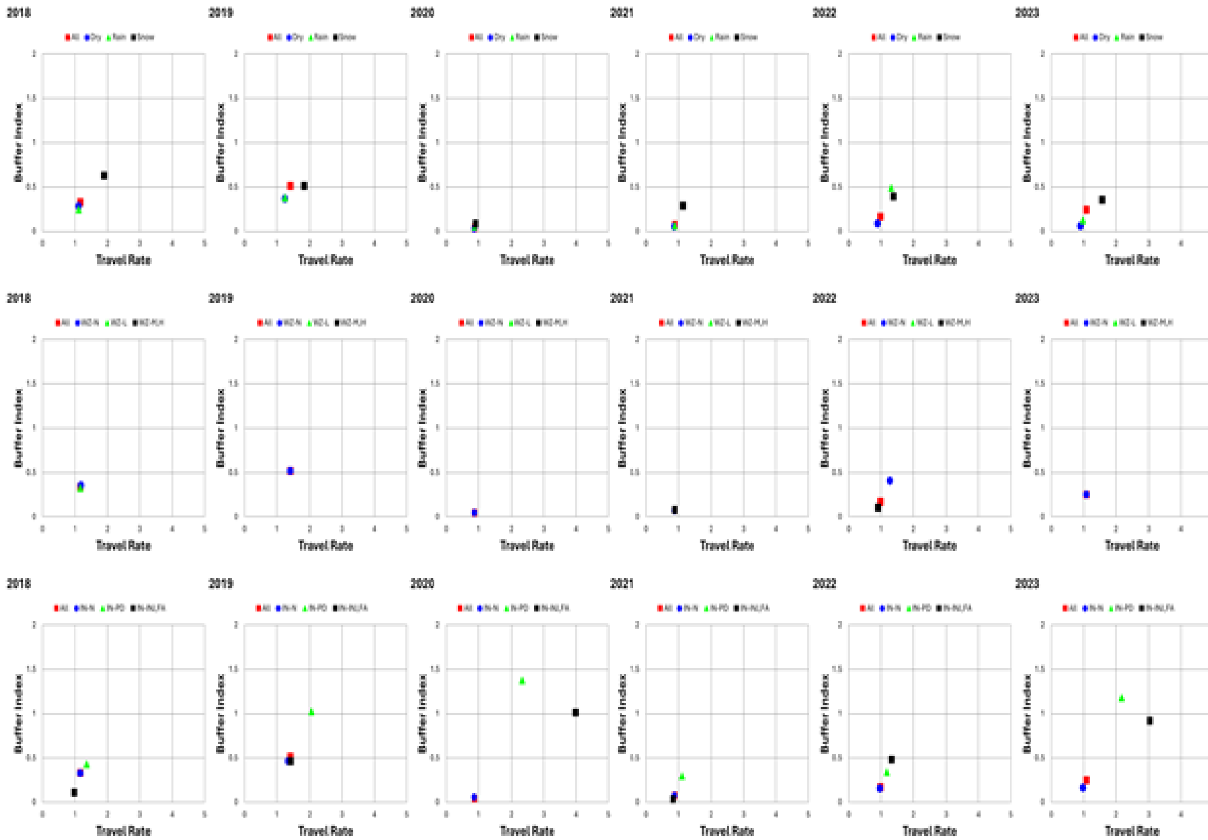
Incident Effects



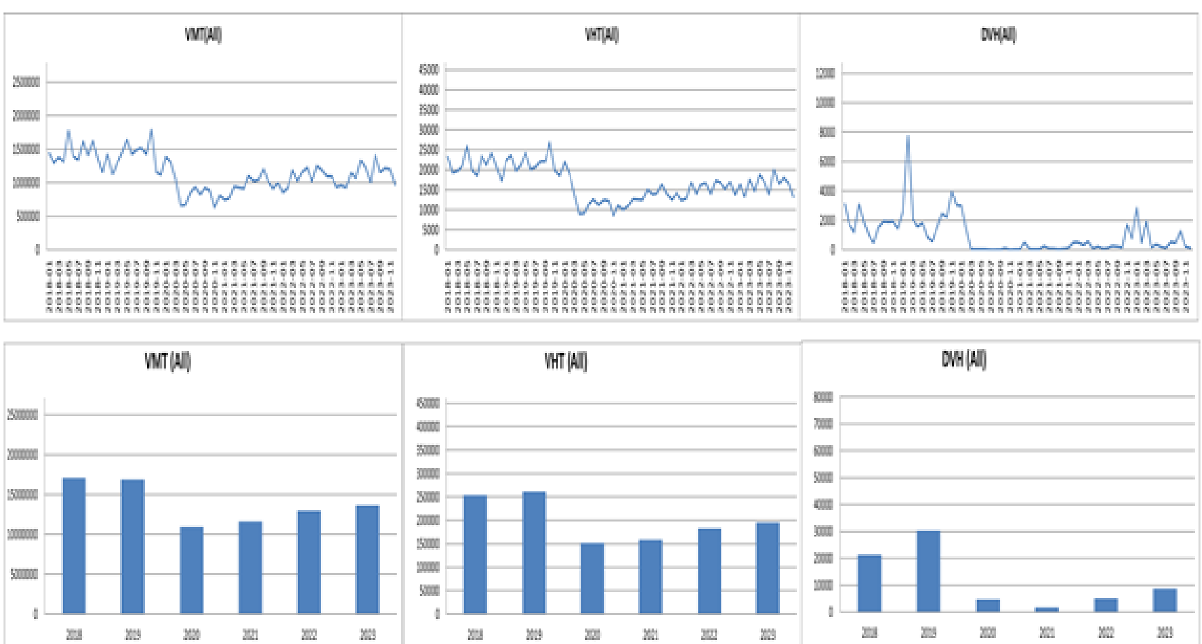
Work-Zone Effects



Yearly Variations of Buffer Index - Travel Rate Relationships

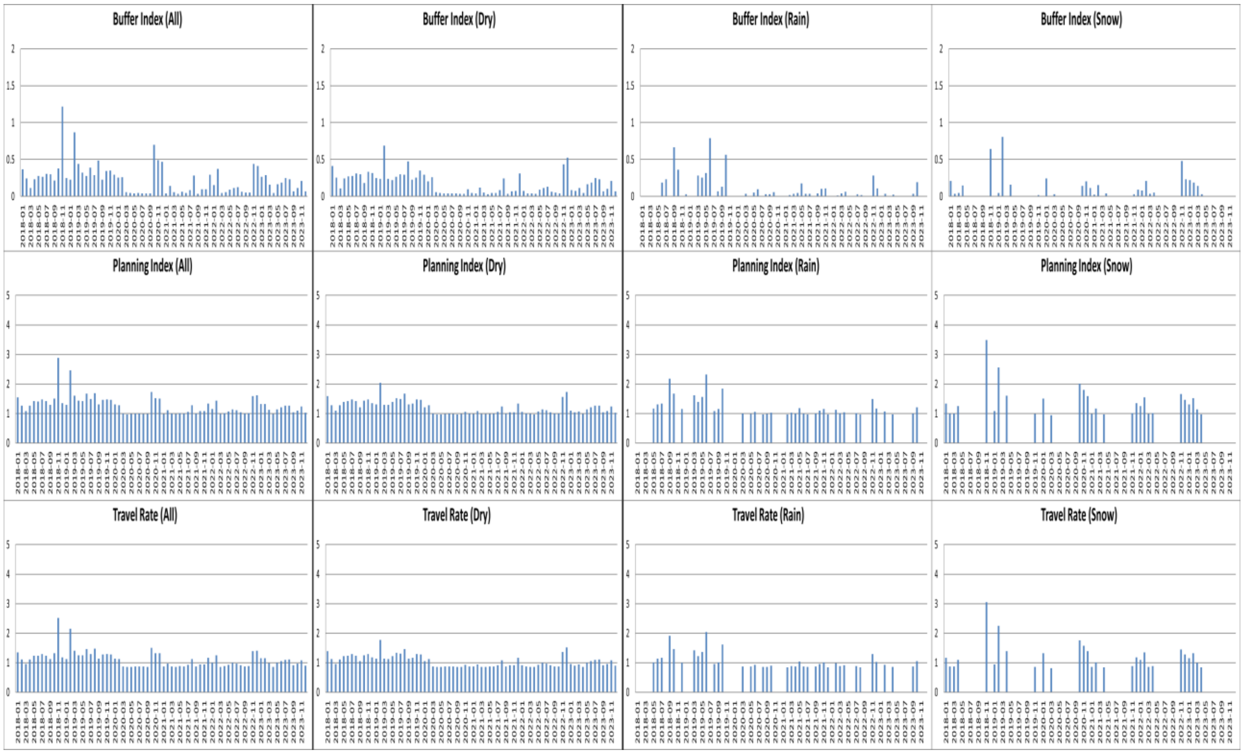


Variations of Traffic-Flow Measures

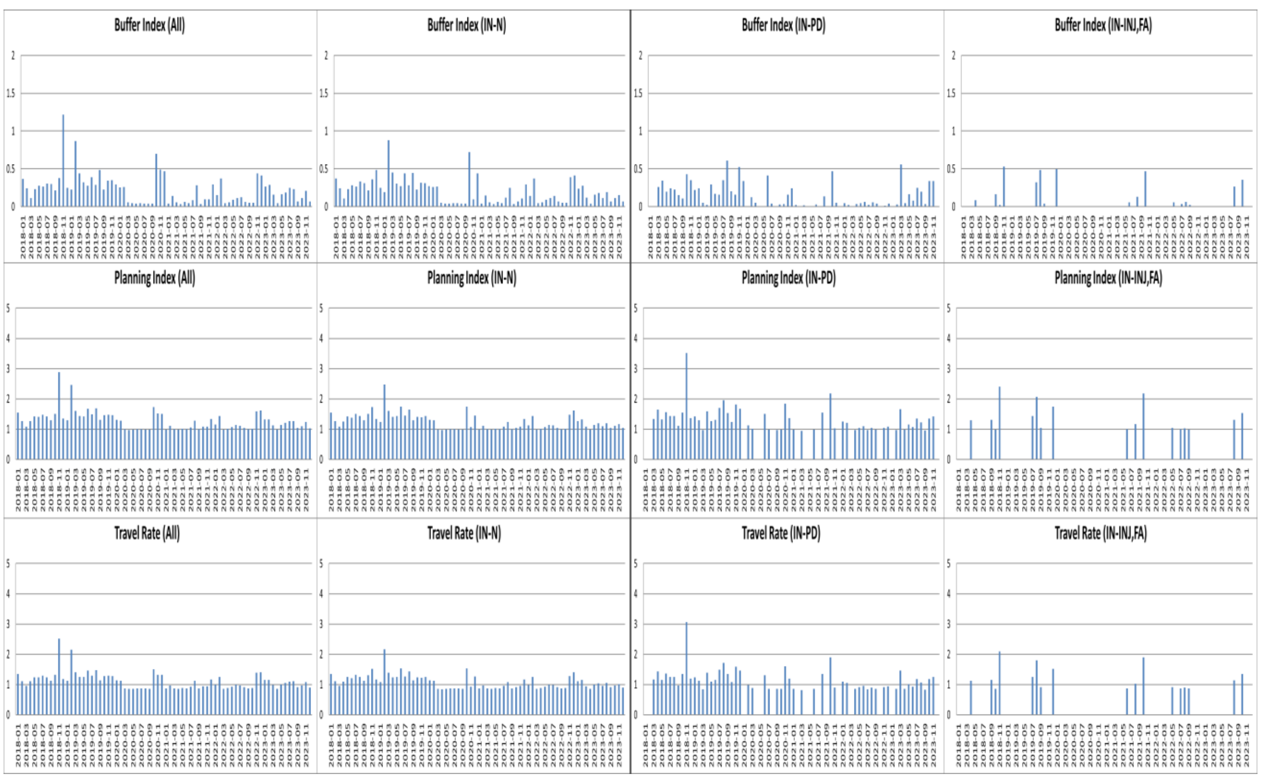


ii) I-35E Corridor A -- SB I494 to I35 for Afternoon Peak Periods

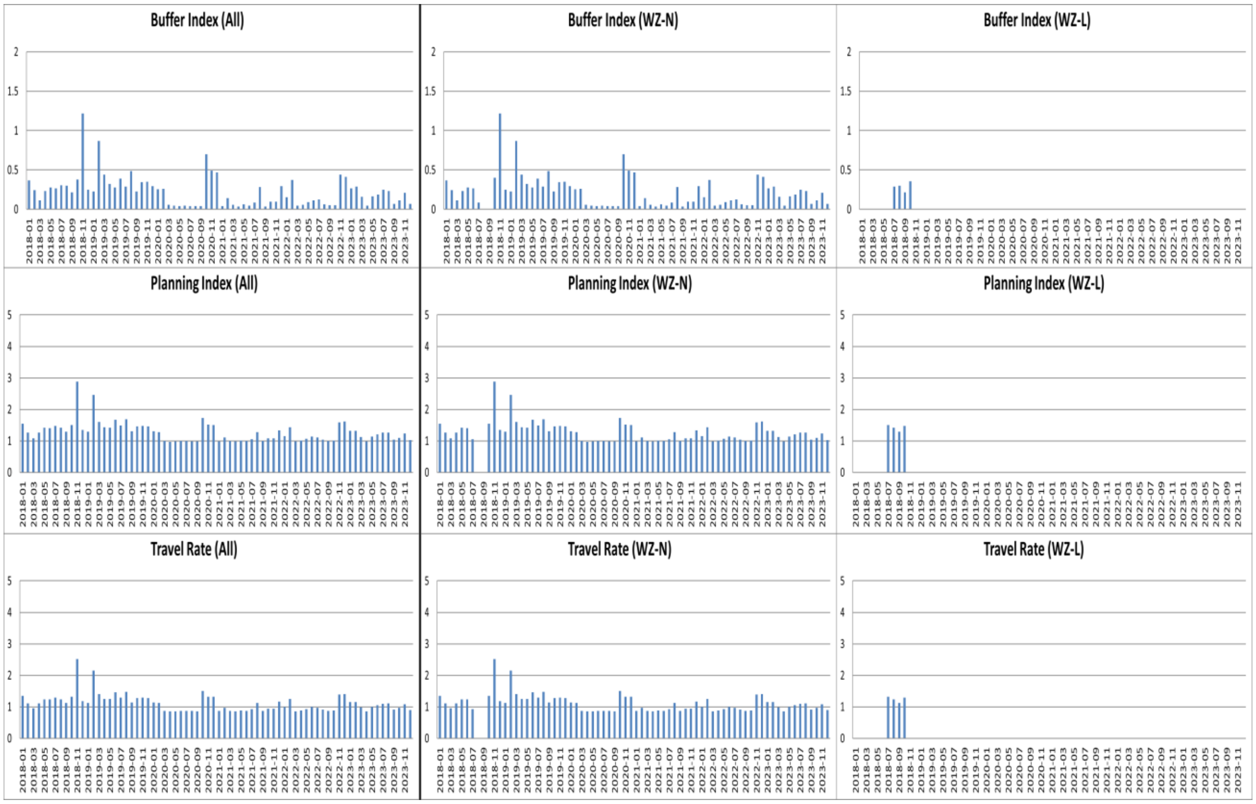
Effects of Weather conditions on Travel-Time Reliability



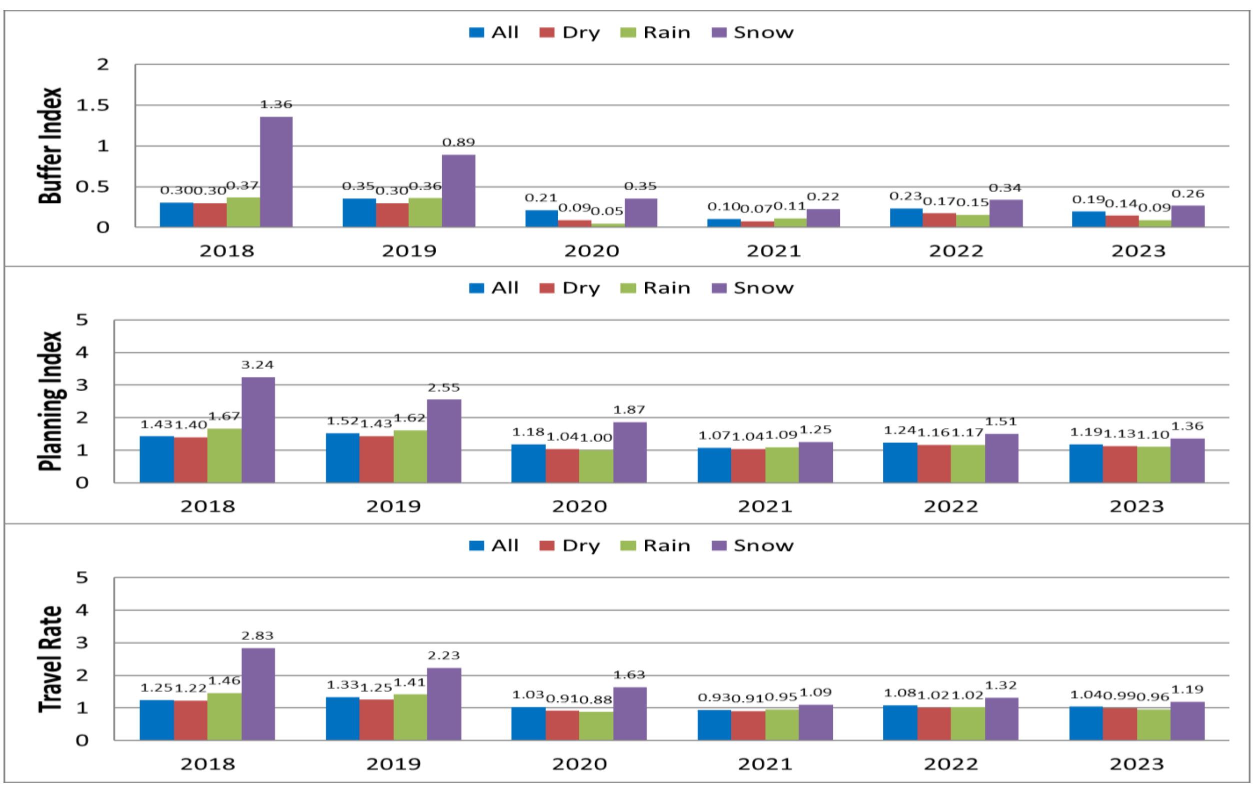
Effects of Incidents



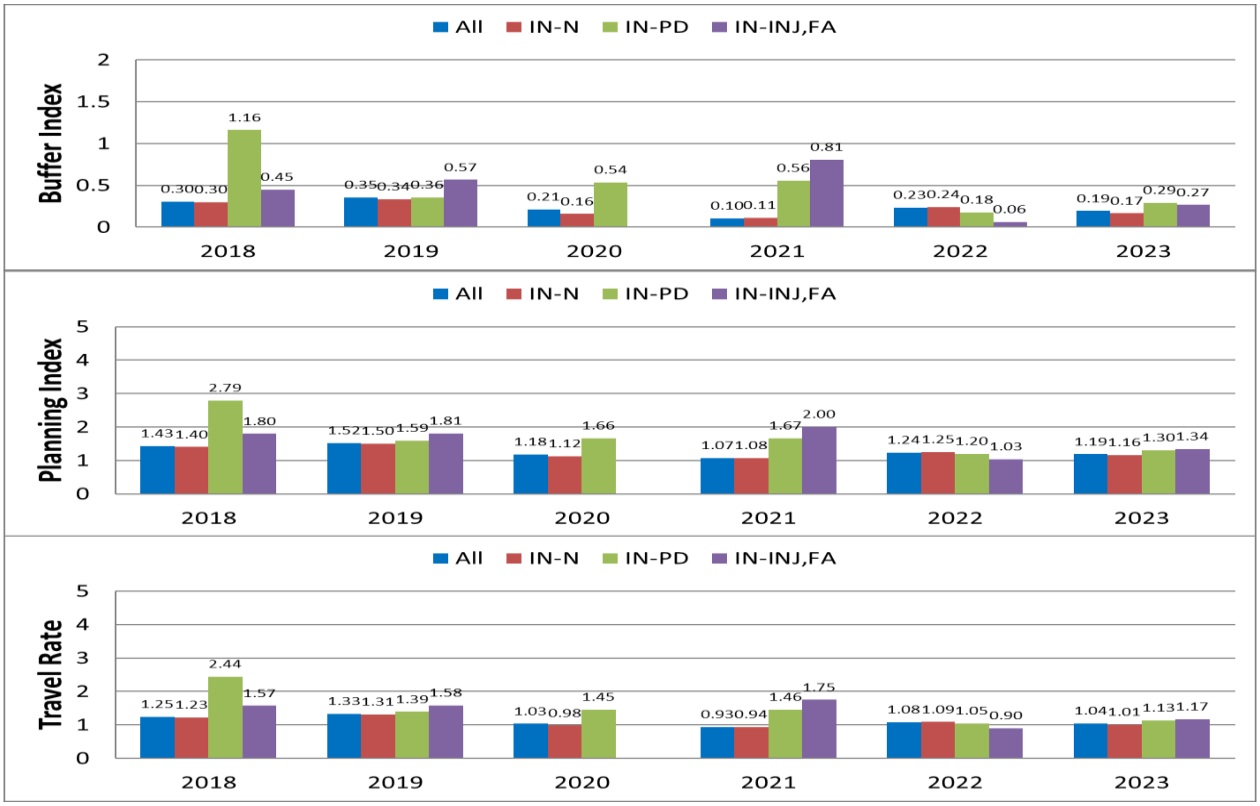
Effects of Work Zones



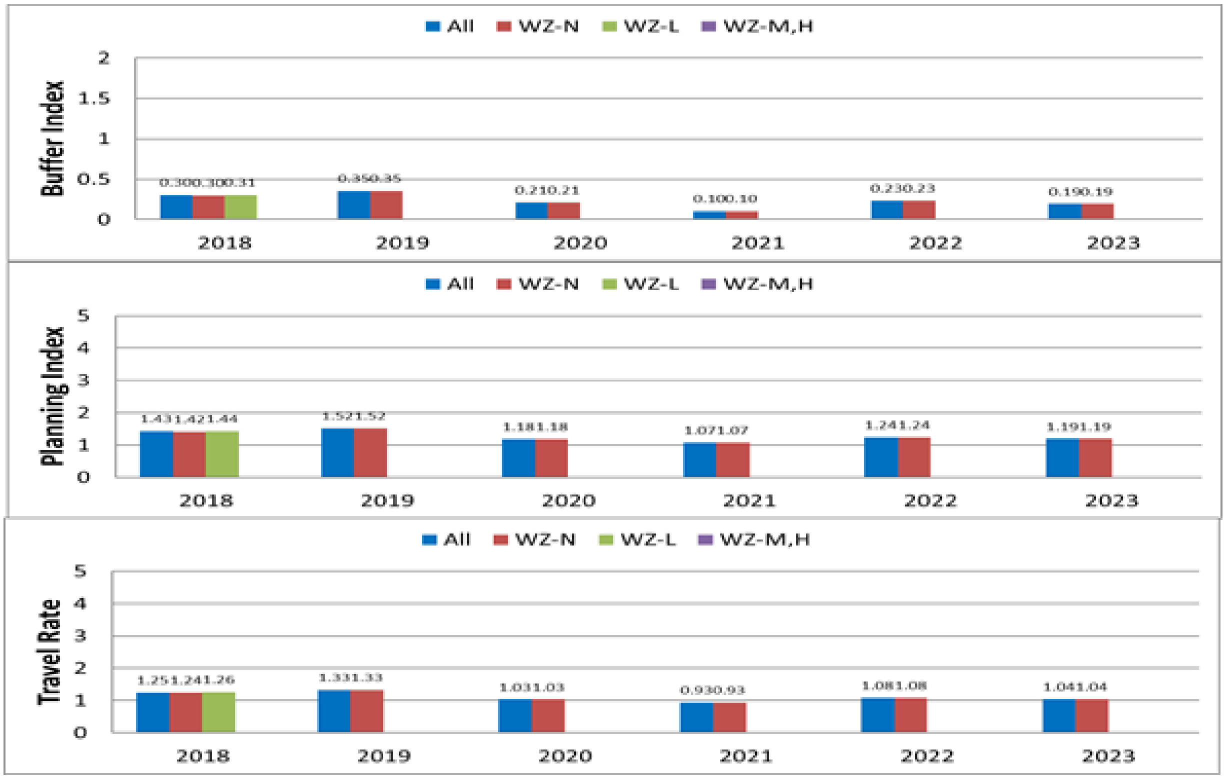
Yearly Variations - *Weather Effects*



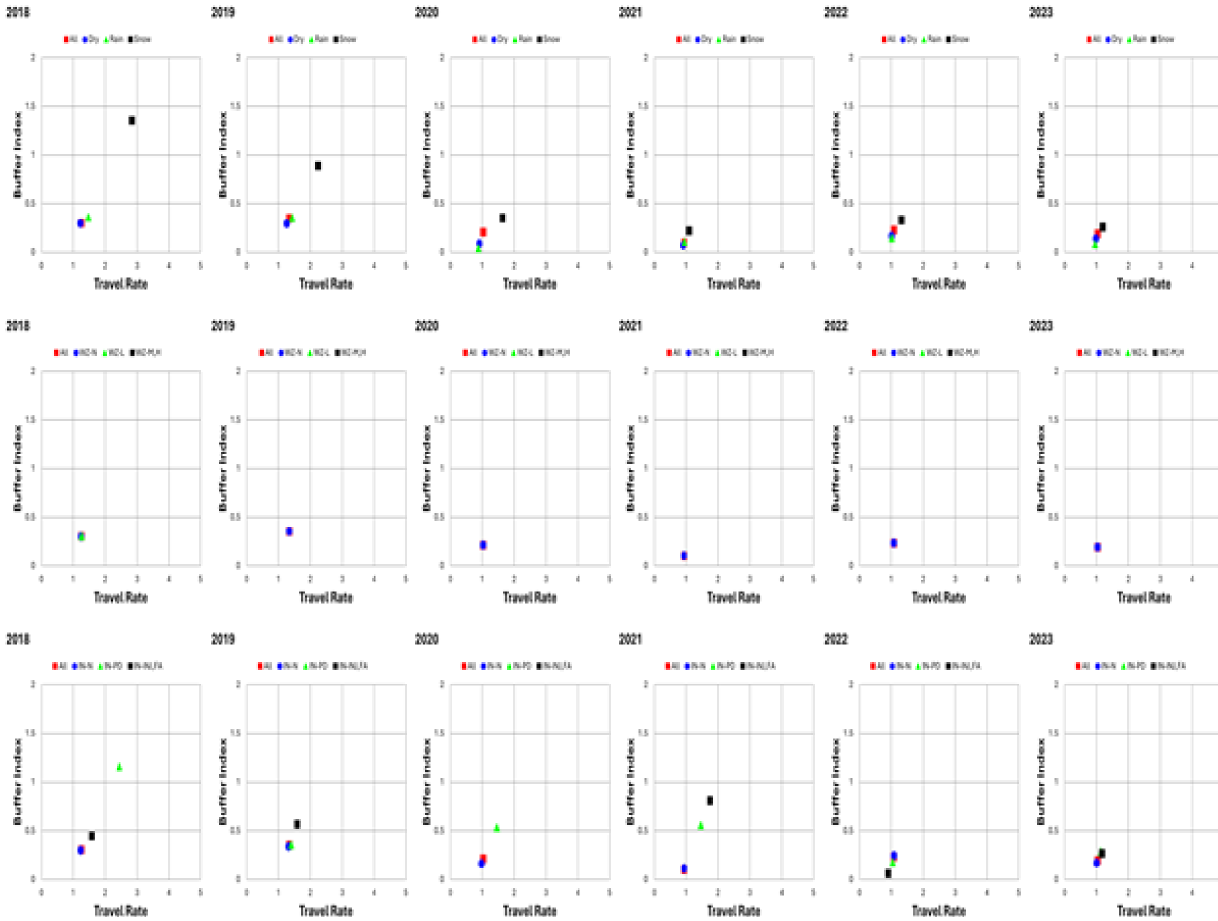
Incident Effects



Work-Zone Effects

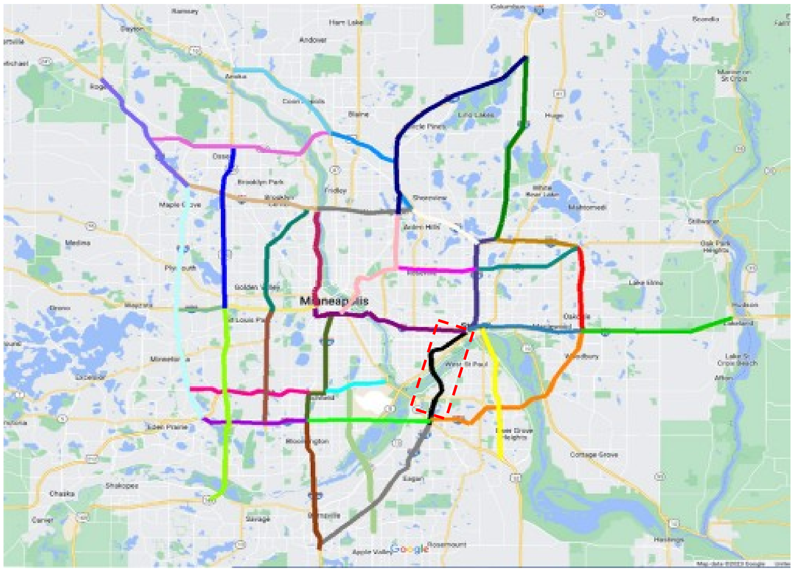


Yearly Variations of Buffer Index - Travel Rate Relationships



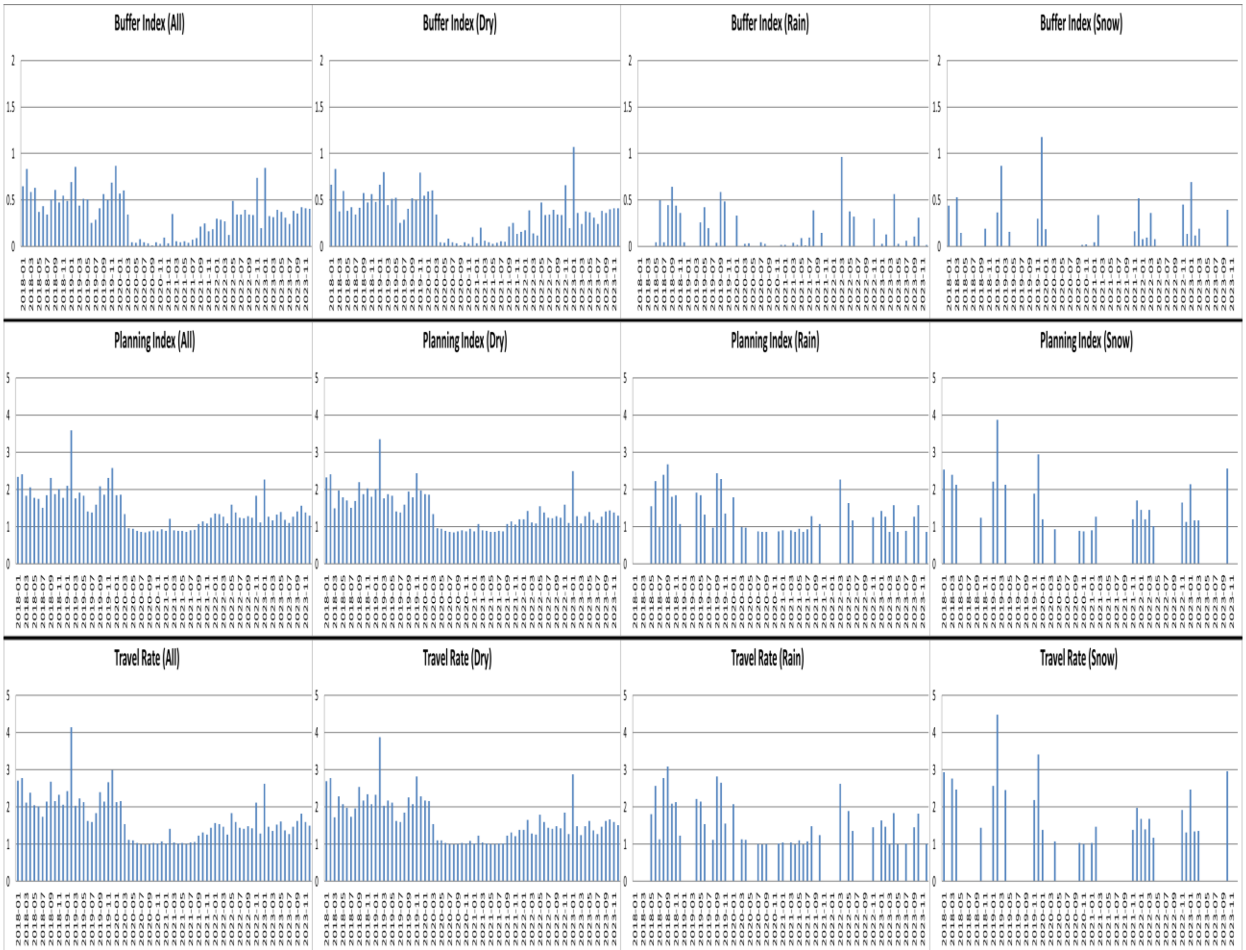
Variations of Traffic-Flow Measures

28) I-35E Corridor B (I494 < -- > STPL)

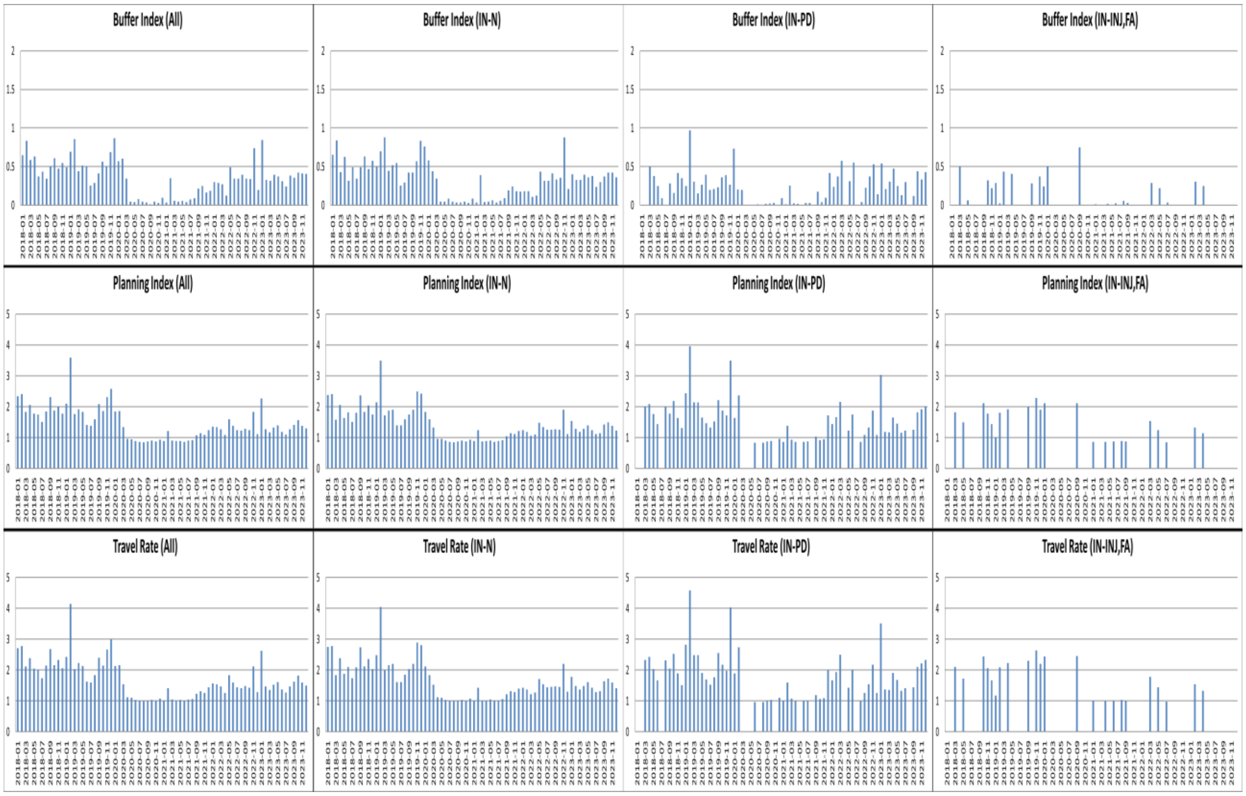


i) I-35E Corridor B -- NB I494 to STPL for Morning Peak Periods

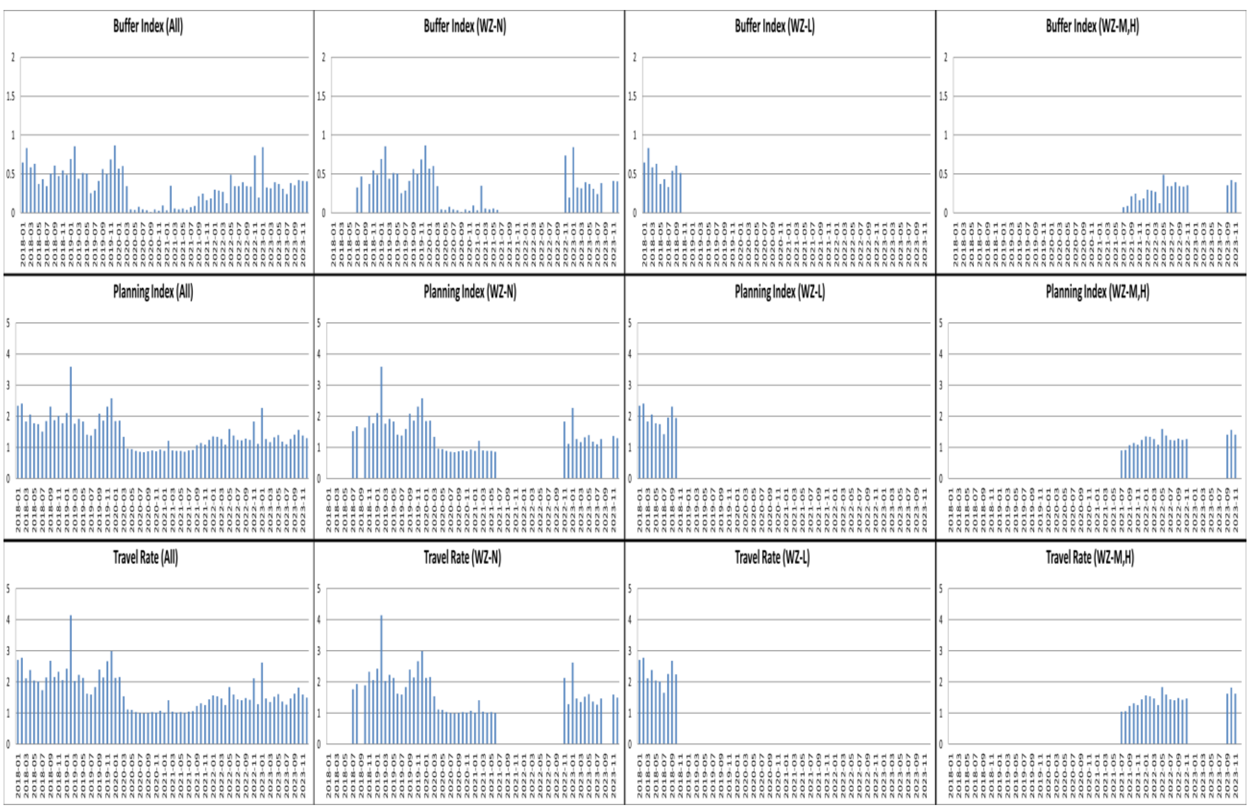
Effects of Weather conditions on Travel-Time Reliability



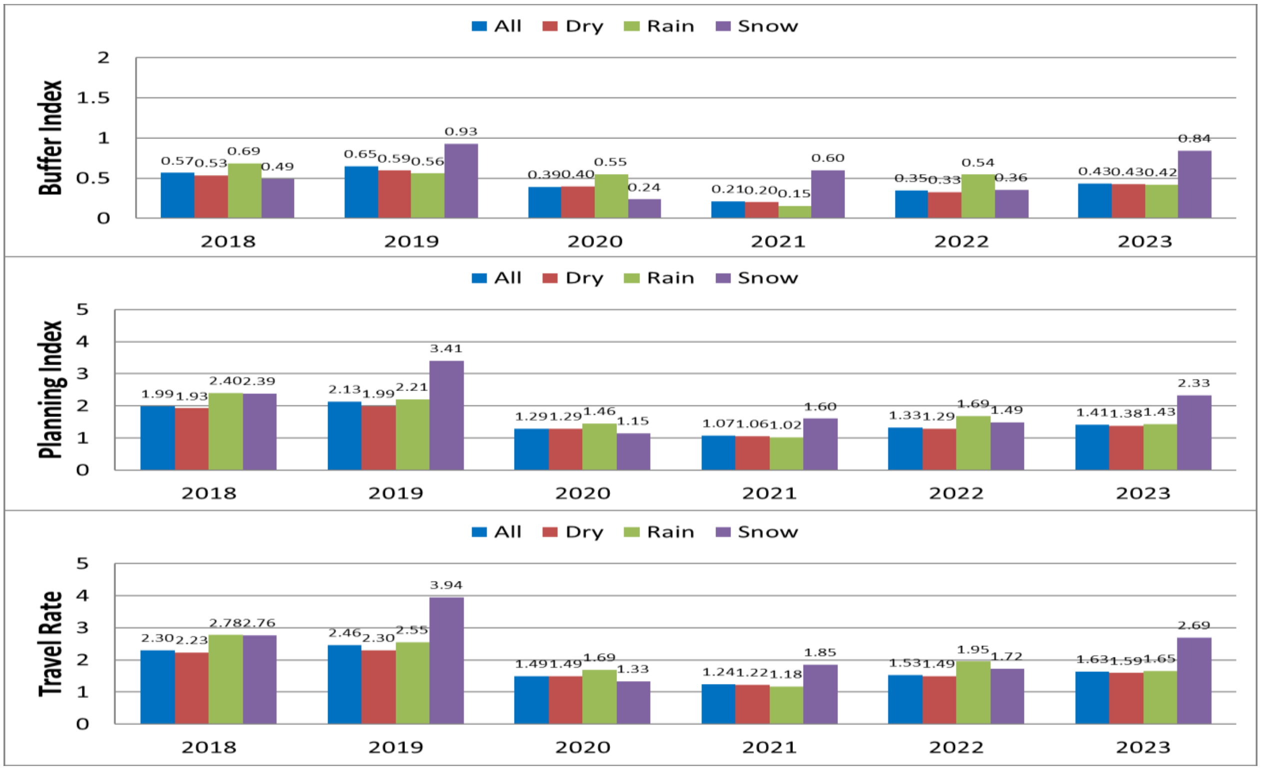
Effects of Incidents



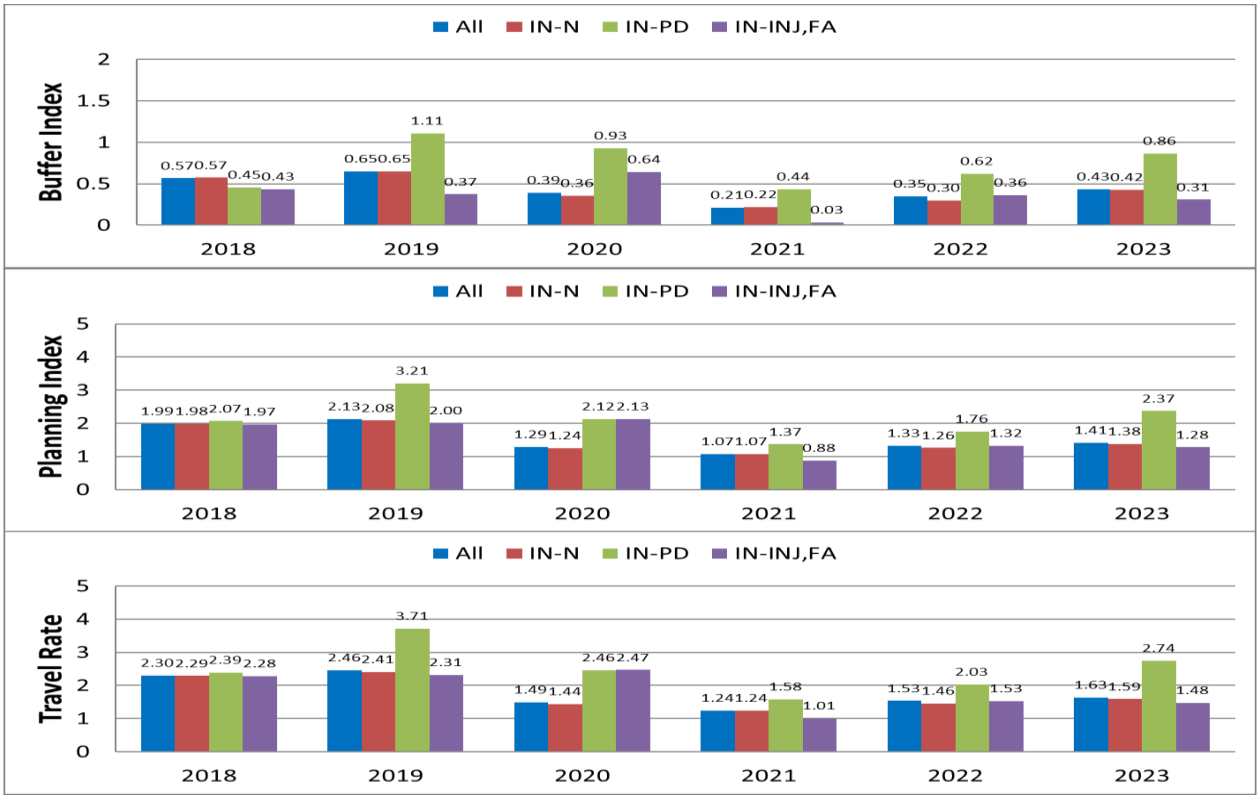
Effects of Work Zones



Yearly Variations - *Weather Effects*

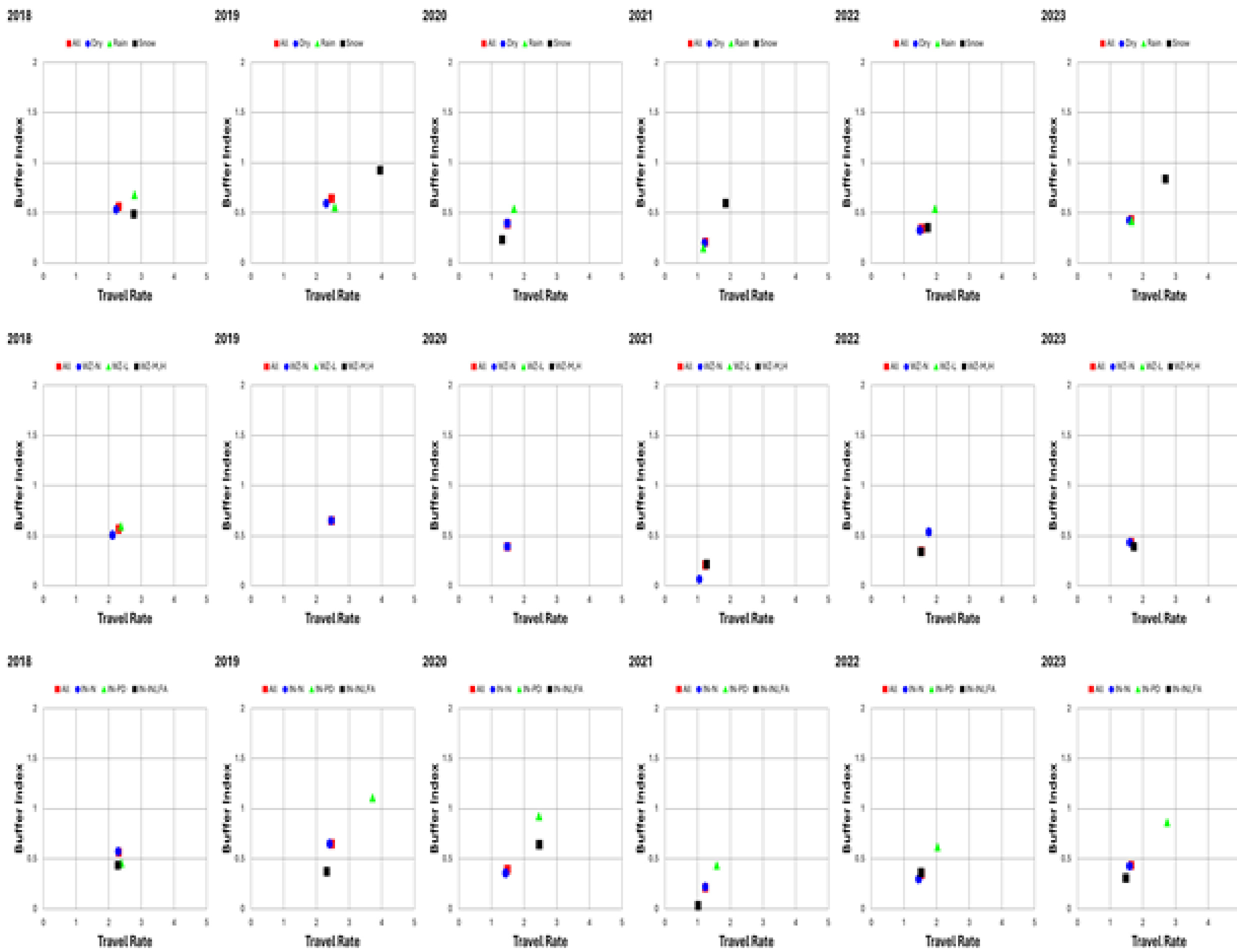


Incident Effects

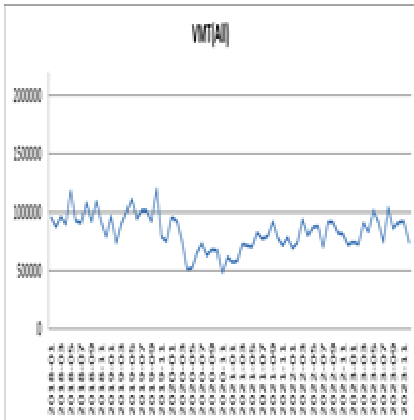


Work-Zone Effects

Yearly Variations of Buffer Index - Travel Rate Relationships



Variations of Traffic-Flow Measures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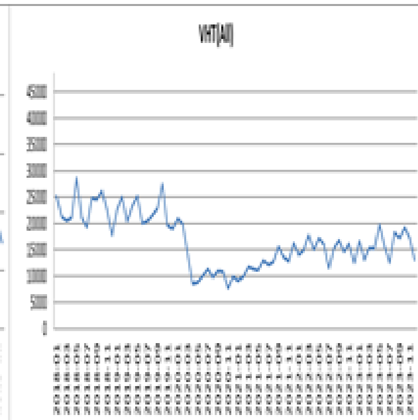
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DVH(All)
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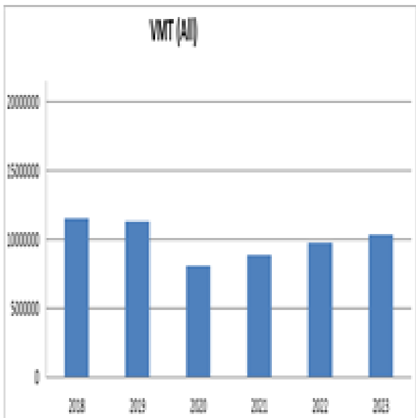
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10000000
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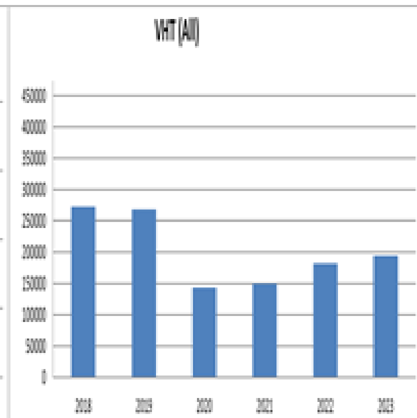
2018
2019
2020
2021
2022
2023


VHT (All)
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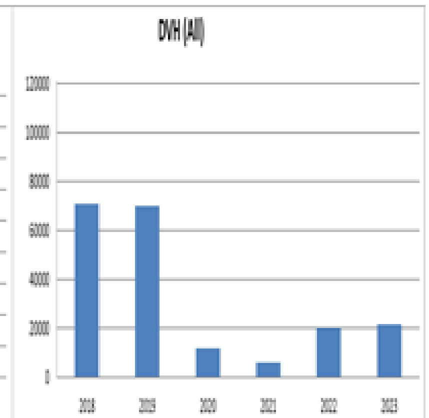
2018
2019
2020
2021
2022
2023


DVH (All)
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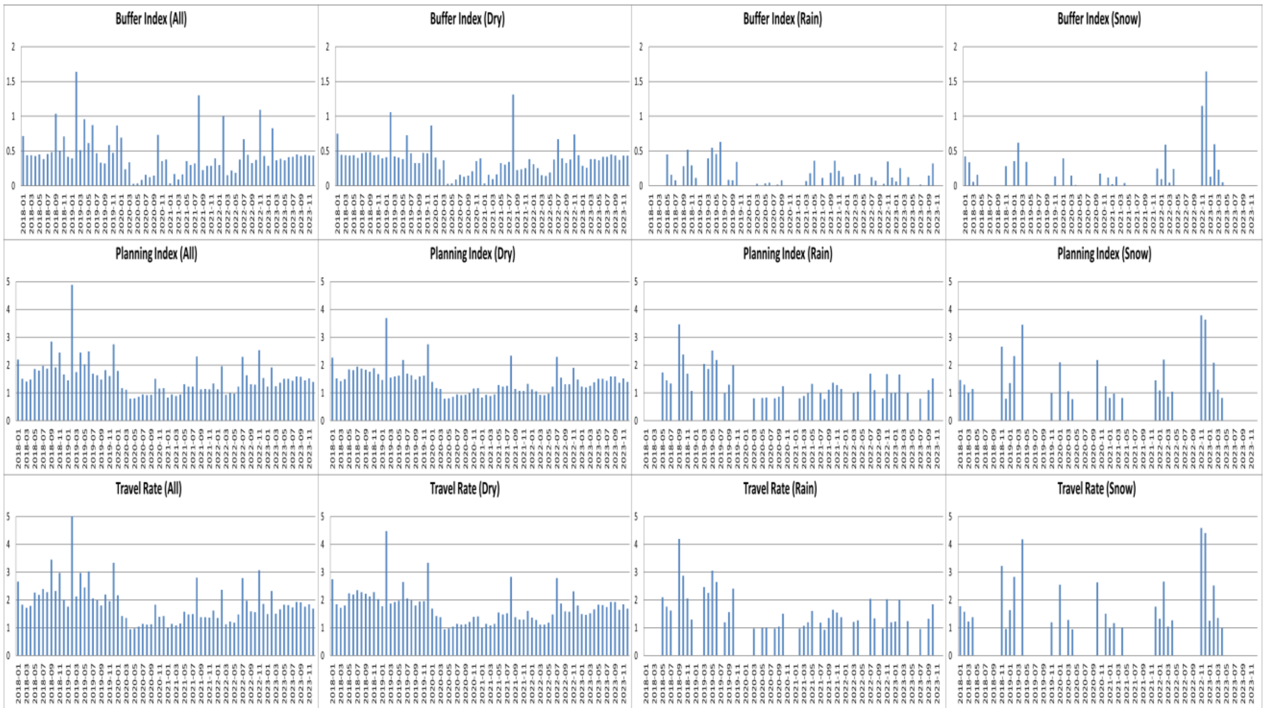
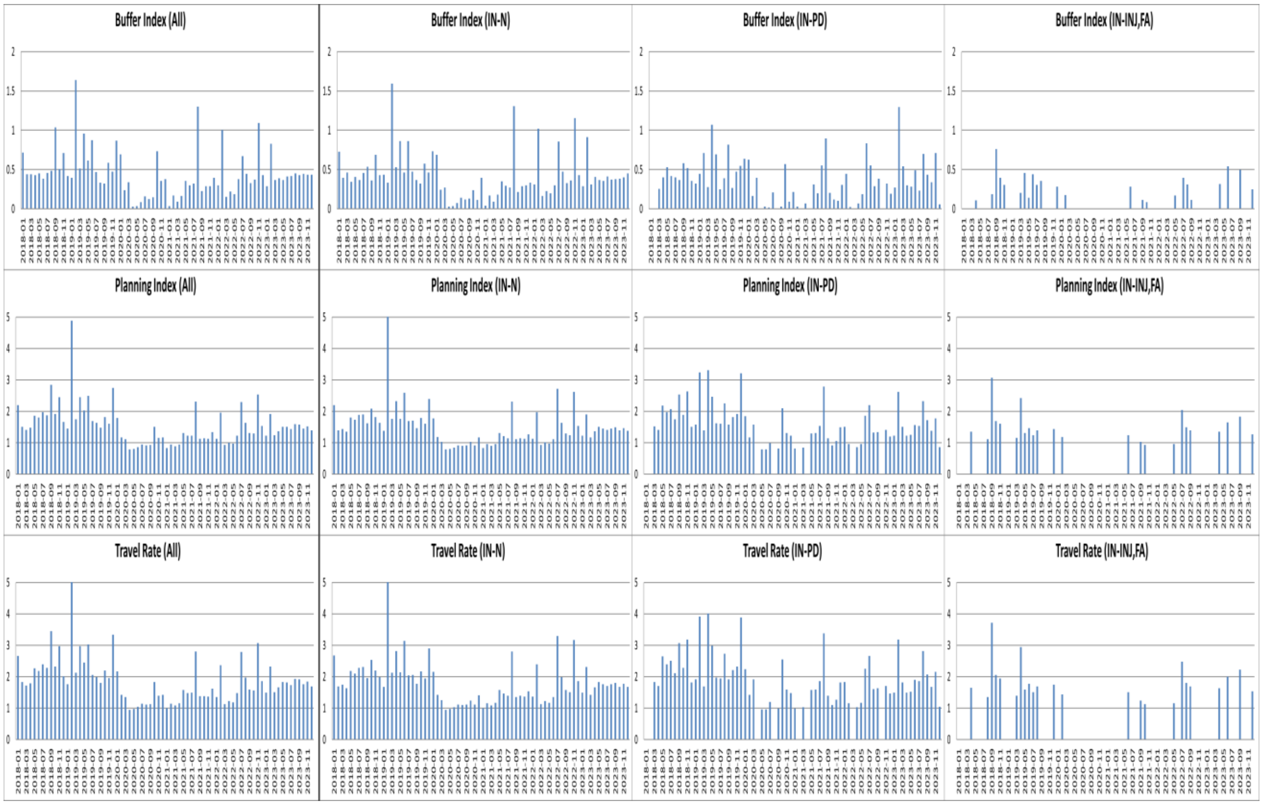
2018
2019
2020
2021
2022
2023

ii) I-35E Corridor B -- SB STPL to I494 for Afternoon Peak Periods

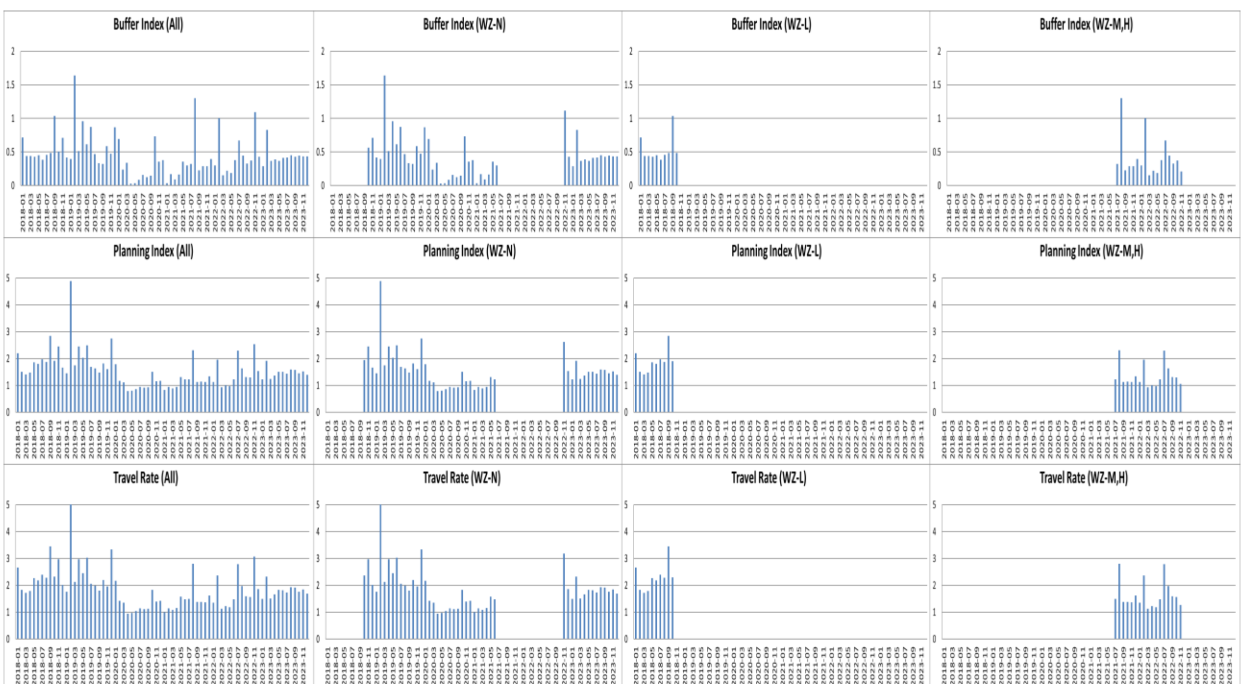
Effects of Weather conditions on Travel-Time Reliability



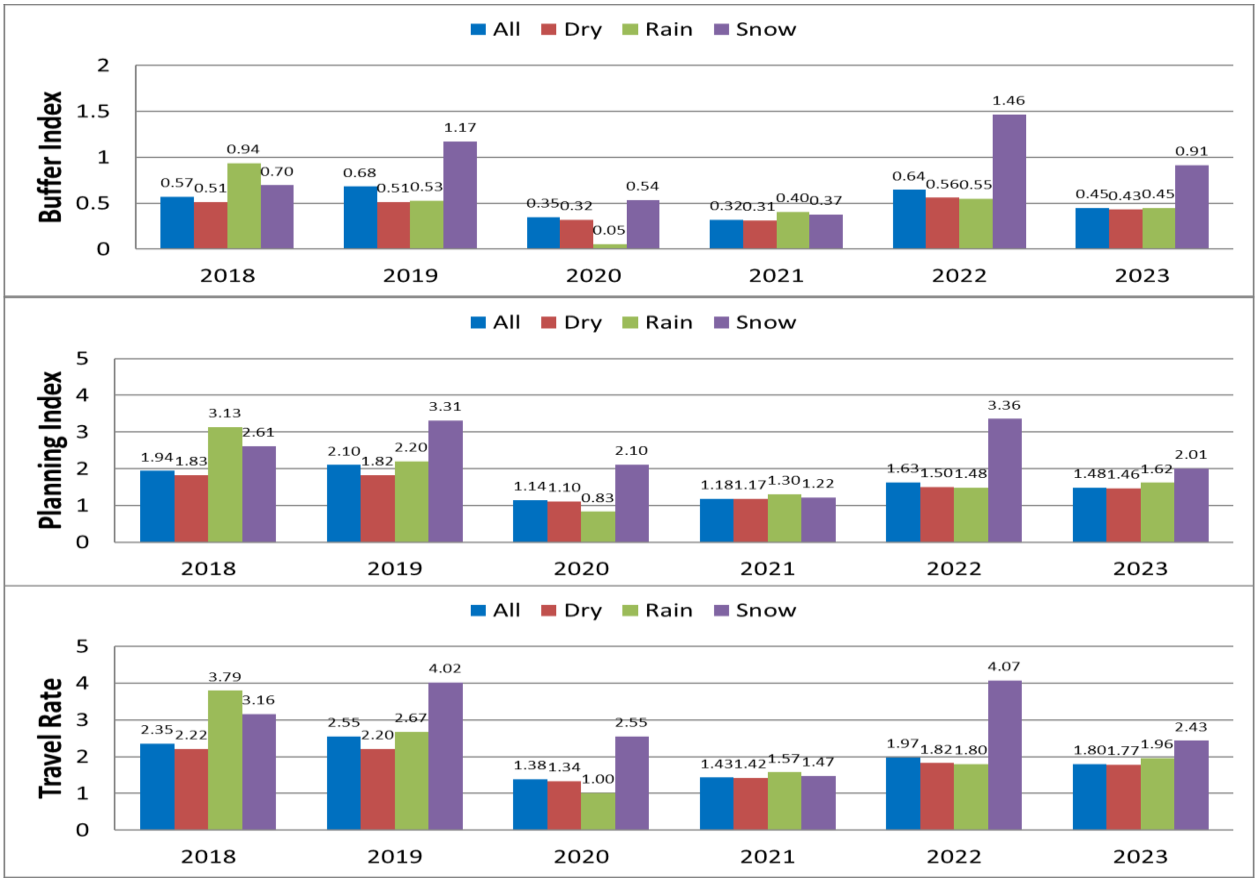
Effects of Incidents



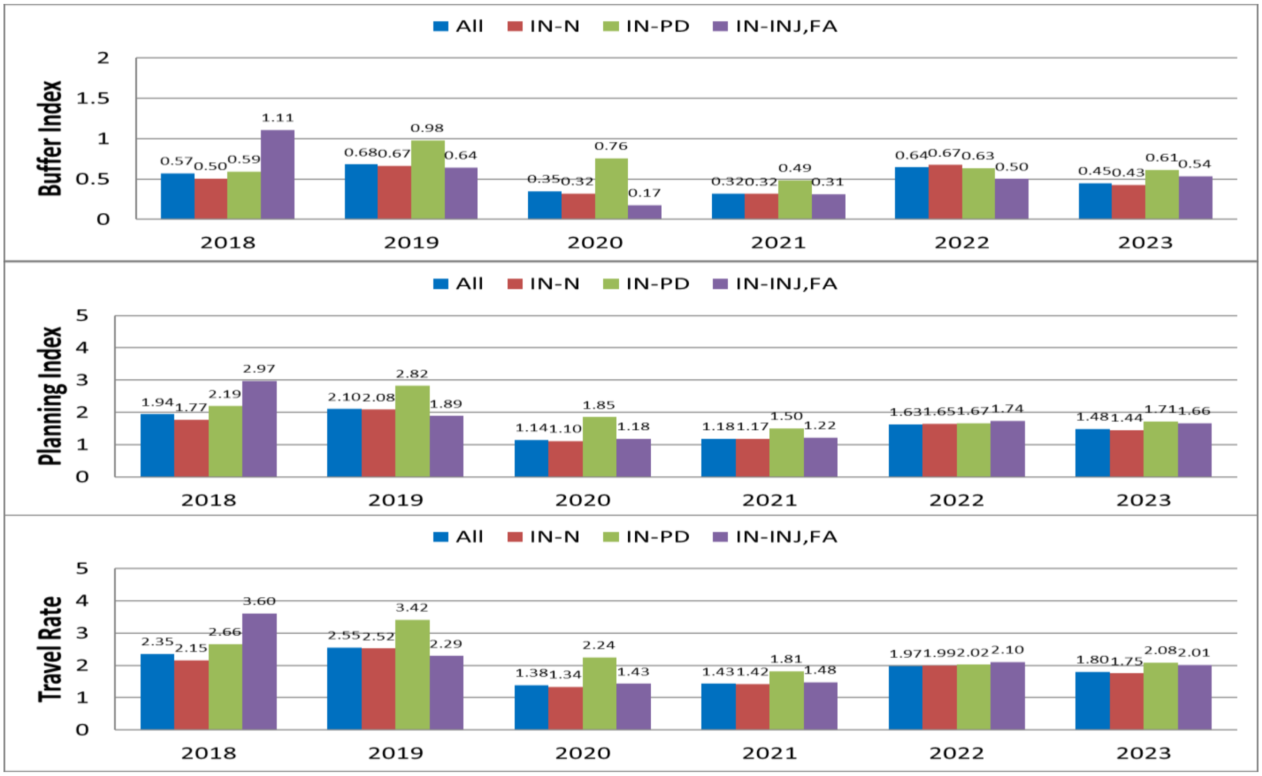
Effects of Work Zones



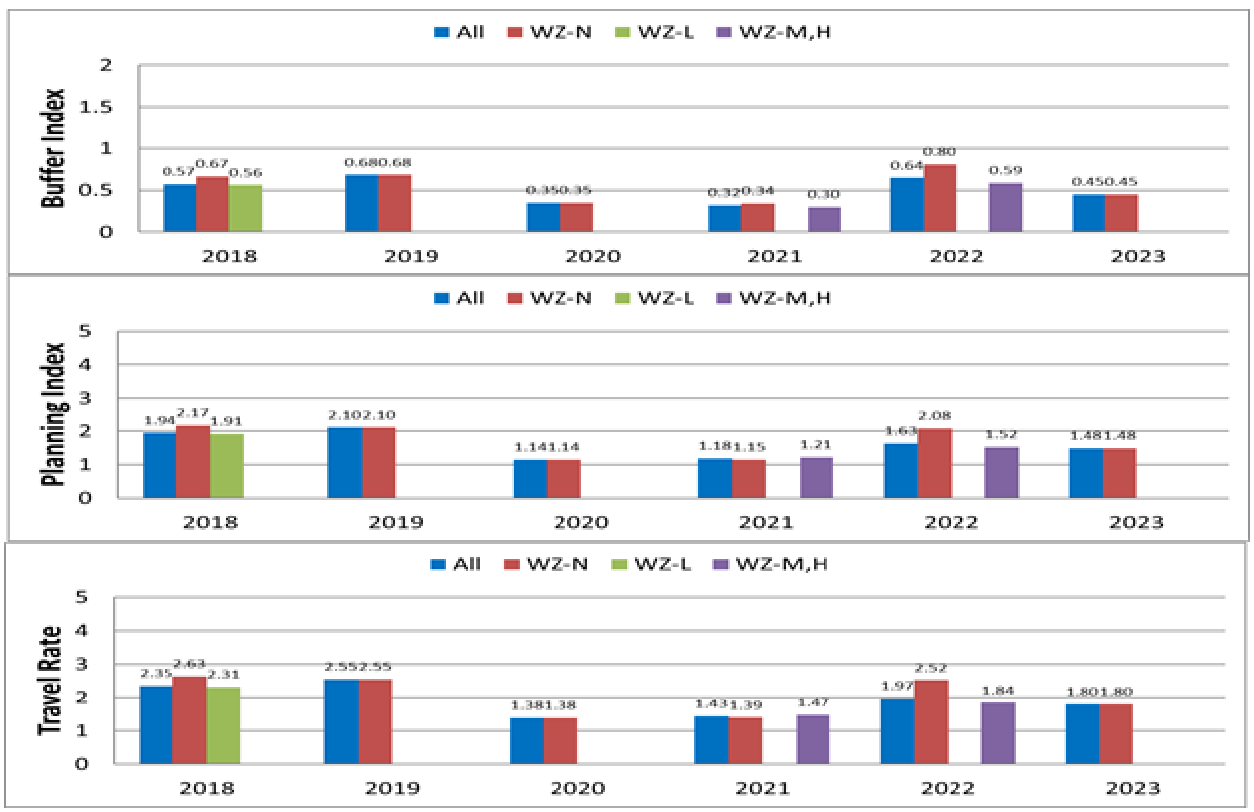
Yearly Variations - *Weather Effects*



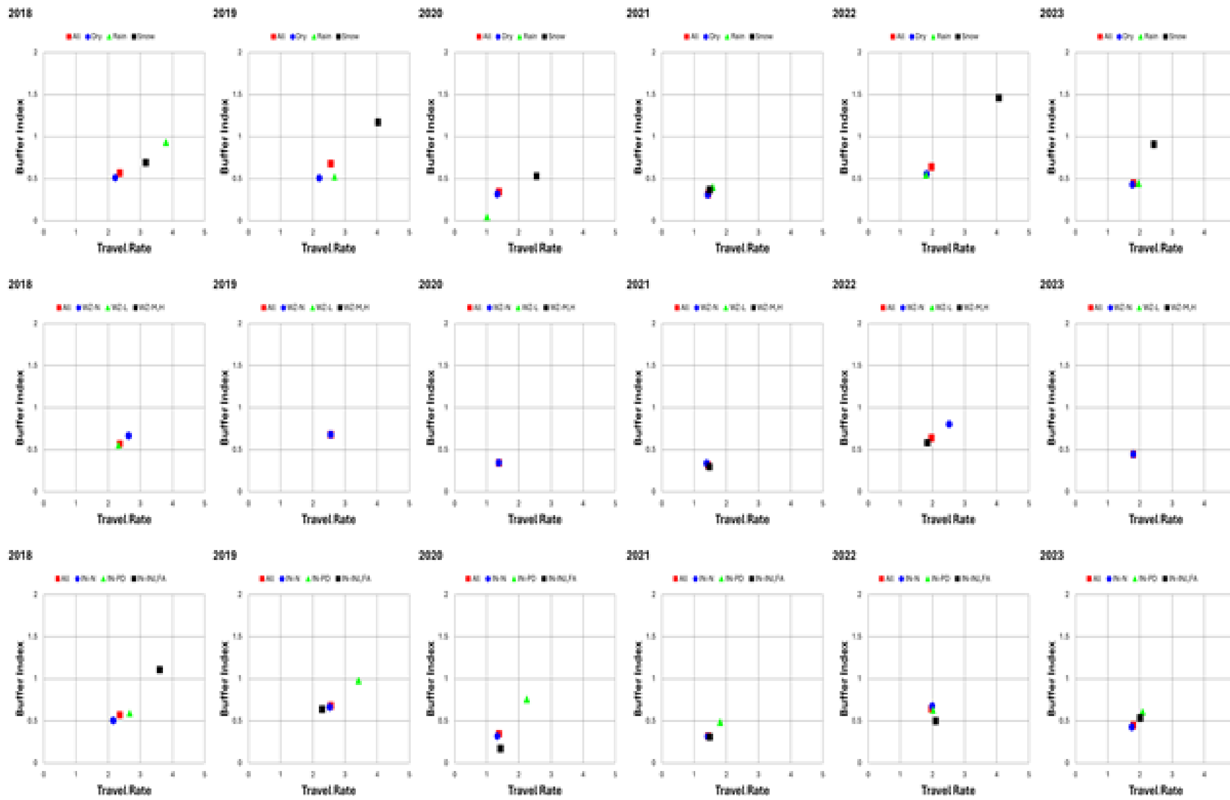
Incident Effects



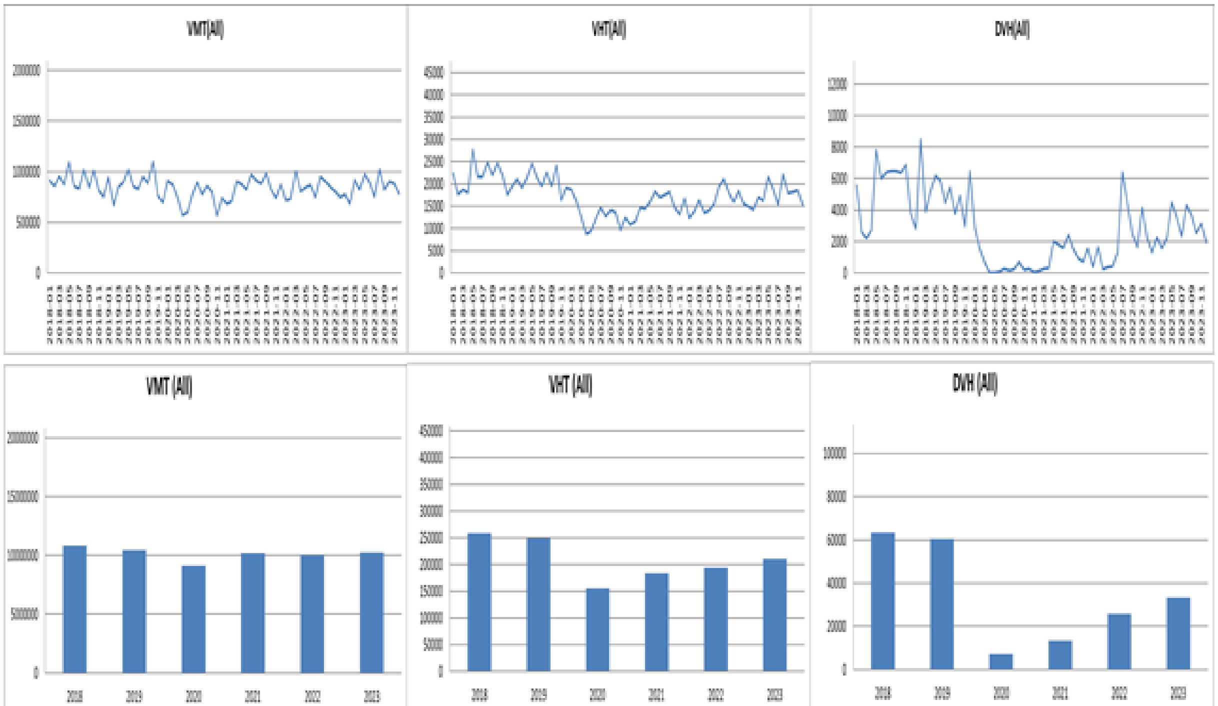
Work-Zone Effects



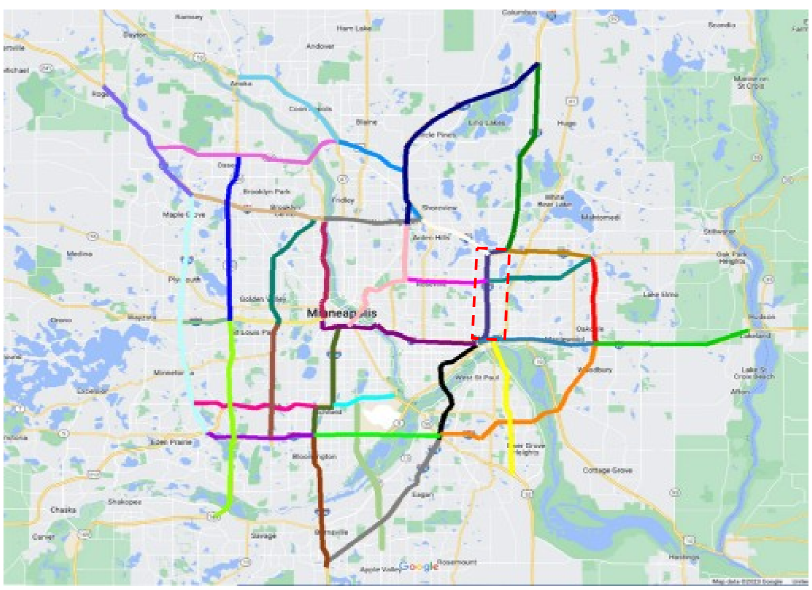
Yearly Variations of Buffer Index - Travel Rate Relationships



Variations of Traffic-Flow Measures

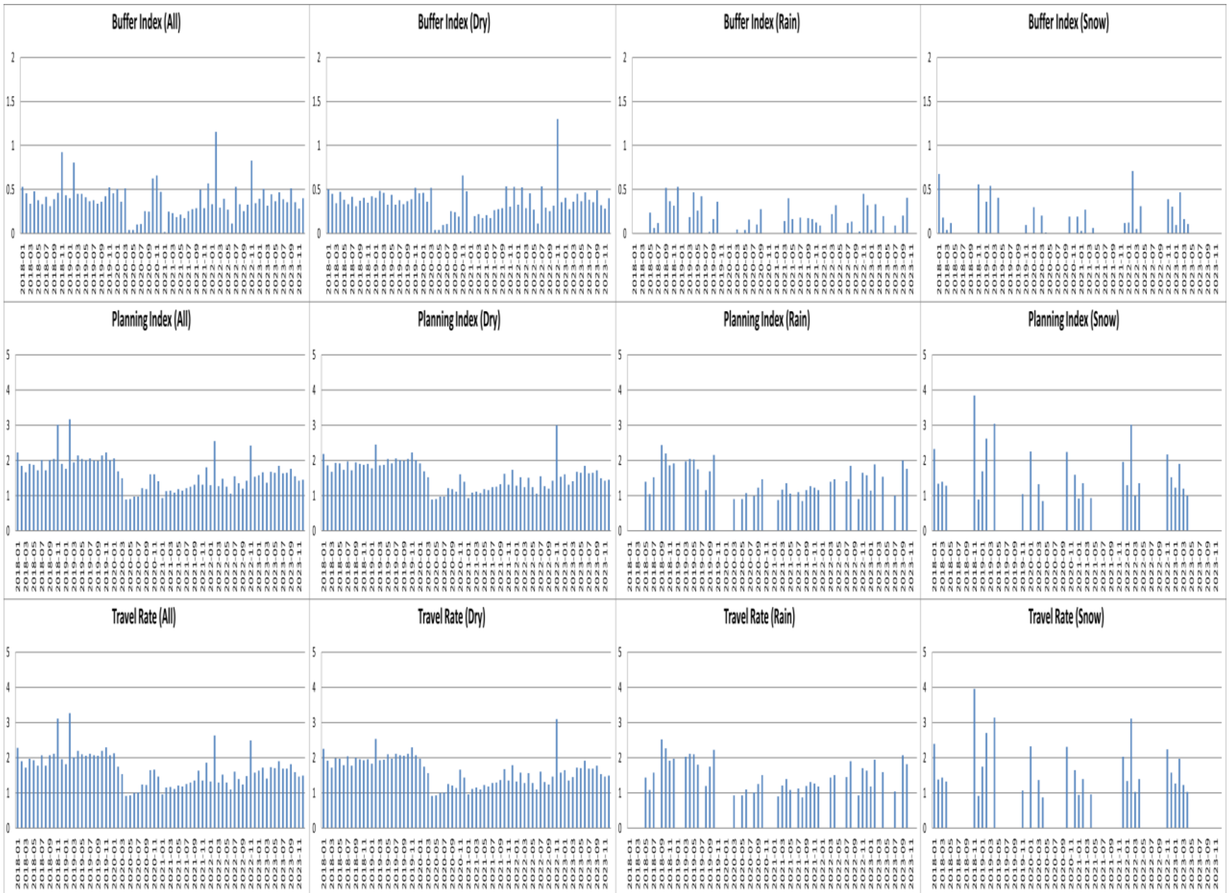


29) I-35E Corridor C (STPL < -- > I694)

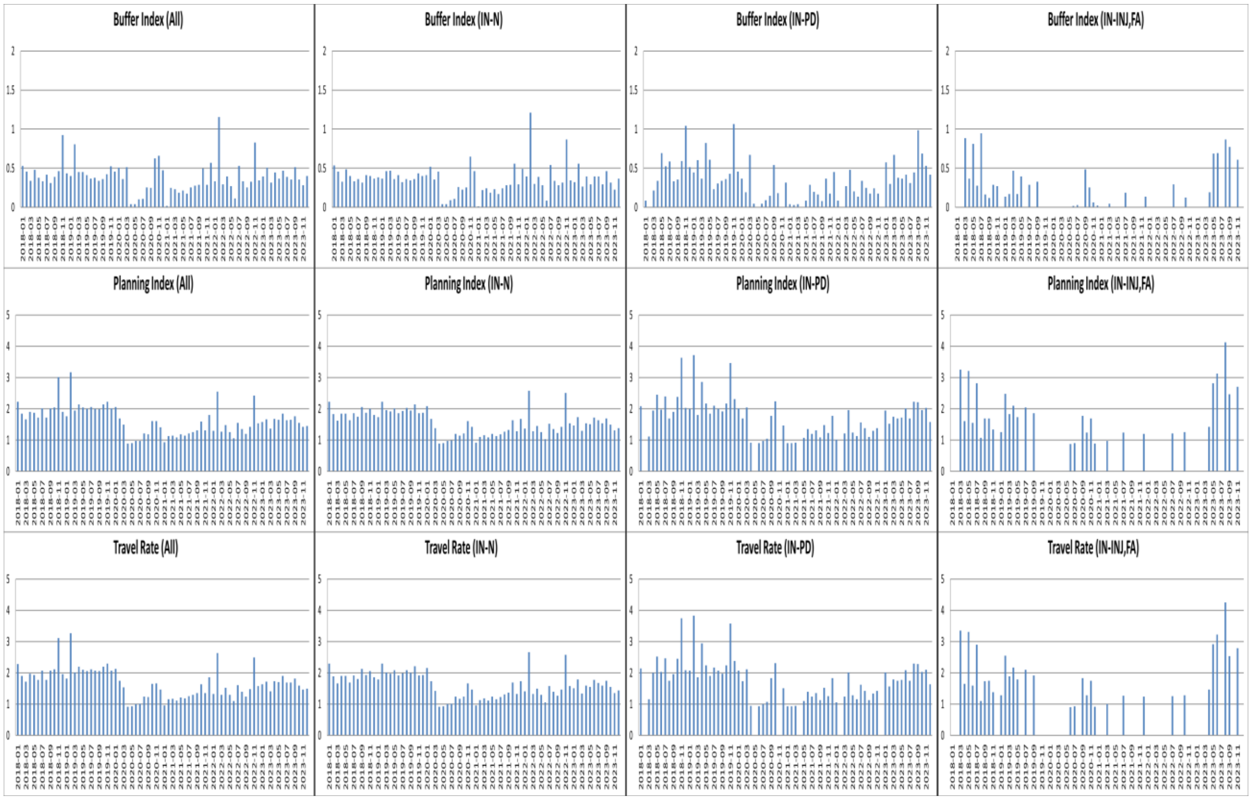


i) I-35E Corridor C -- NB STPL to I694 for Afternoon Peak Periods

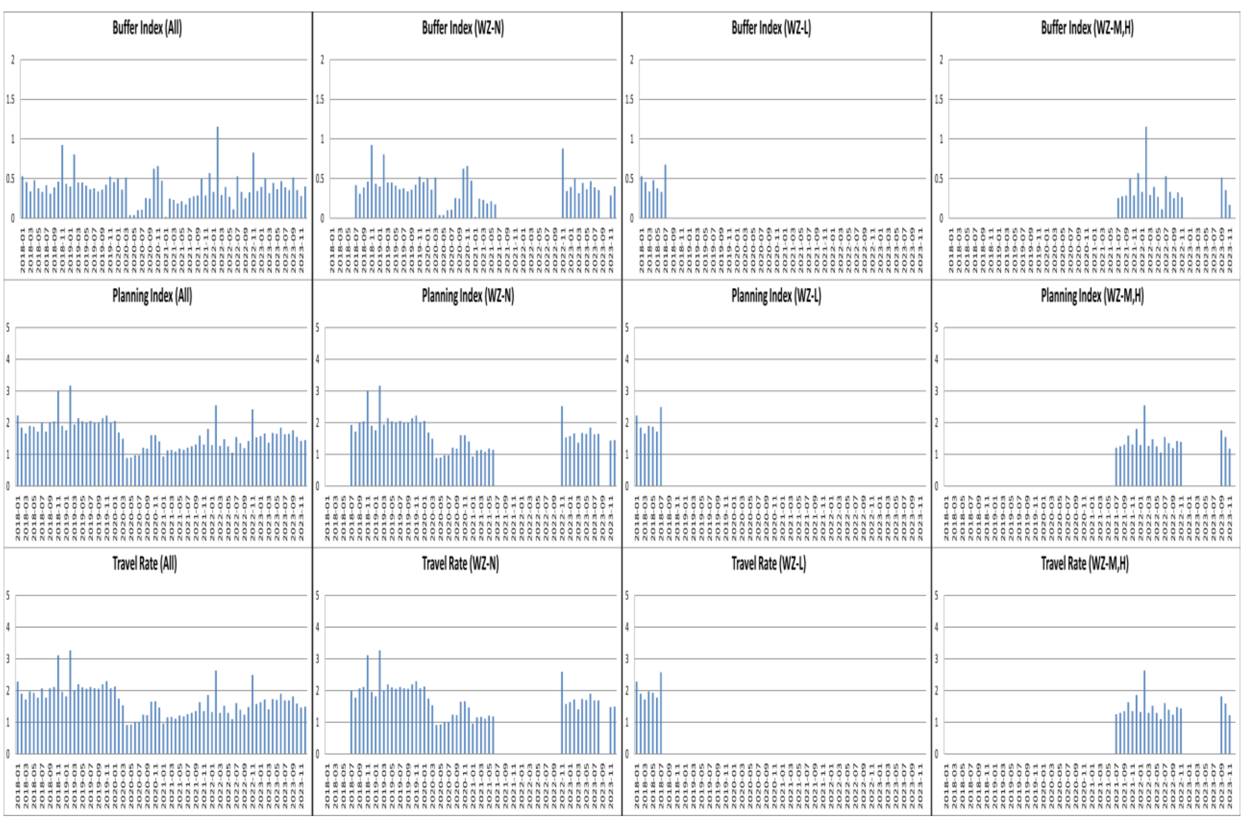
Effects of Weather conditions on Travel-Time Reliability



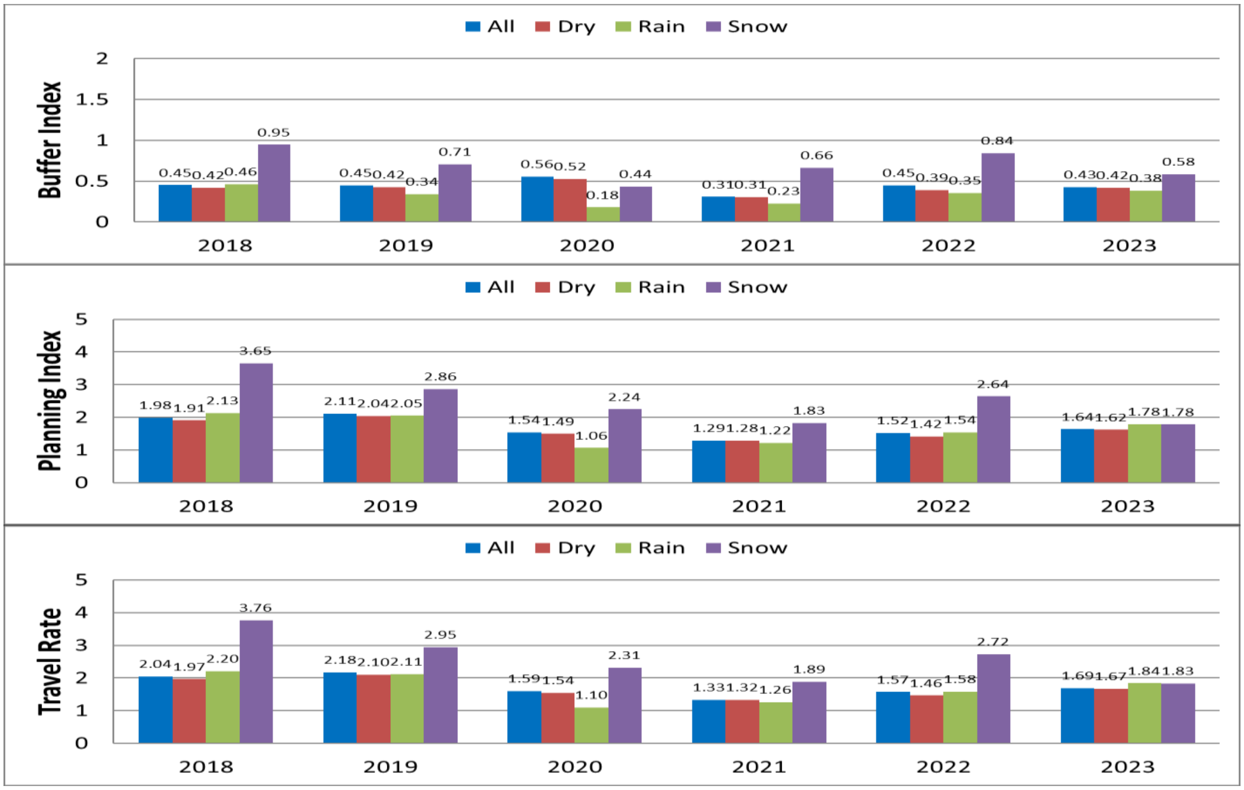
Effects of Incidents



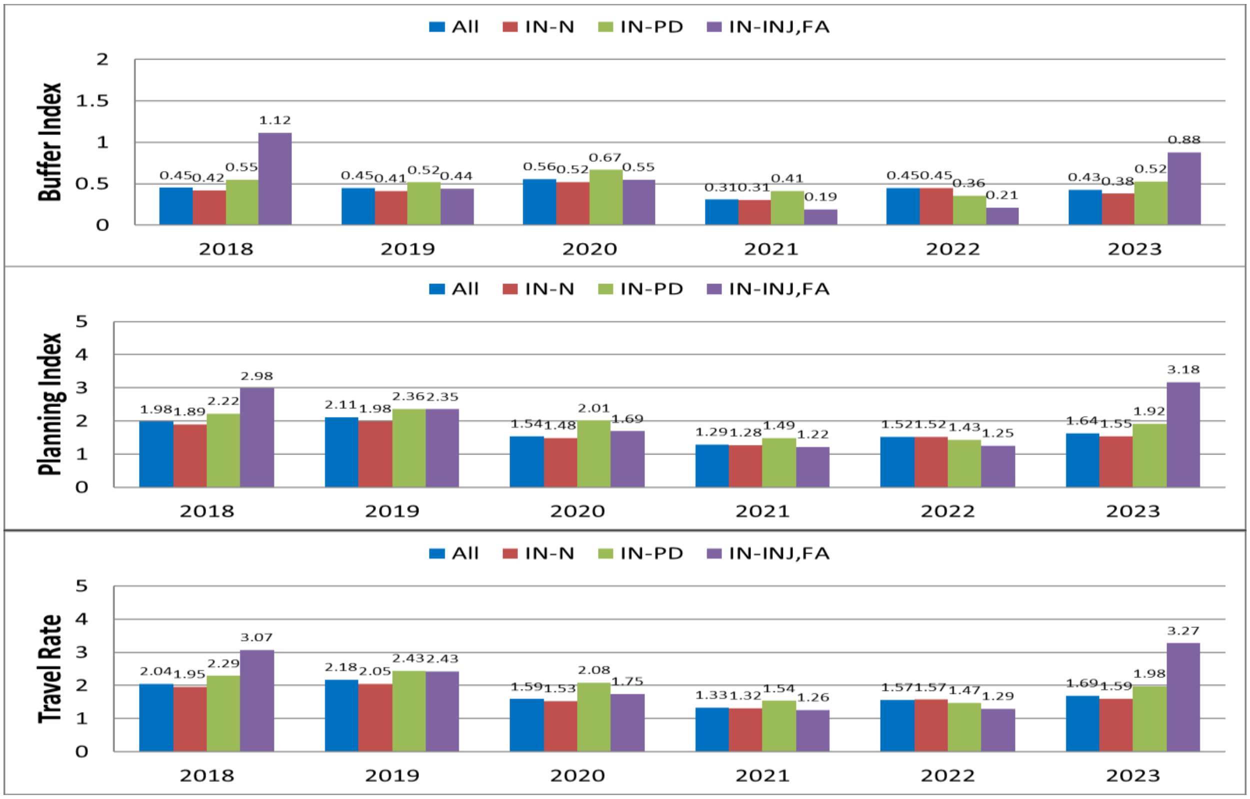
Effects of Work Zones



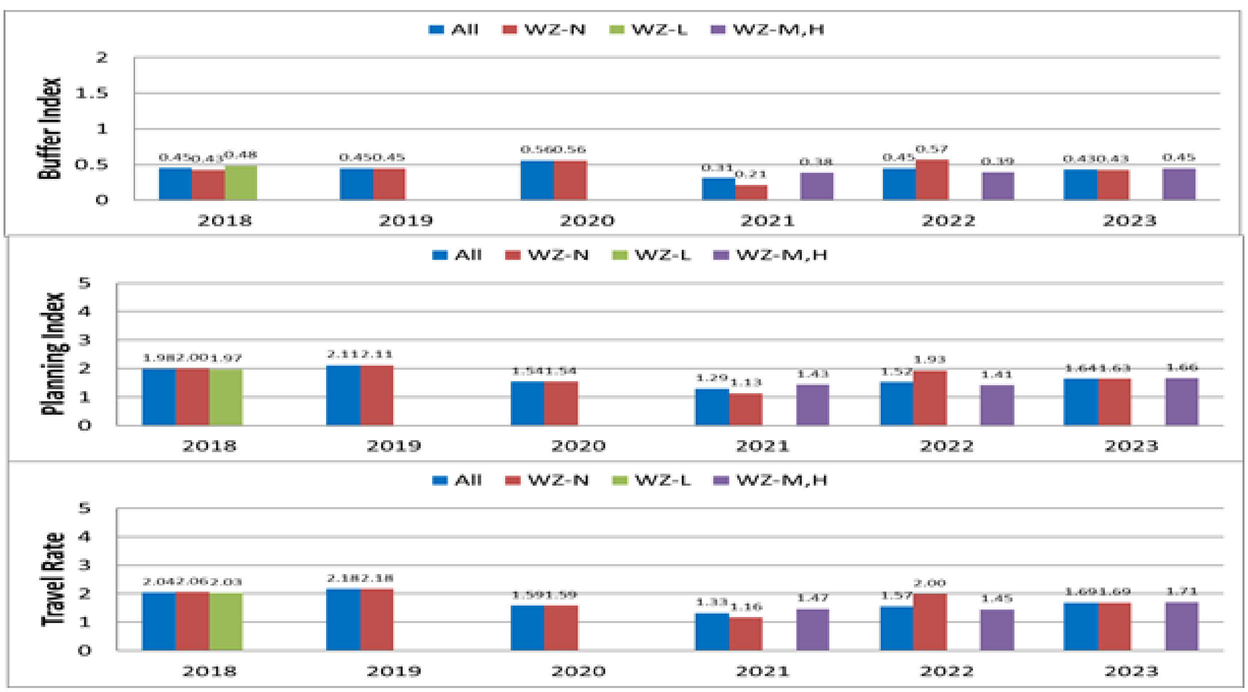
Yearly Variations - *Weather Effects*



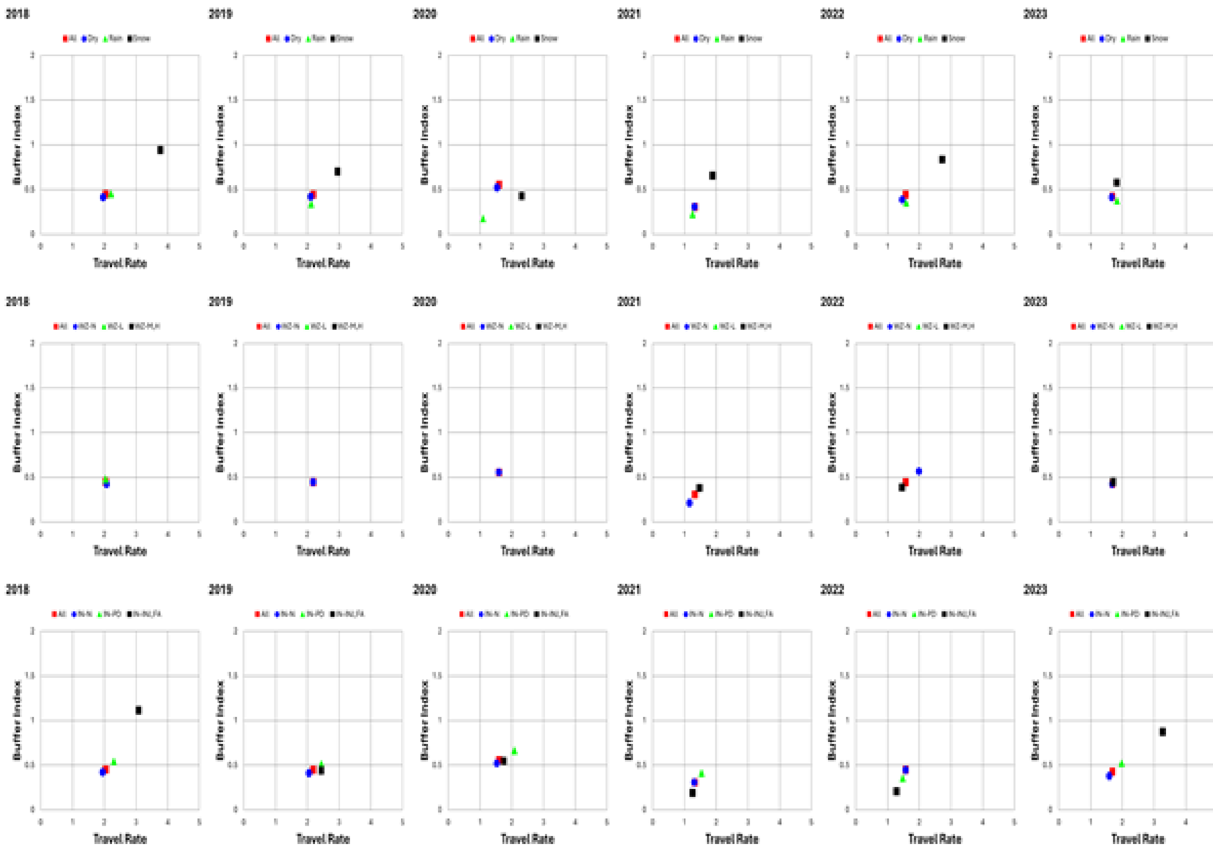
Incident Effects



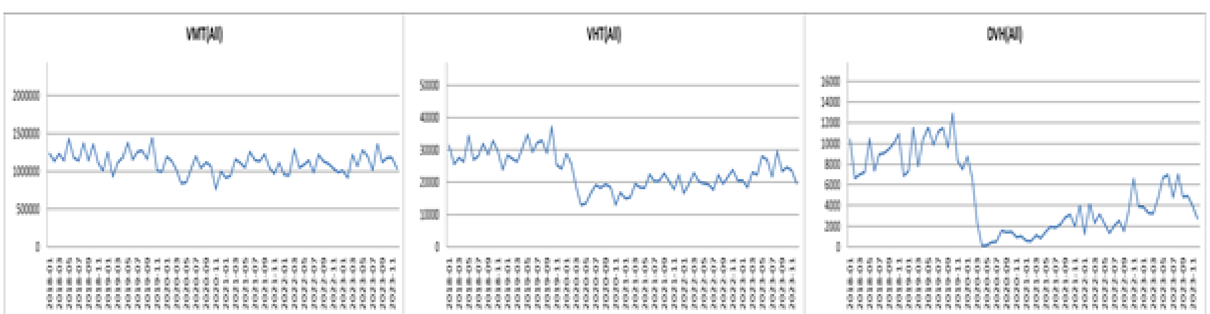
Work-Zone Effects

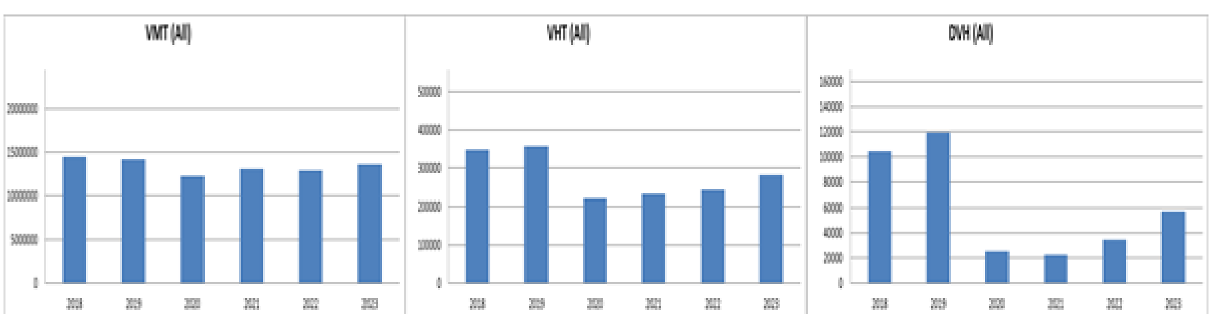


Yearly Variations of Buffer Index - Travel Rate Relationships



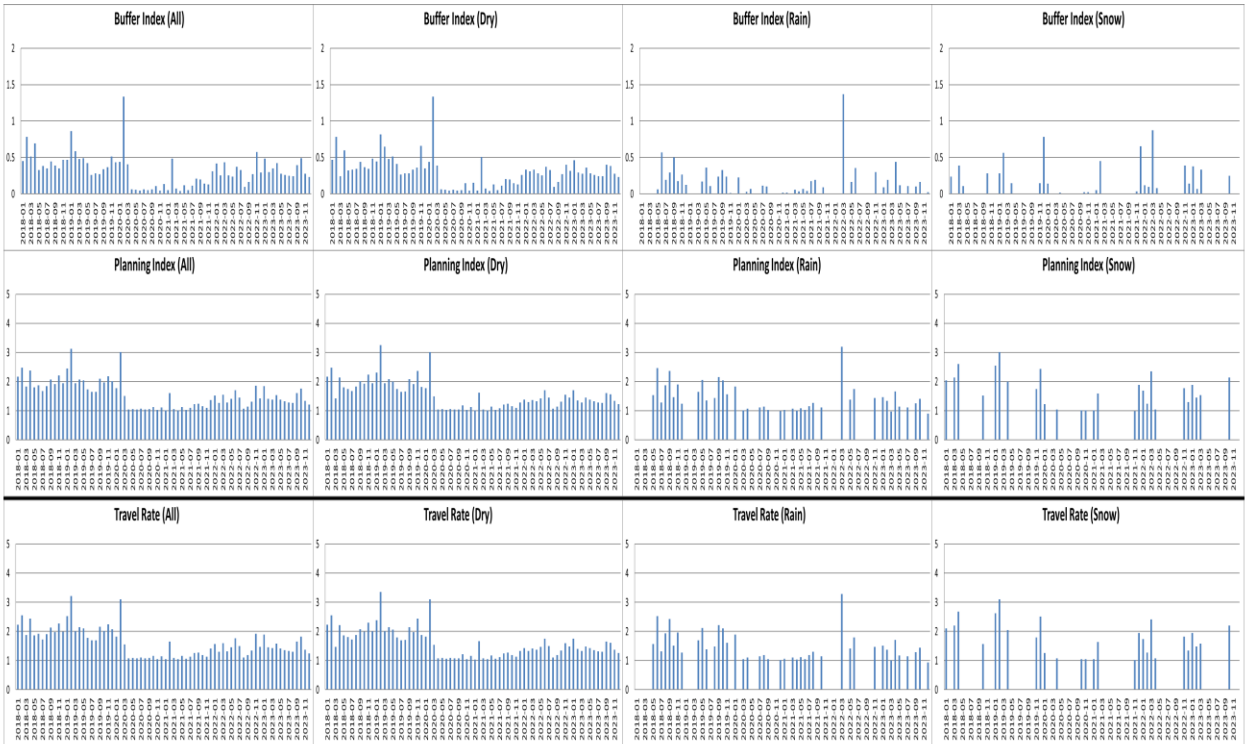
Variations of Traffic-Flow Measures



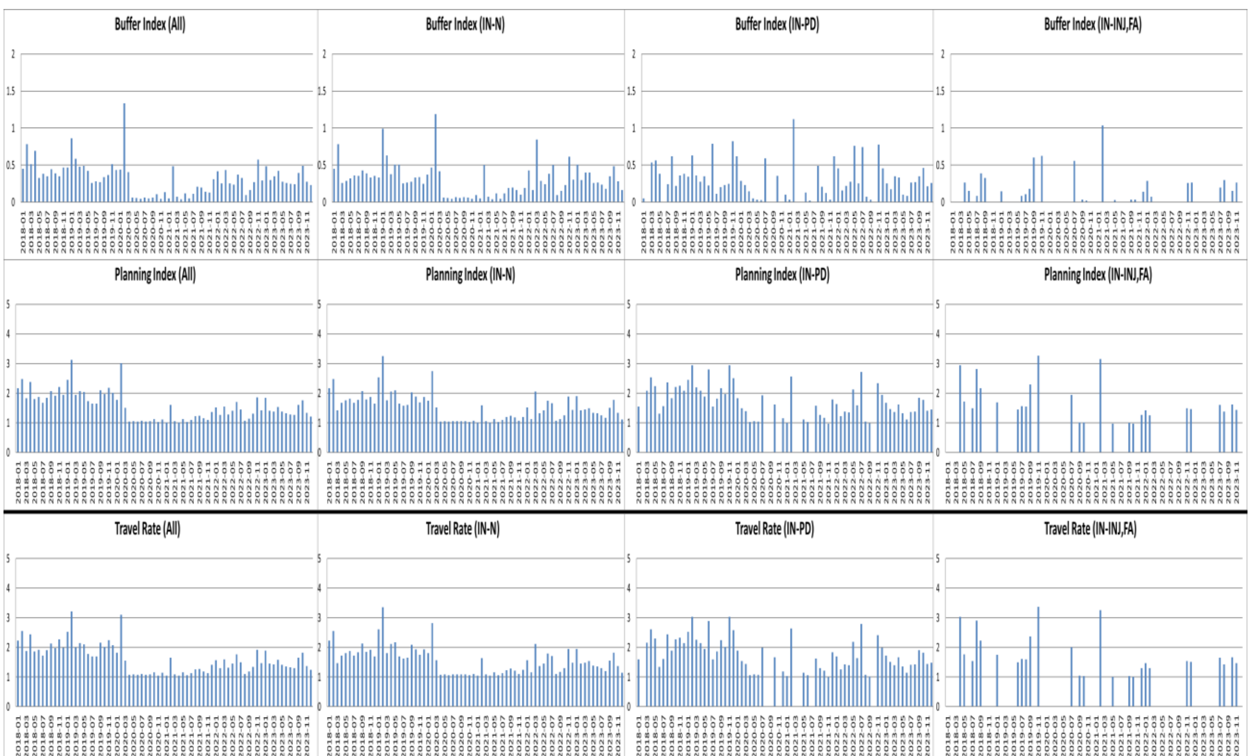


ii) I-35E Corridor C -- SB I694 to STPL for Morning Peak Periods

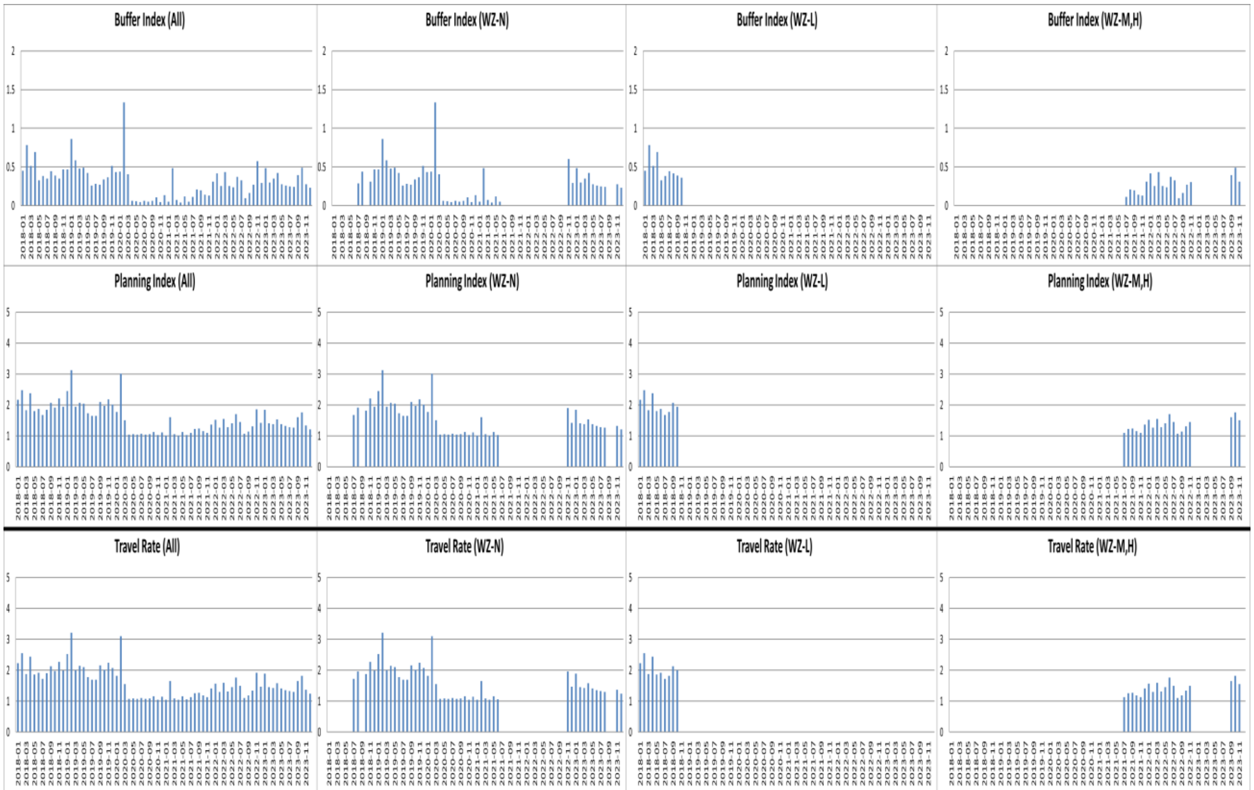
Effects of Weather conditions on Travel-Time Reliability



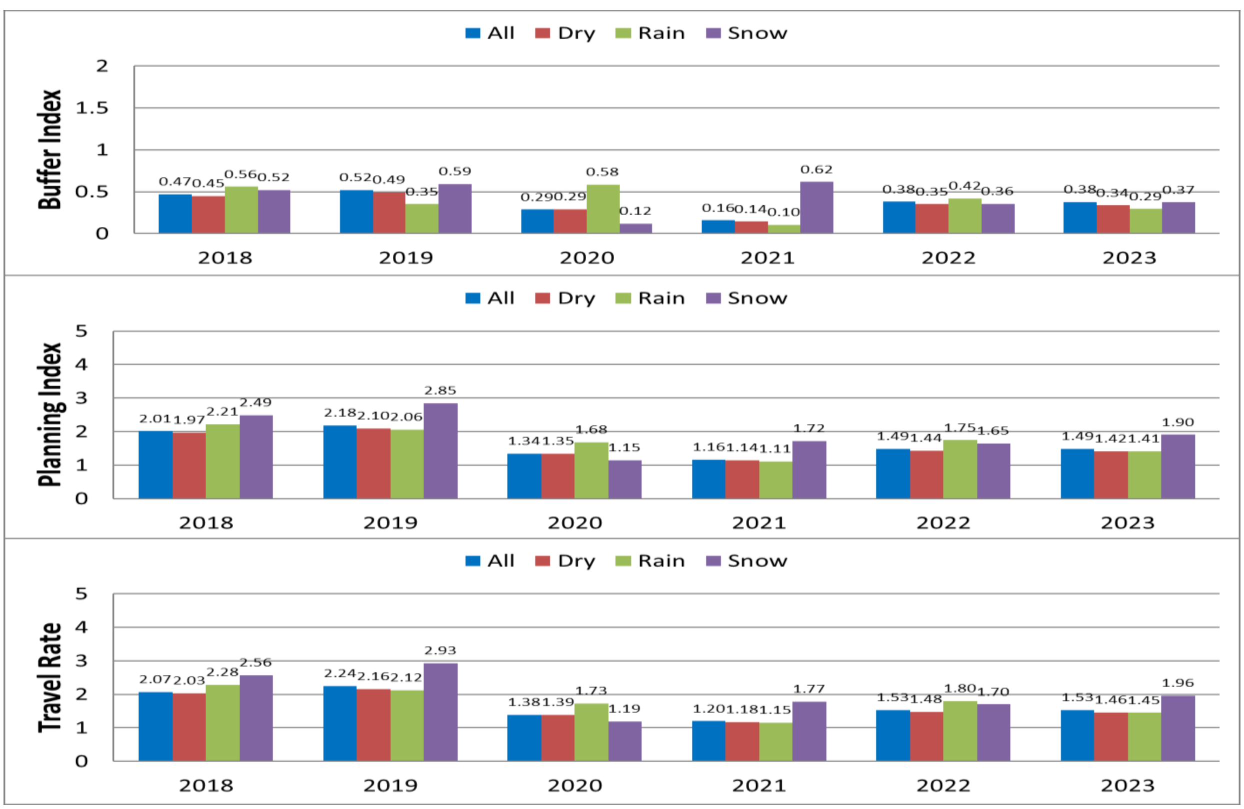
Effects of Incidents



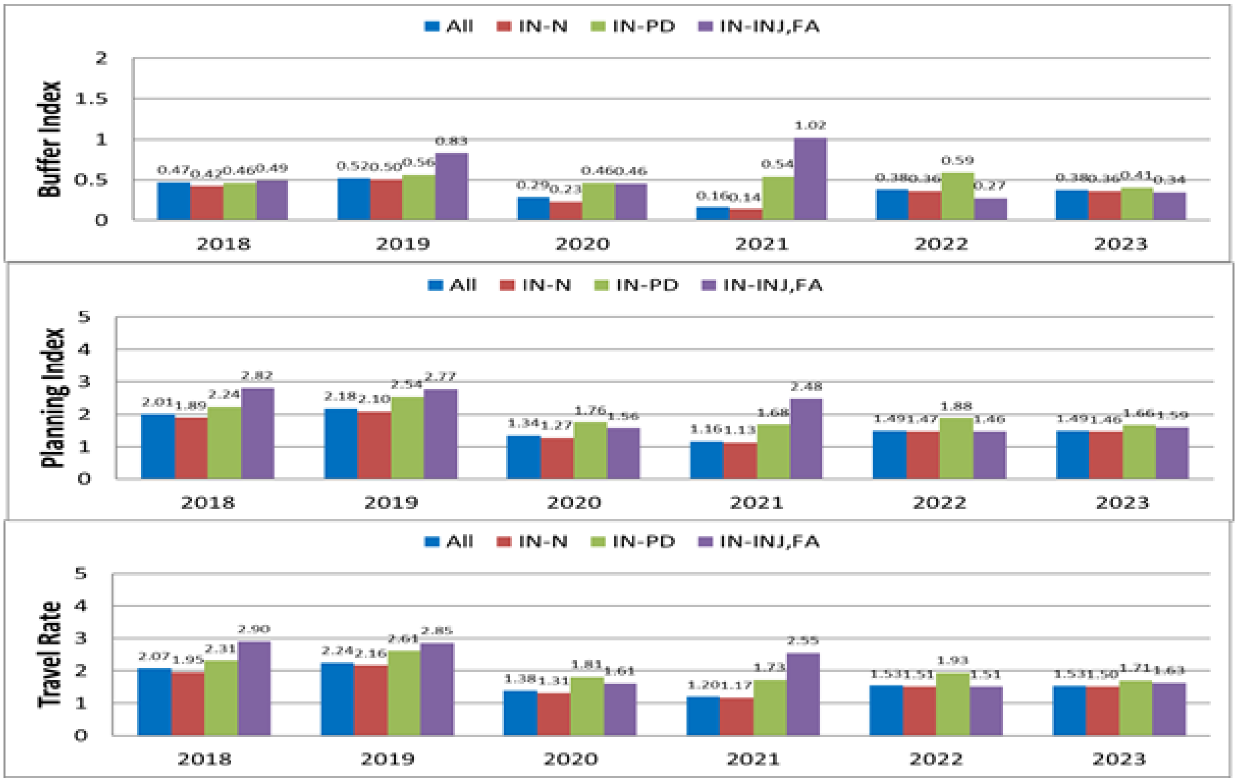
Effects of Work Zones



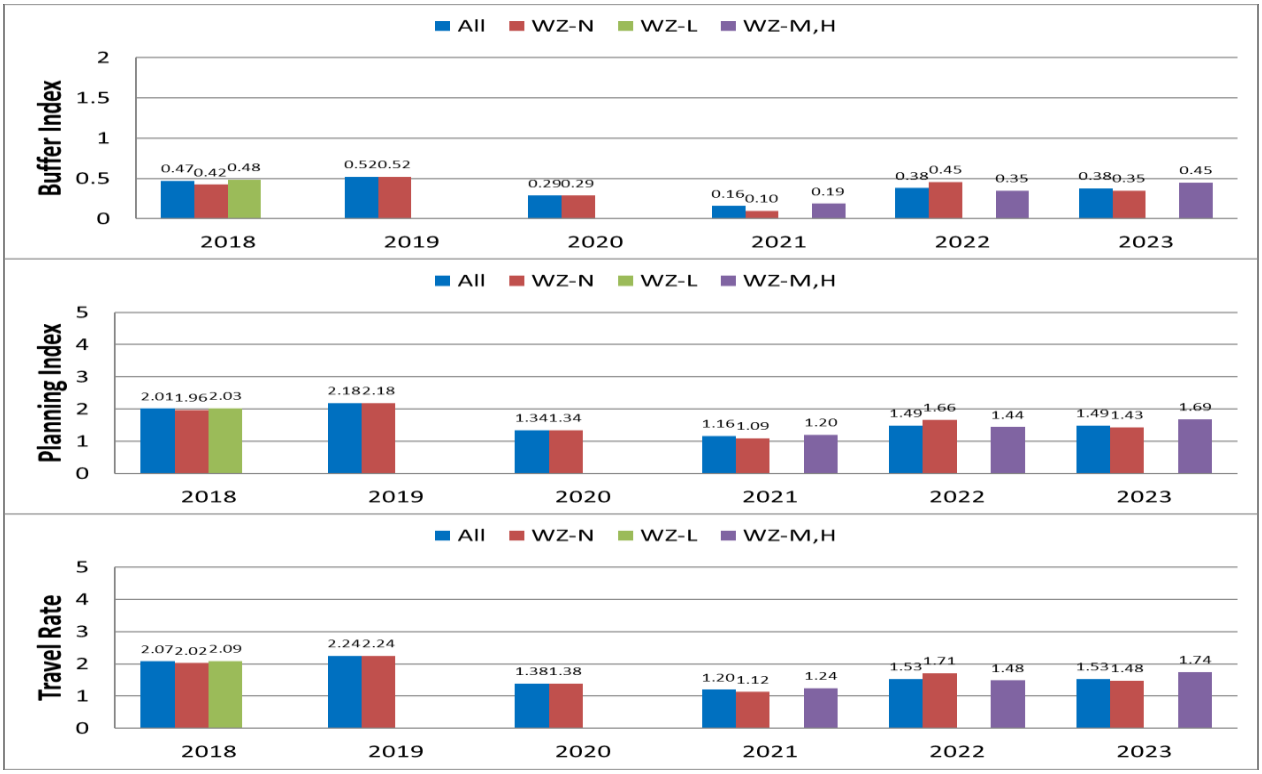
Yearly Variations - *Weather Effects*



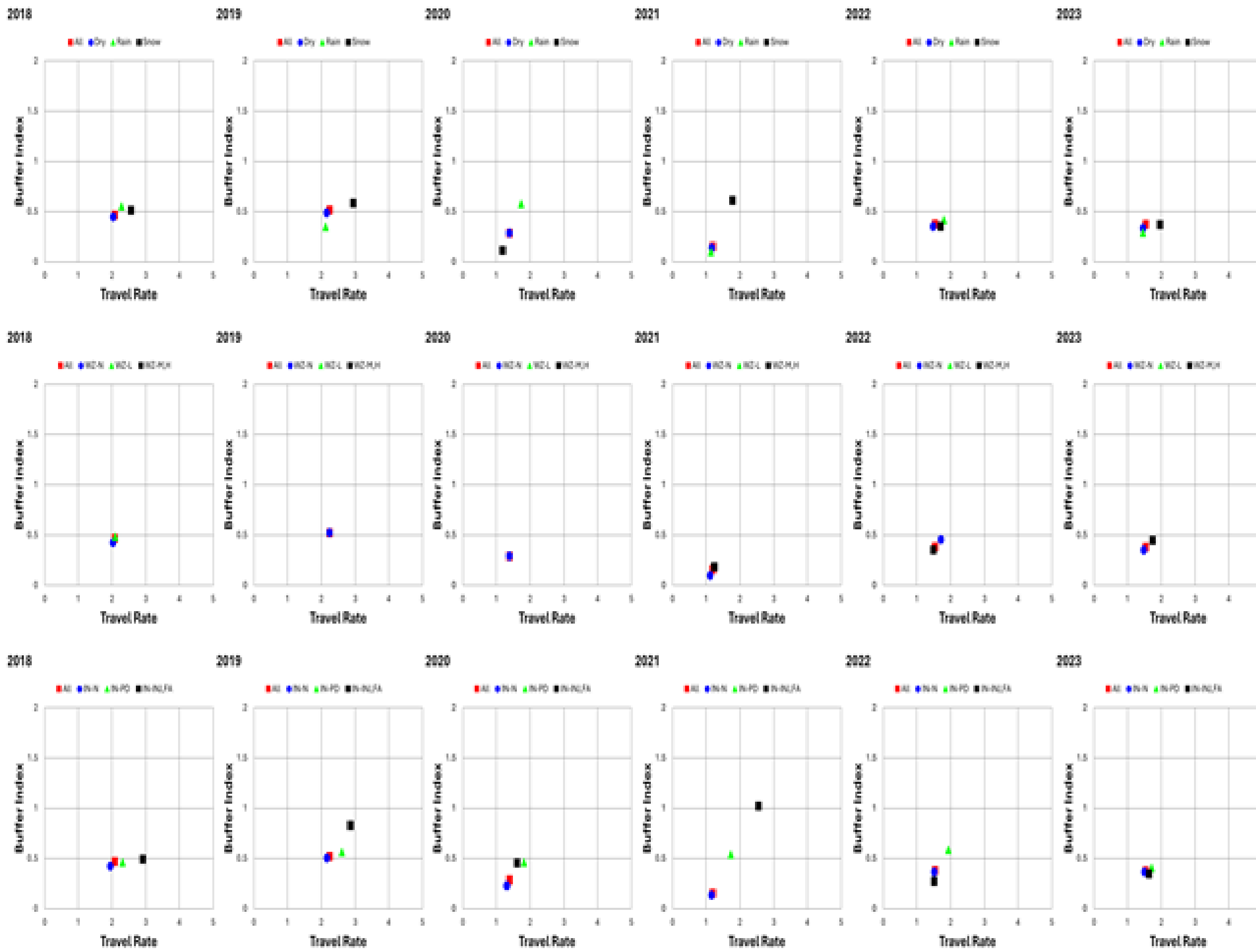
Incident Effects



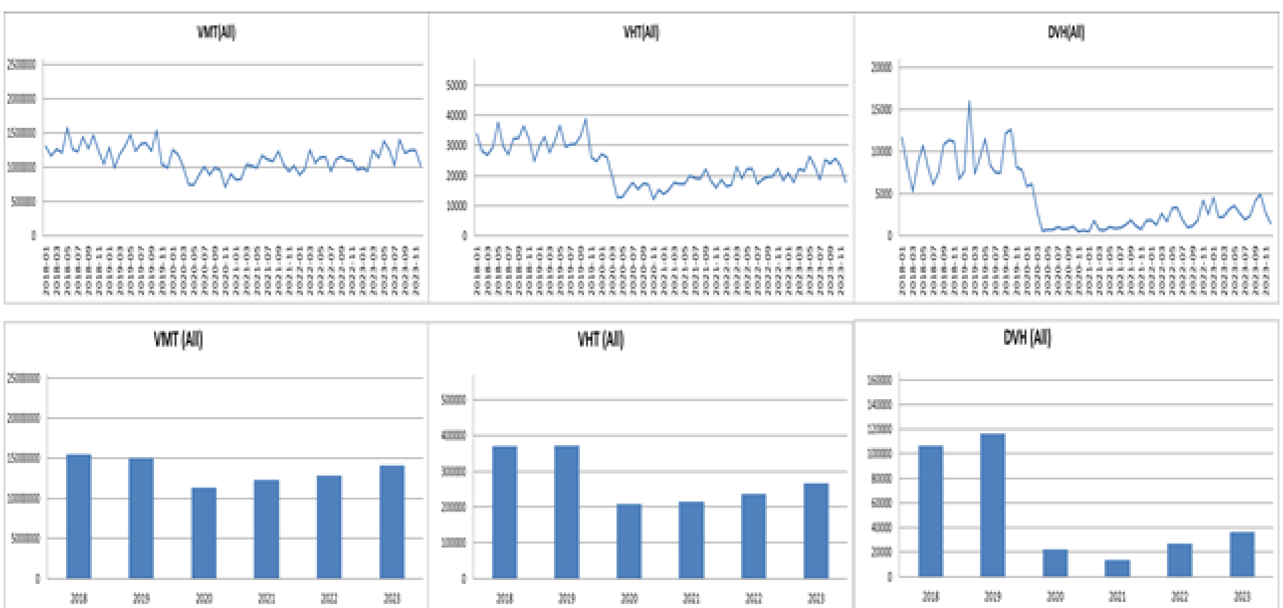
Work-Zone Effects



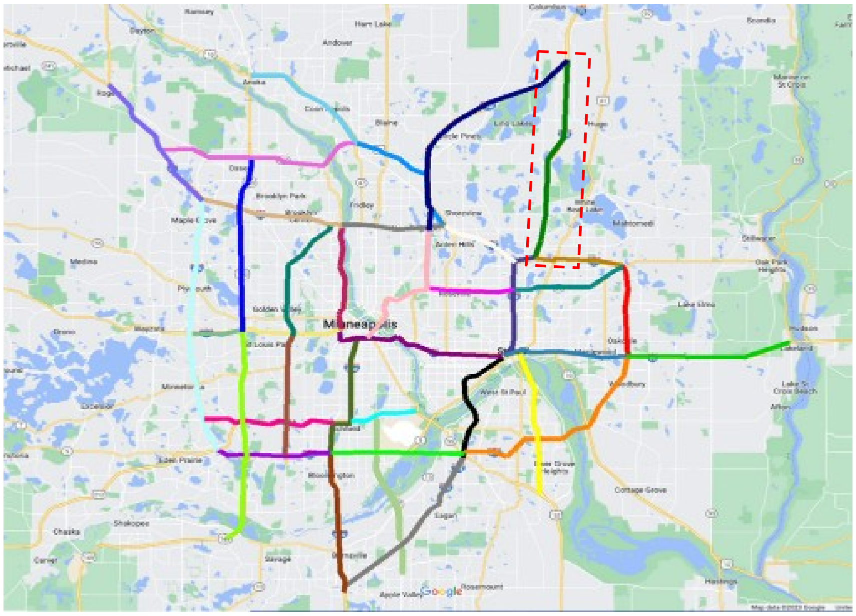
Yearly Variations of Buffer Index - Travel Rate Relationships



Variations of Traffic-Flow Measures

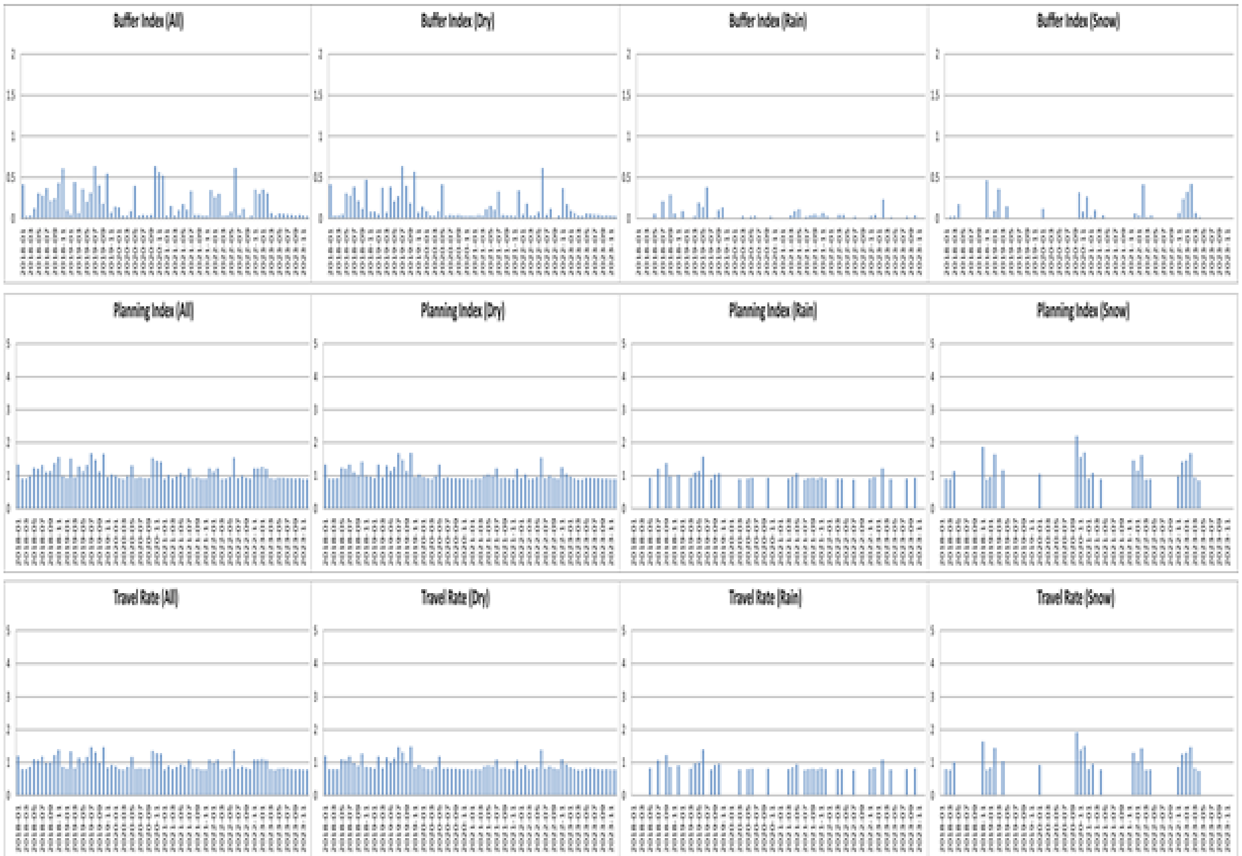


30) I-35E Corridor D (I694 < -- > I35)

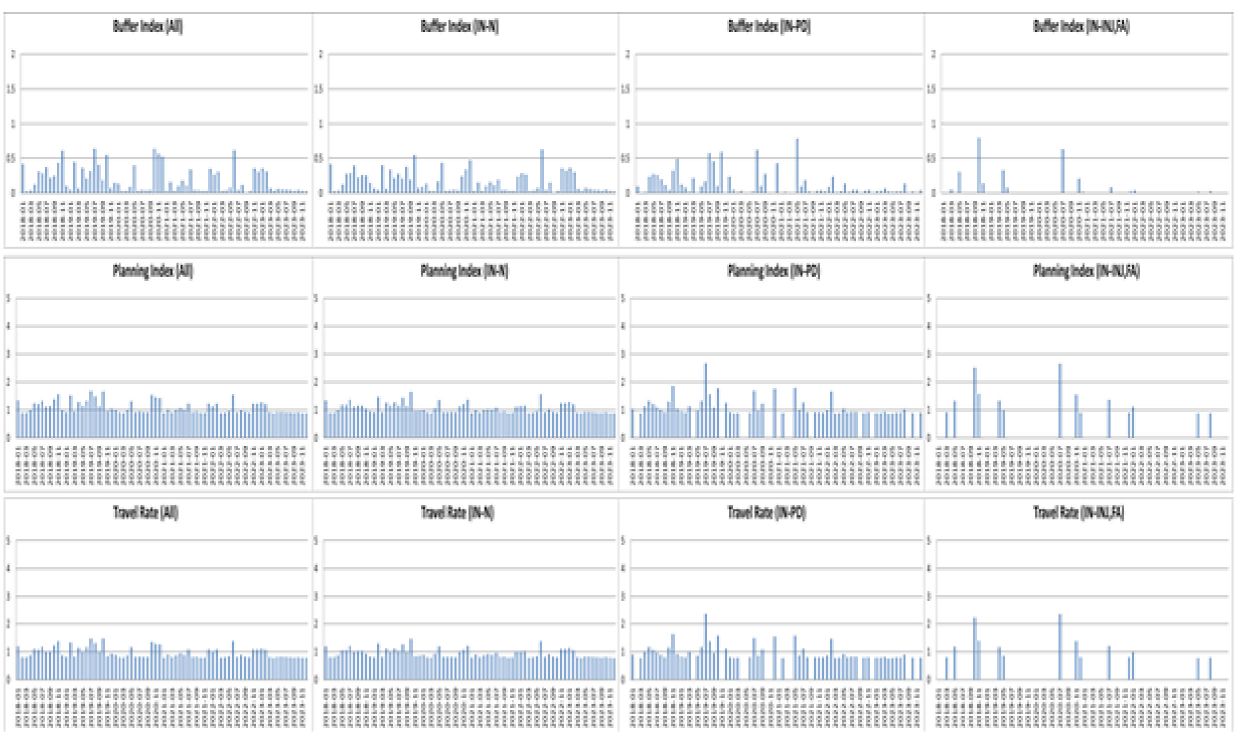


i) I-35E Corridor D -- NB I694 to I35 for Afternoon Peak Periods

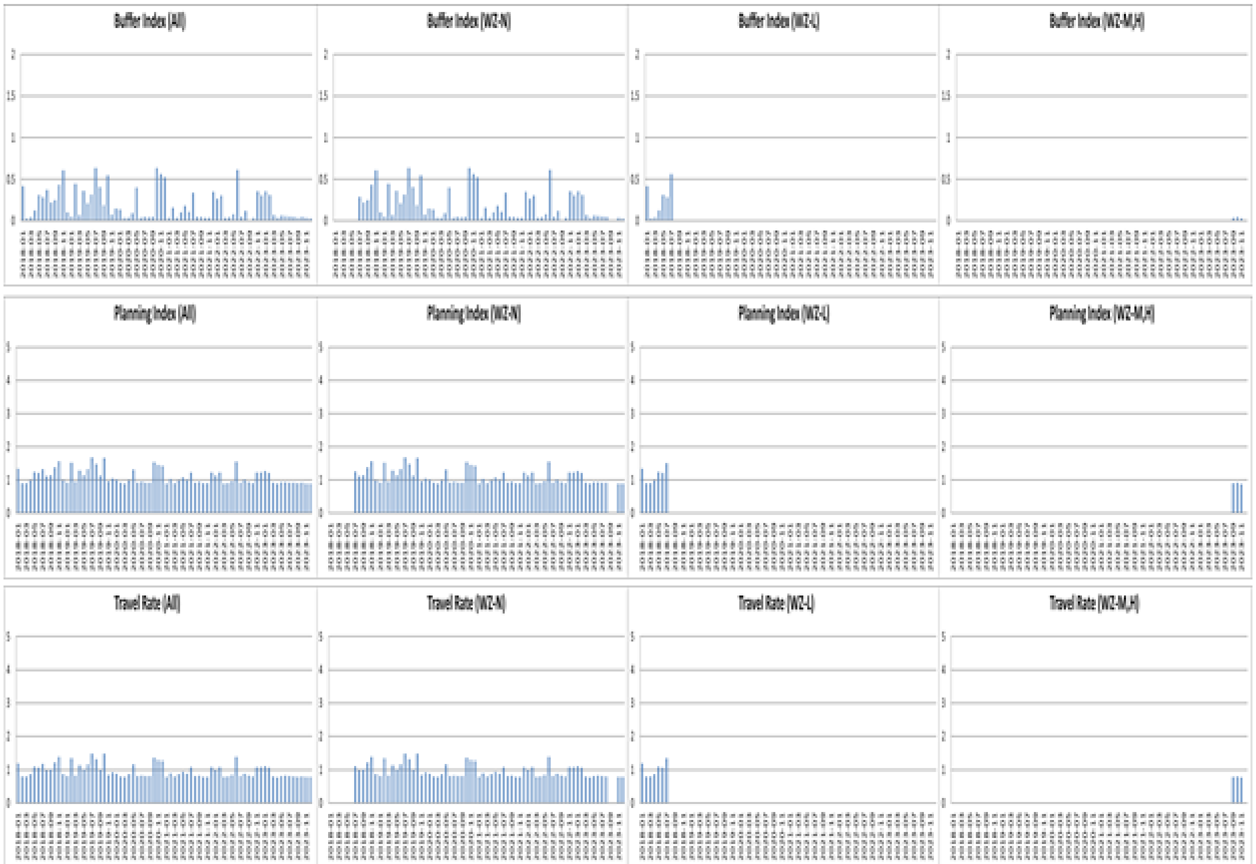
Effects of Weather conditions on Travel-Time Reliability



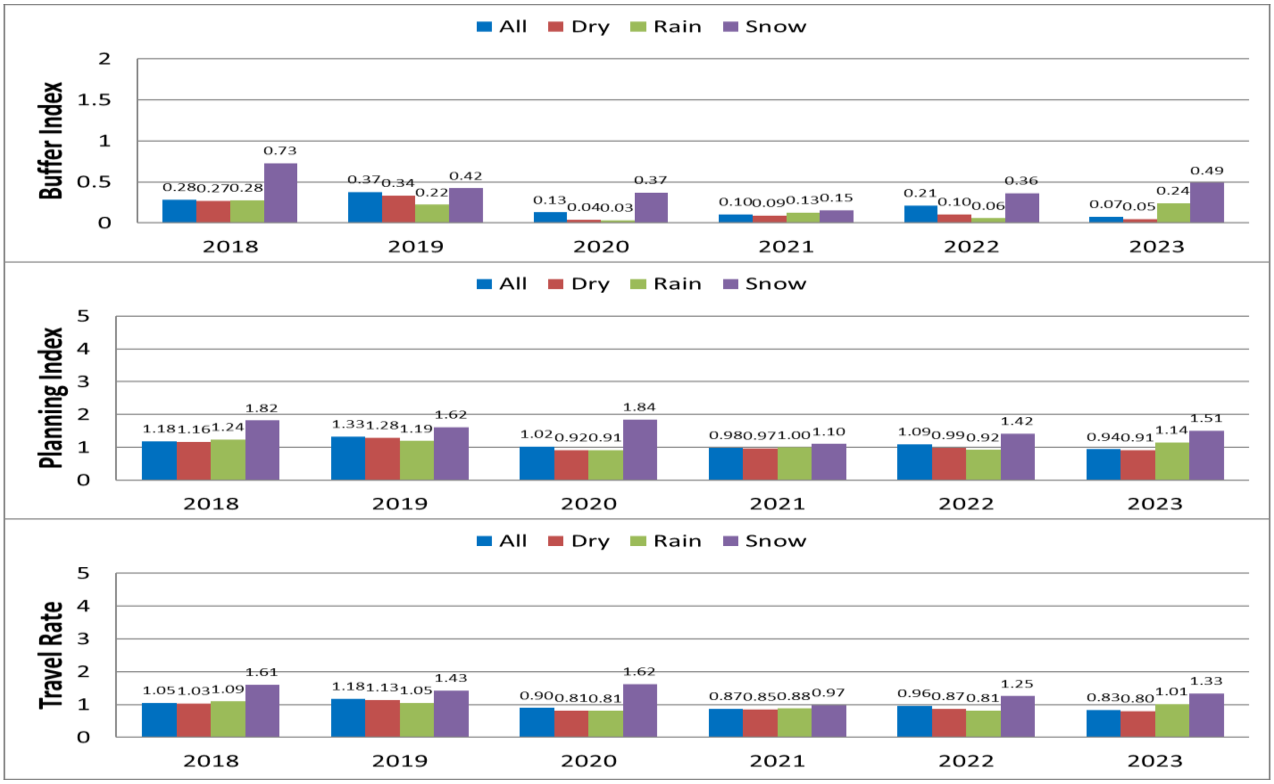
Effects of Incidents



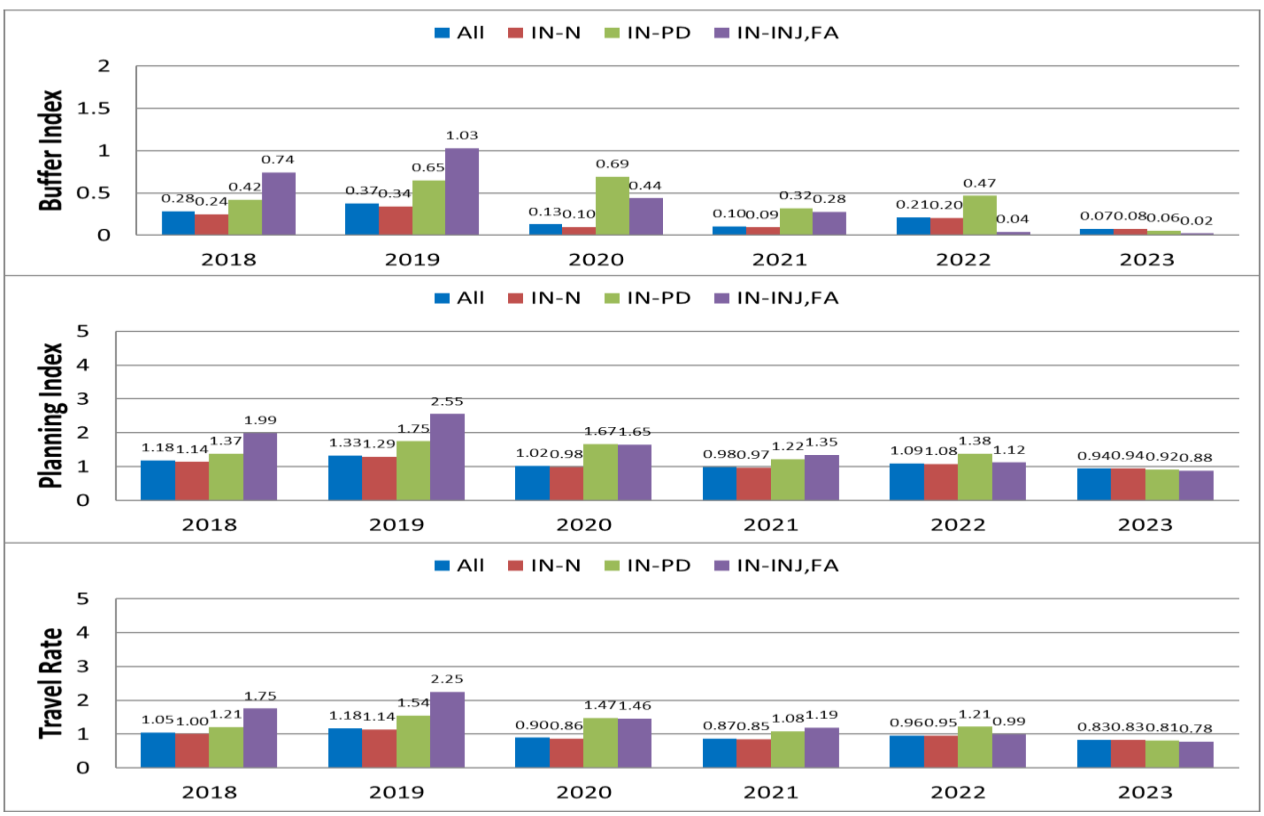
Effects of Work Zones



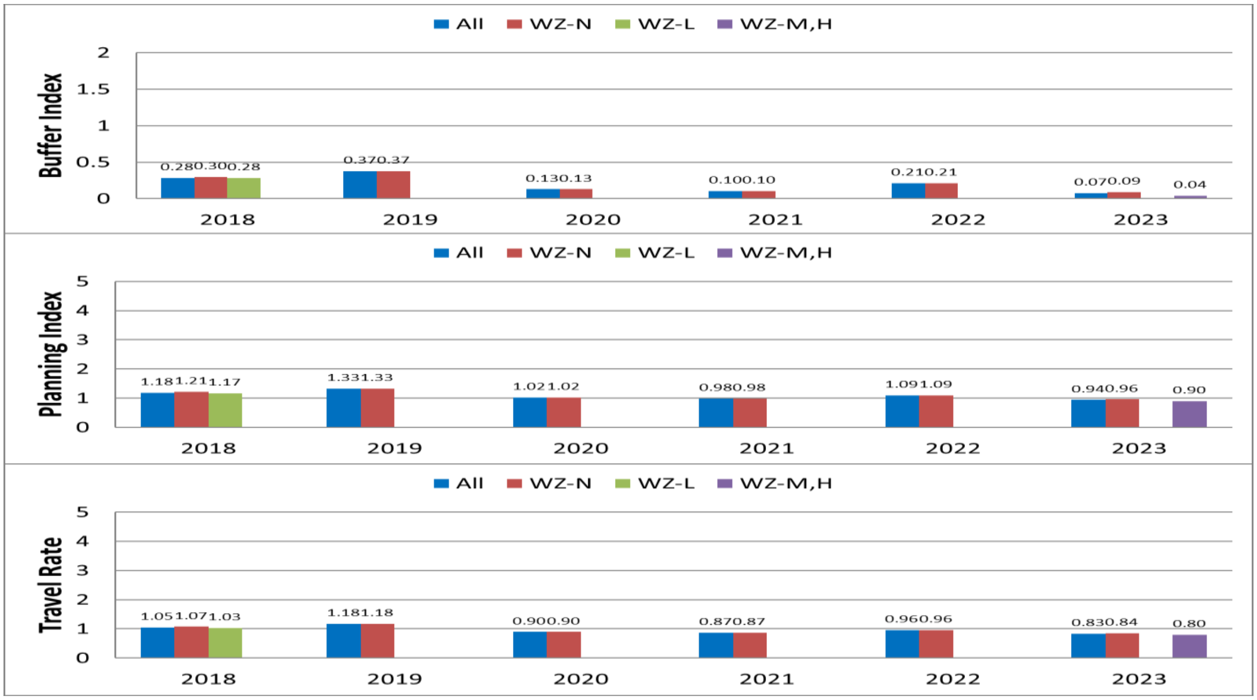
Yearly Variations - ***Weather Effects***



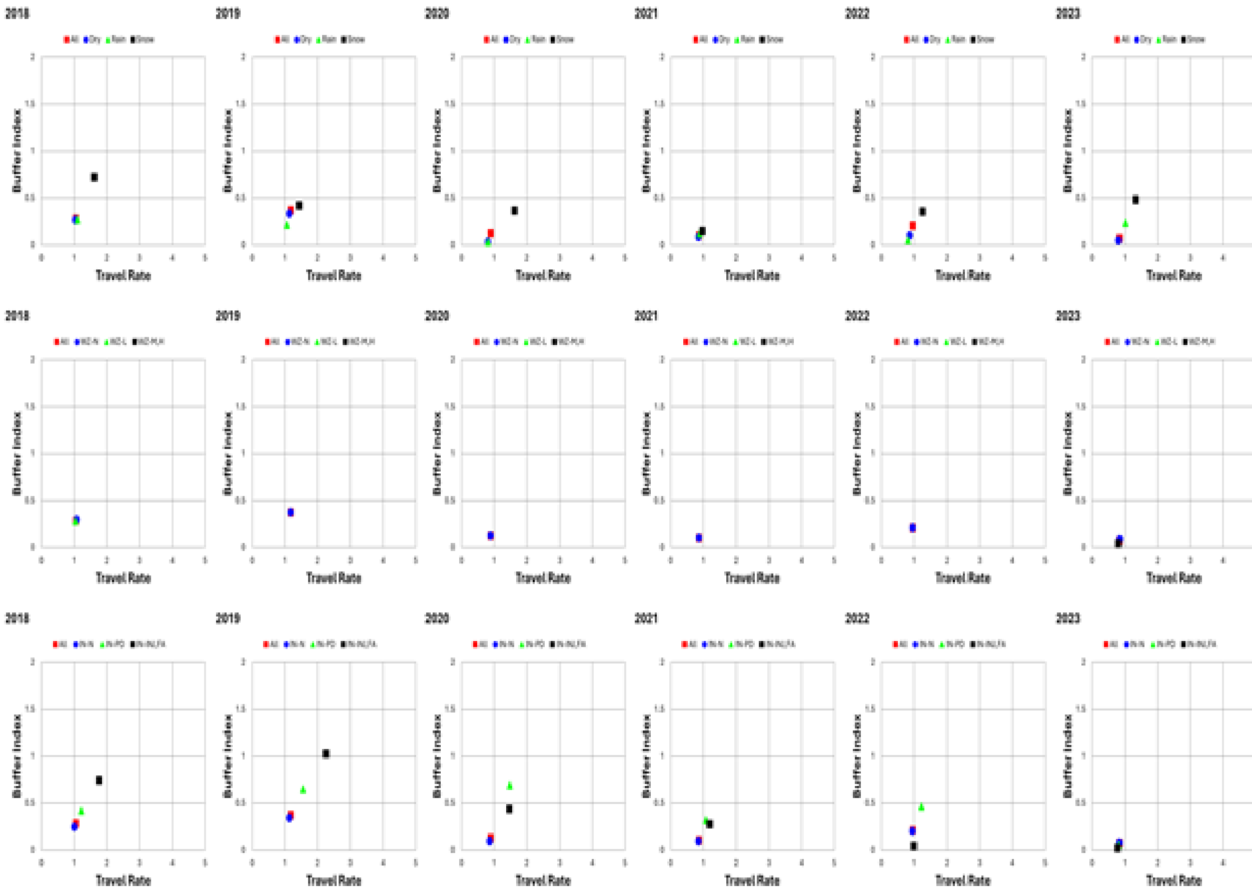
Incident Effects



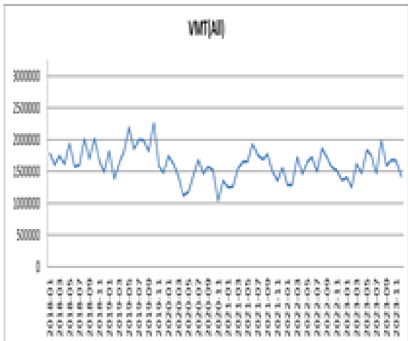
Work-Zone Effects



Yearly Variations of Buffer Index - Travel Rate Relationships



Variations of Traffic-Flow Measures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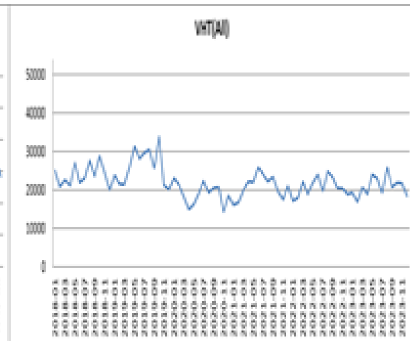
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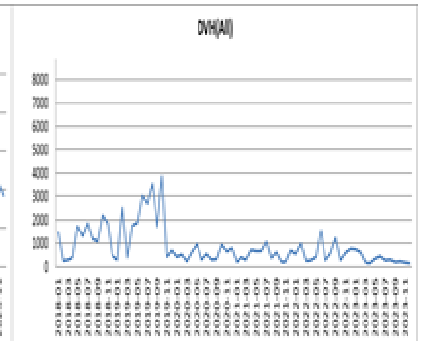
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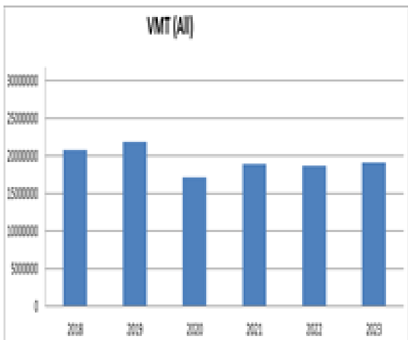
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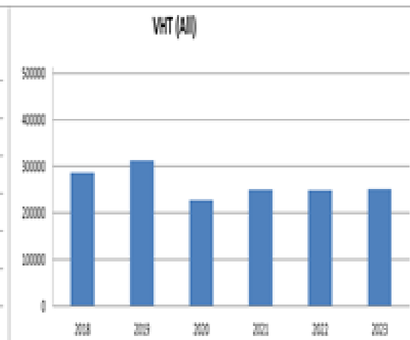
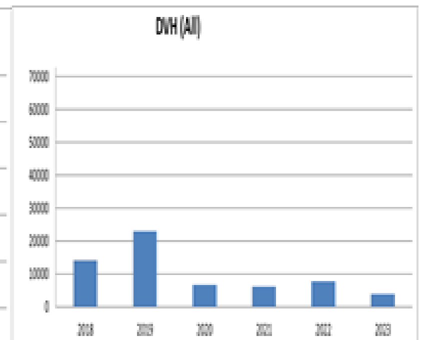
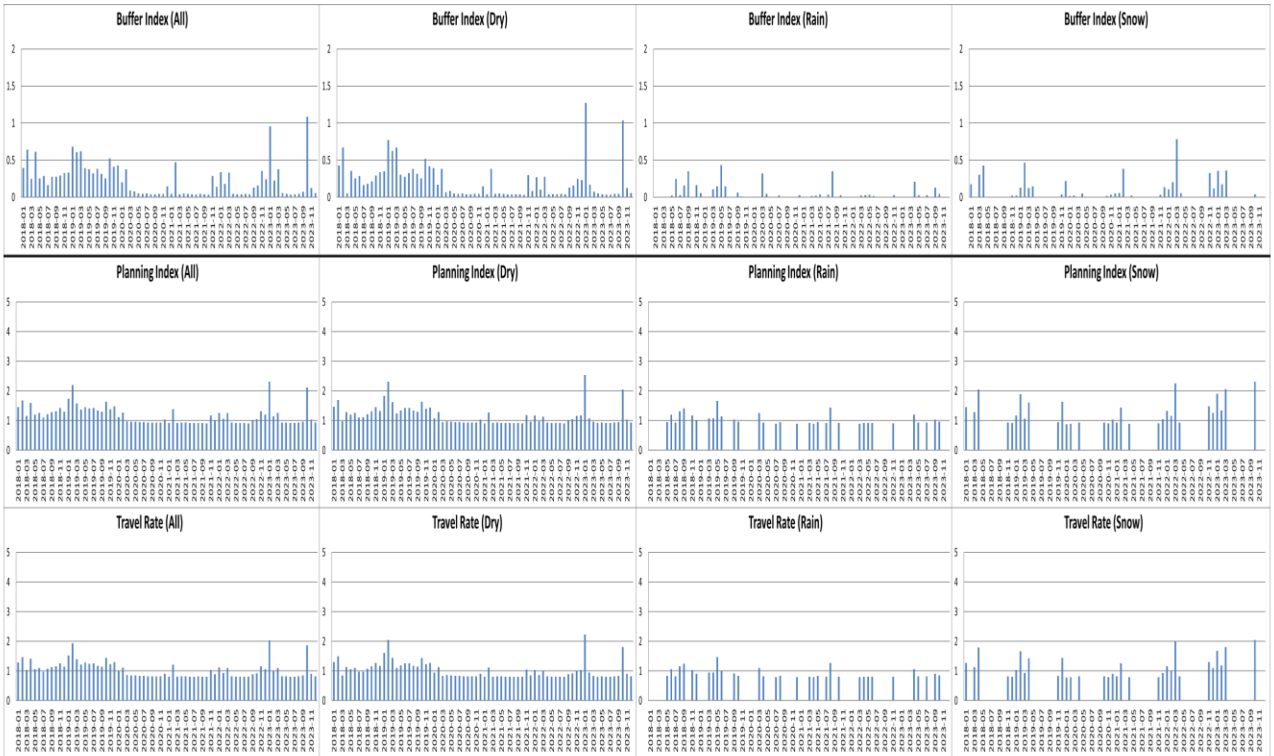
2018
2019
2020
2021
2022
2023


VHT (All)
500000
400000
300000
200000
100000
0
2018
2019
2020
2021
2022
2023

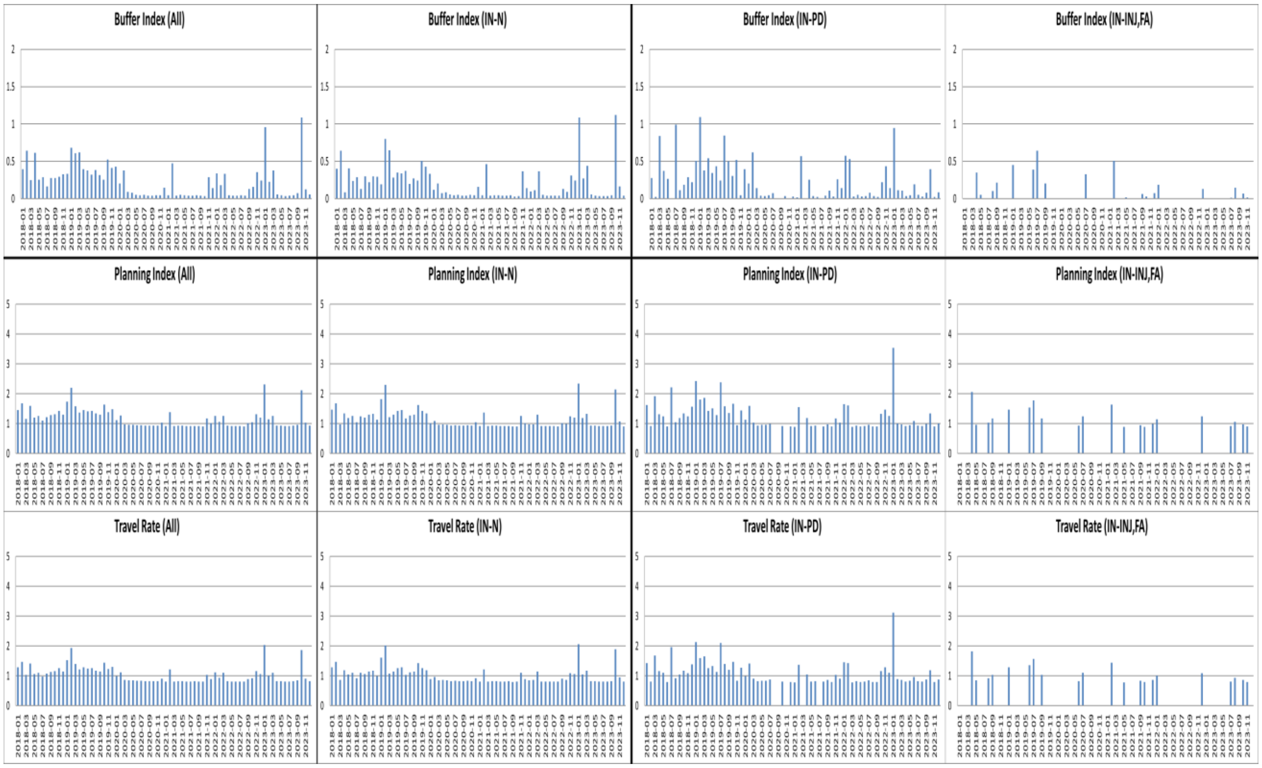

DVH (All)
70000
60000
50000
40000
30000
20000
10000
0
2018
2019
2020
2021
2022
2023

ii) I-35E Corridor D -- SB I35 to I694 for Morning Peak Periods

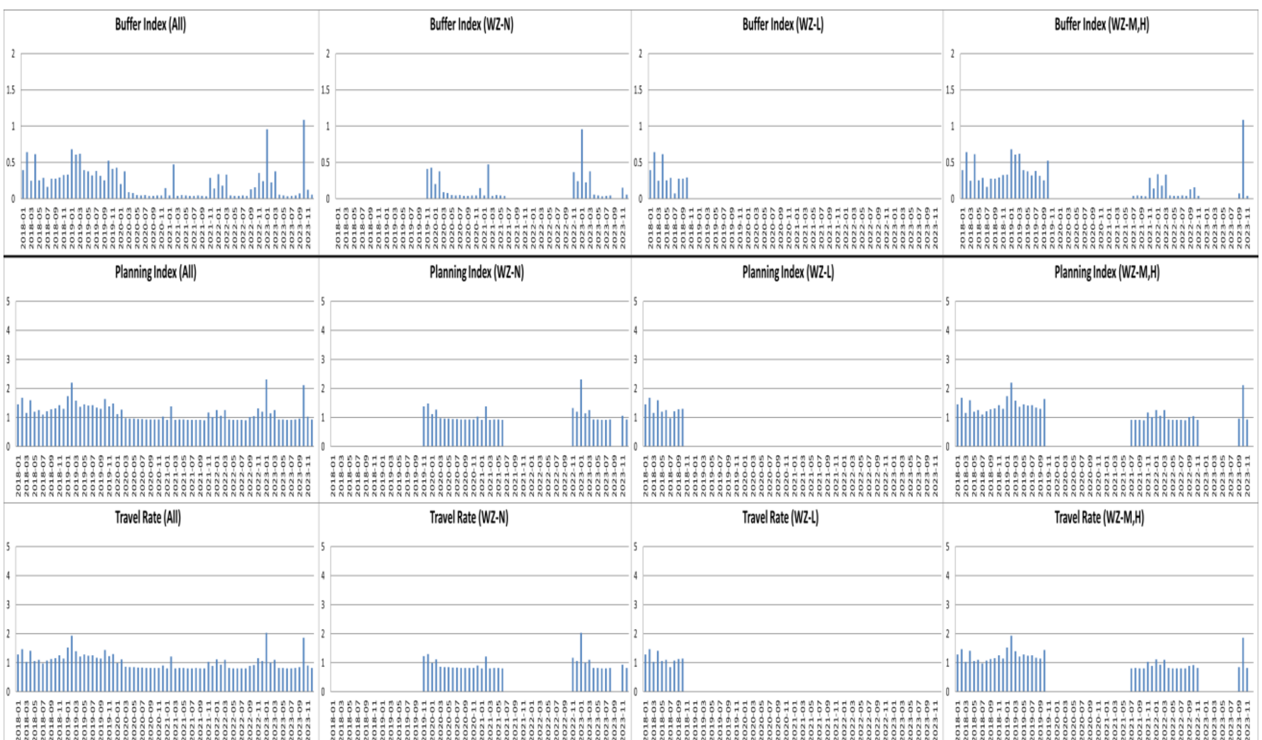
Effects of Weather conditions on Travel-Time Reliability



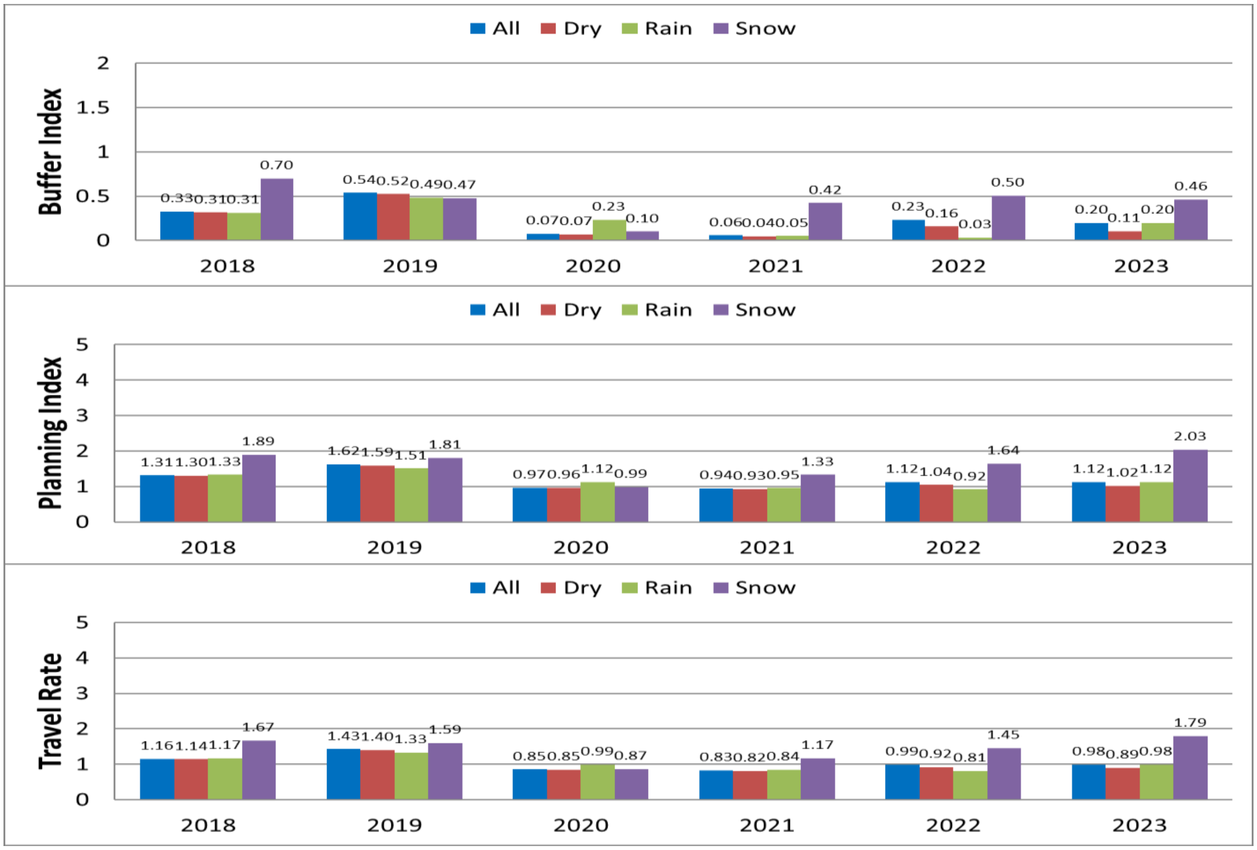
Effects of Incidents



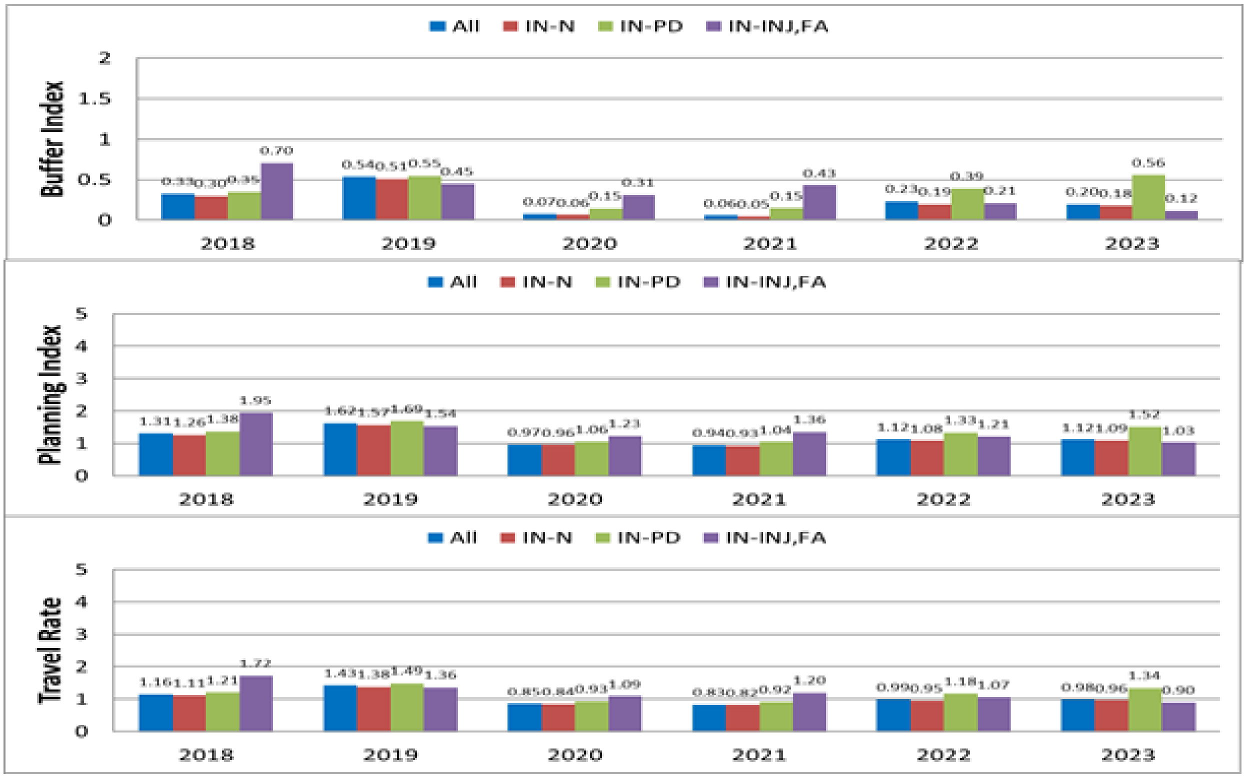
Effects of Work Zones



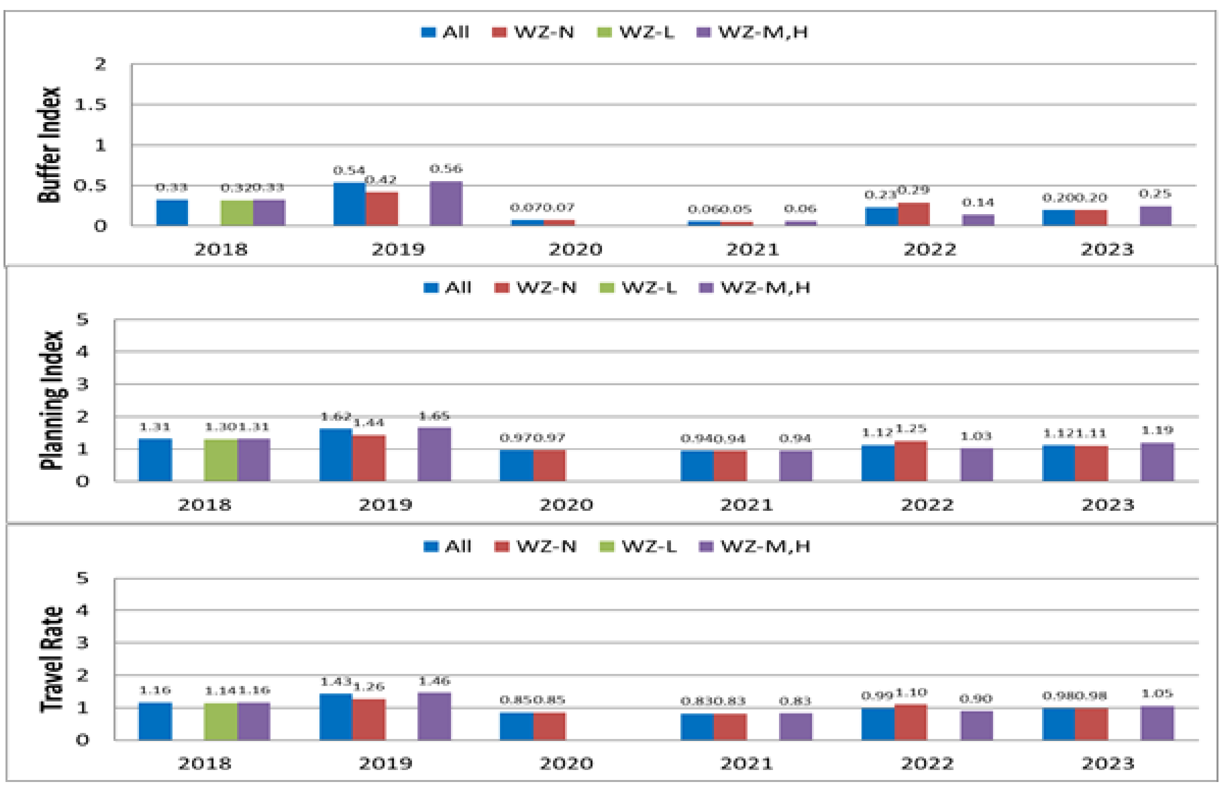
Yearly Variations - *Weather Effects*



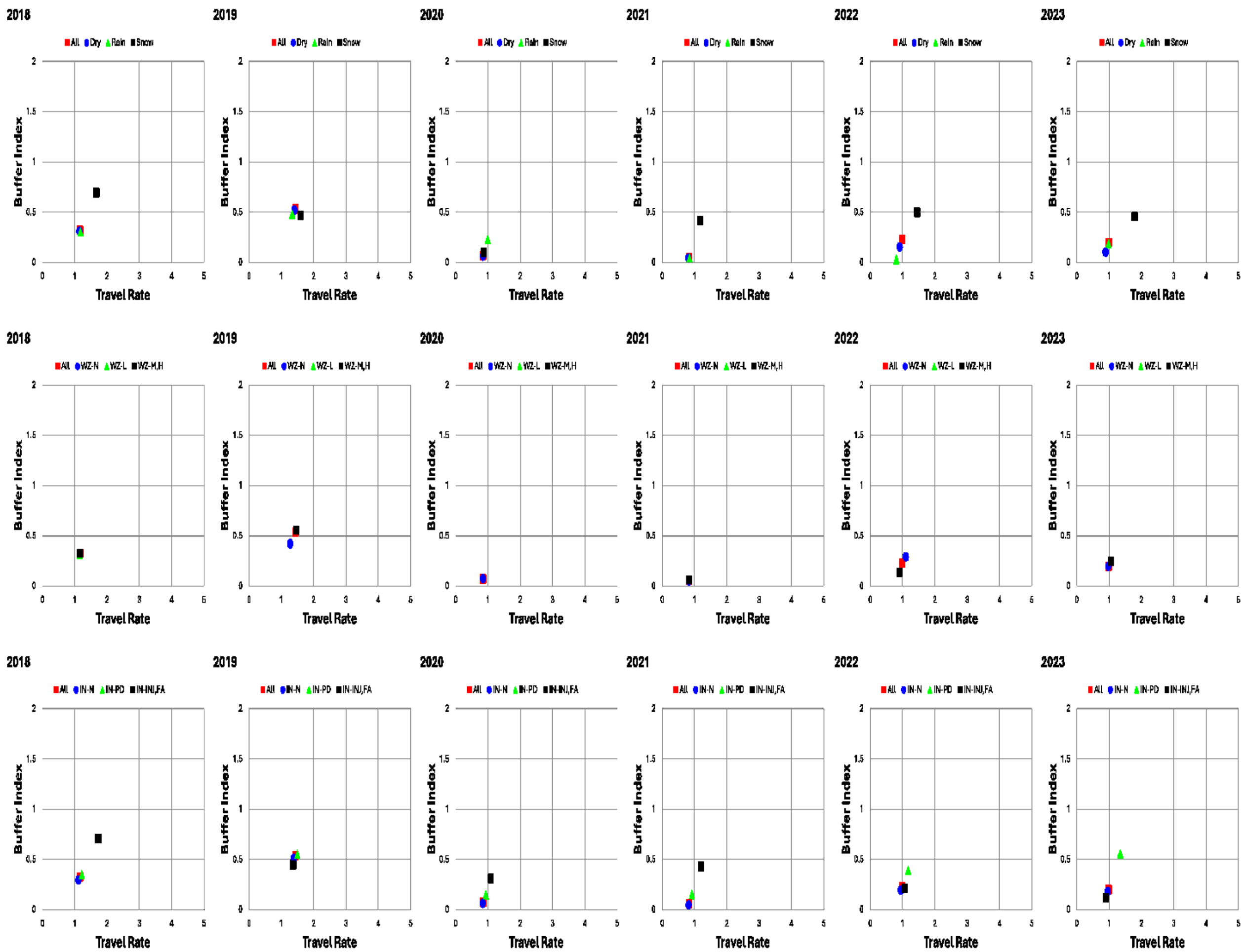
Incident Effects



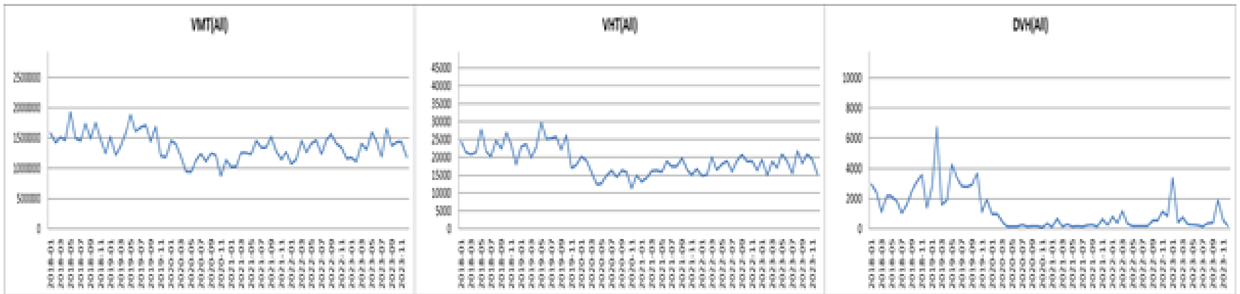
Work-Zone Effects

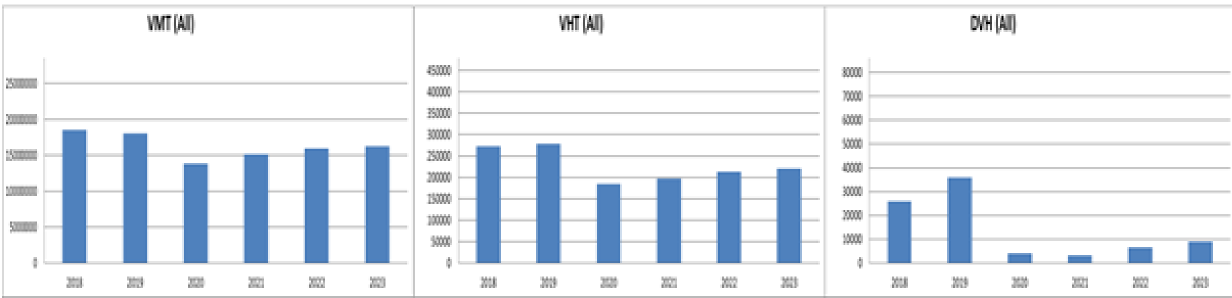


Yearly Variations of Buffer Index - Travel Rate Relationships

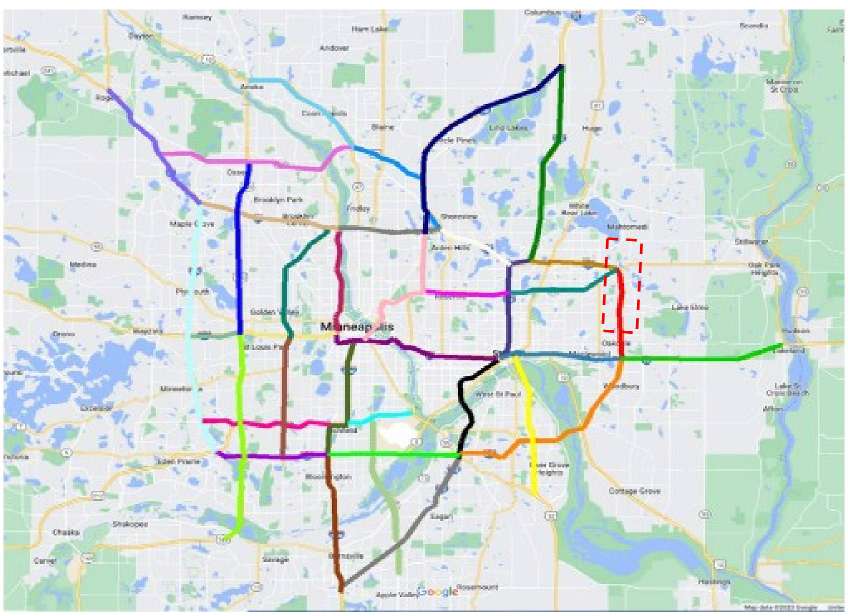


Variations of Traffic-Flow Measures



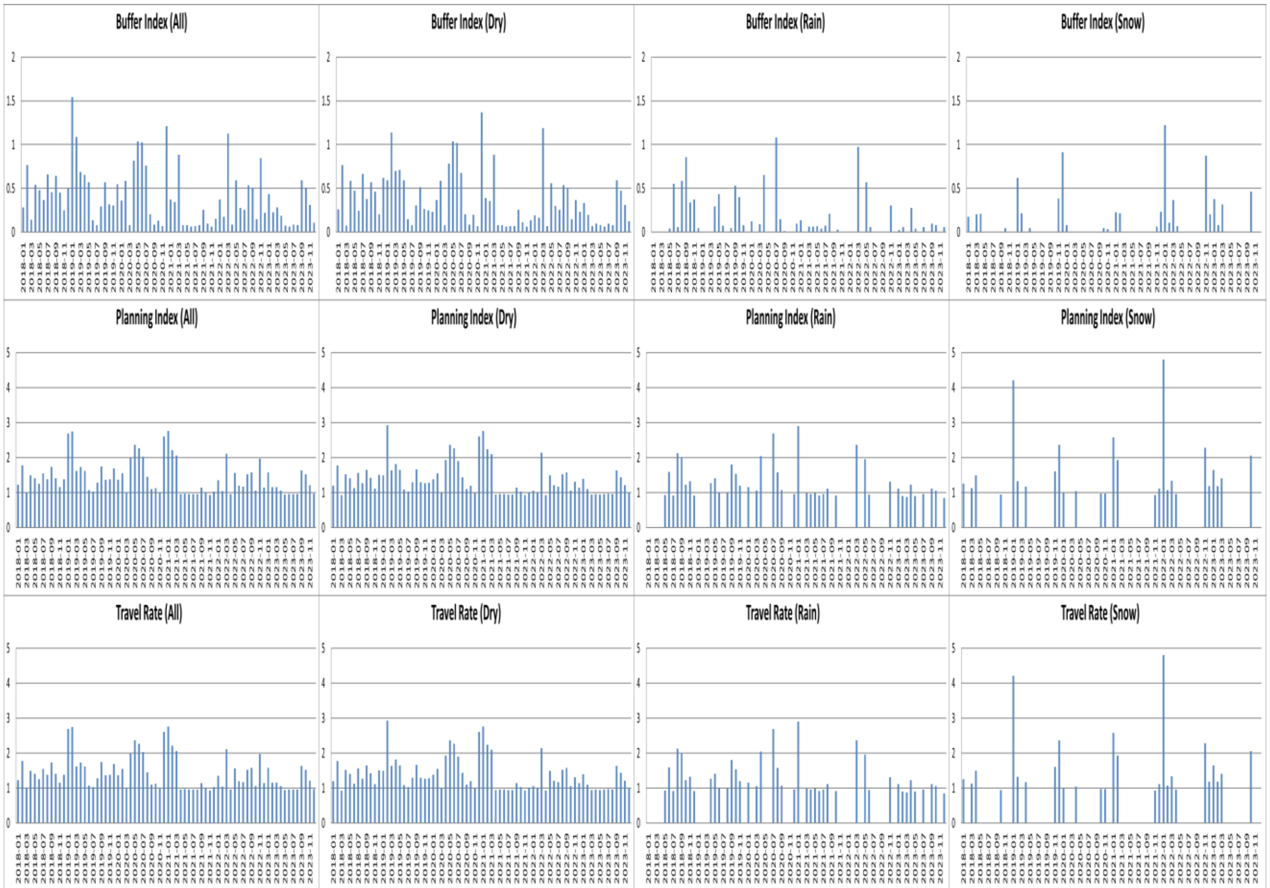


31) I-694 Corridor A (I-94 to TH36)

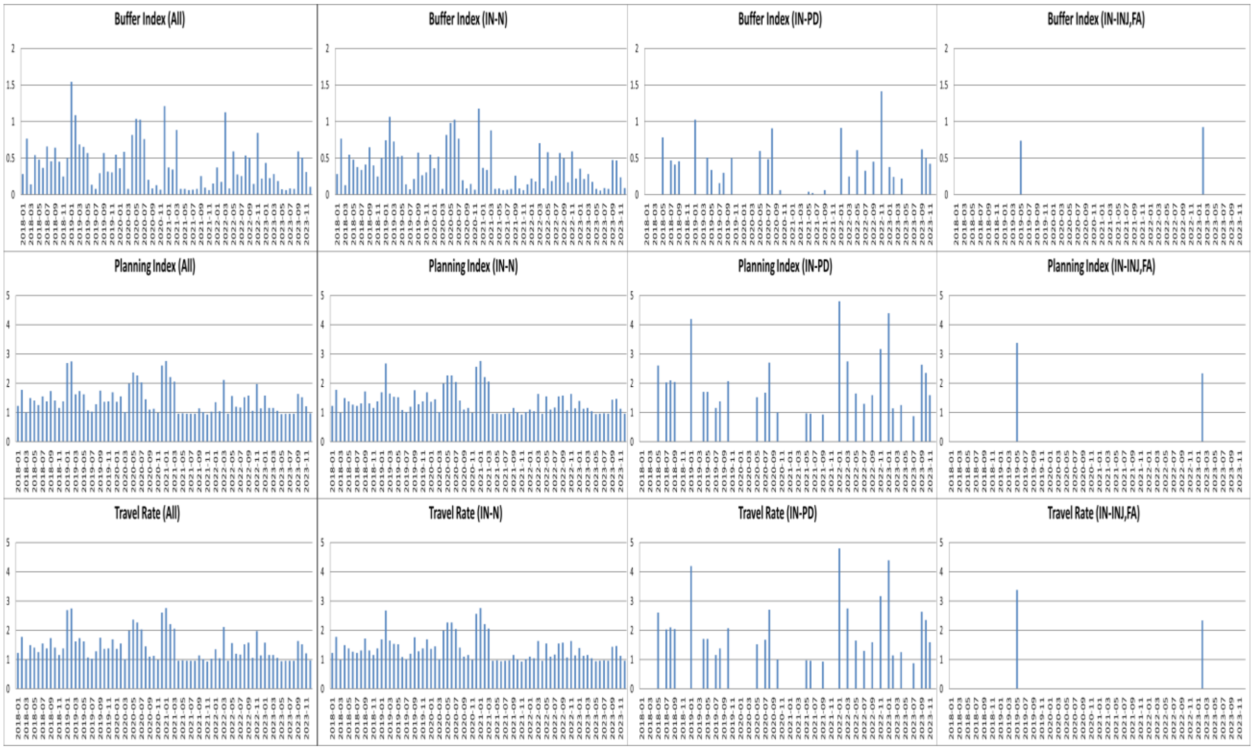


i) I-694 Corridor A -- NB I-94 to TH36 for Morning Peak Periods

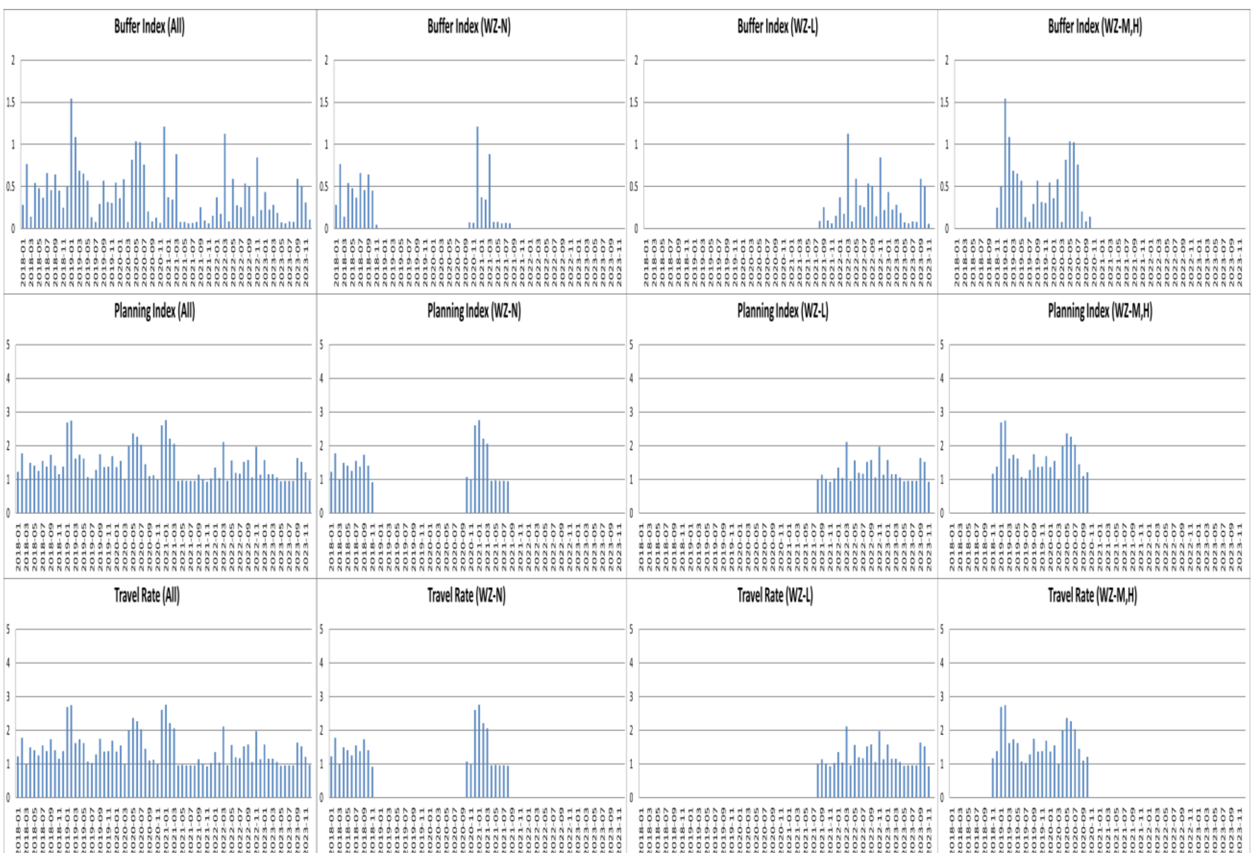
Effects of Weather conditions on Travel-Time Reliability



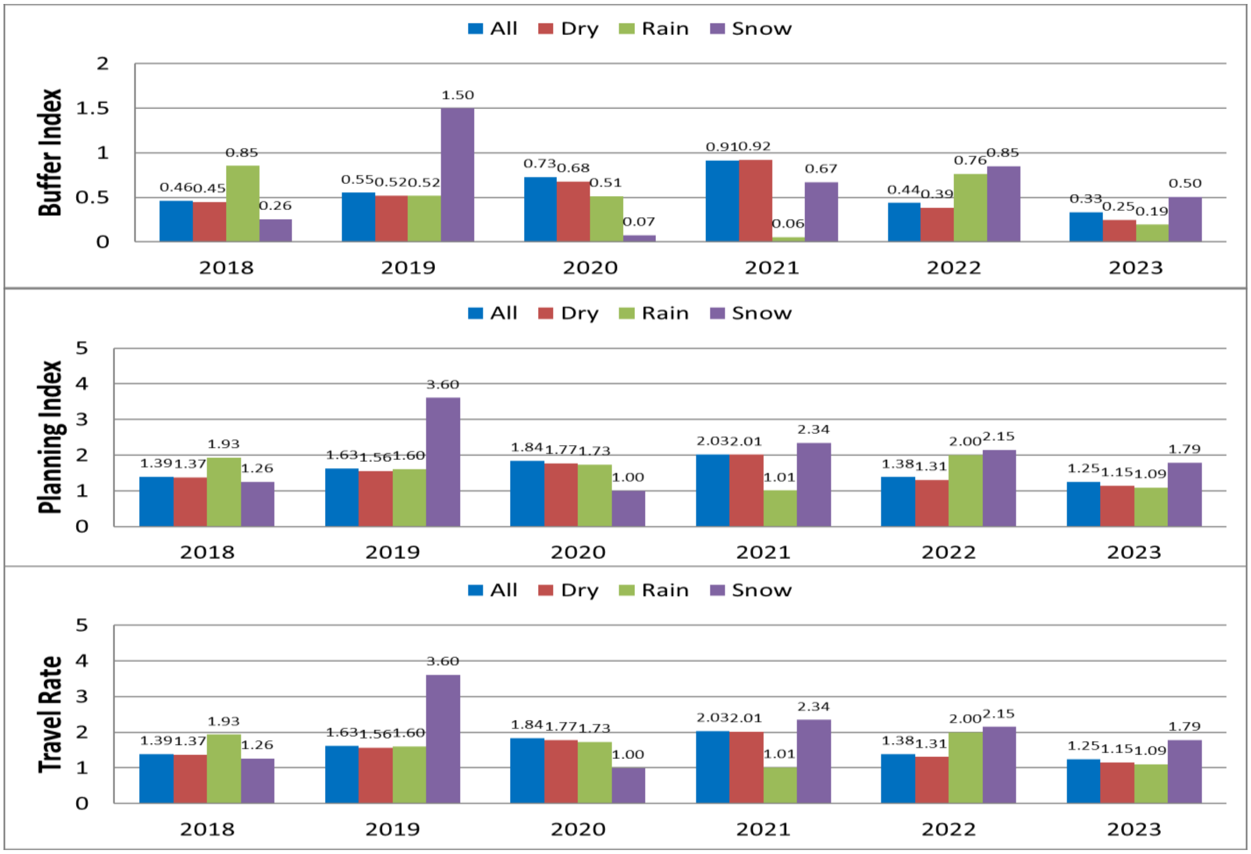
Effects of Incidents



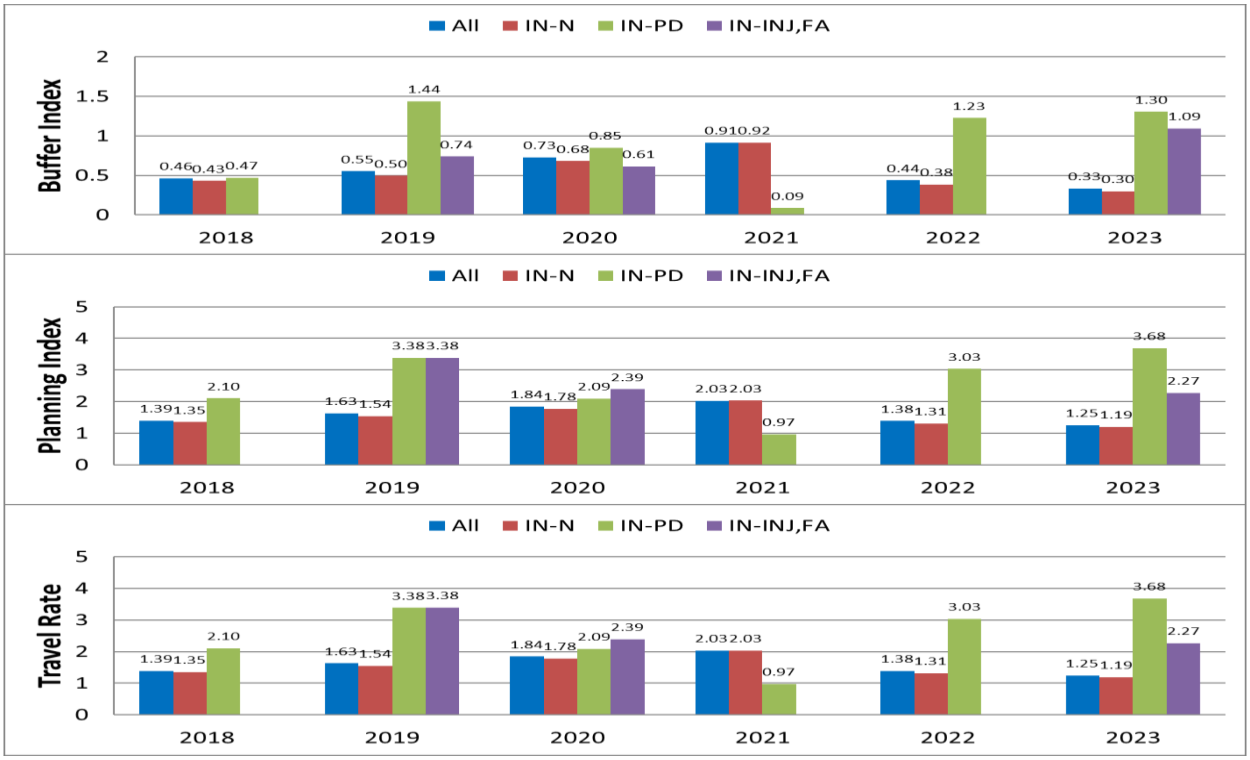
Effects of Work Zones



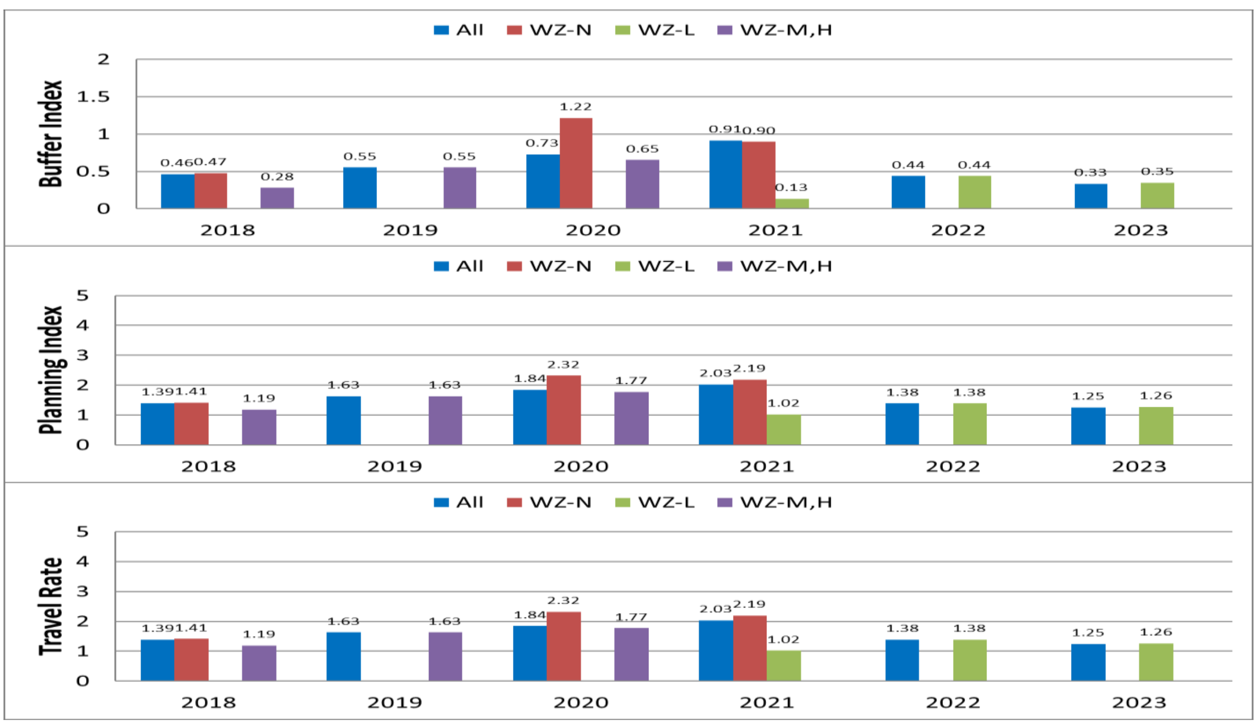
Yearly Variations - *Weather Effects*



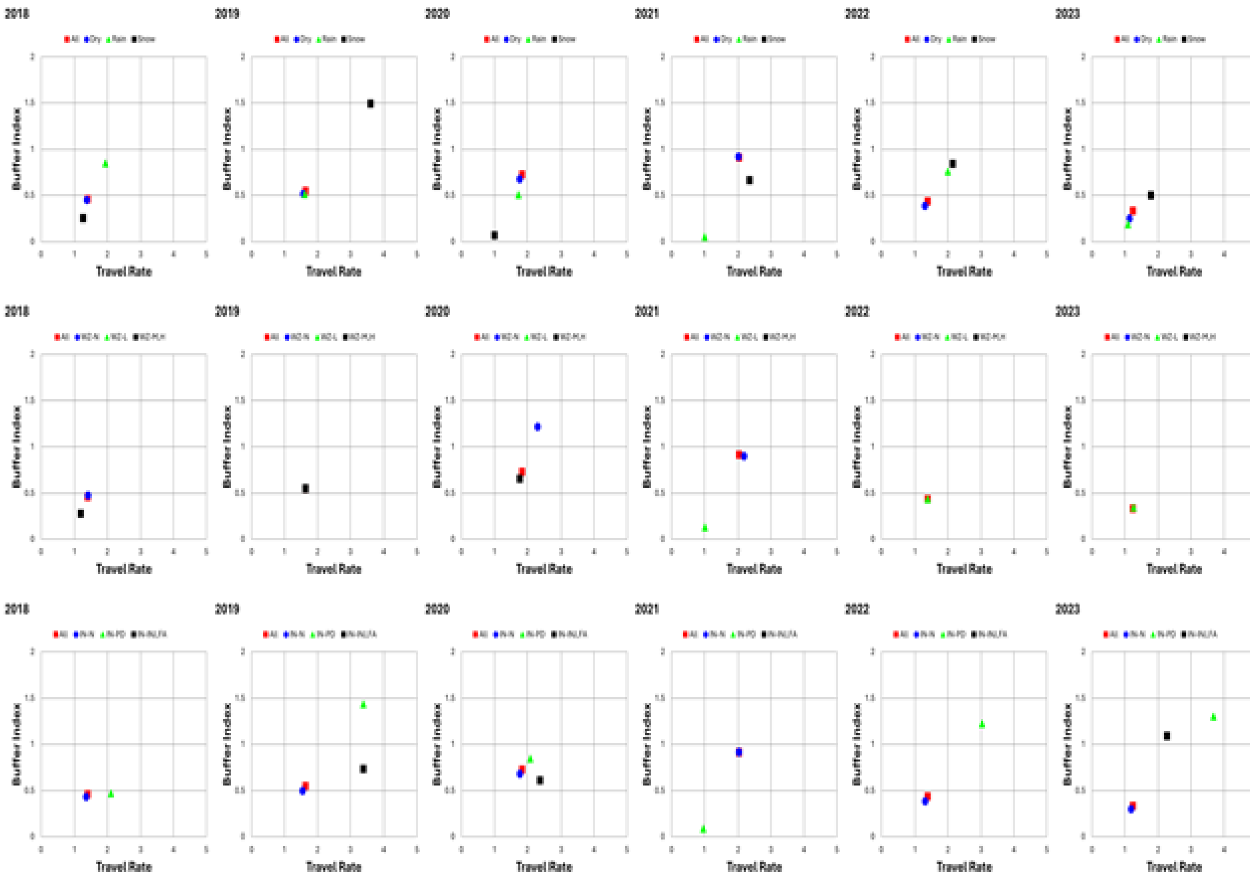
Incident Effects



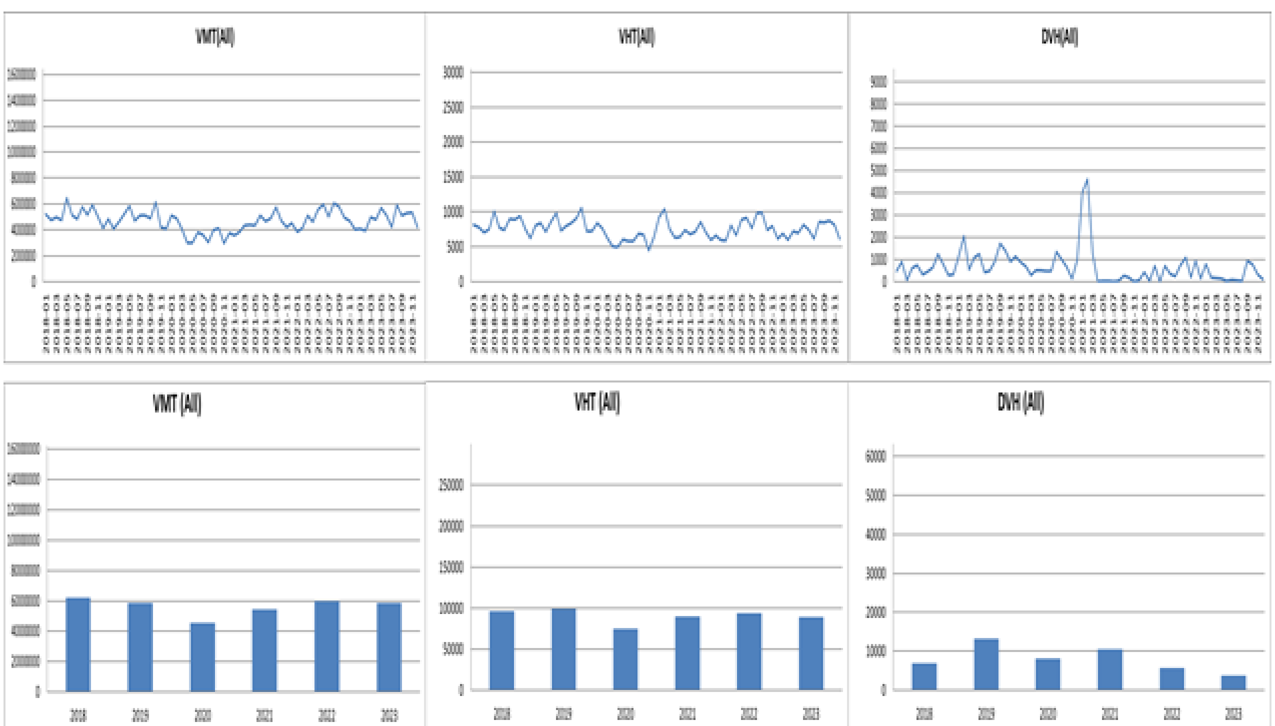
Work-Zone Effects



Yearly Variations of Buffer Index - Travel Rate Relationships

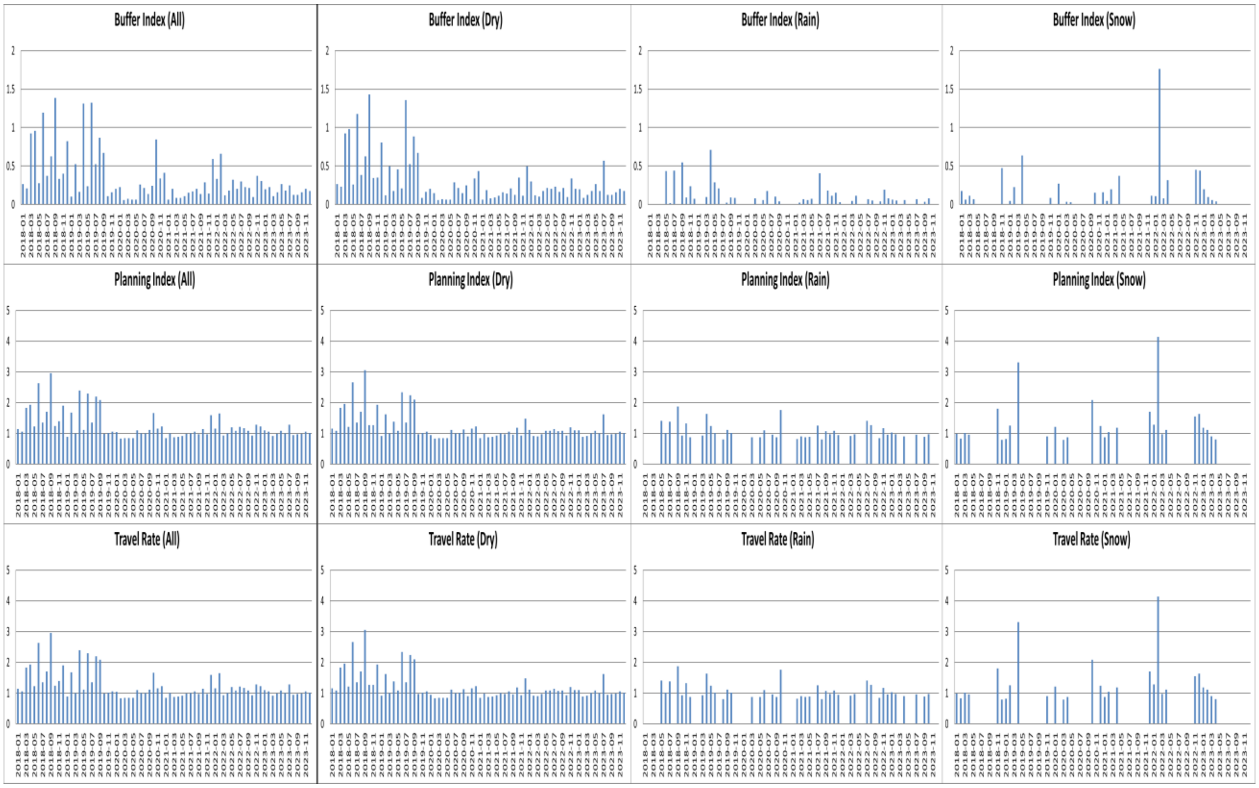


Variations of Traffic-Flow Measures

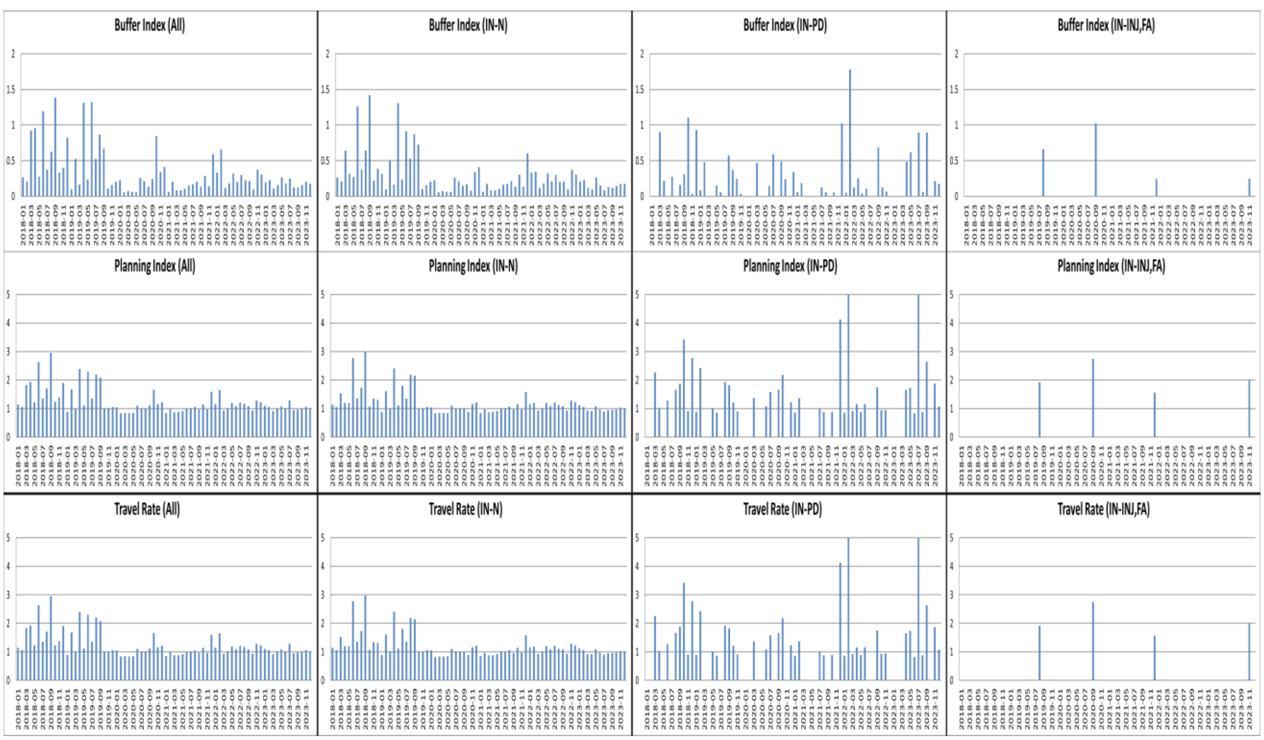


ii) I-694 Corridor A -- SB TH36 to I94 for Afternoon Peak Periods

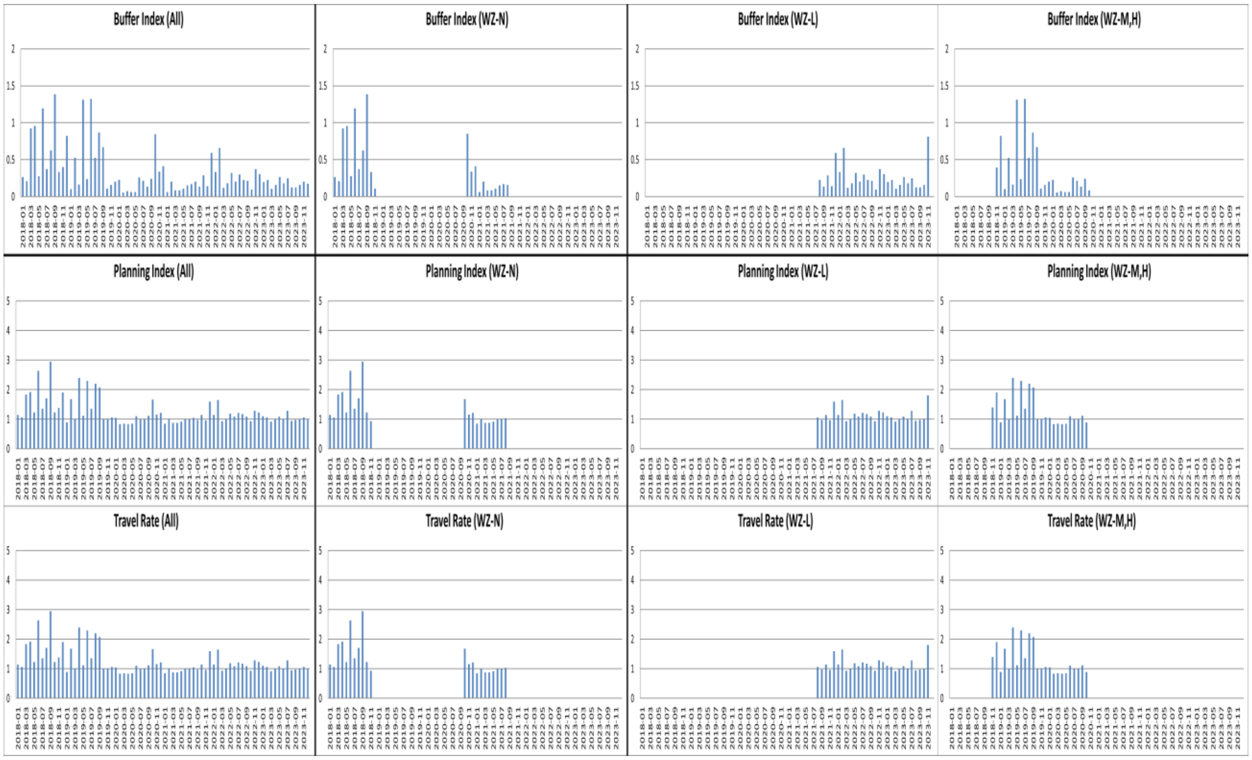
Effects of Weather conditions on Travel-Time Reliability



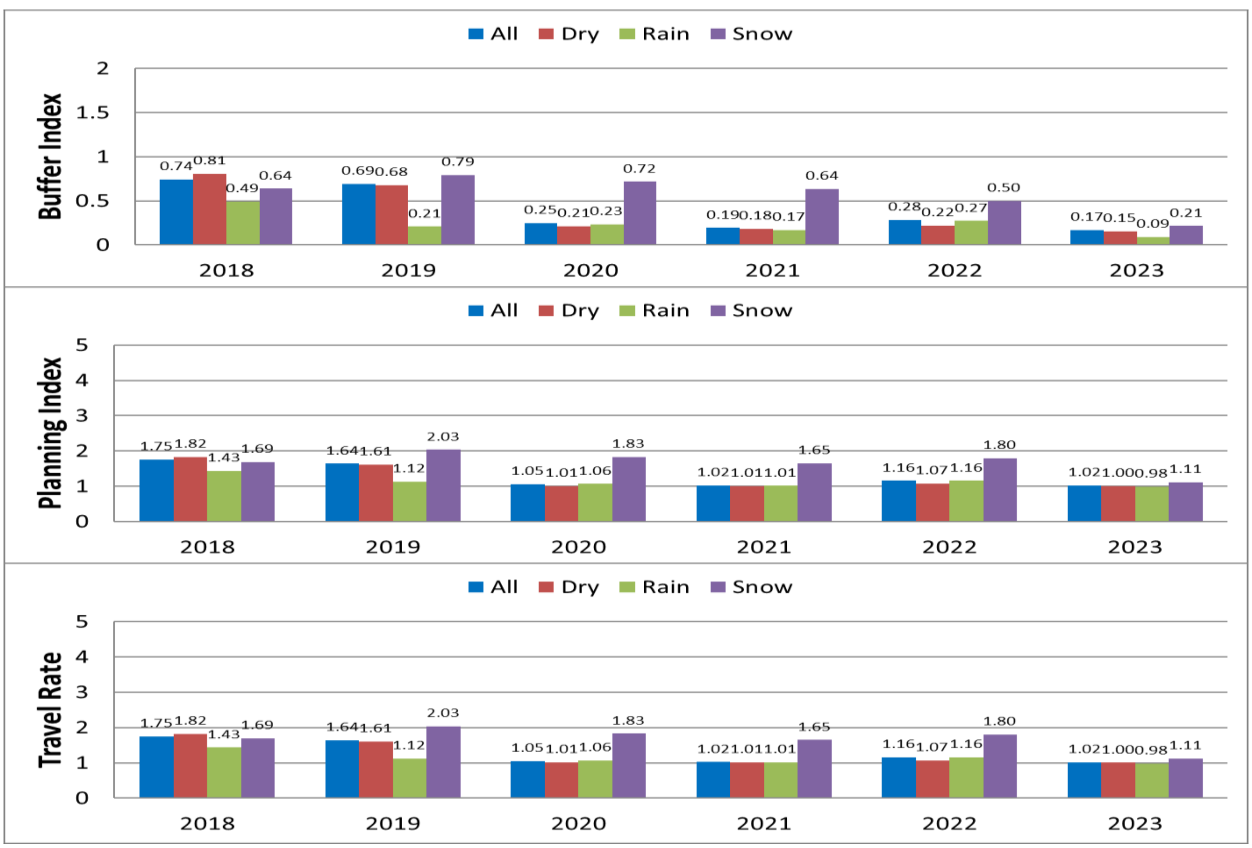
Effects of Incidents



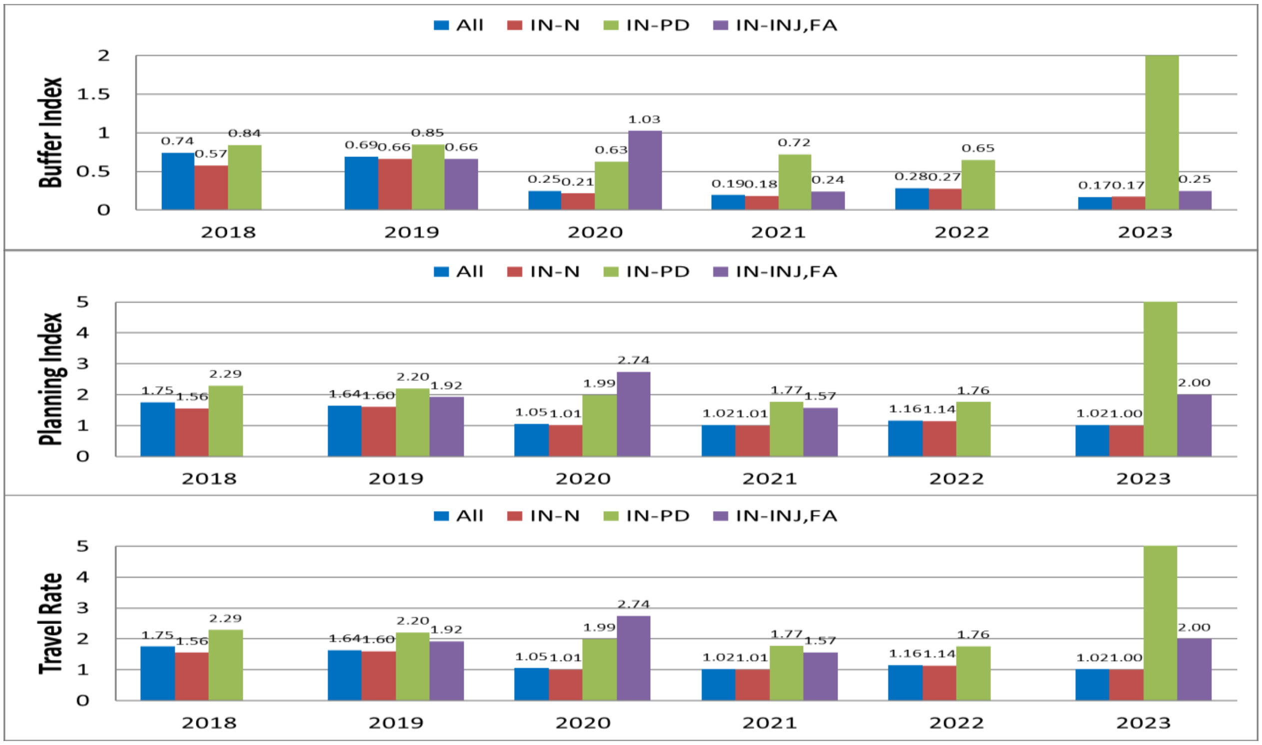
Effects of Work Zones



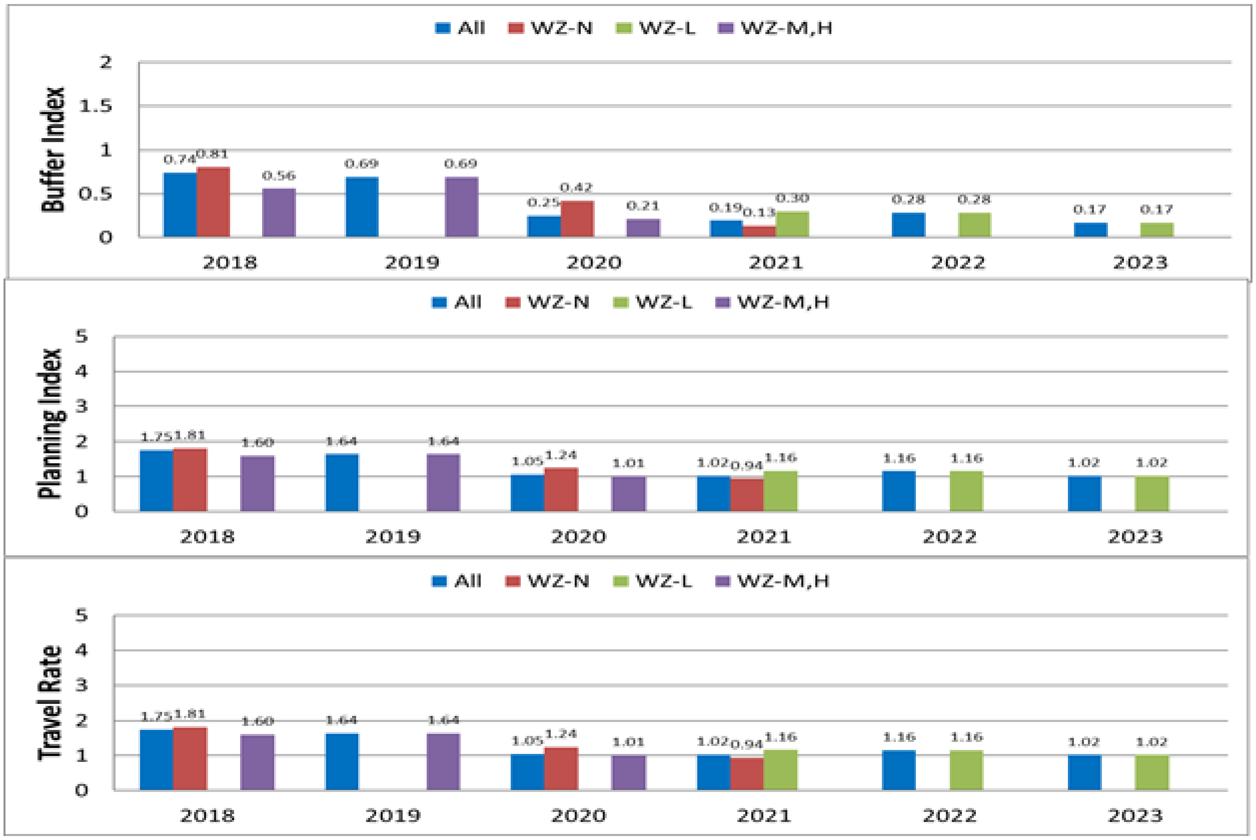
Yearly Variations - *Weather Effects*



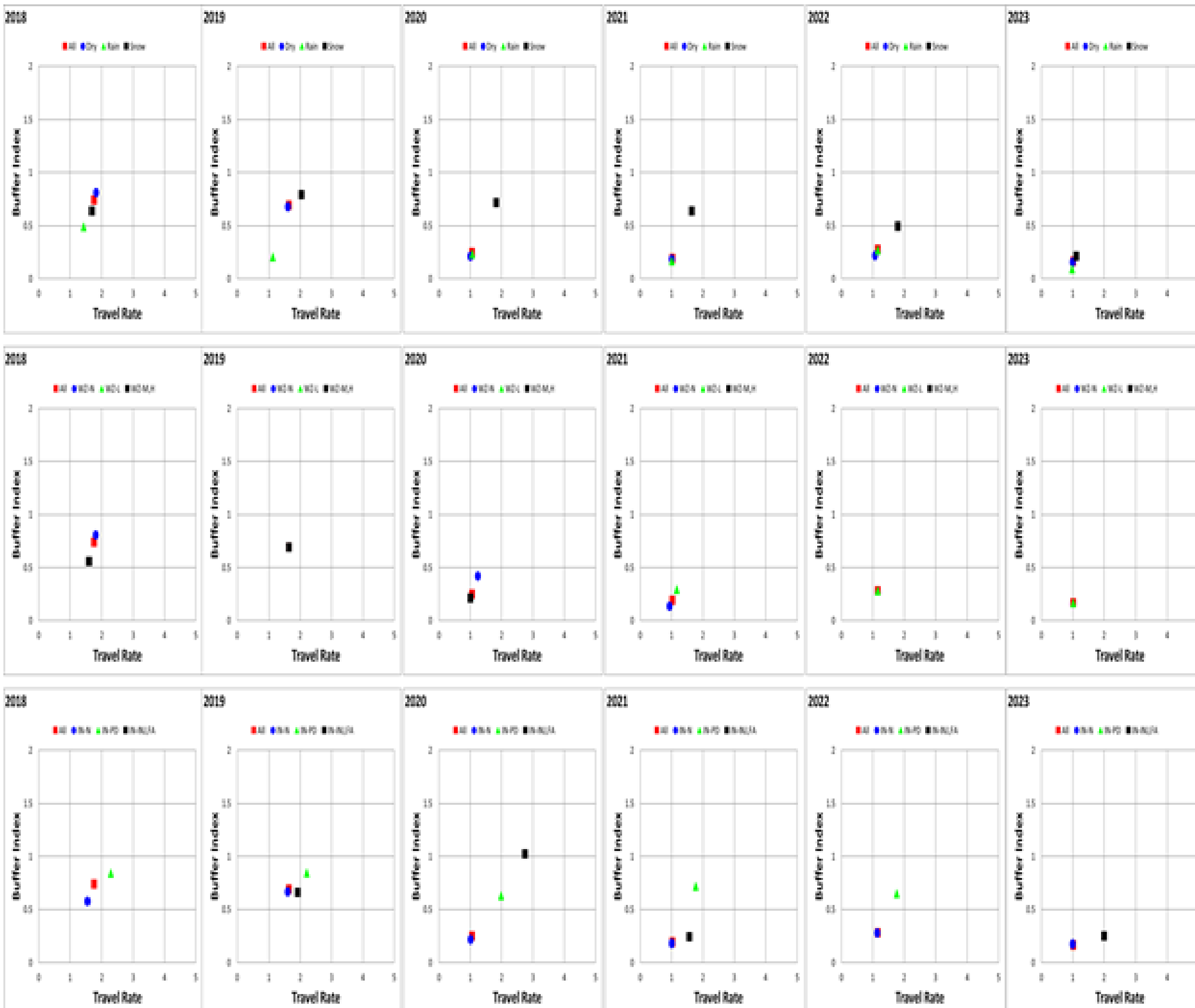
Incident Effects



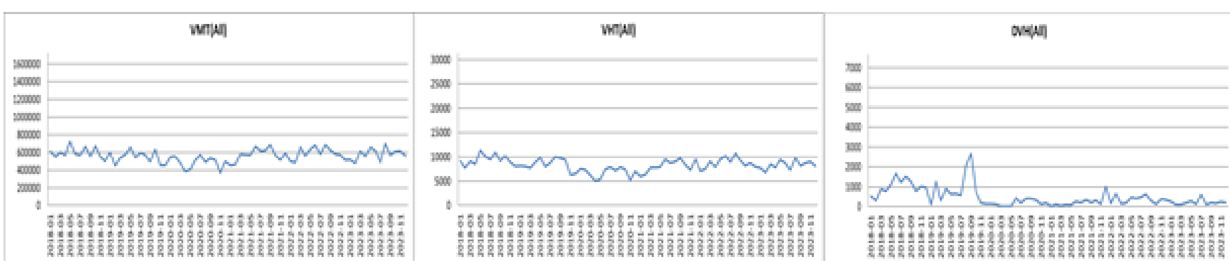
Work-Zone Effects

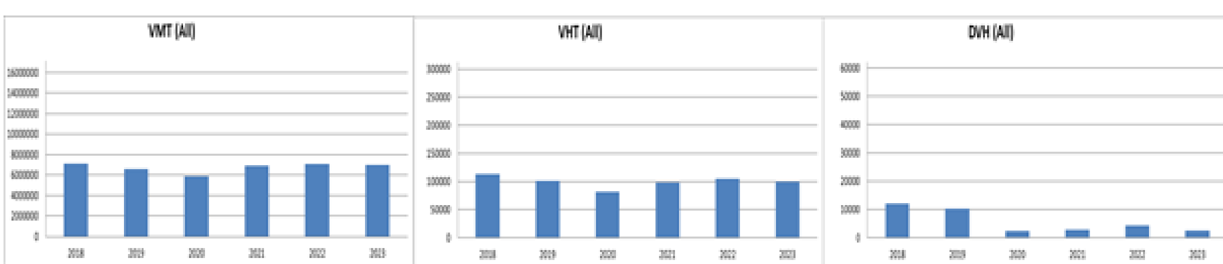


Yearly Variations of Buffer Index - Travel Rate Relationships

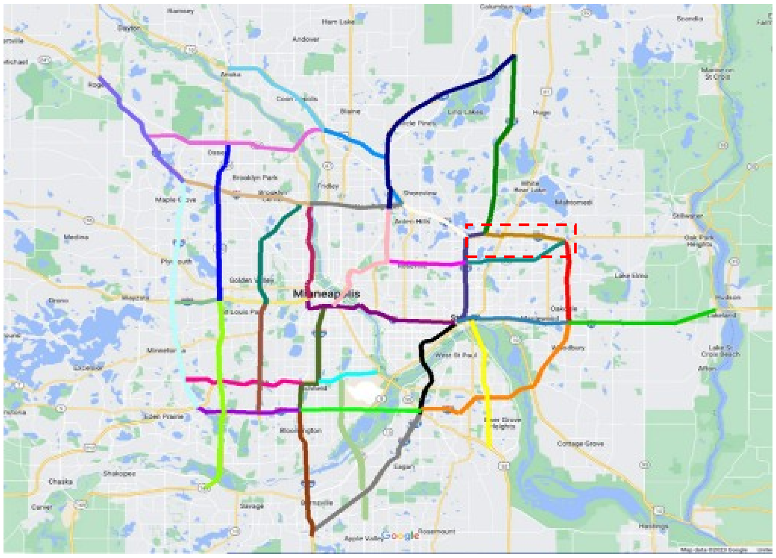


Variations of Traffic-Flow Measures



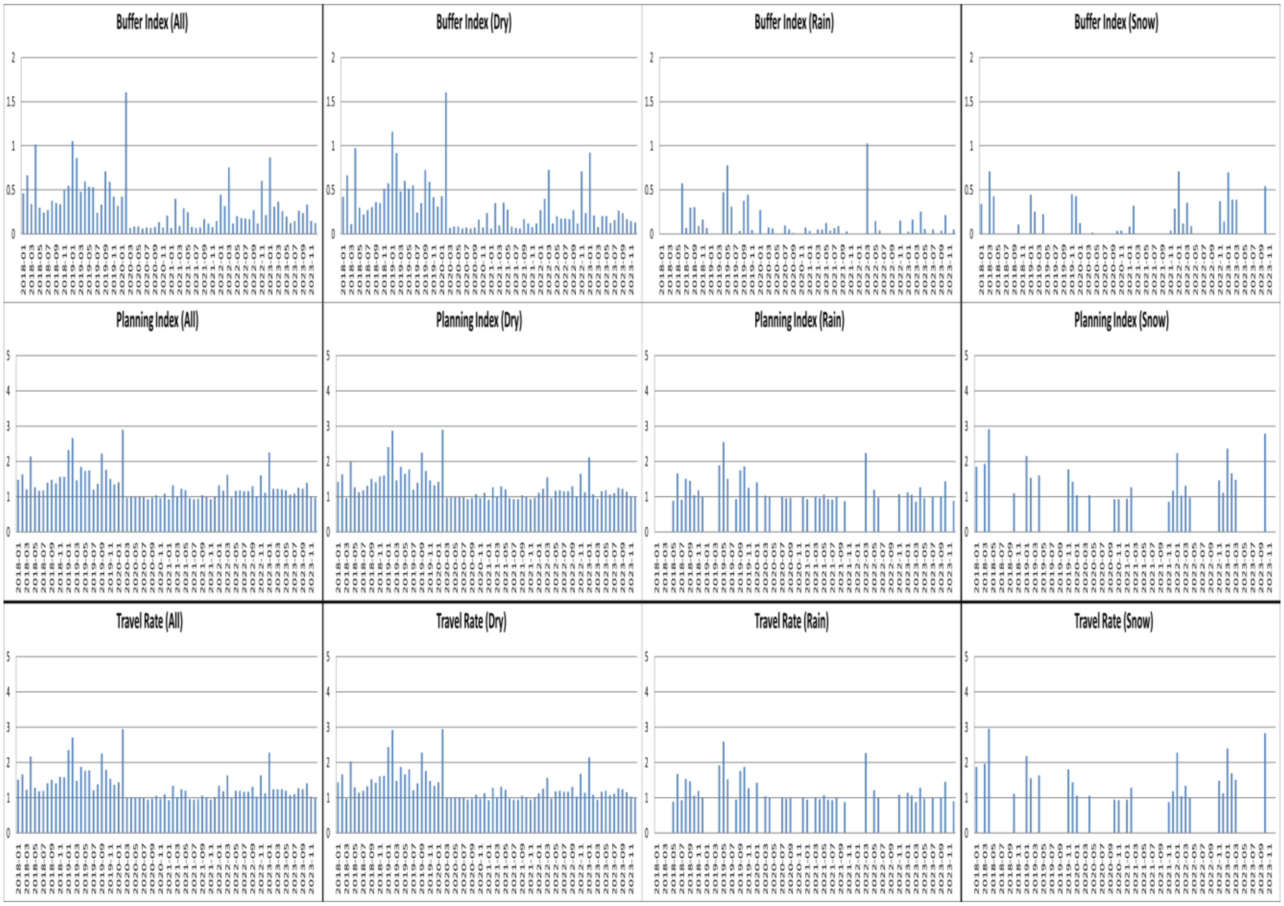


32) I-694 Corridor B (TH36 < -- > I-35E)

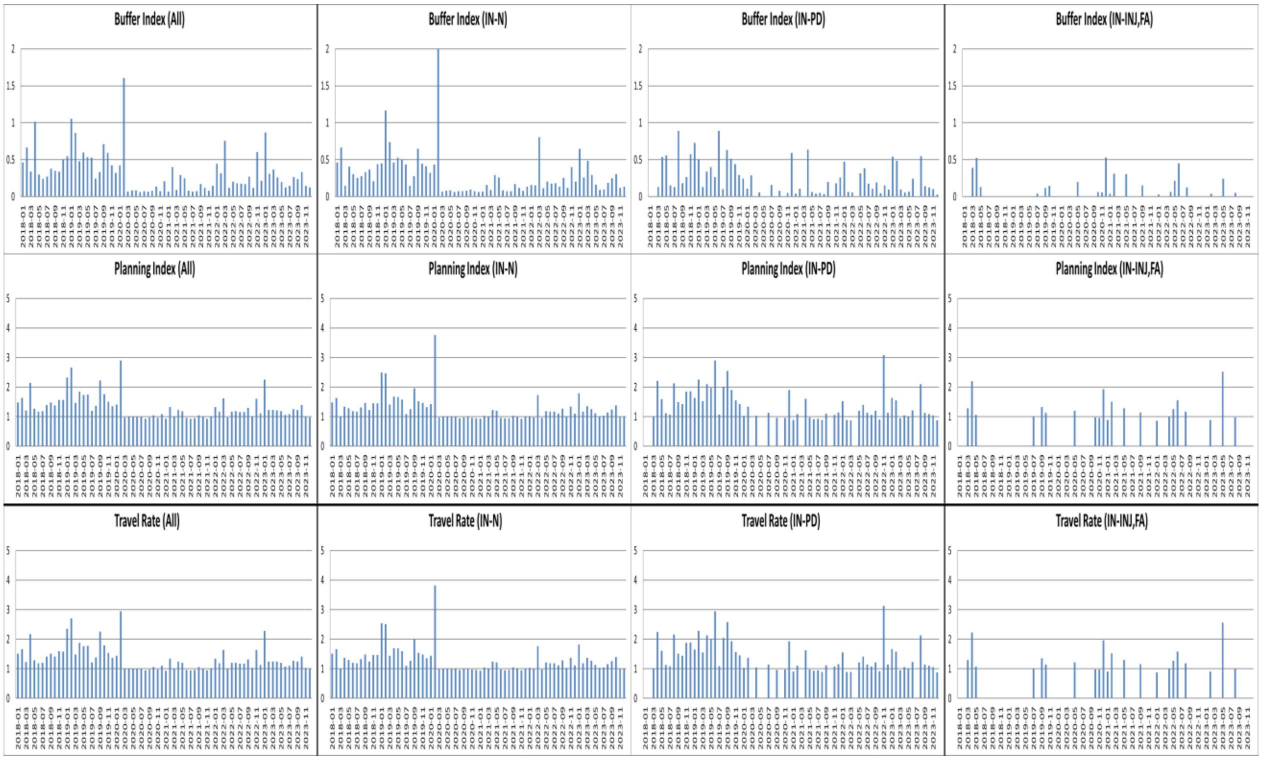


i) I-694 Corridor B -- WB TH36 to I-35E for Morning Peak Periods

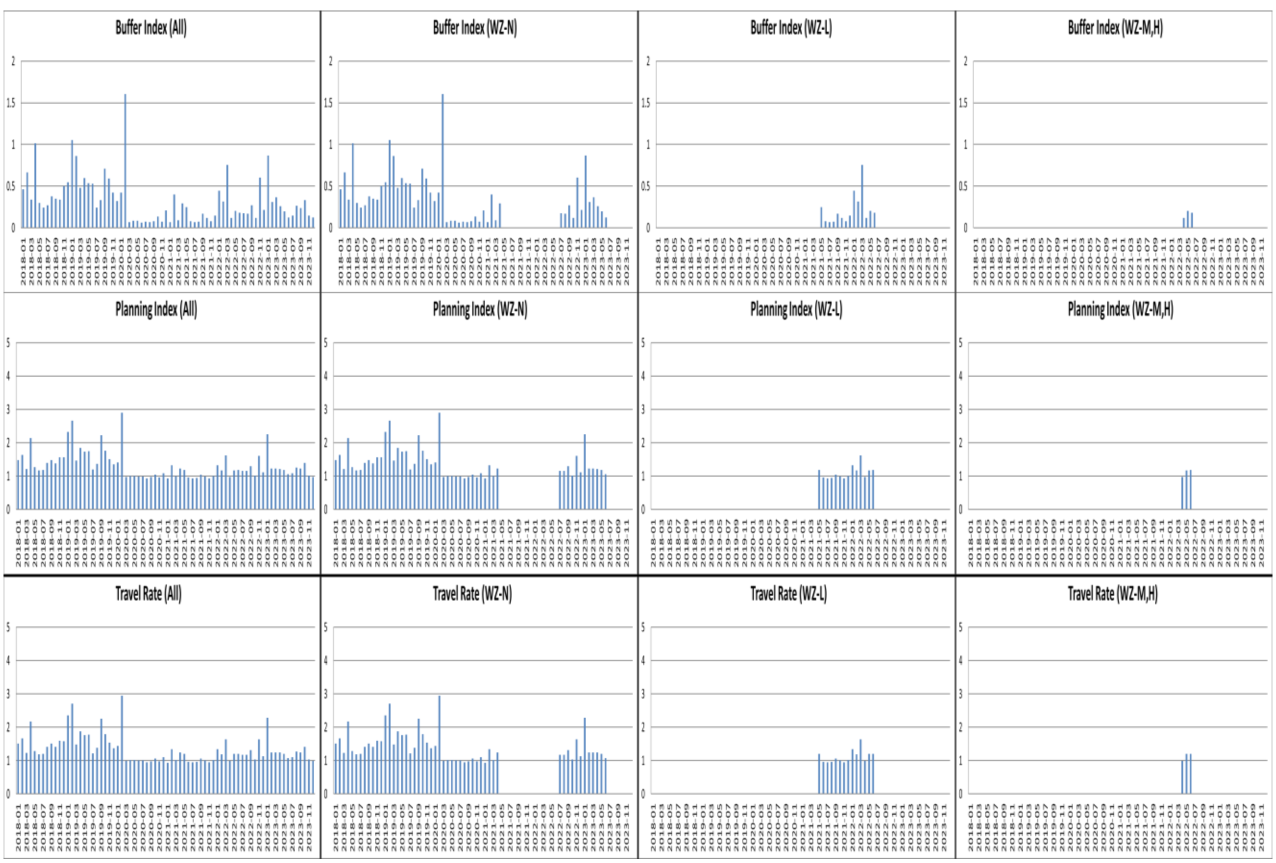
Effects of Weather conditions on Travel-Time Reliability



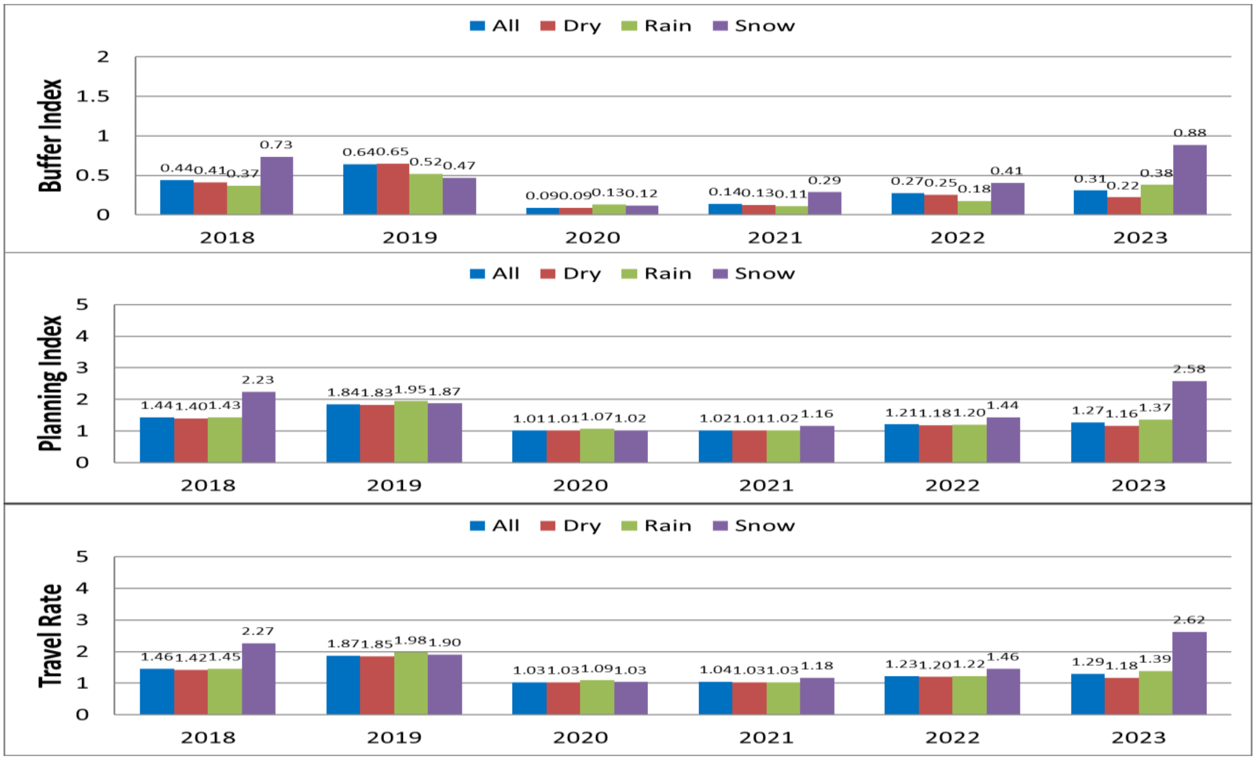
Effects of Incidents



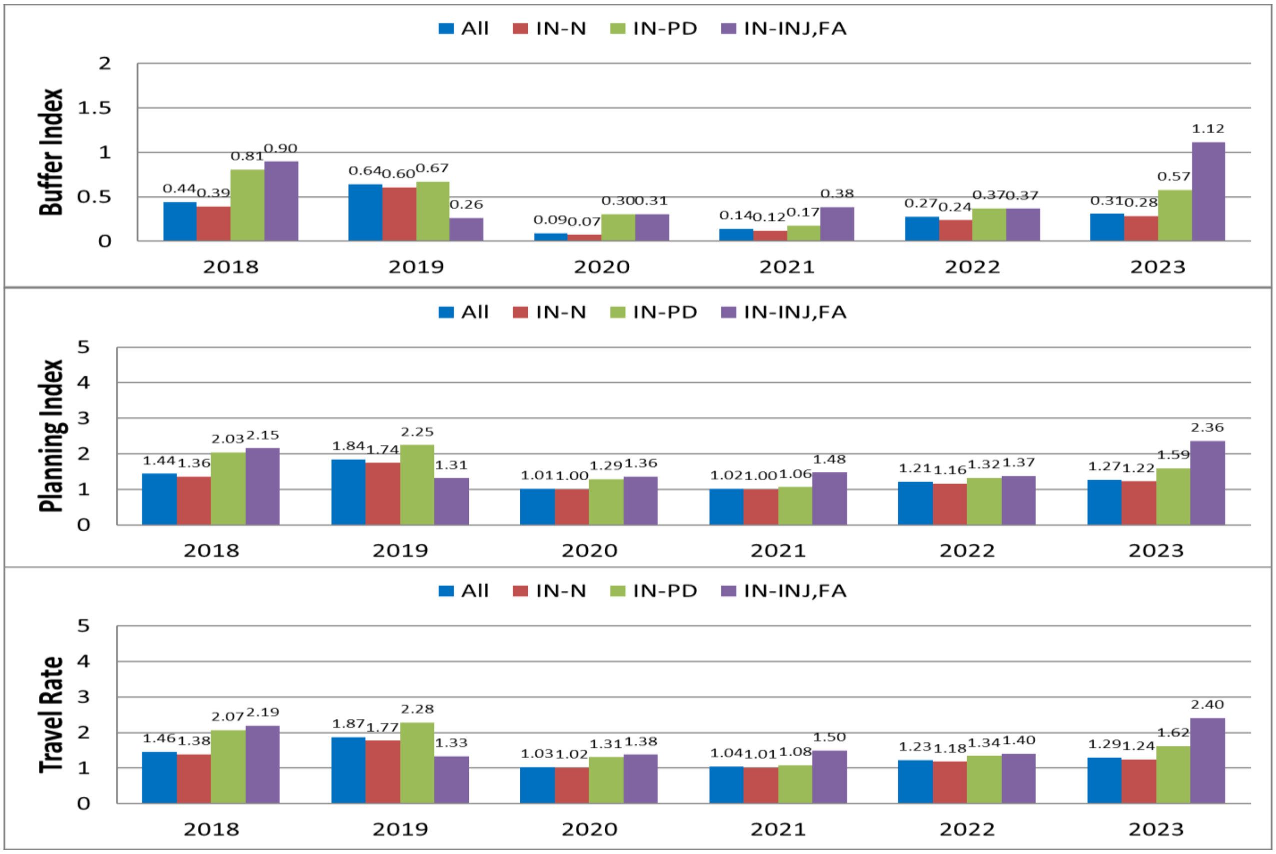
Effects of Work Zones



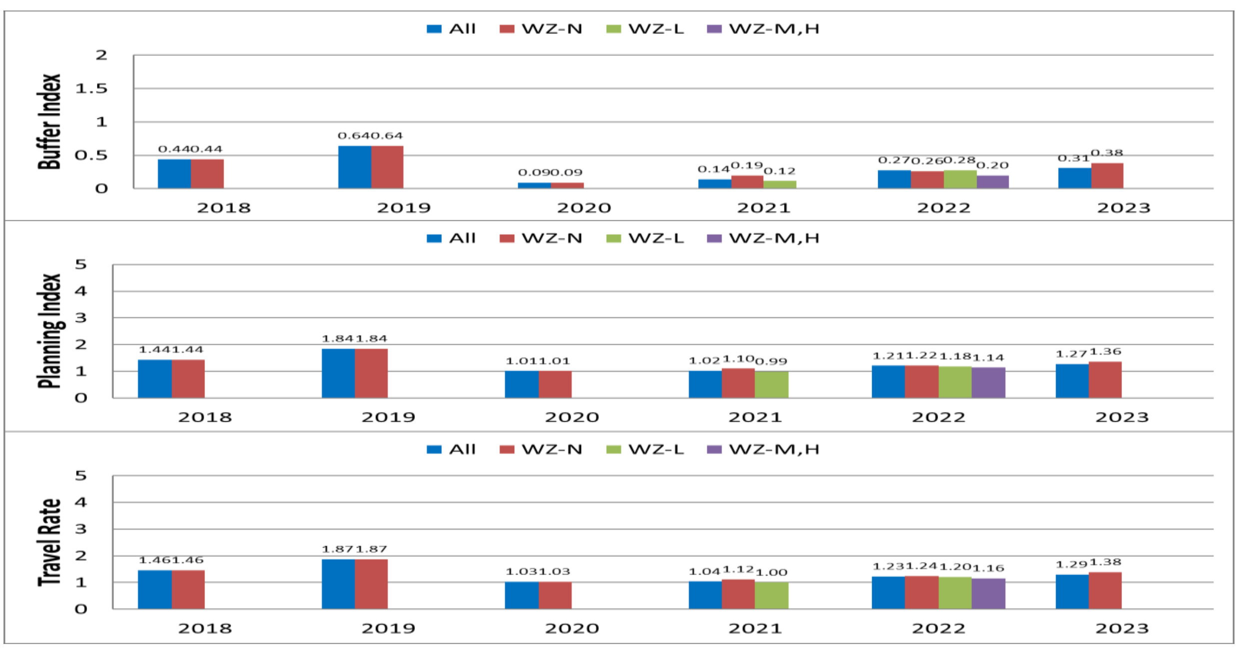
Yearly Variations - *Weather Effects*



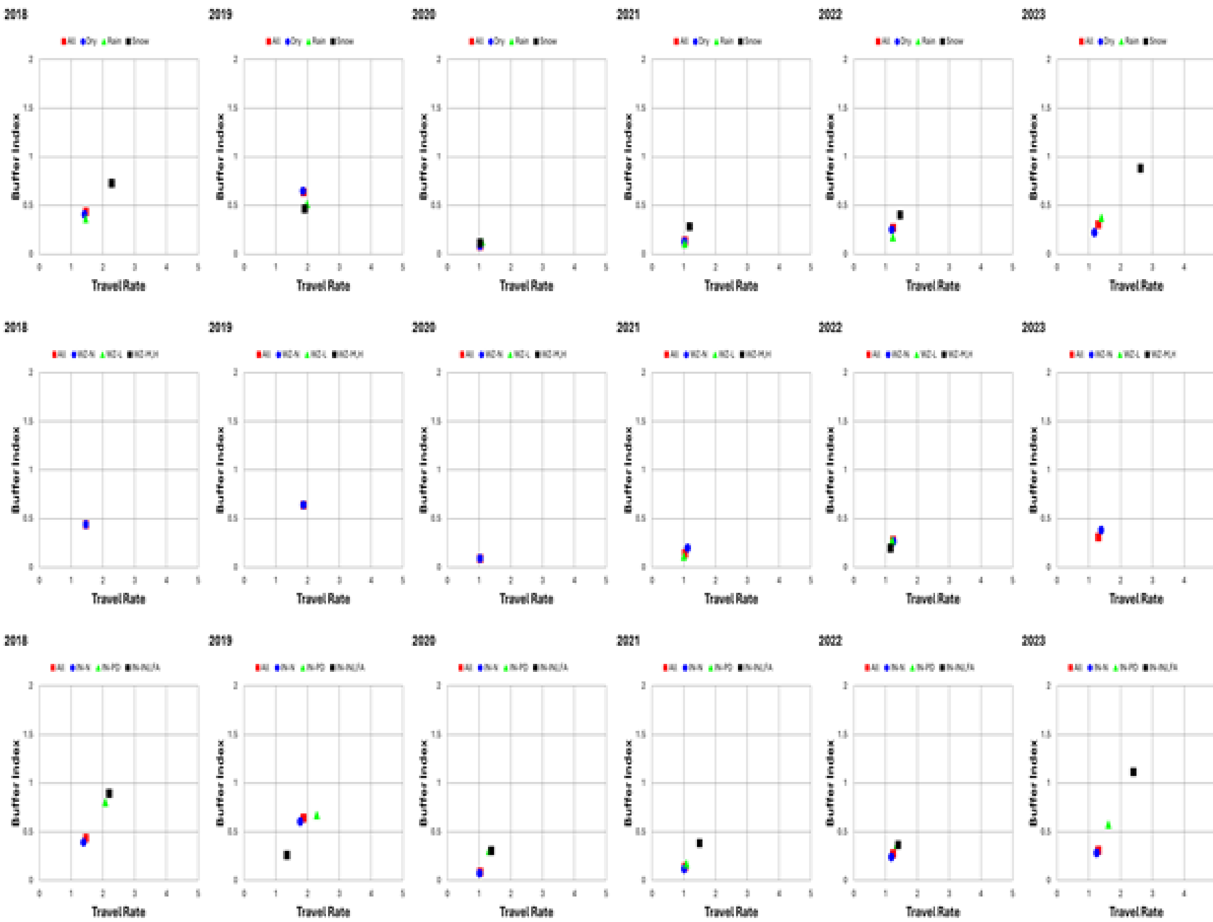
Incident Effects



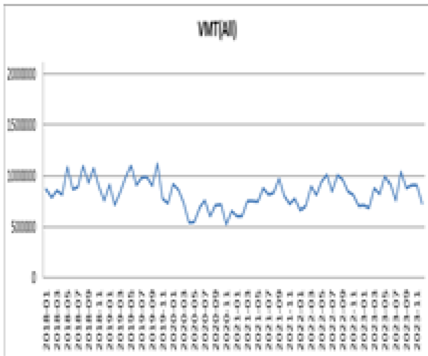
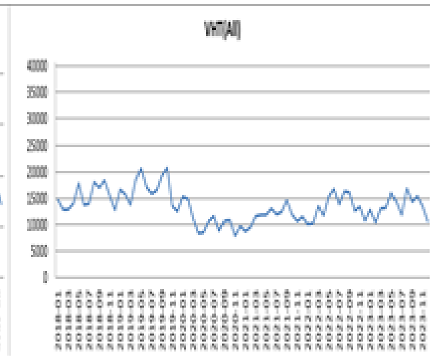
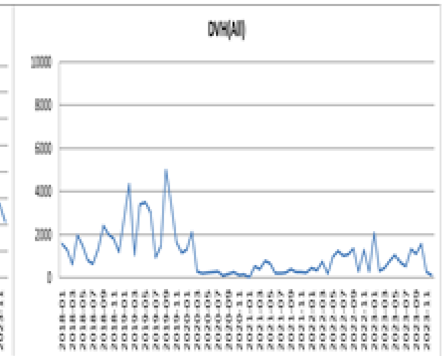
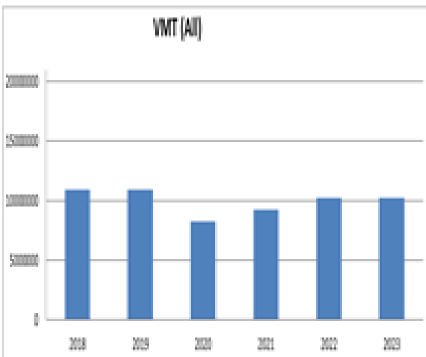
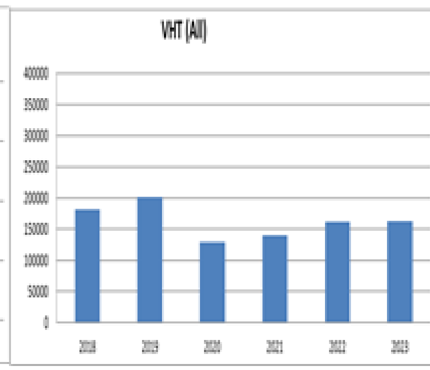
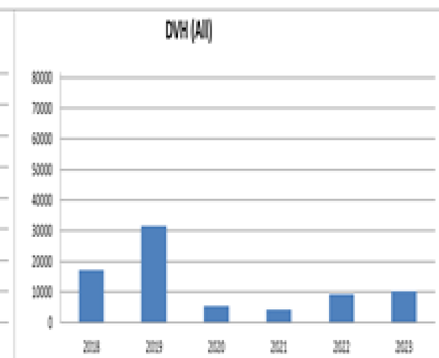
Work-Zone Effects



Yearly Variations of Buffer Index - Travel Rate Relationships



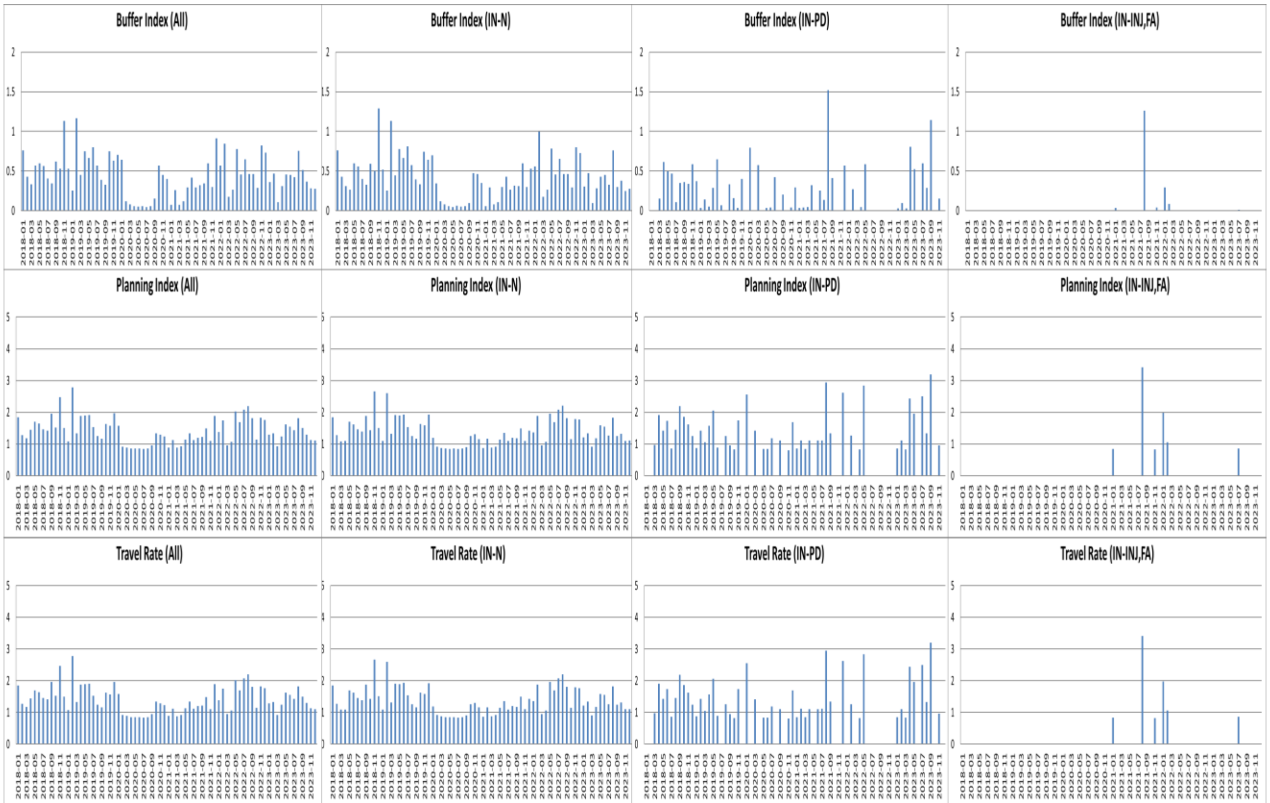
Variations of Traffic-Flow Measures


VMT(All)

VHT(All)

DVH(All)

VMT (All)

VHT (All)

DVH (All)

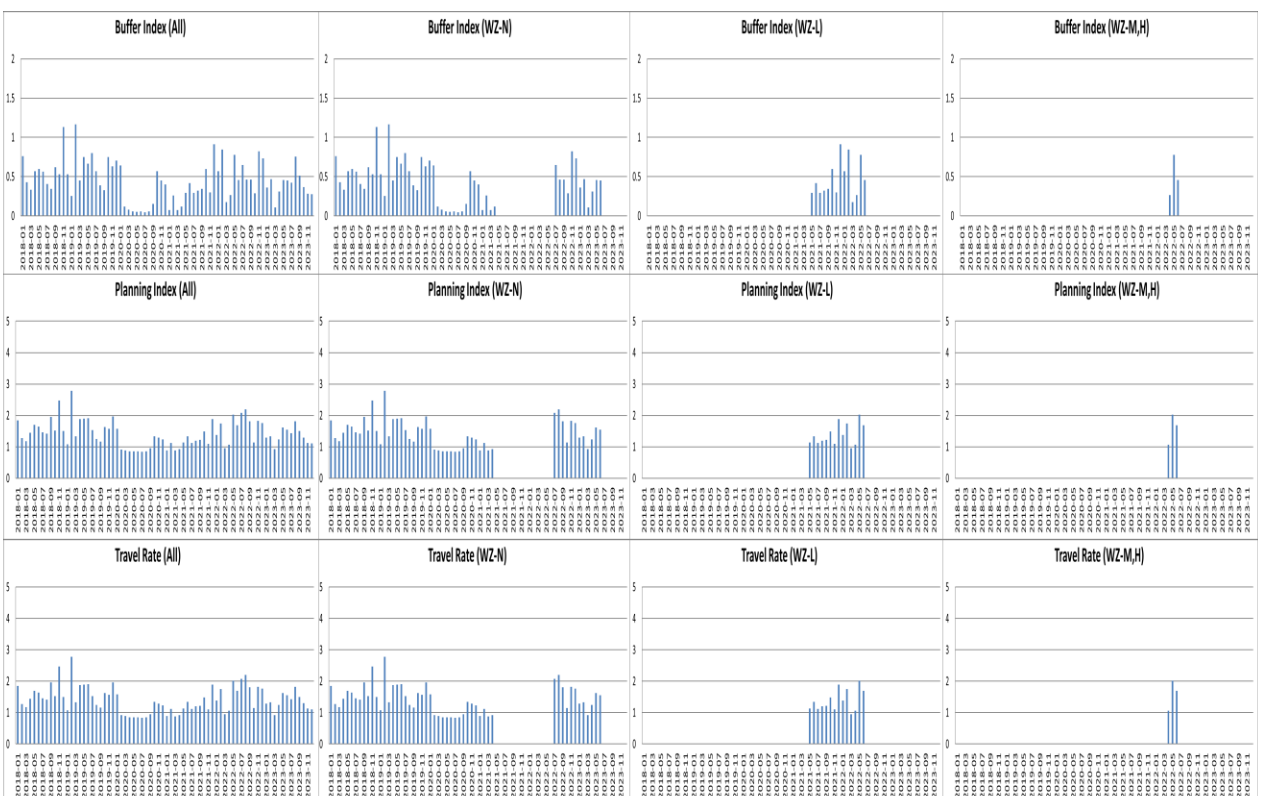
ii) I-694 Corridor B -- EB I35E to TH36 for Afternoon Peak Periods

Effects of Weather conditions on Travel-Time Reliability

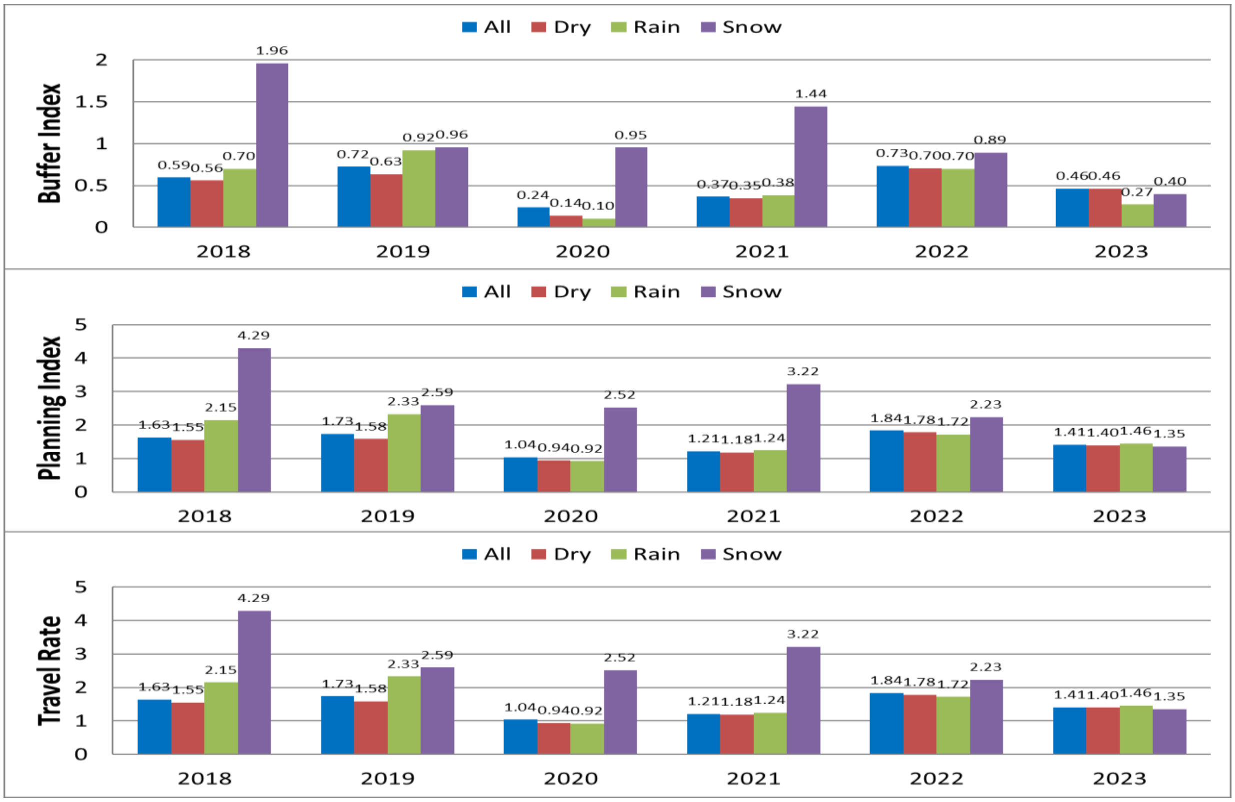
Effects of Incidents



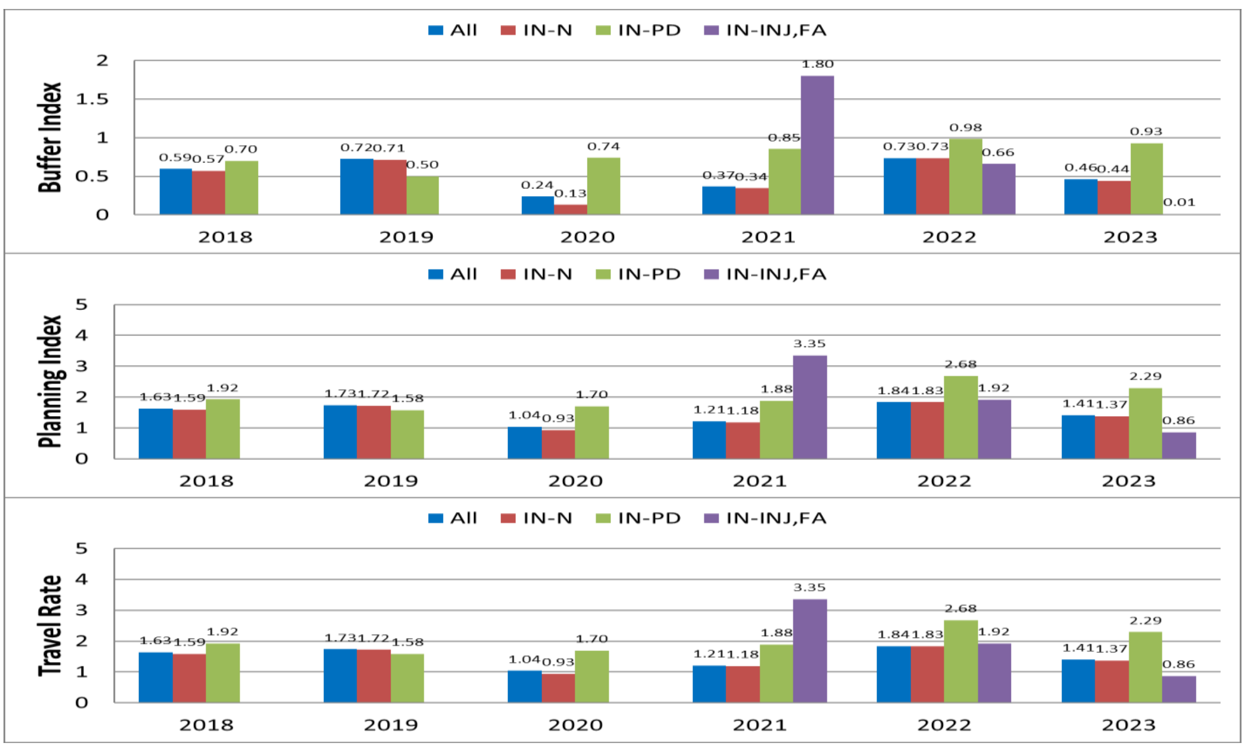
Effects of Work Zones



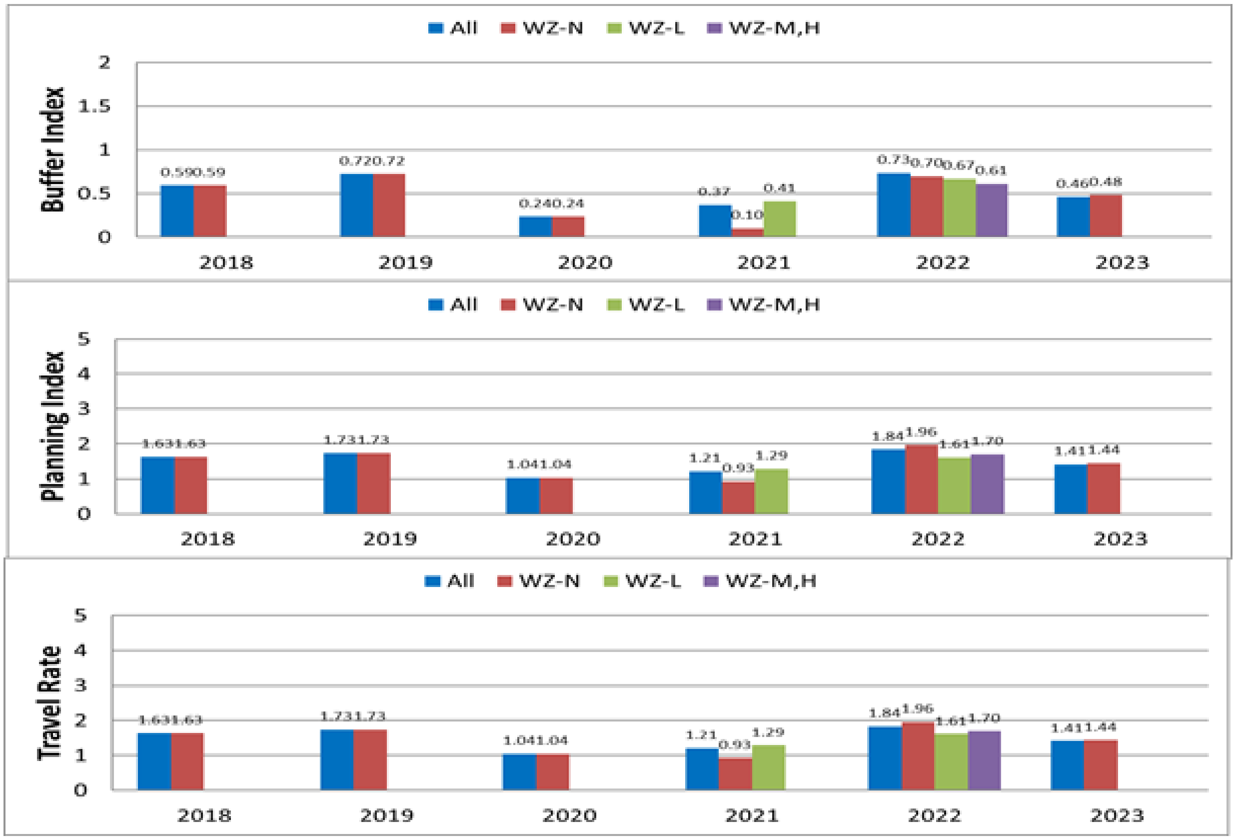
Yearly Variations - *Weather Effects*



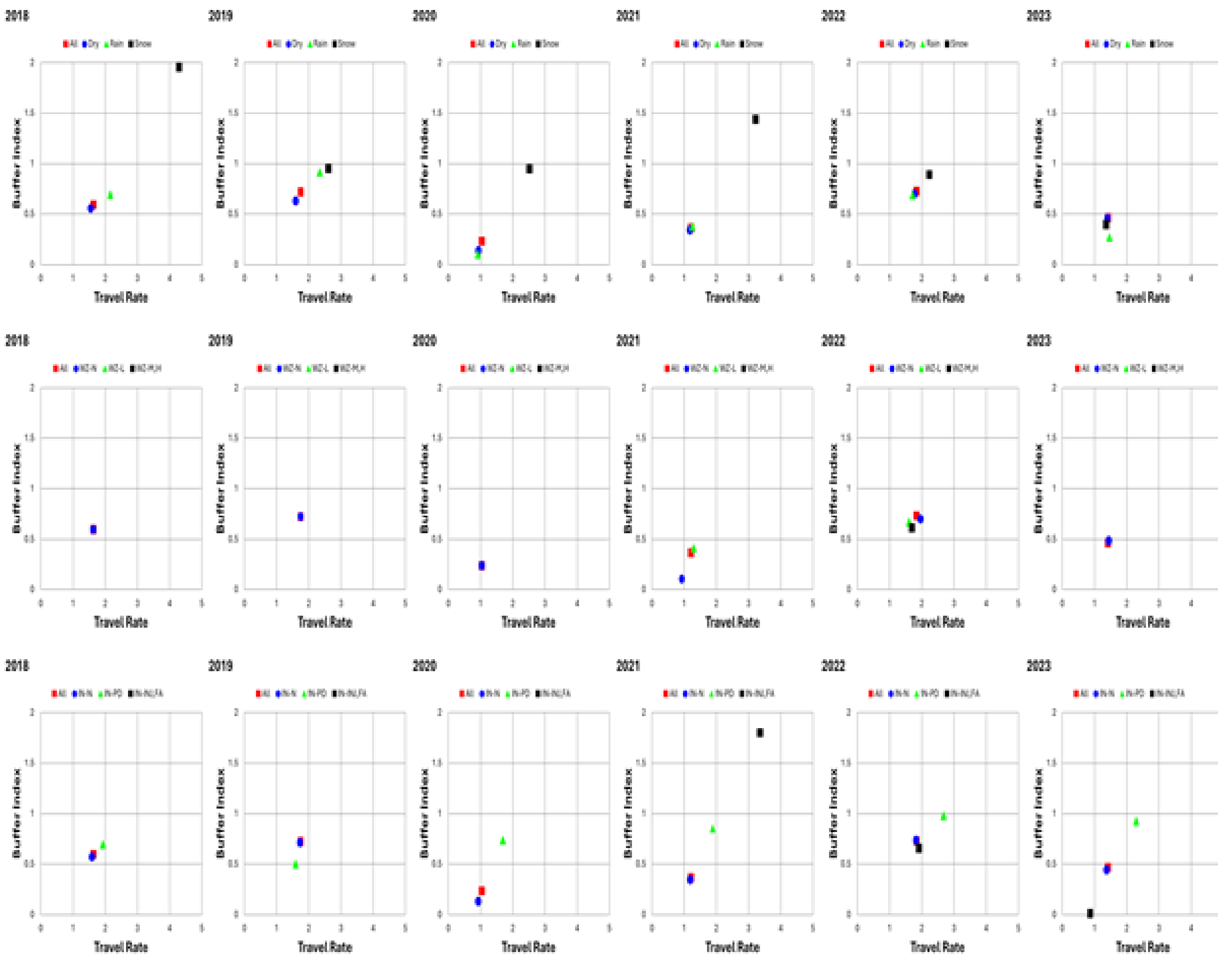
Incident Effects



Work-Zone Effects

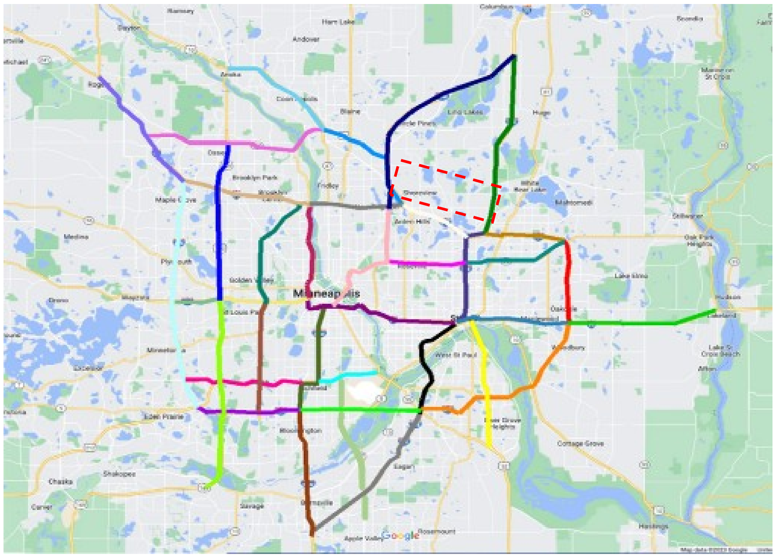


Yearly Variations of Buffer Index - Travel Rate Relationships



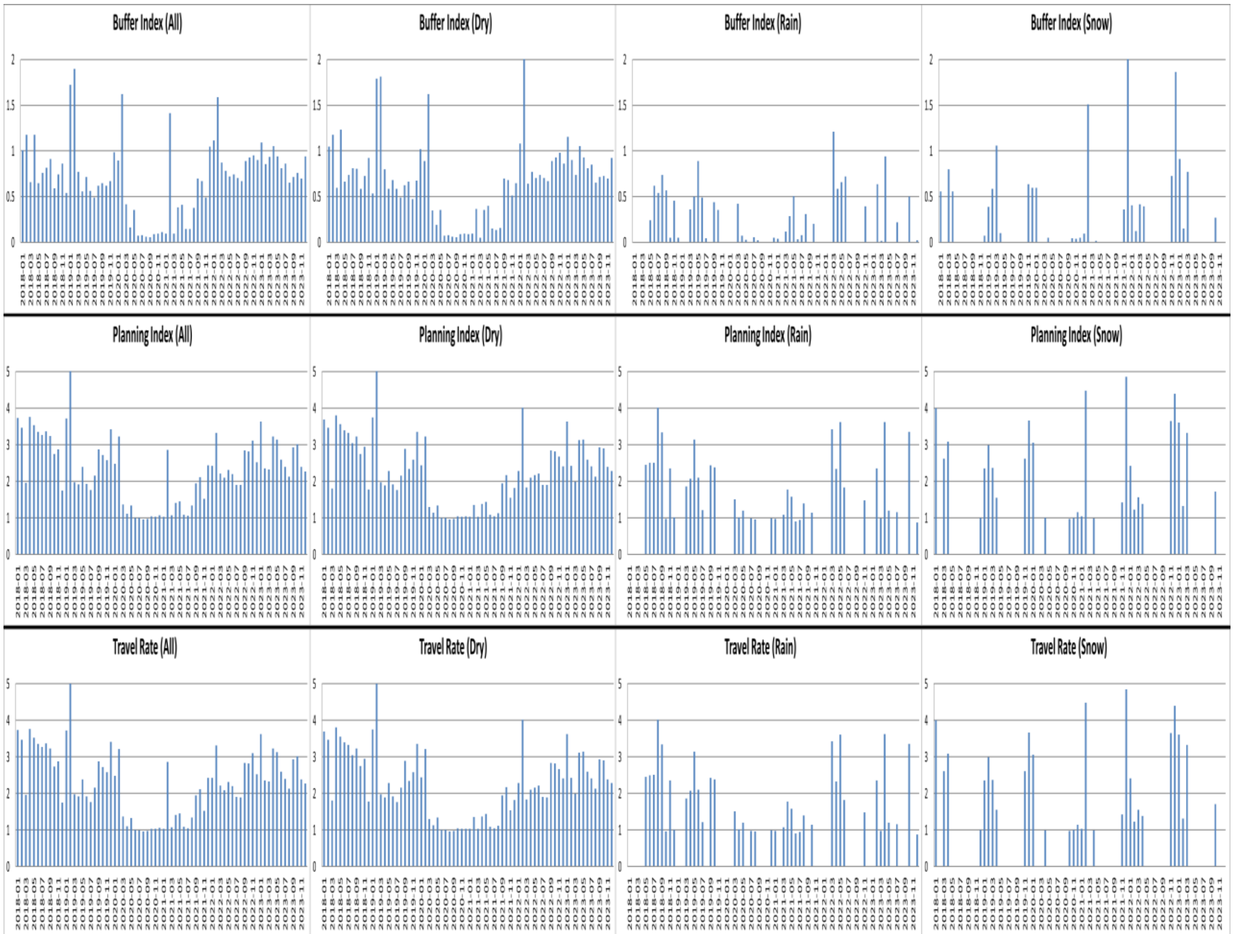
Variations of Traffic-Flow Measures

33) I-694 Corridor C (TH10 < -- > TH252)



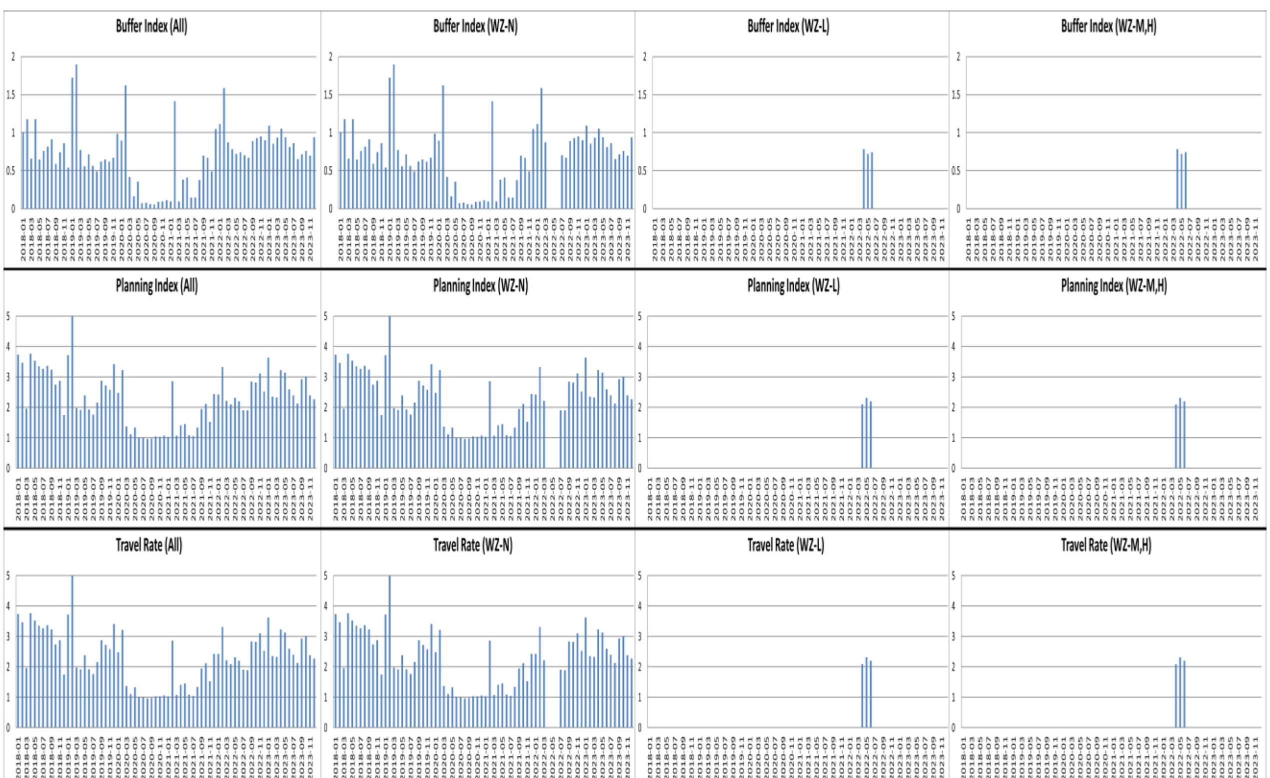
i) I-694 Corridor C -- WB TH 10 to TH252 for Morning Peak Periods

Effects of Weather conditions on Travel-Time Reliability

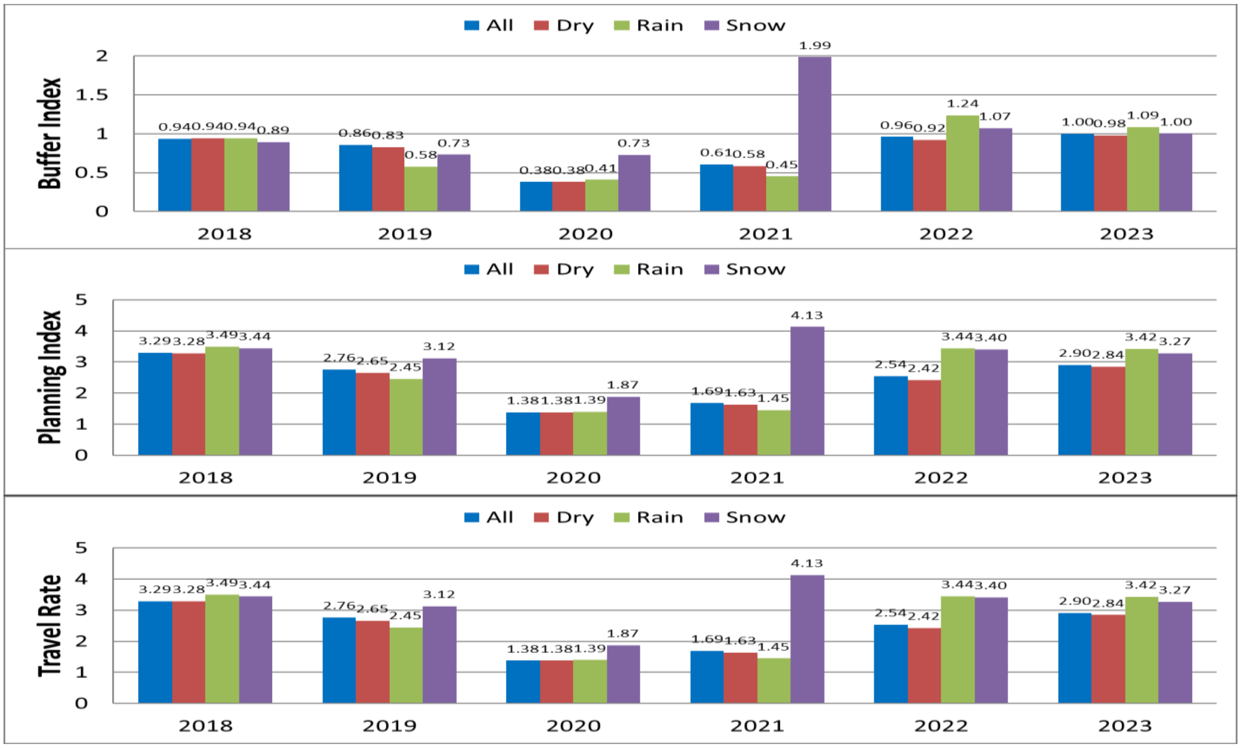


Effects of Incidents

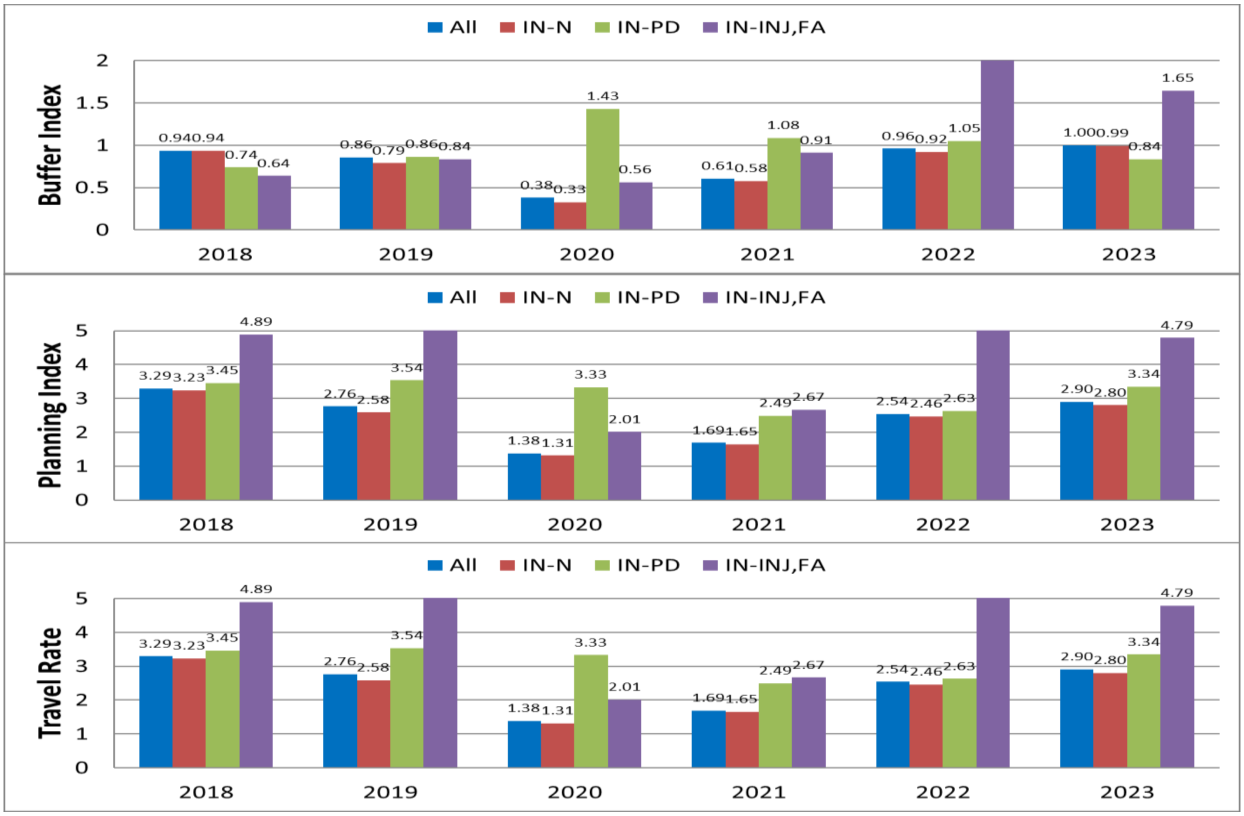
Effects of Work Zones



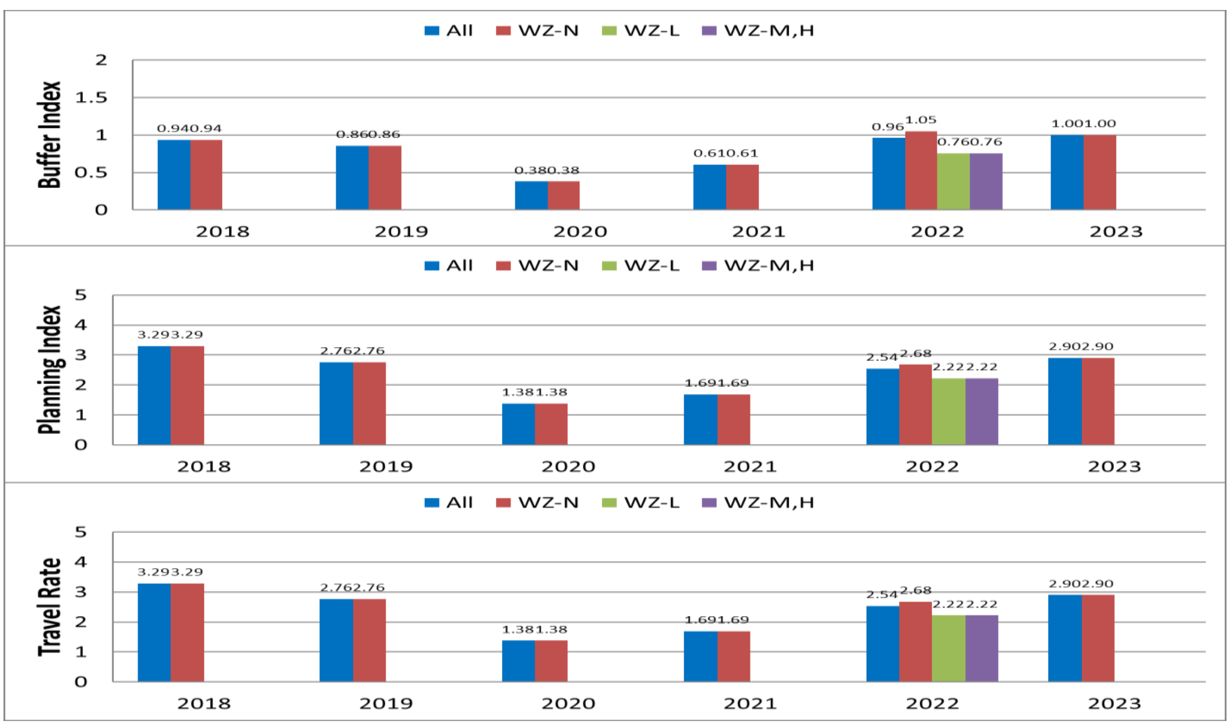
Yearly Variations - *Weather Effects*



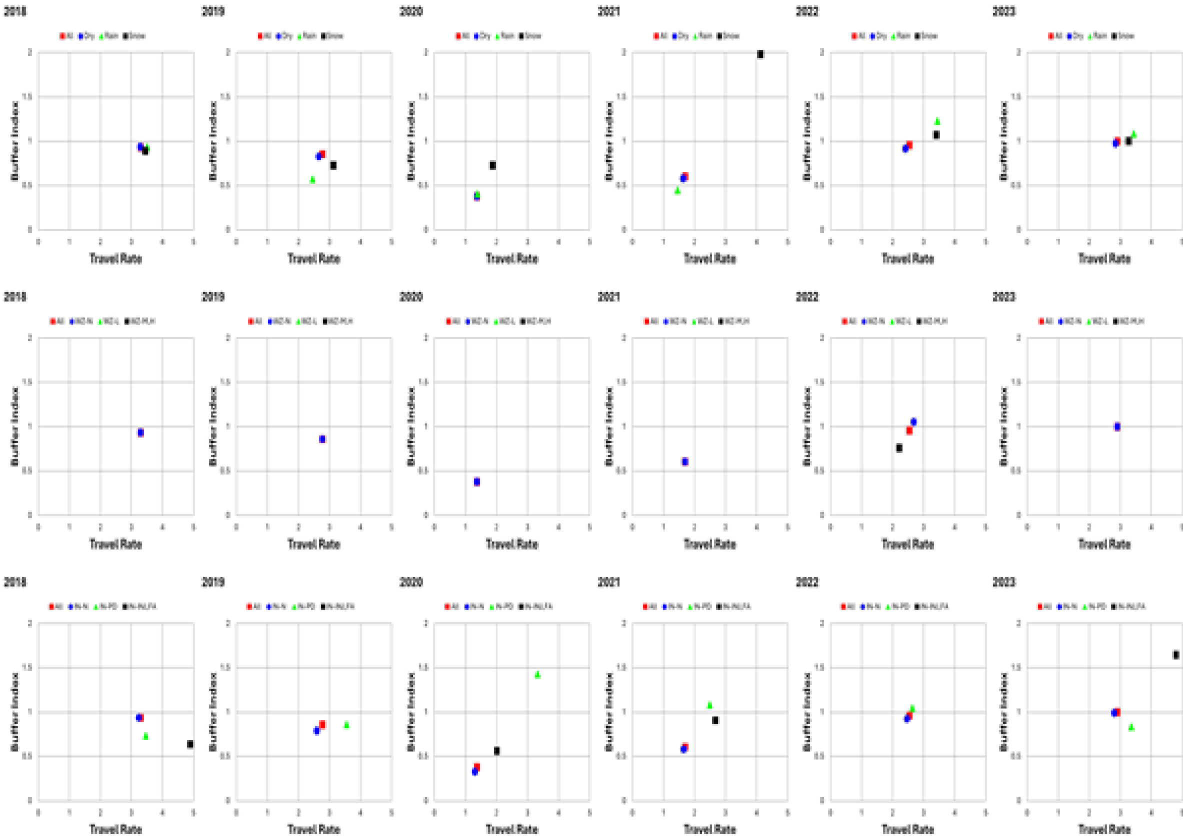
Incident Effects



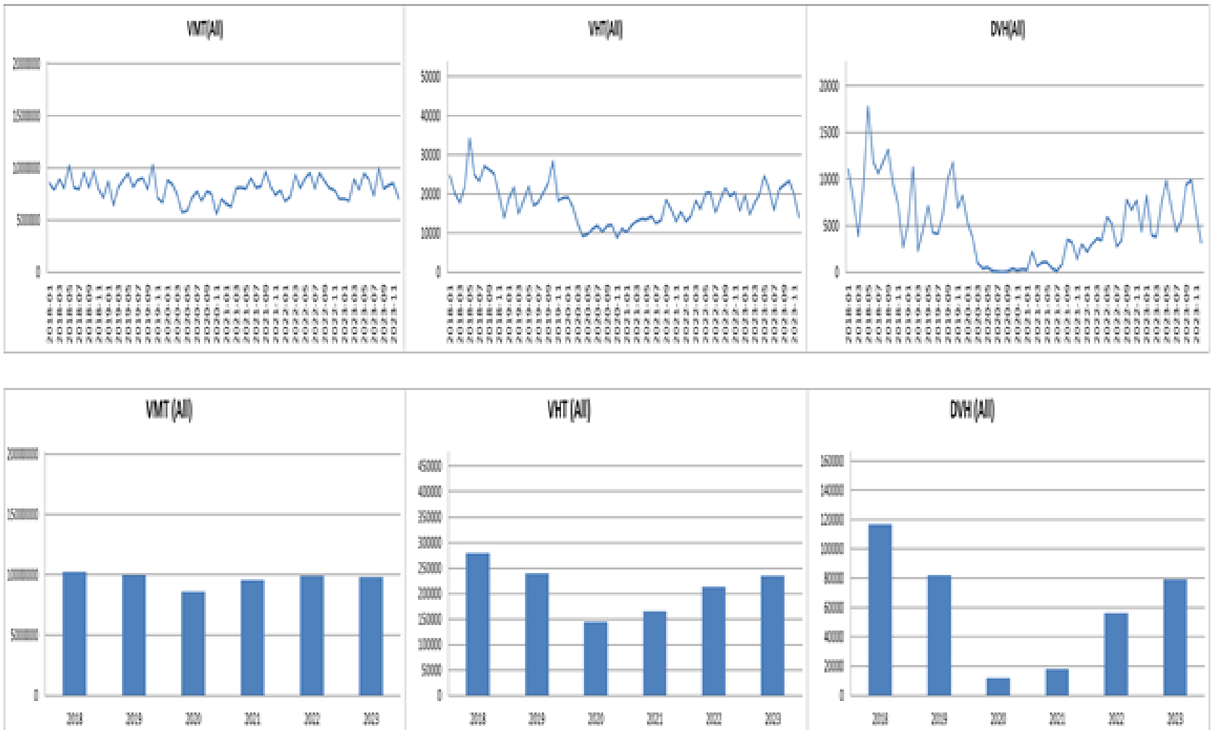
Work-Zone Effects



Yearly Variations of Buffer Index - Travel Rate Relationships

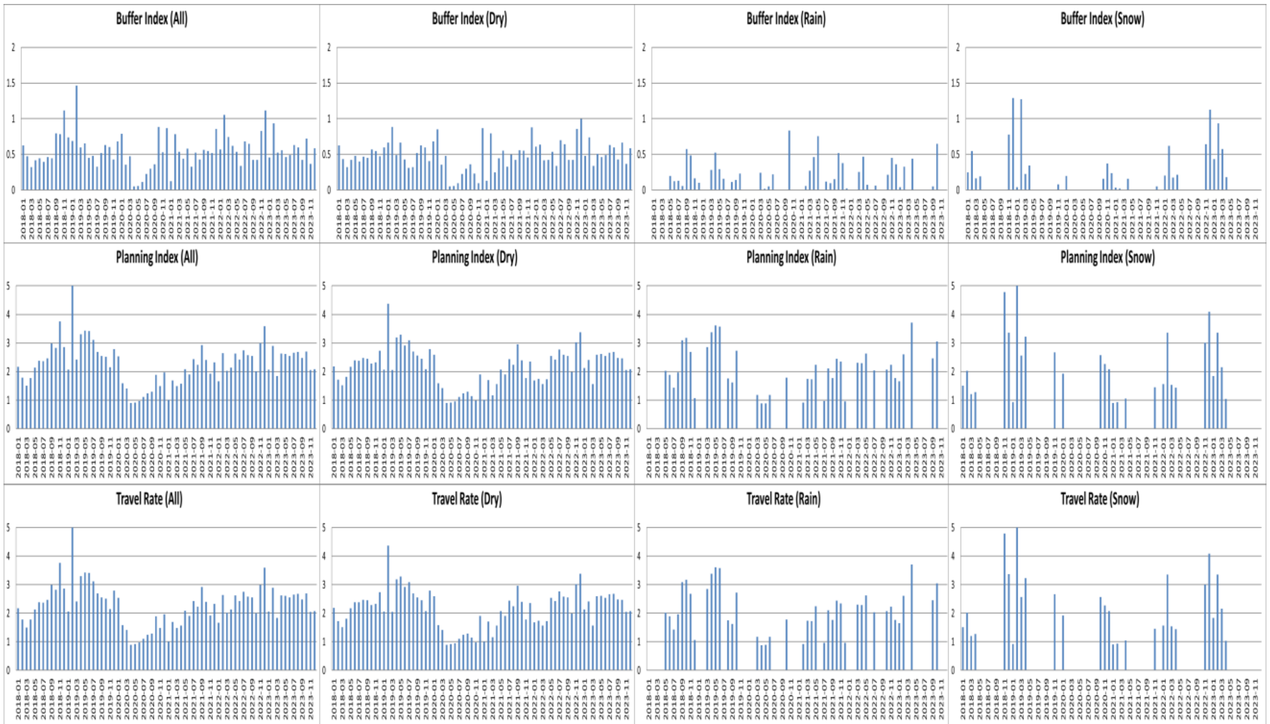


Variations of Traffic-Flow Measures

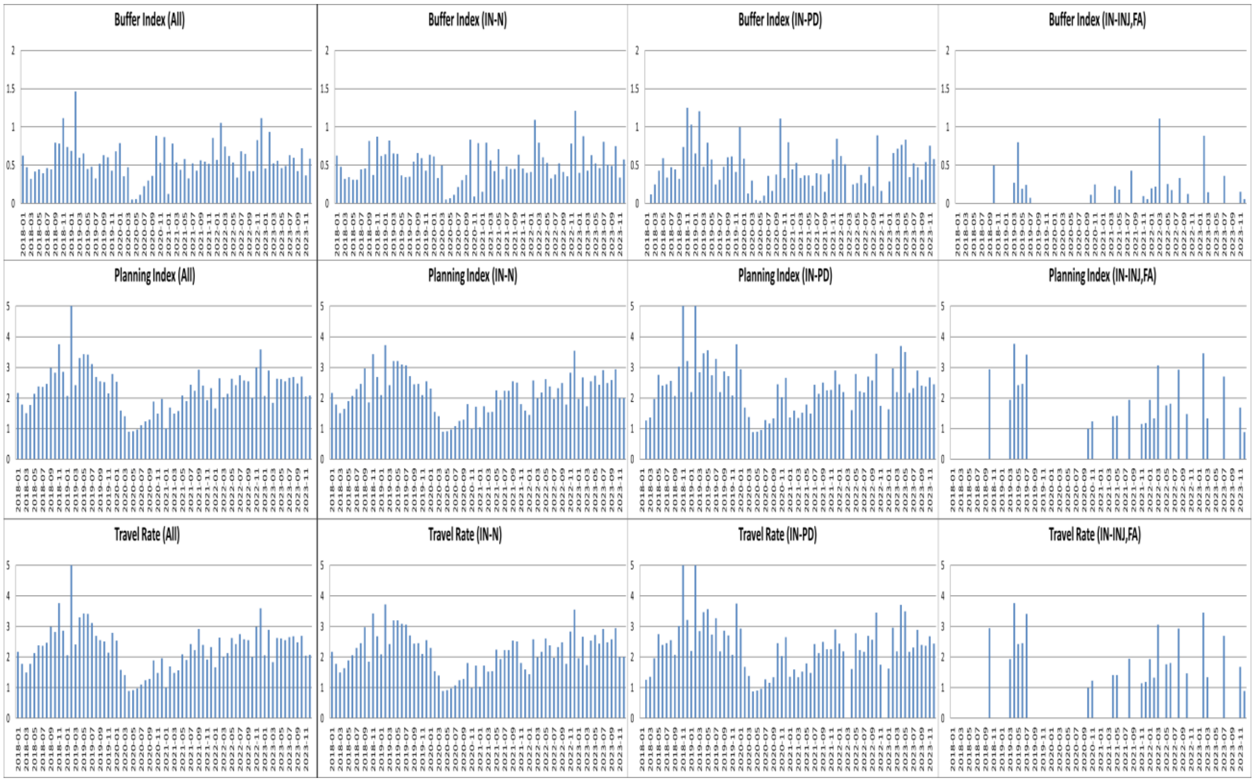

VMT(All)
VHT(All)
DVH(All)
VMT (All)
VHT (All)
DVH (All)
2018
2019
2020
2021
2022
2023

ii) I-694 Corridor C -- EB TH252 to TH 10 for Afternoon Peak Periods

Effects of Weather conditions on Travel-Time Reliability

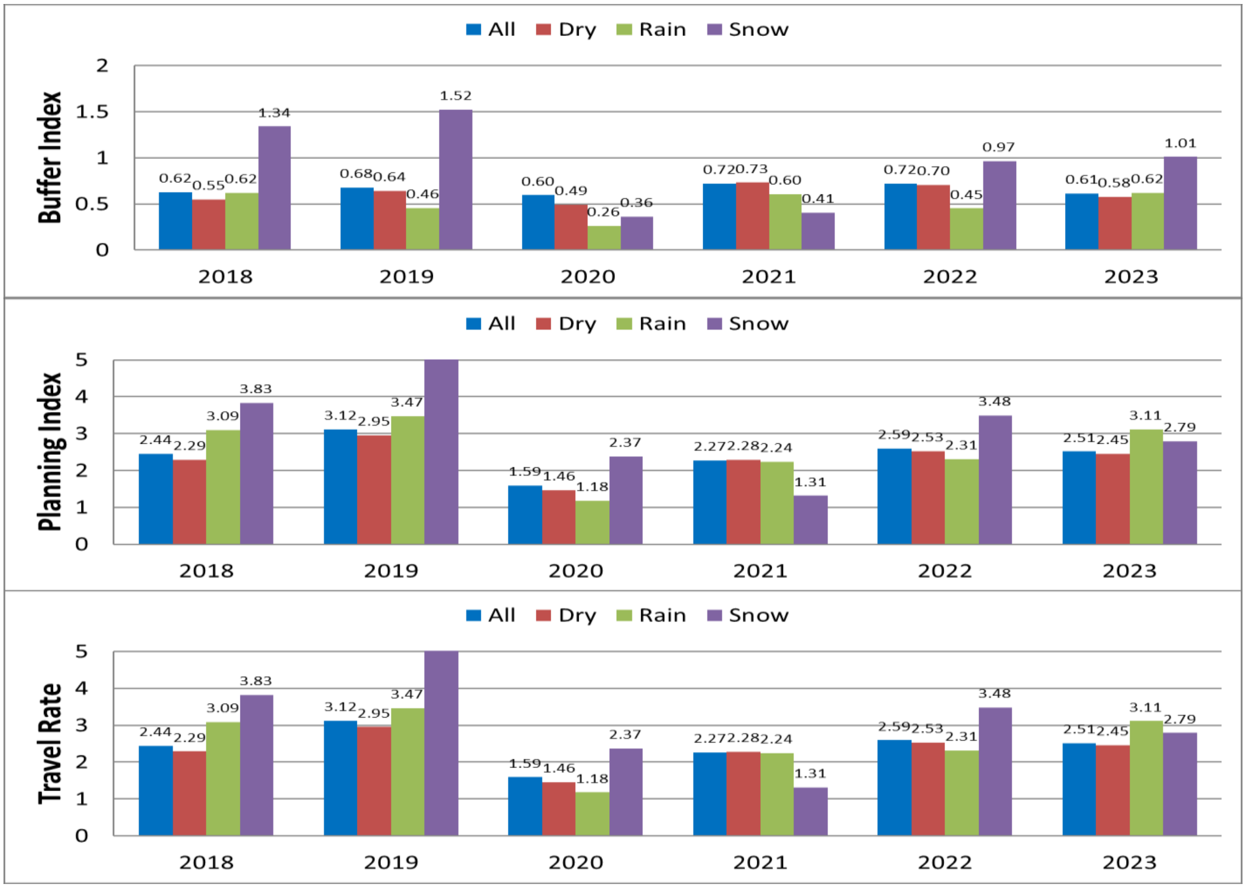


Effects of Incidents

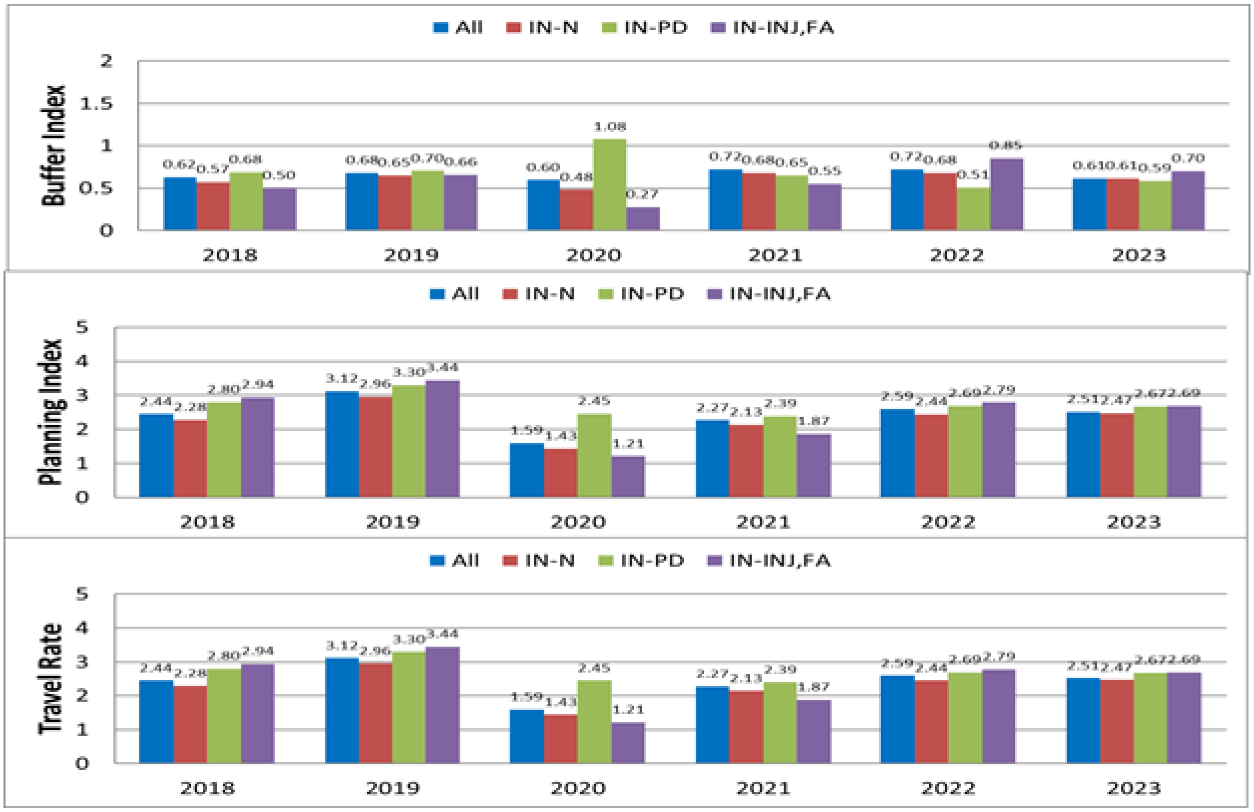


Effects of Work Zones

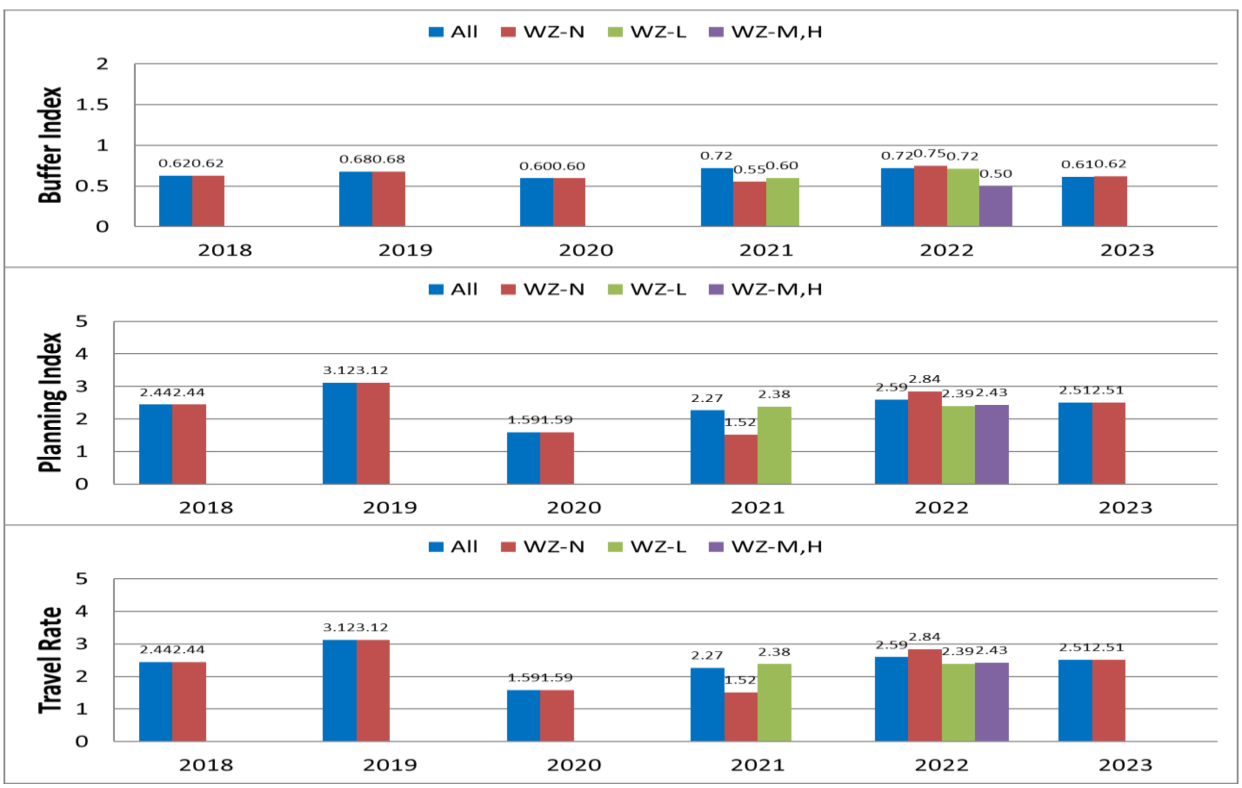
Yearly Variations - *Weather Effects*



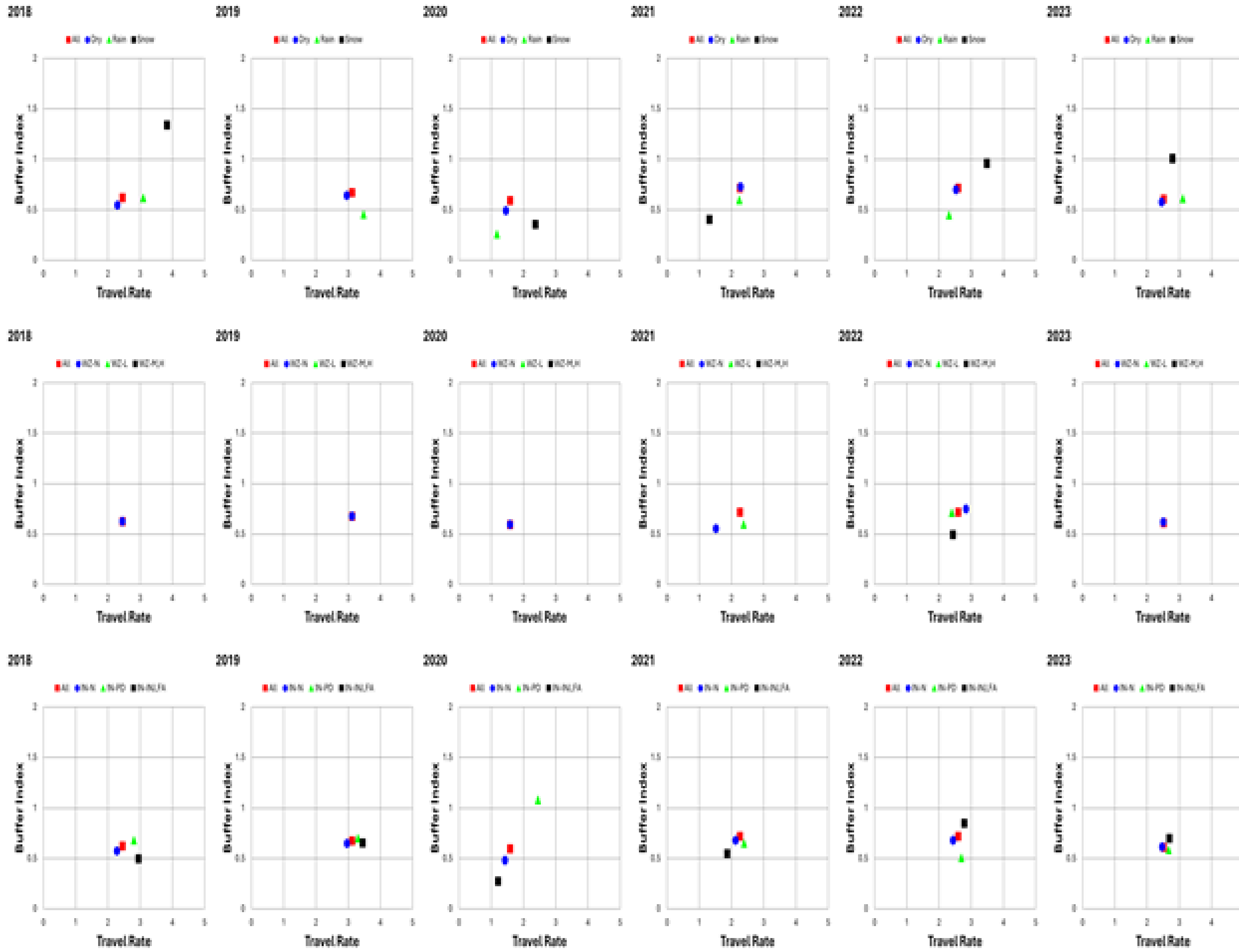
Incident Effects



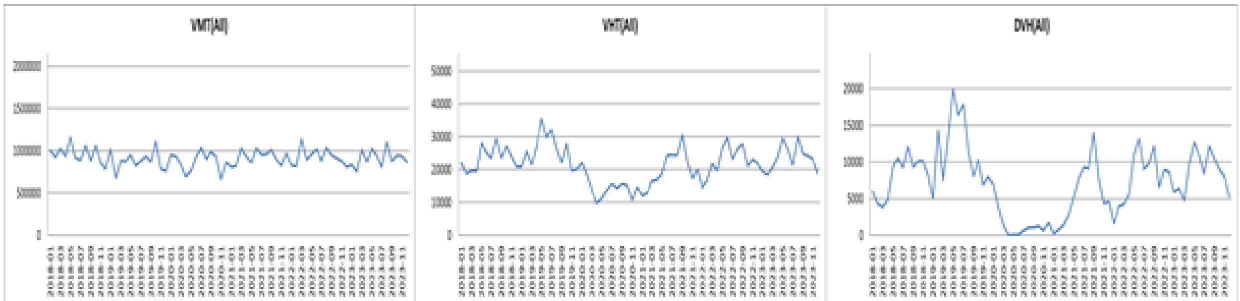
Work-Zone Effects

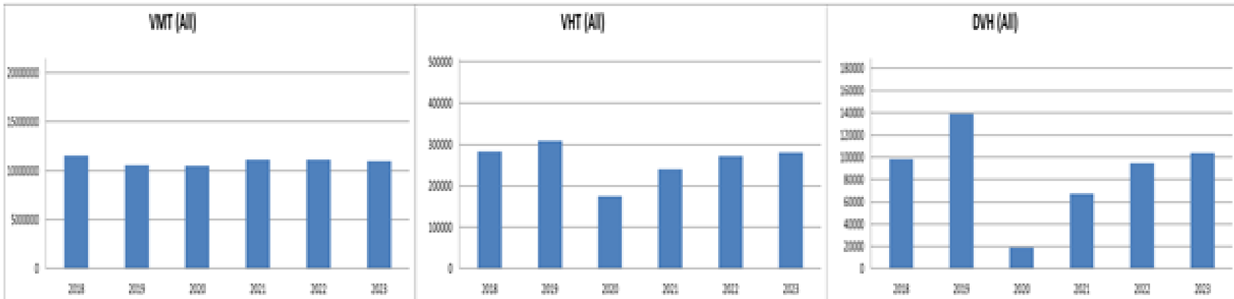


Yearly Variations of Buffer Index - Travel Rate Relationships

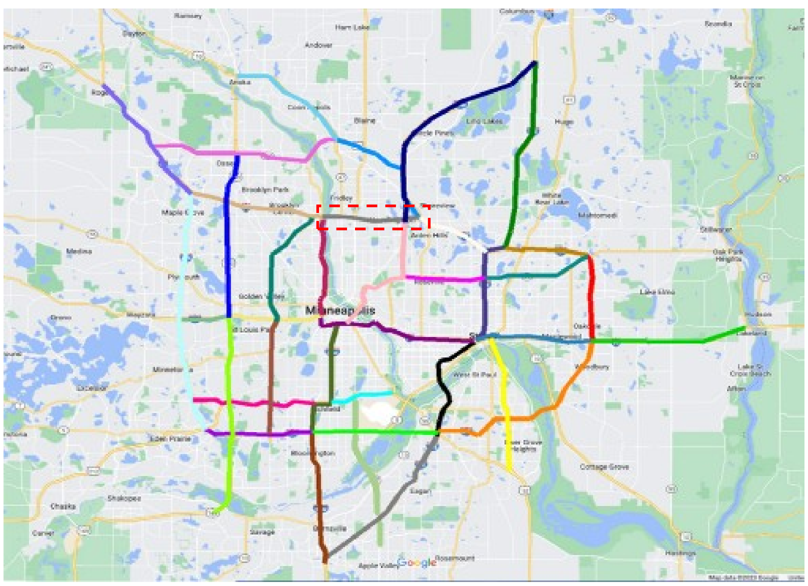


Variations of Traffic-Flow Measures



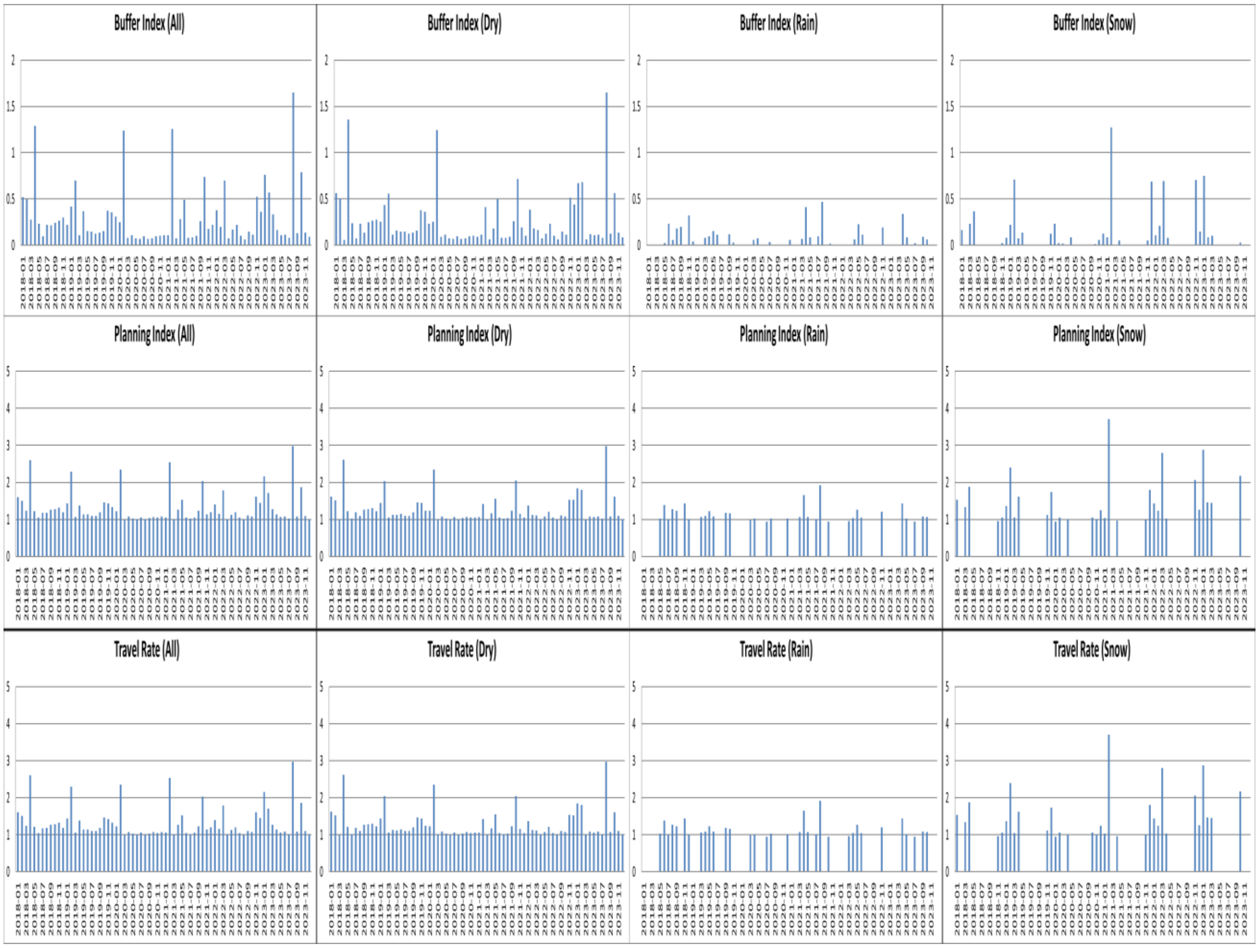


34) I-694 Corridor D (TH10 < -- > I35E)

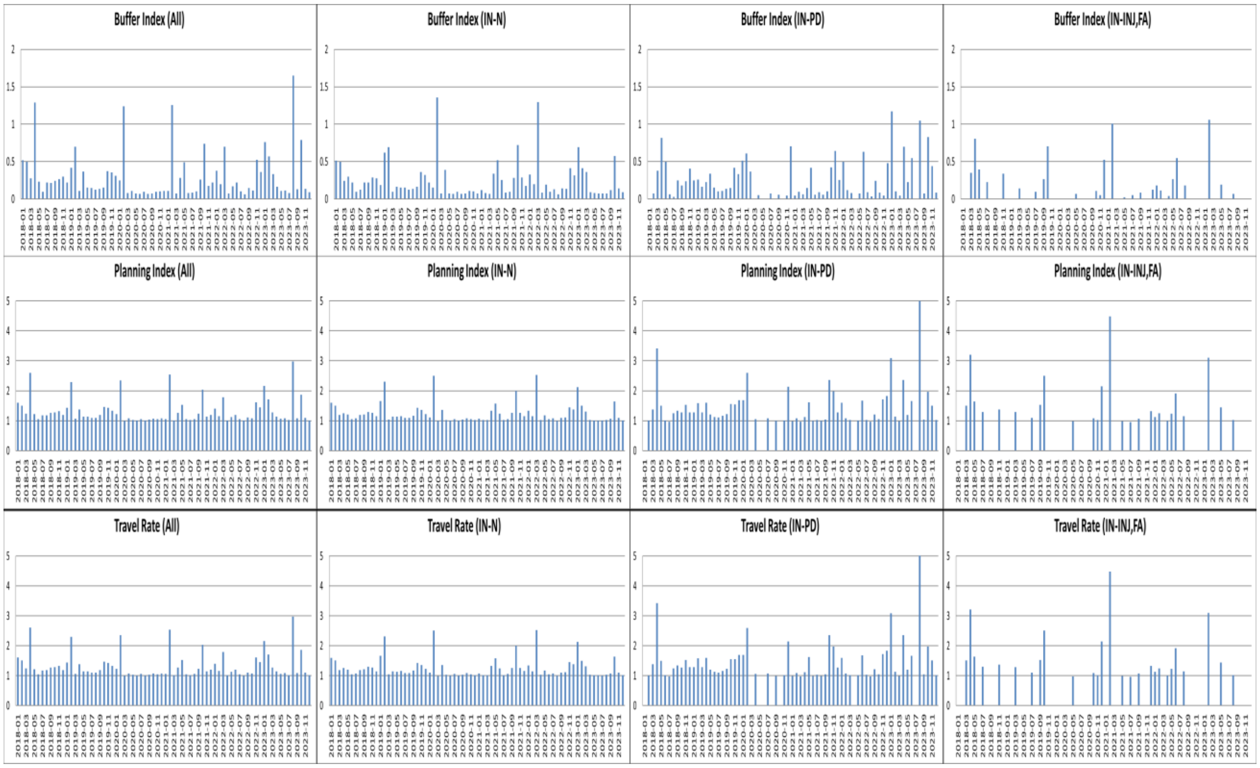


i) I-694 Corridor D -- WB I35E to TH10 for Morning Peak Periods

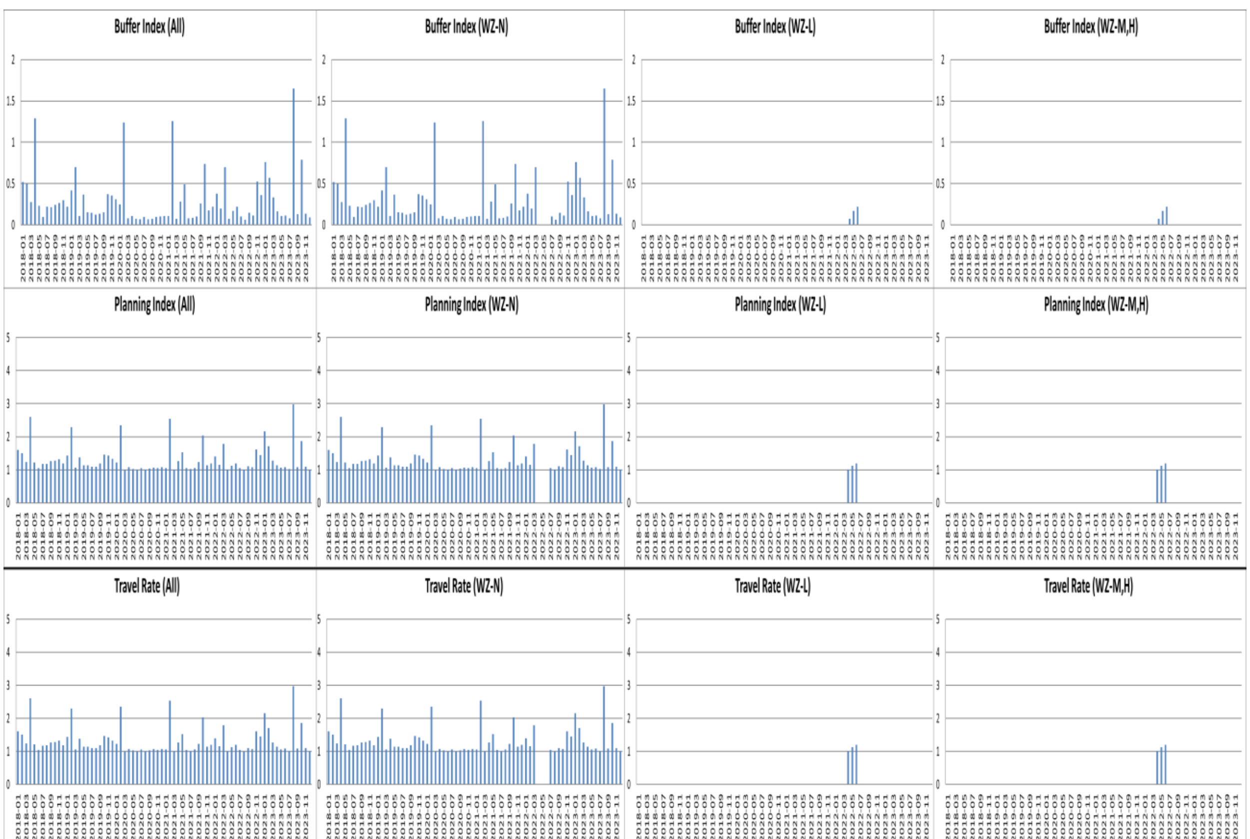
Effects of Weather conditions on Travel-Time Reliability



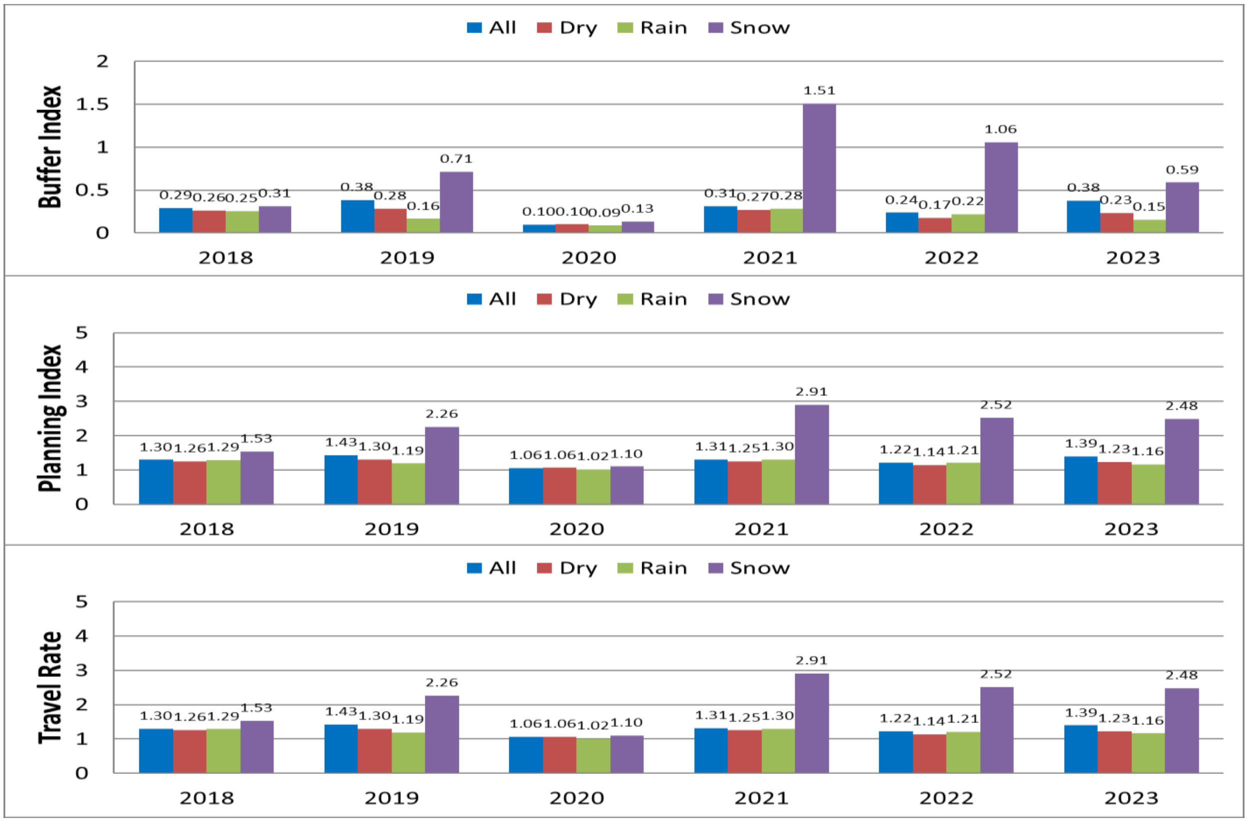
Effects of Incidents



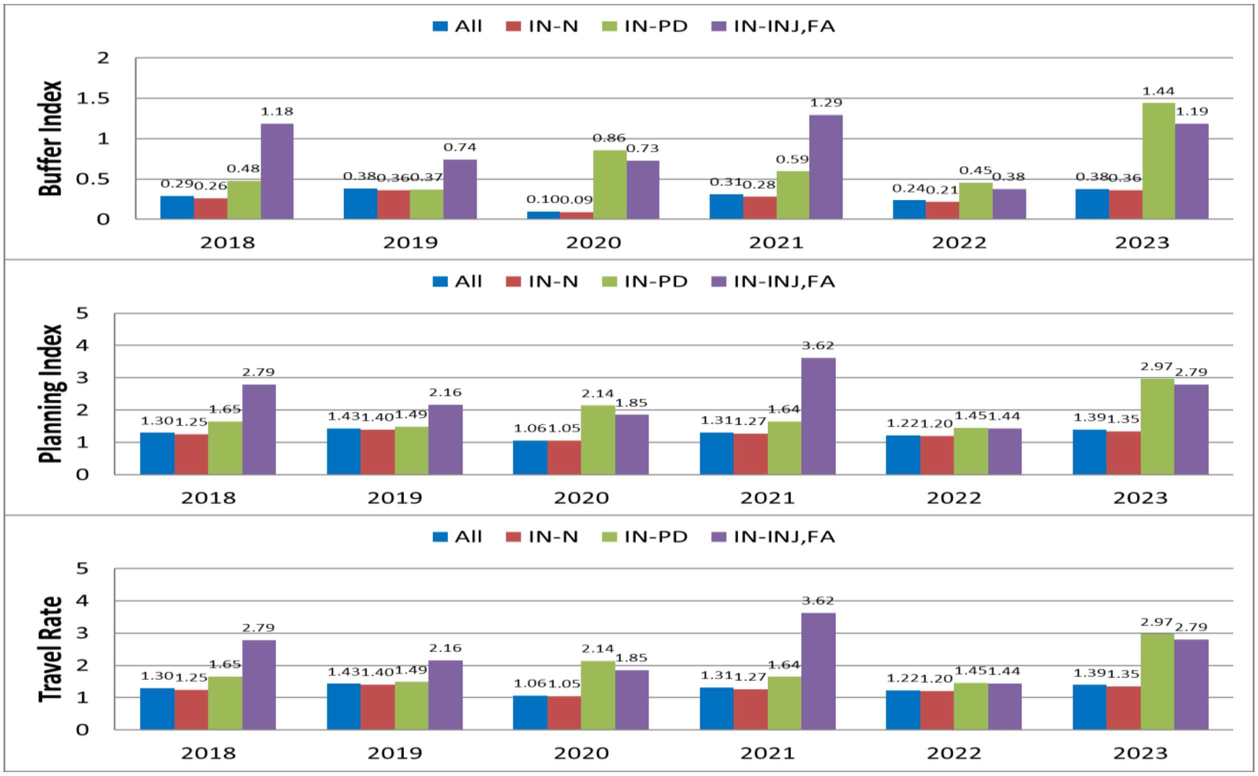
Effects of Work Zones



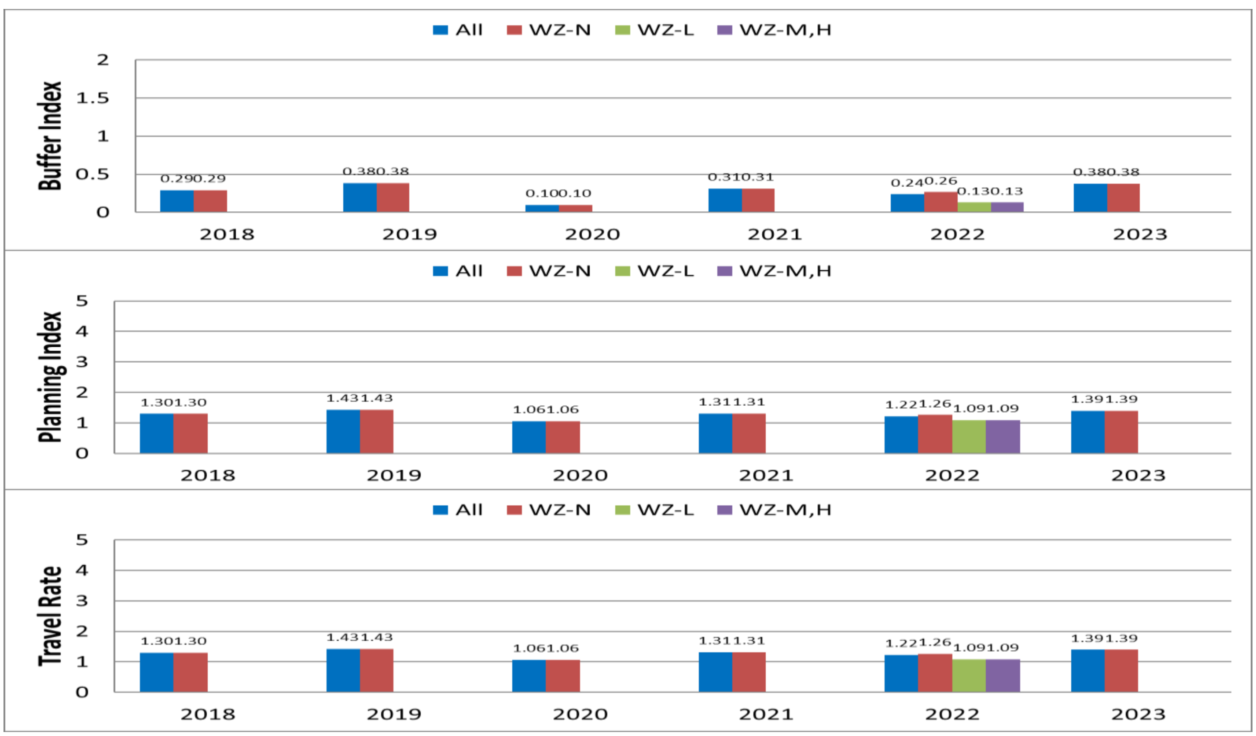
Yearly Variations - *Weather Effects*



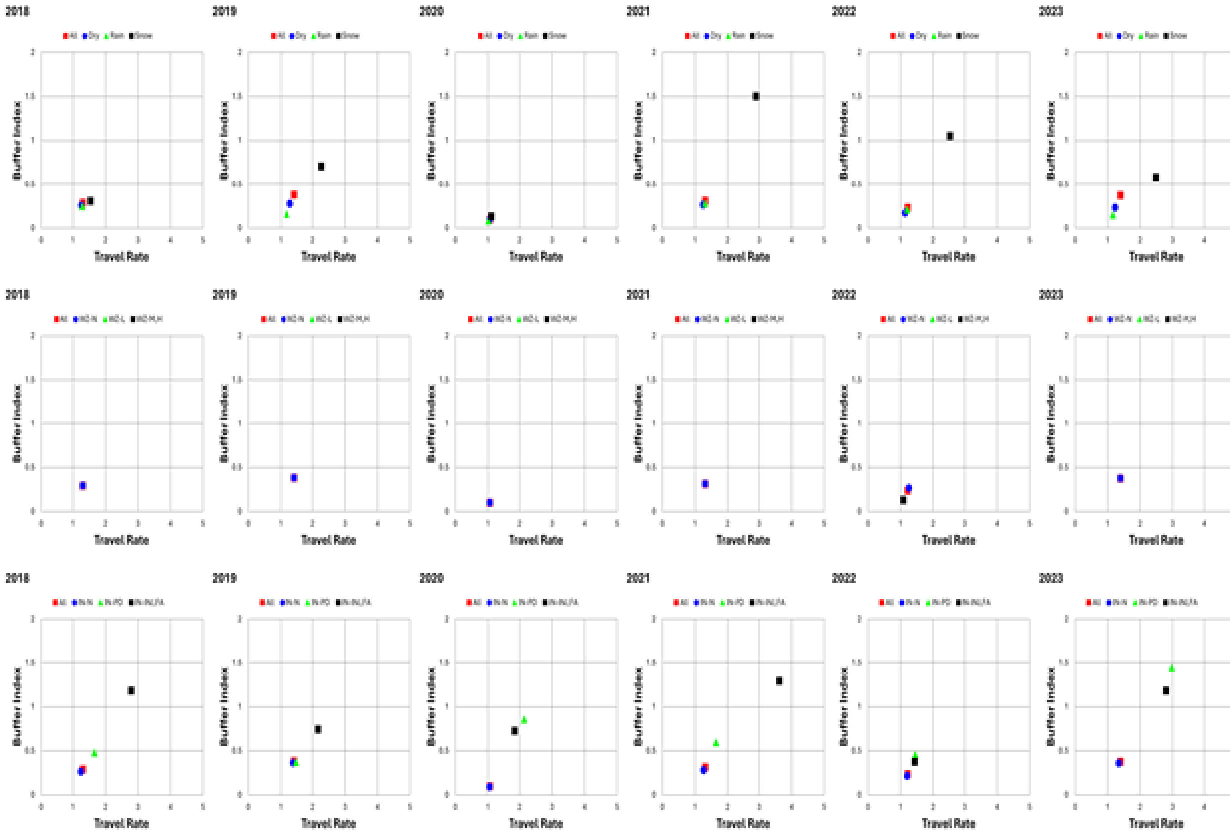
Incident Effects



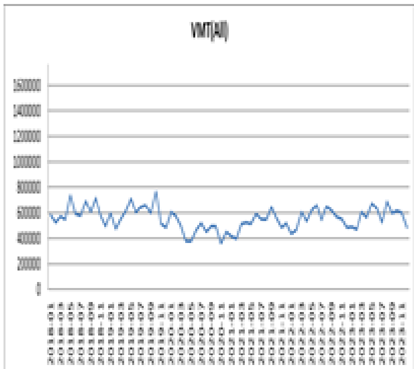
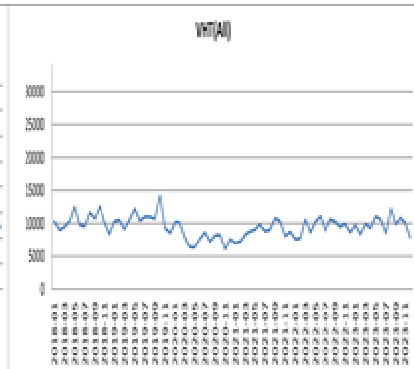
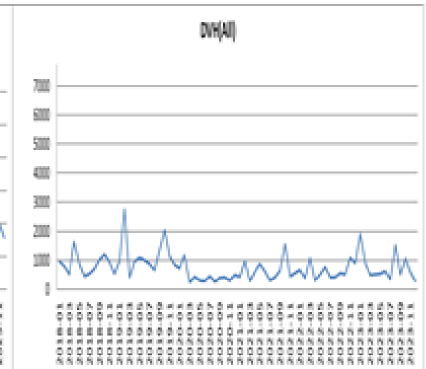
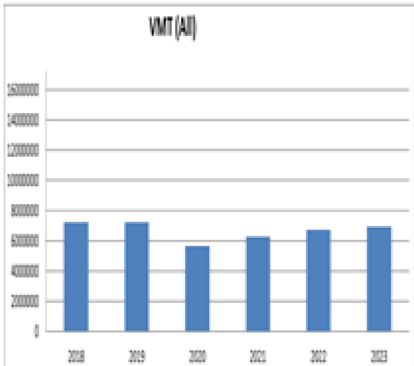
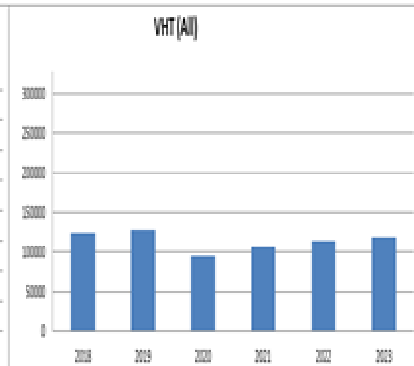
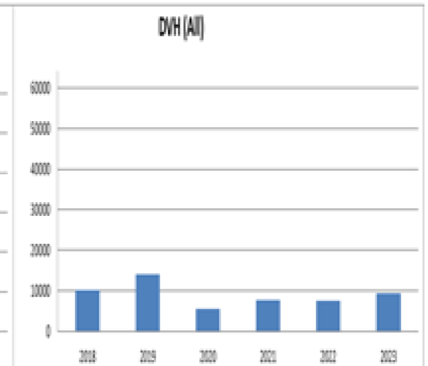
Work-Zone Effects



Yearly Variations of Buffer Index - Travel Rate Relationships

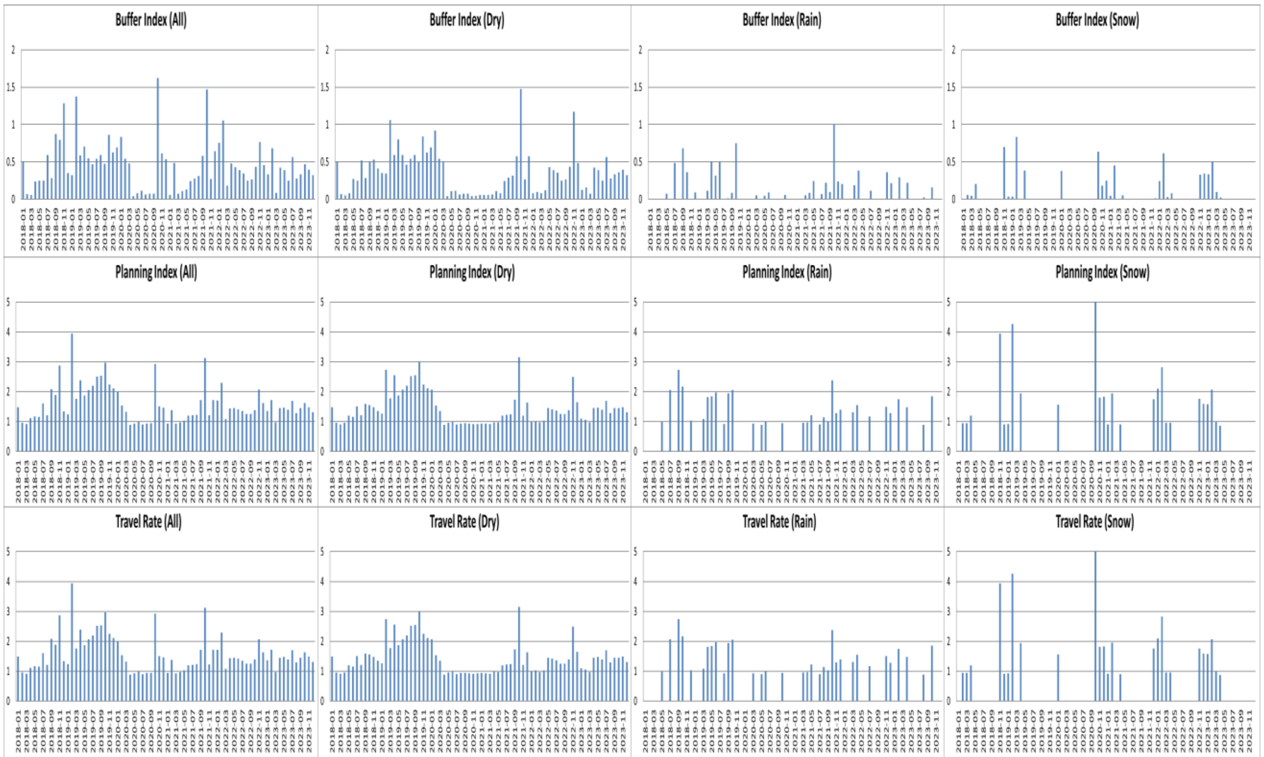


Variations of Traffic-Flow Measures


VMT(All)

VHT(All)

DVH(All)

VMT (All)
2018
2019
2020
2021
2022
2023

VHT (All)
2018
2019
2020
2021
2022
2023

DVH (All)
2018
2019
2020
2021
2022
2023

ii I-694 Corridor D -- EB TH10 to I35E for Afternoon Peak Periods

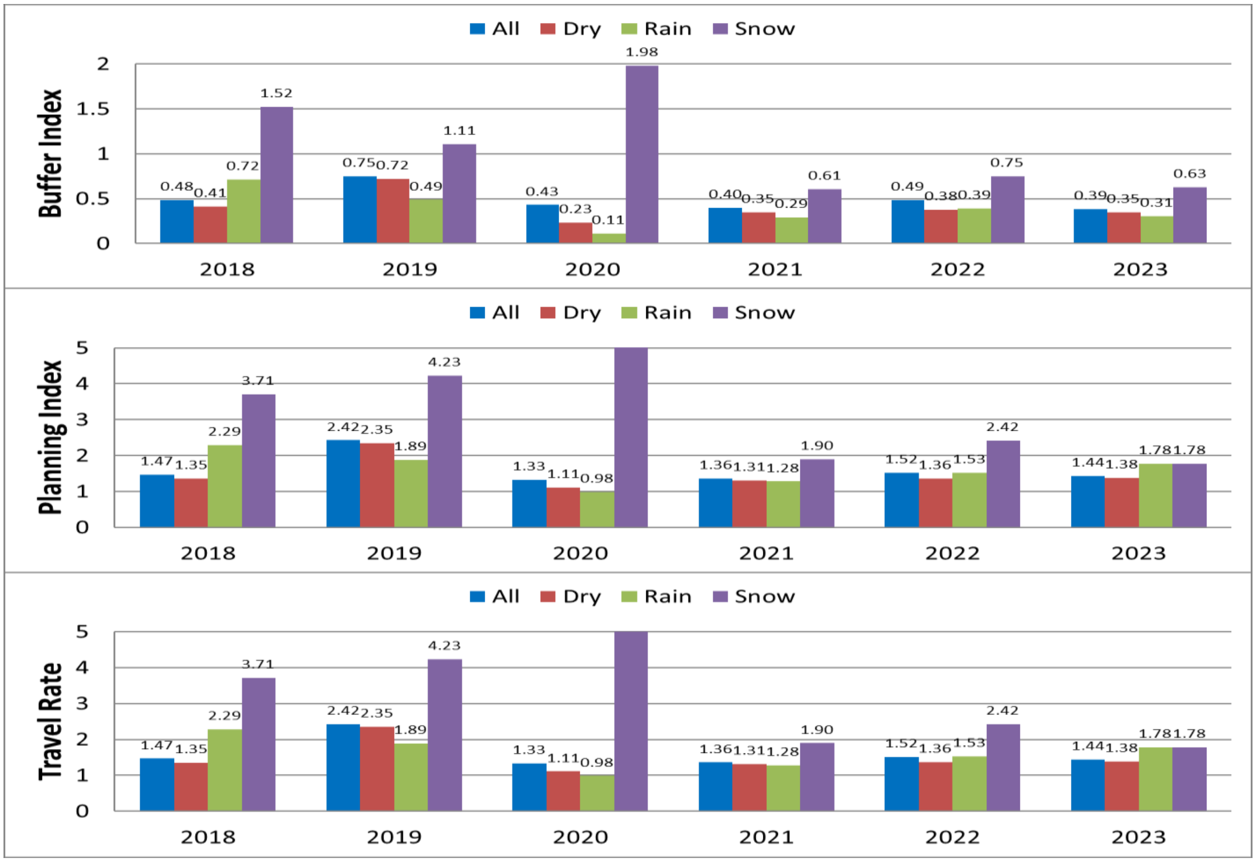
Effects of Weather conditions on Travel-Time Reliability



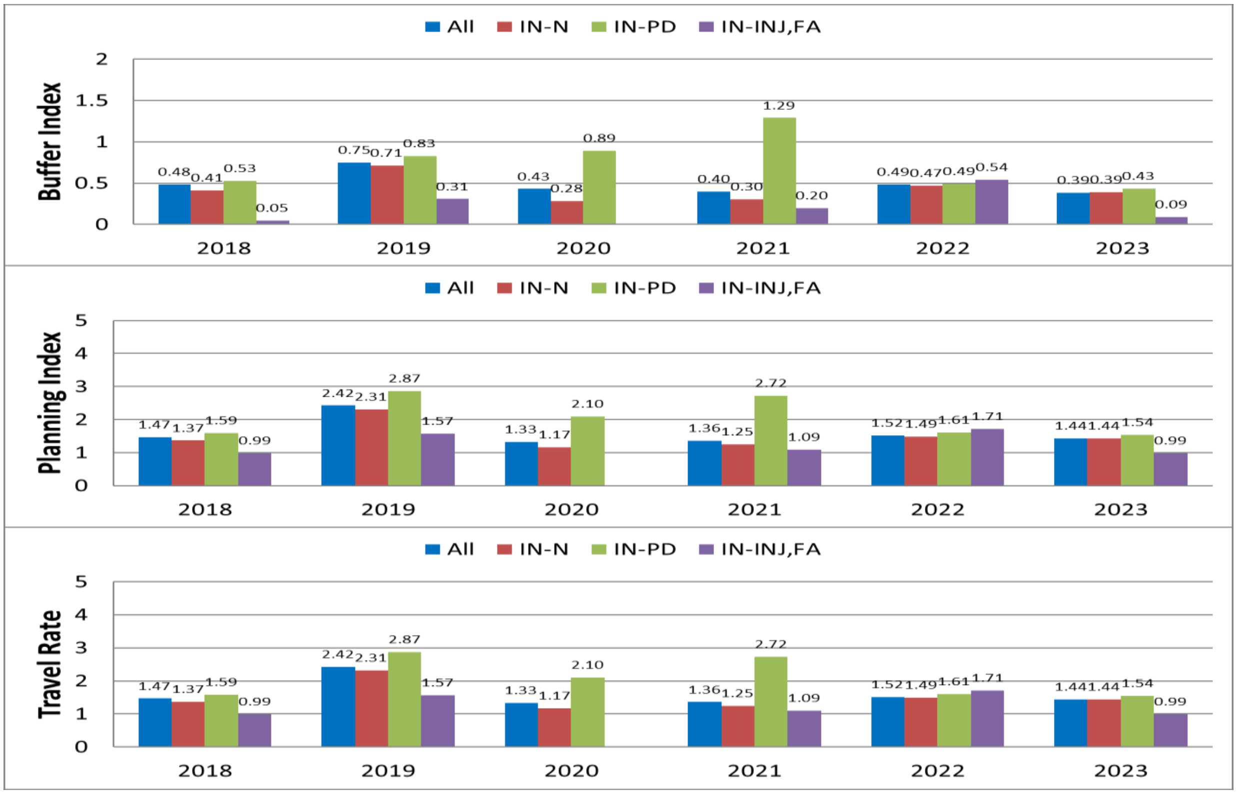
Effects of Incidents

Effects of Work Zones

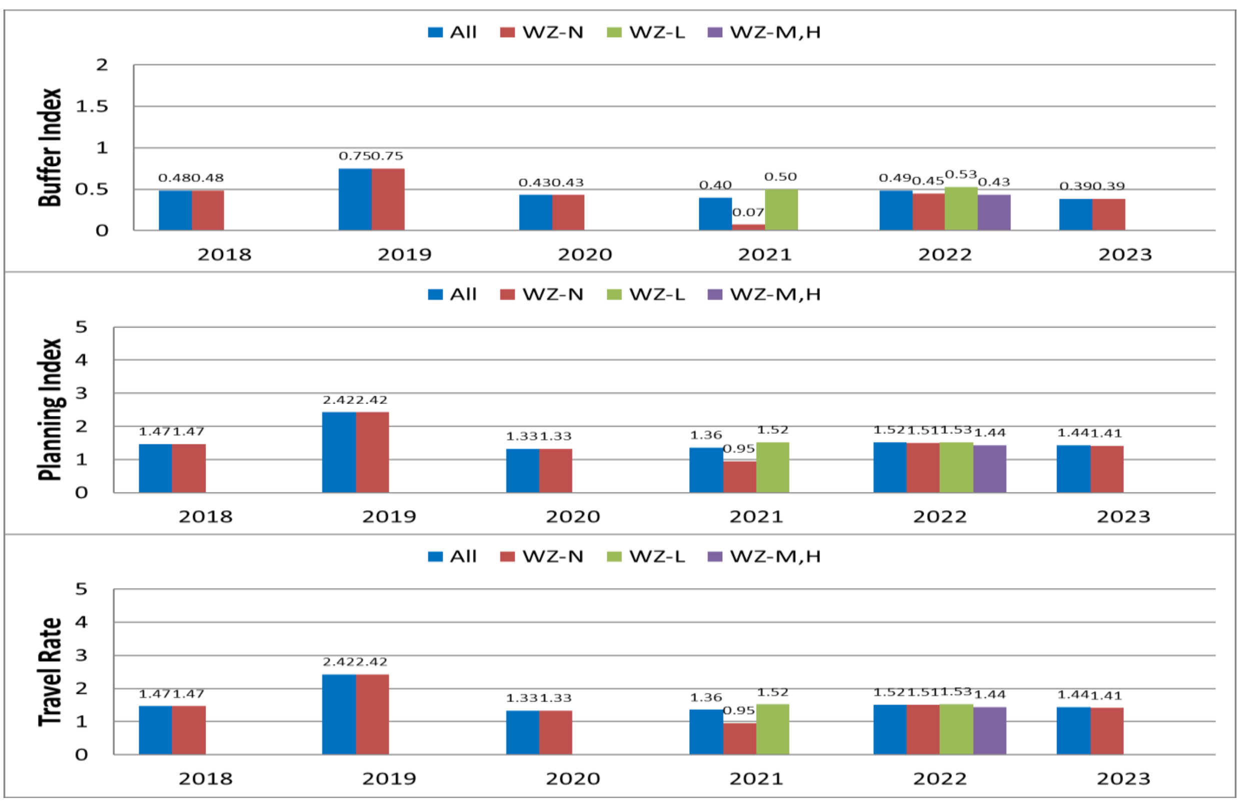
Yearly Variations - *Weather Effects*



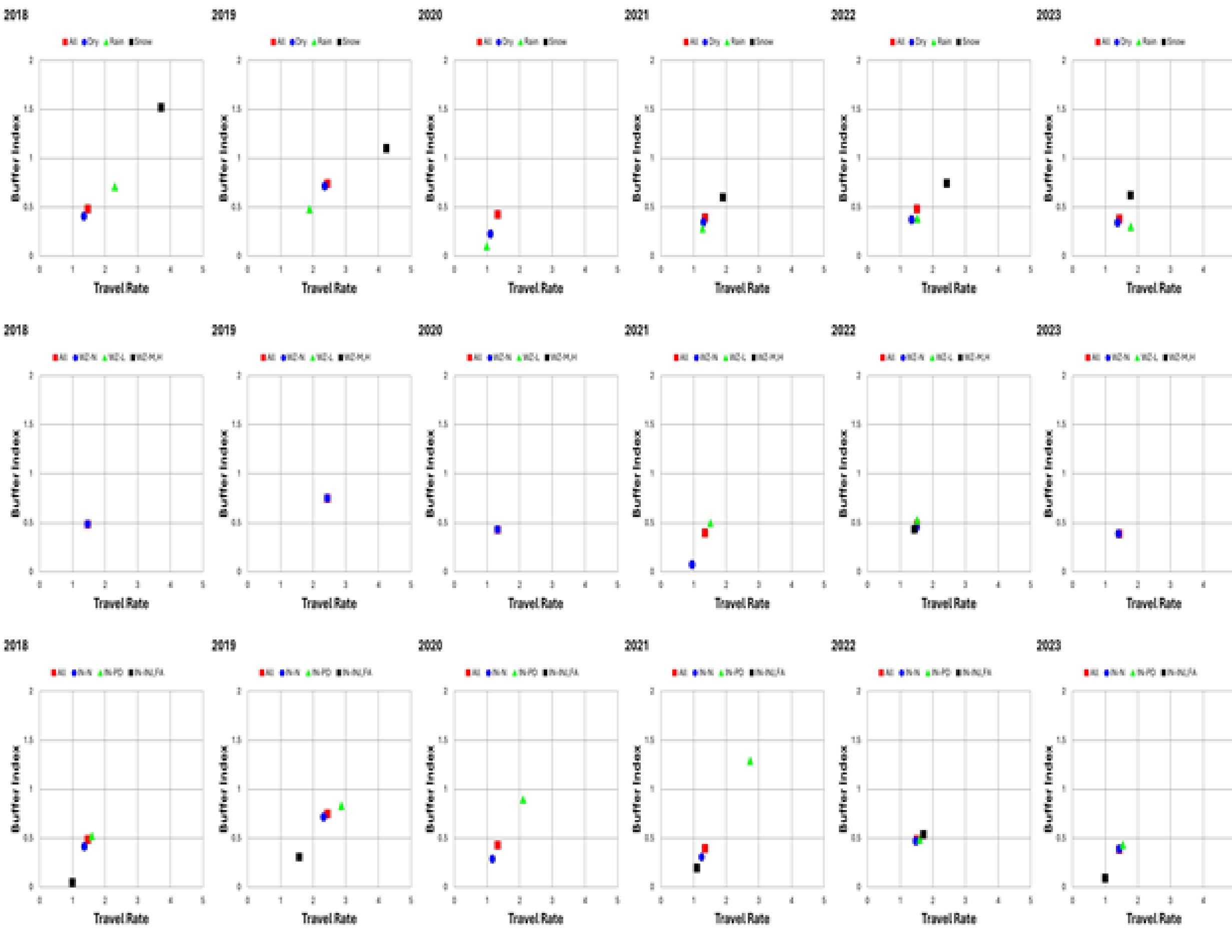
Incident Effects



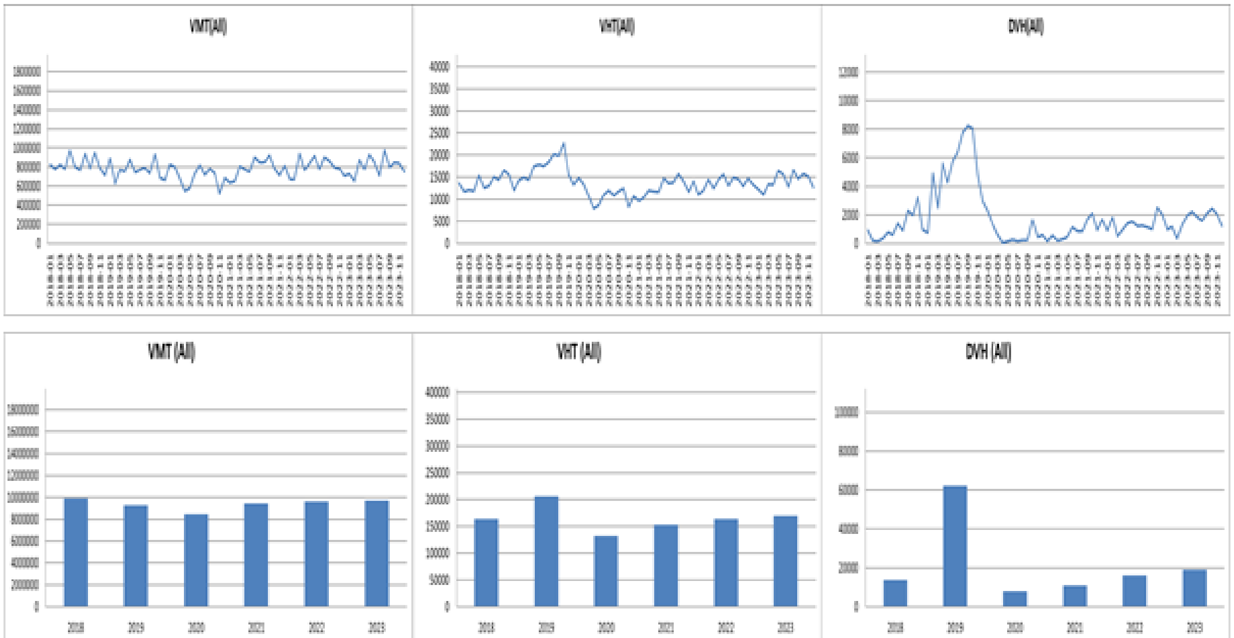
Work-Zone Effects



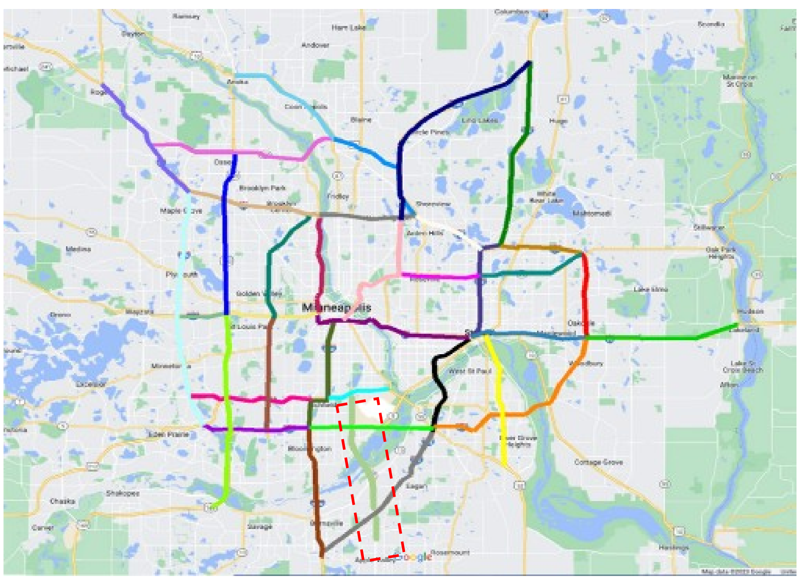
Yearly Variations of Buffer Index - Travel Rate Relationships



Variations of Traffic-Flow Measures

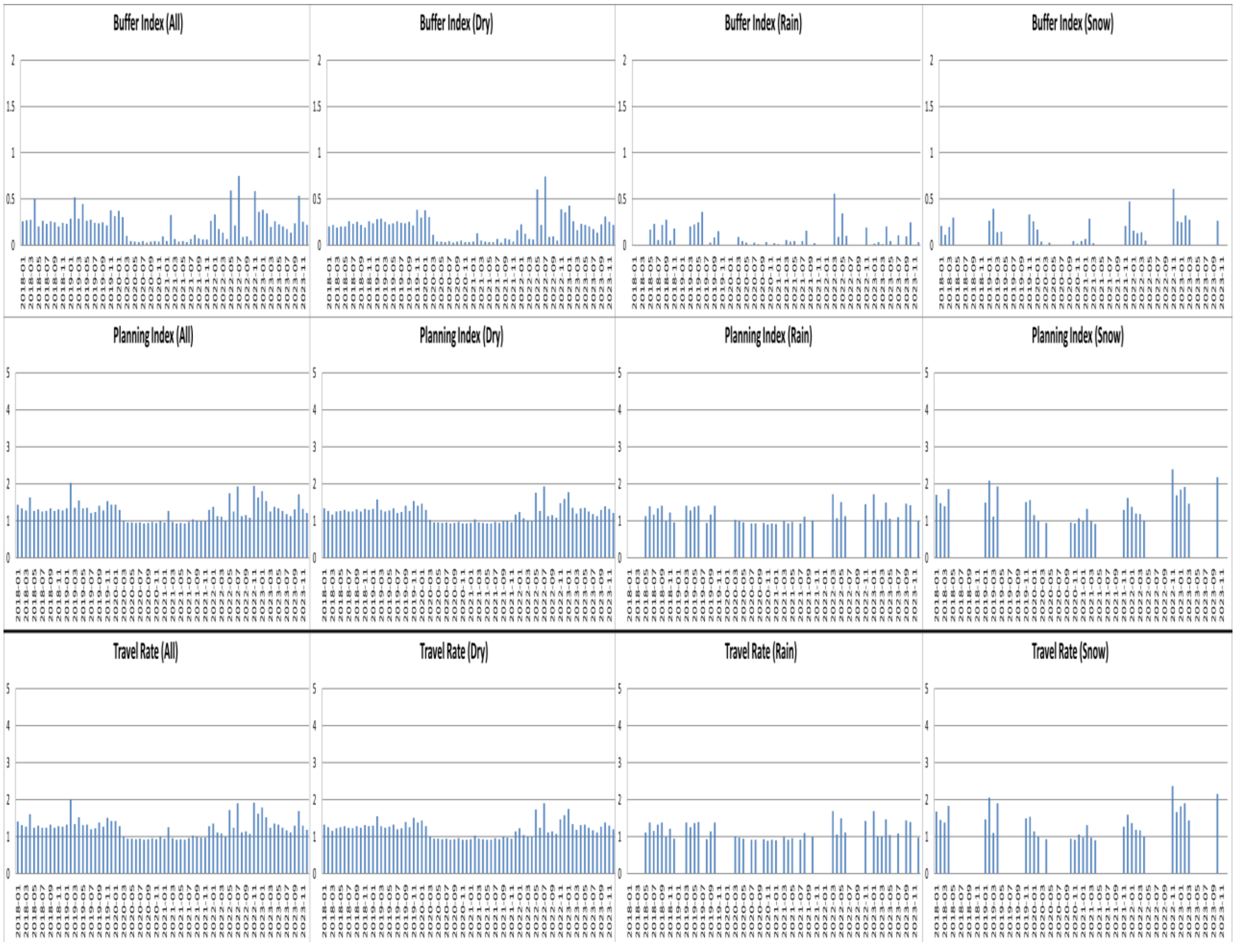


35) T.H.77 (127th to TH62)

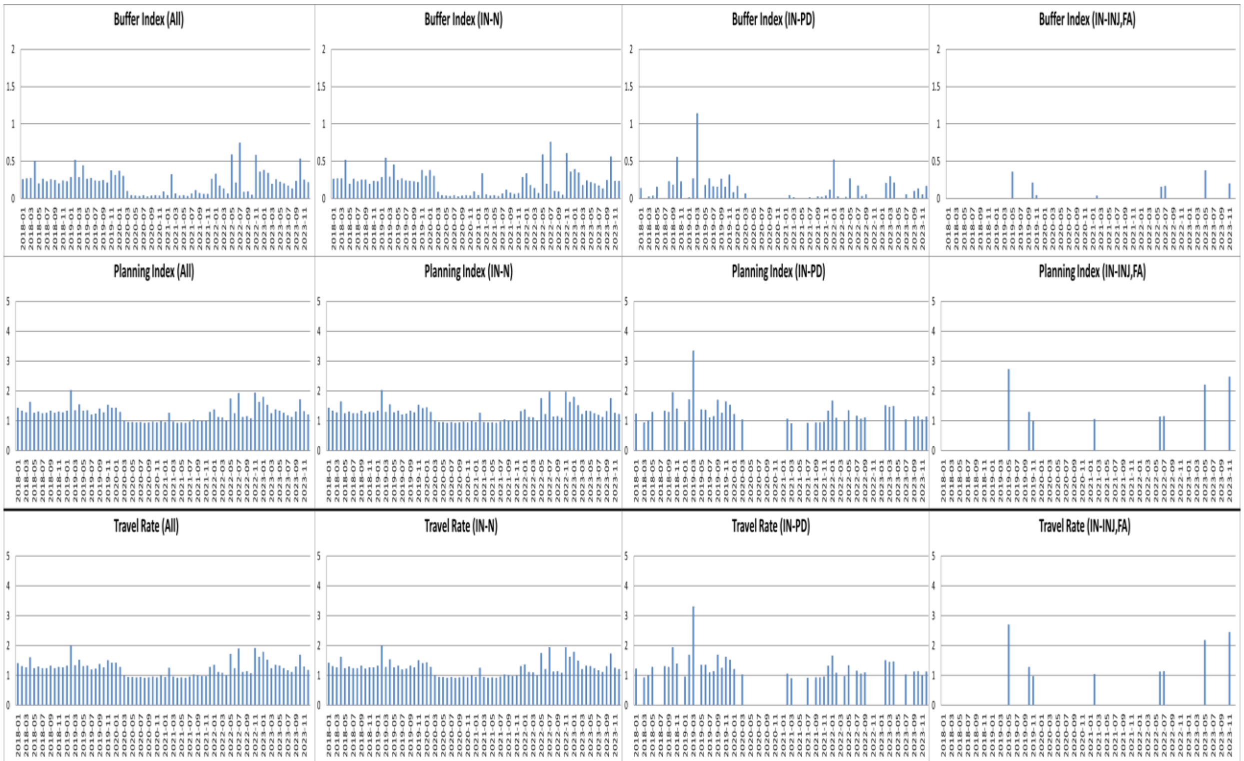


i) T.H 77 NB 127th to TH62 for Morning Peak Periods

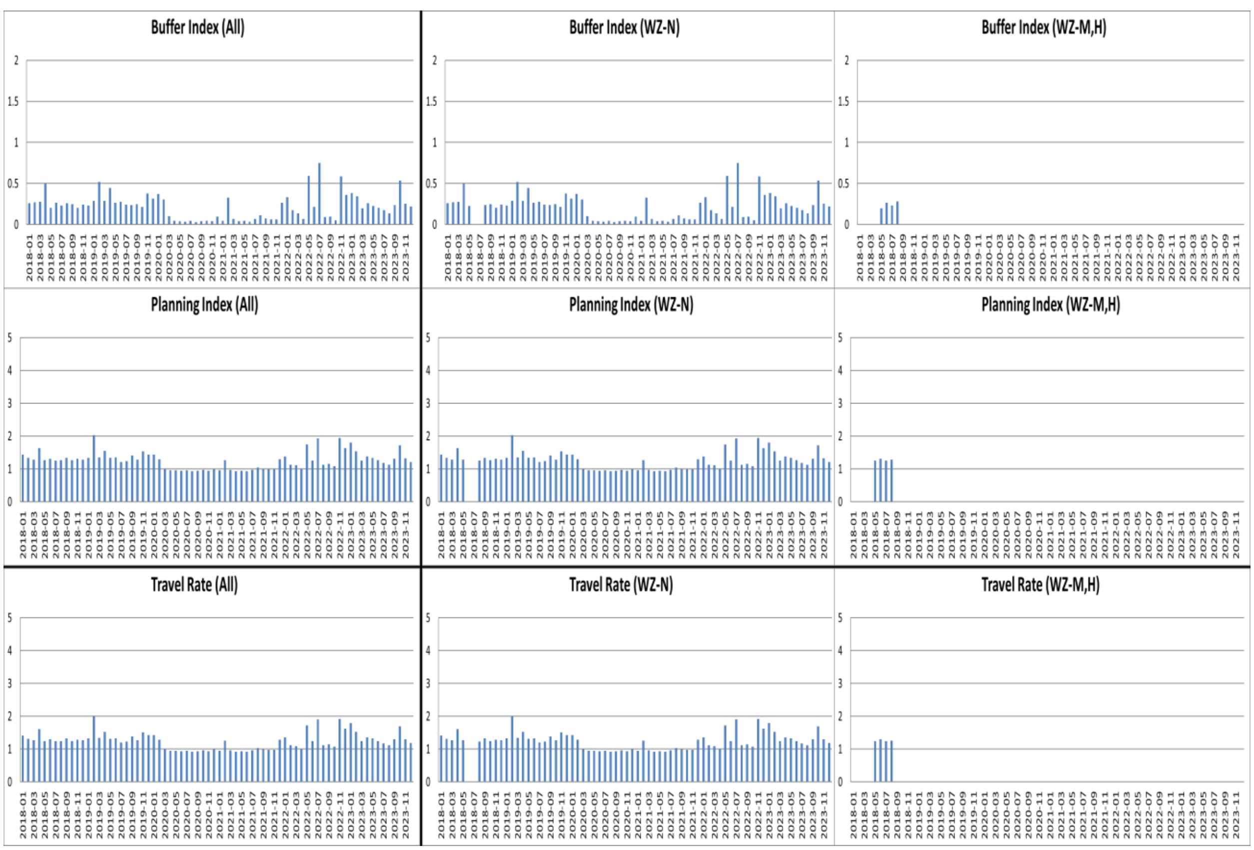
Effects of Weather conditions on Travel-Time Reliability



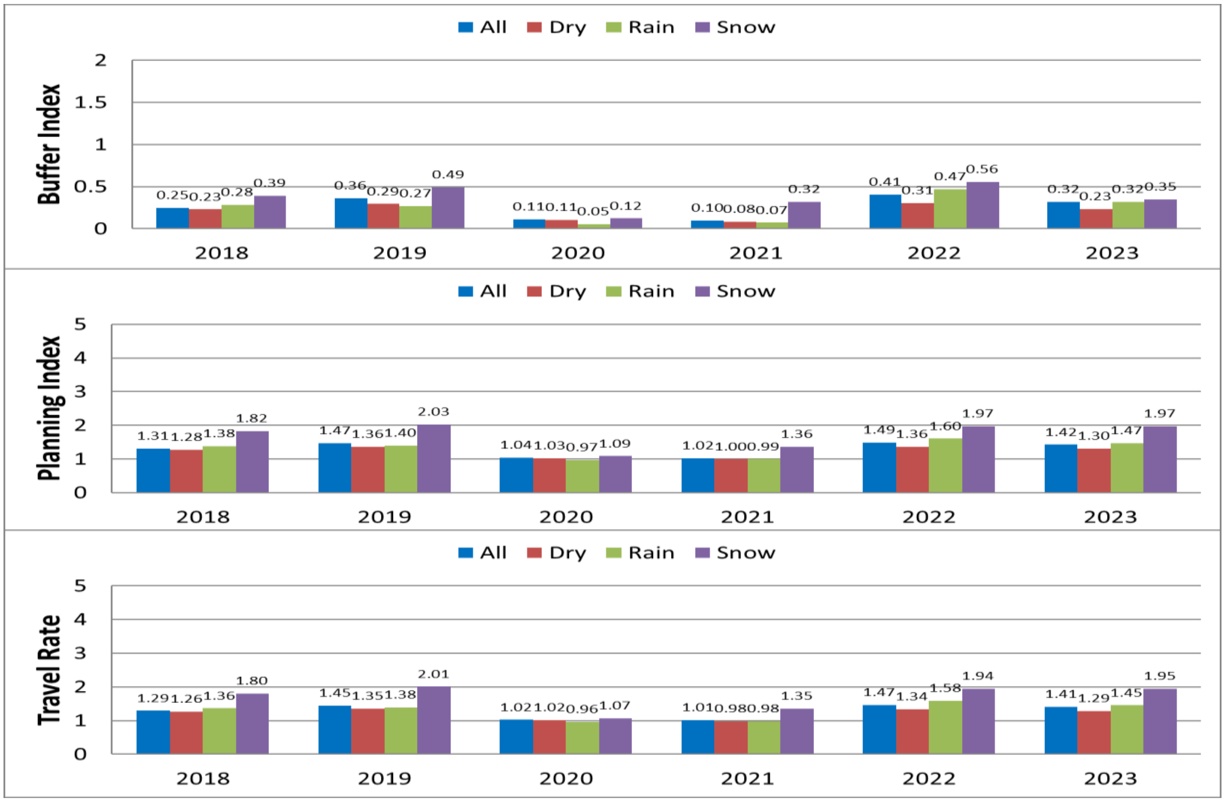
Effects of Incidents



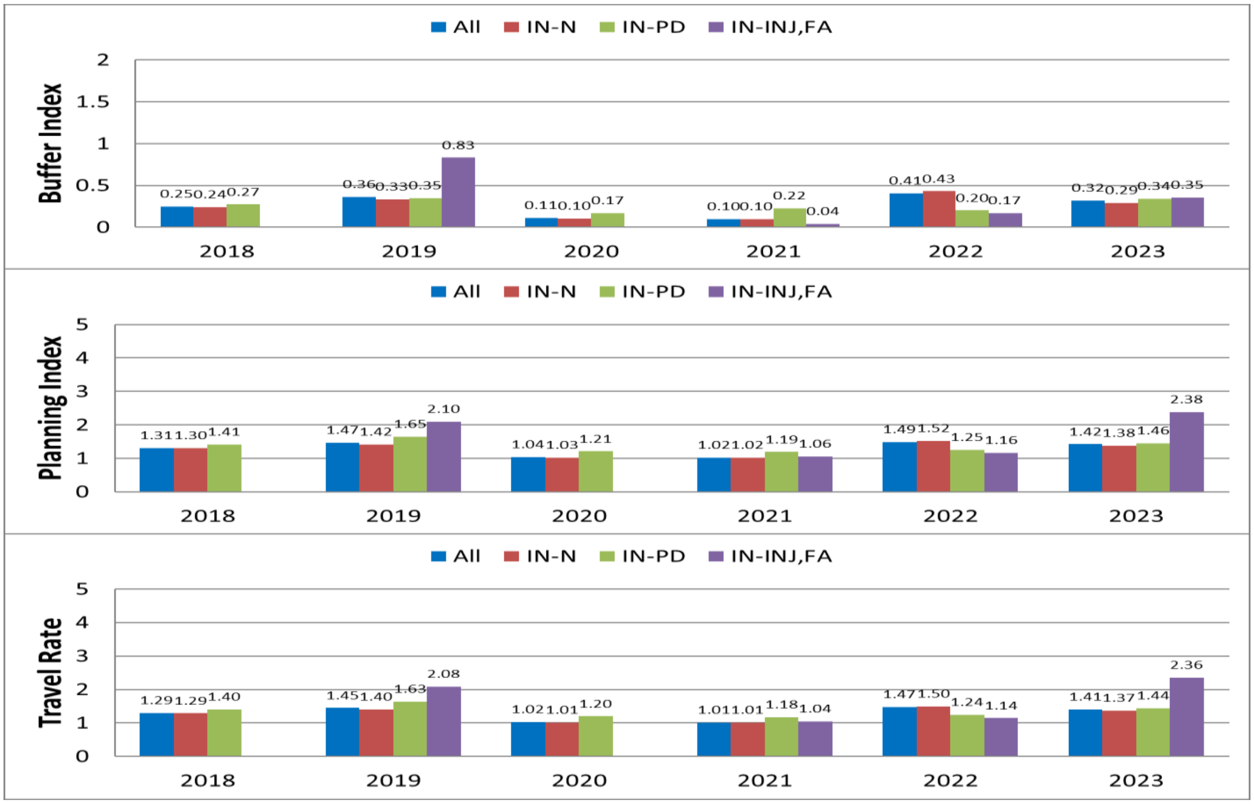
Effects of Work Zones



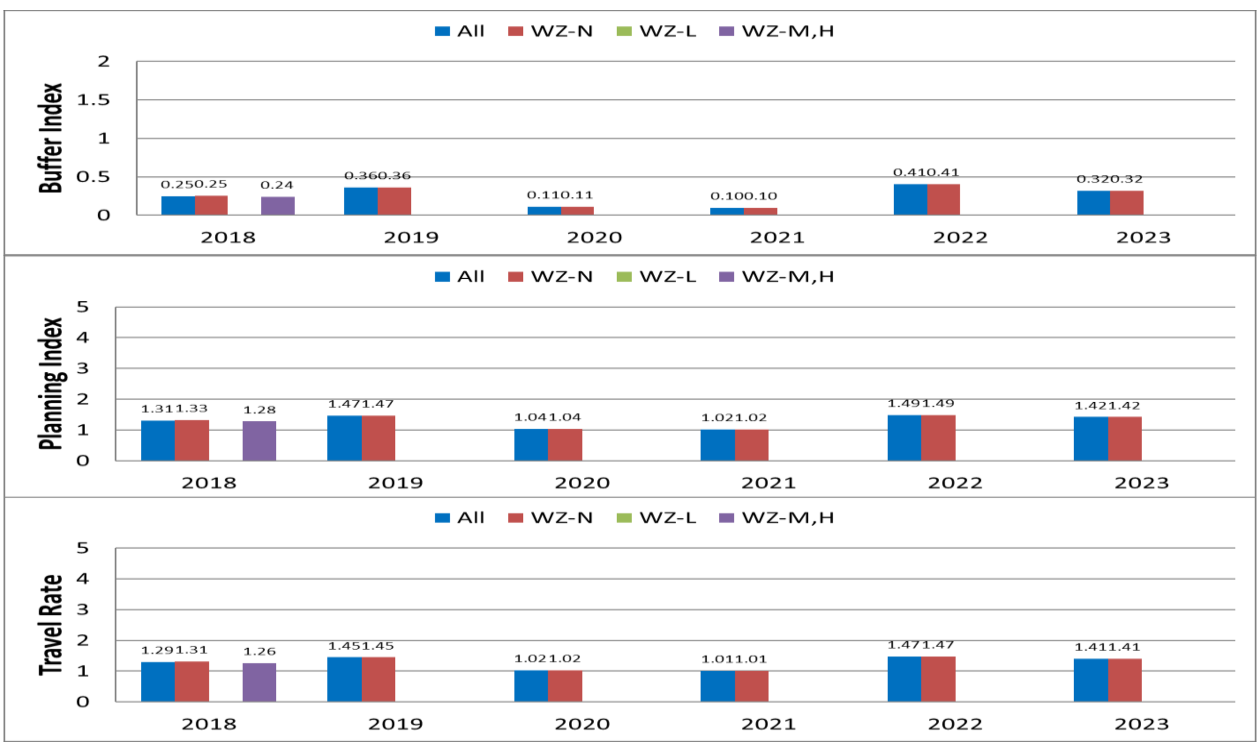
Yearly Variations - *Weather Effects*



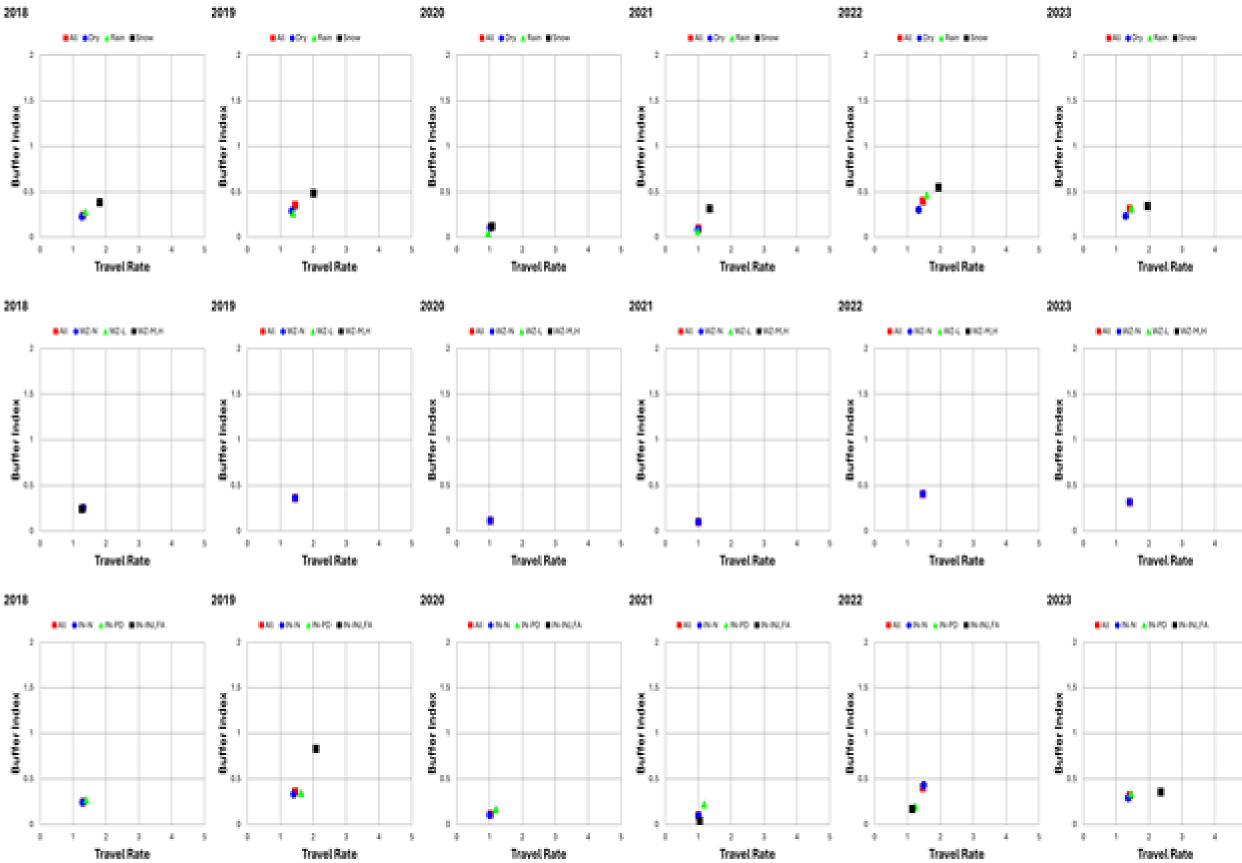
Incident Effects



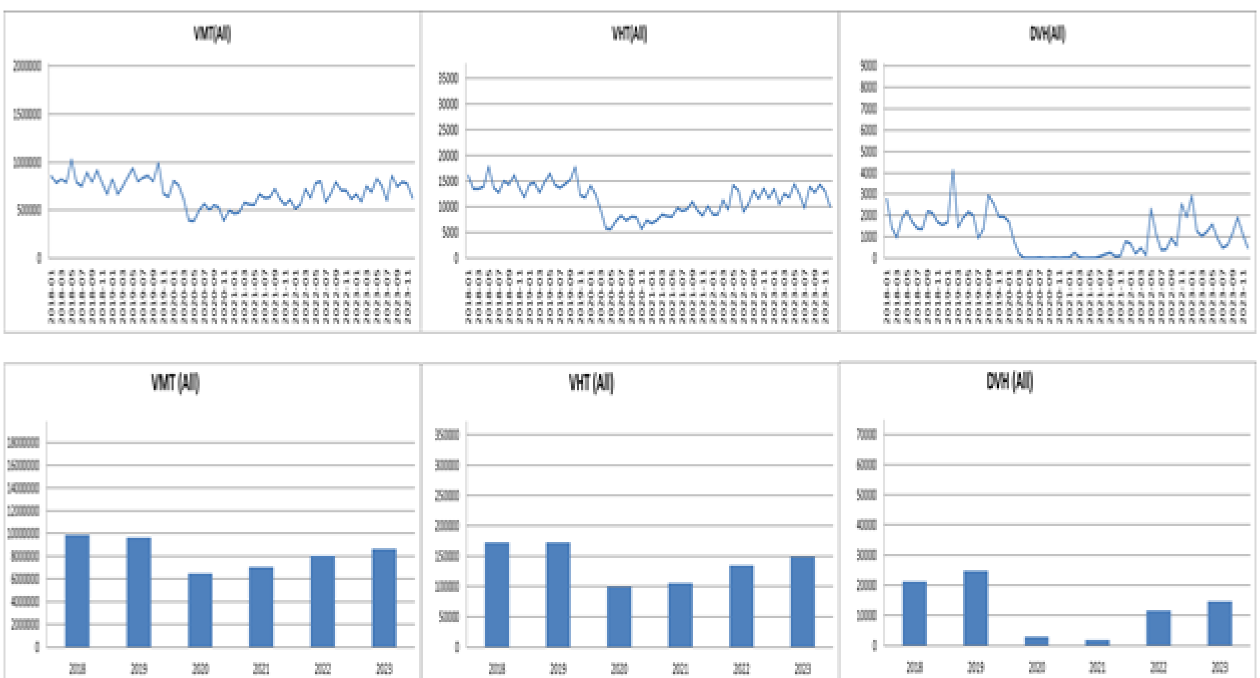
Work-Zone Effects



Yearly Variations of Buffer Index - Travel Rate Relationships

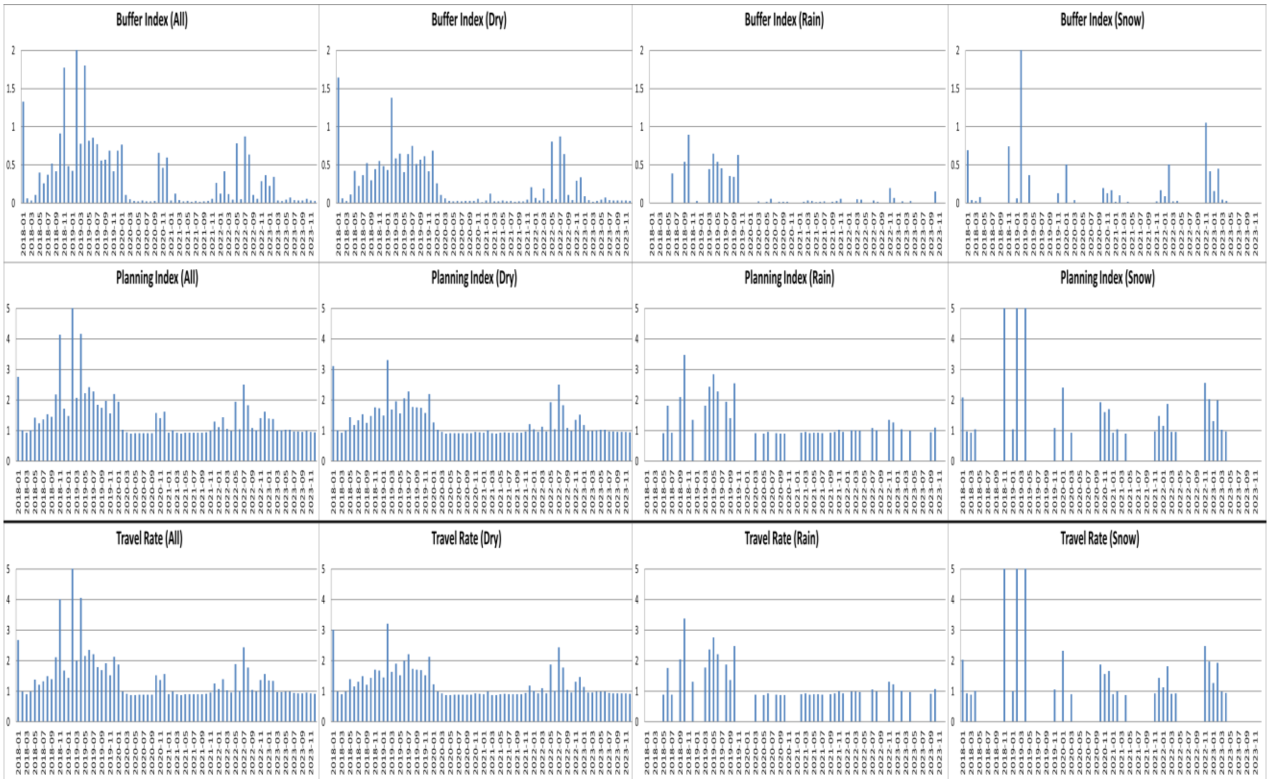


Variations of Traffic-Flow Measures

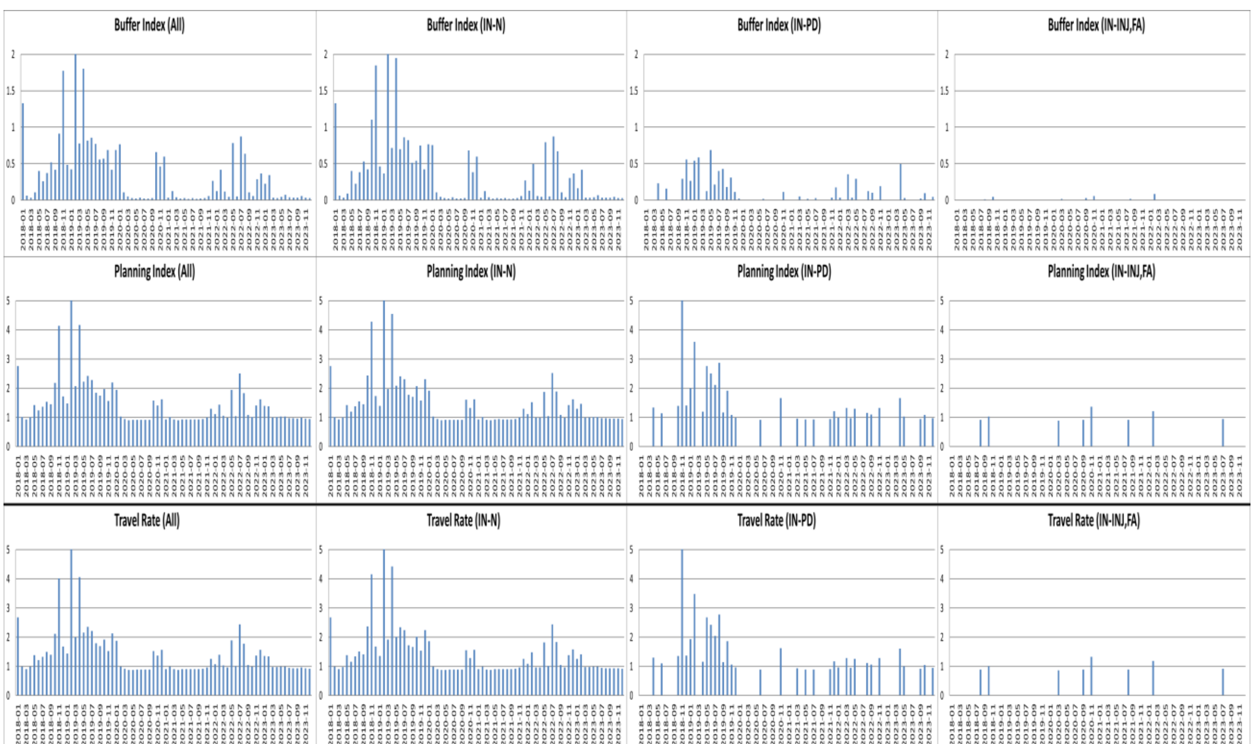


ii) T.H 77 SB TH62 to 127th for Afternoon Peak Periods

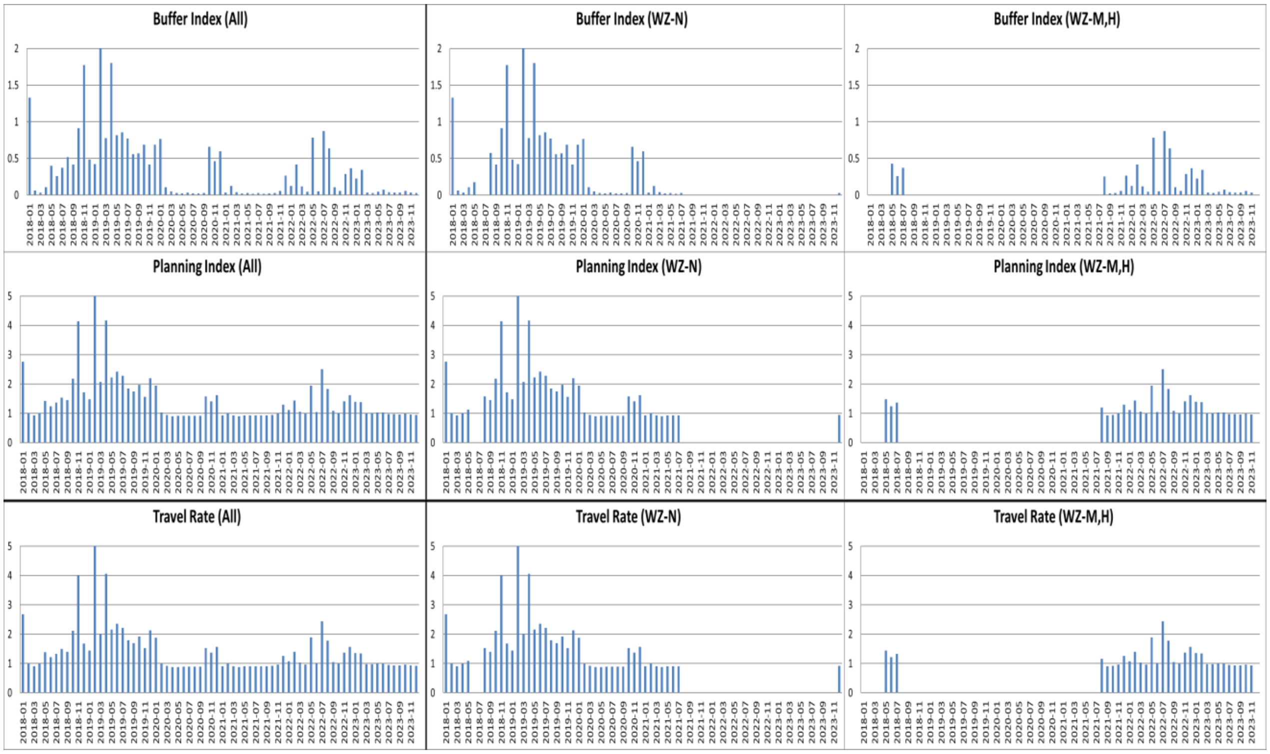
Effects of Weather conditions on Travel-Time Reliability



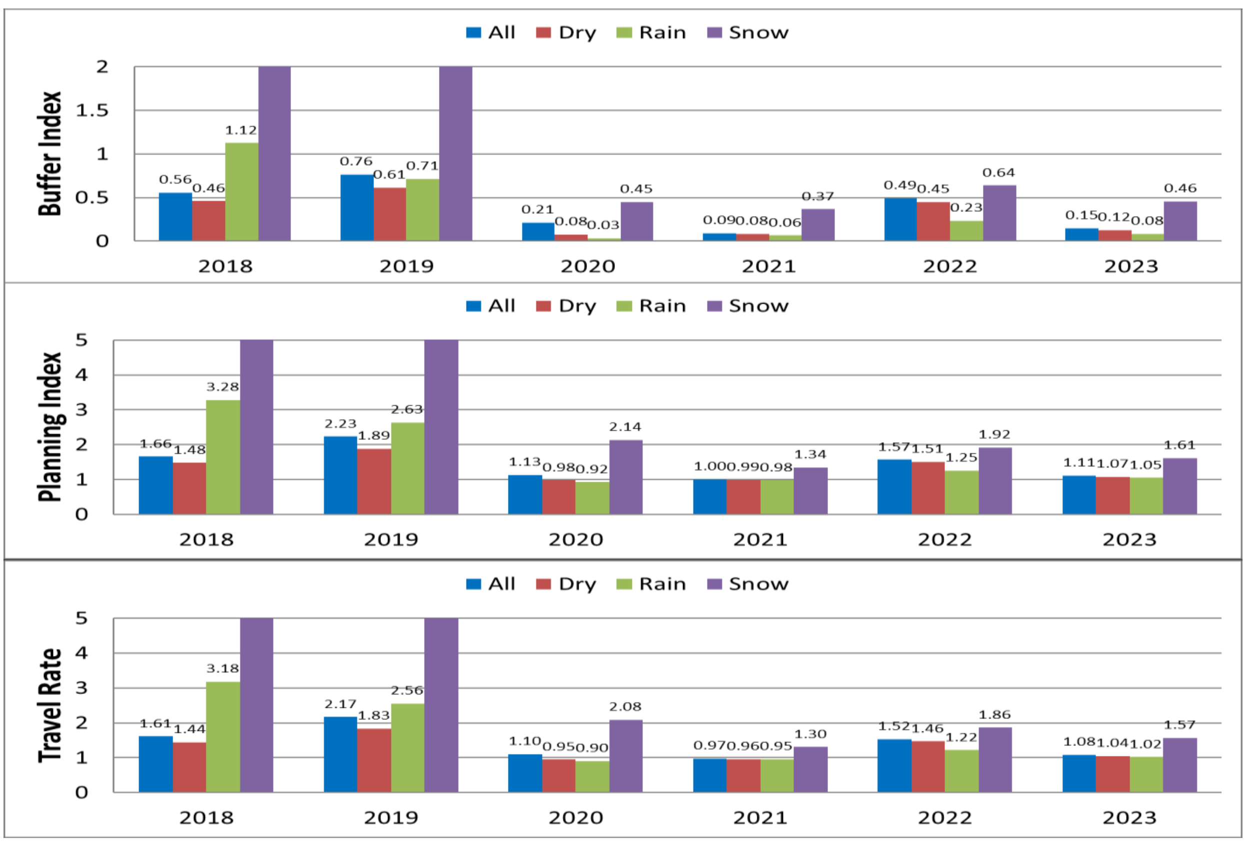
Effects of Incidents



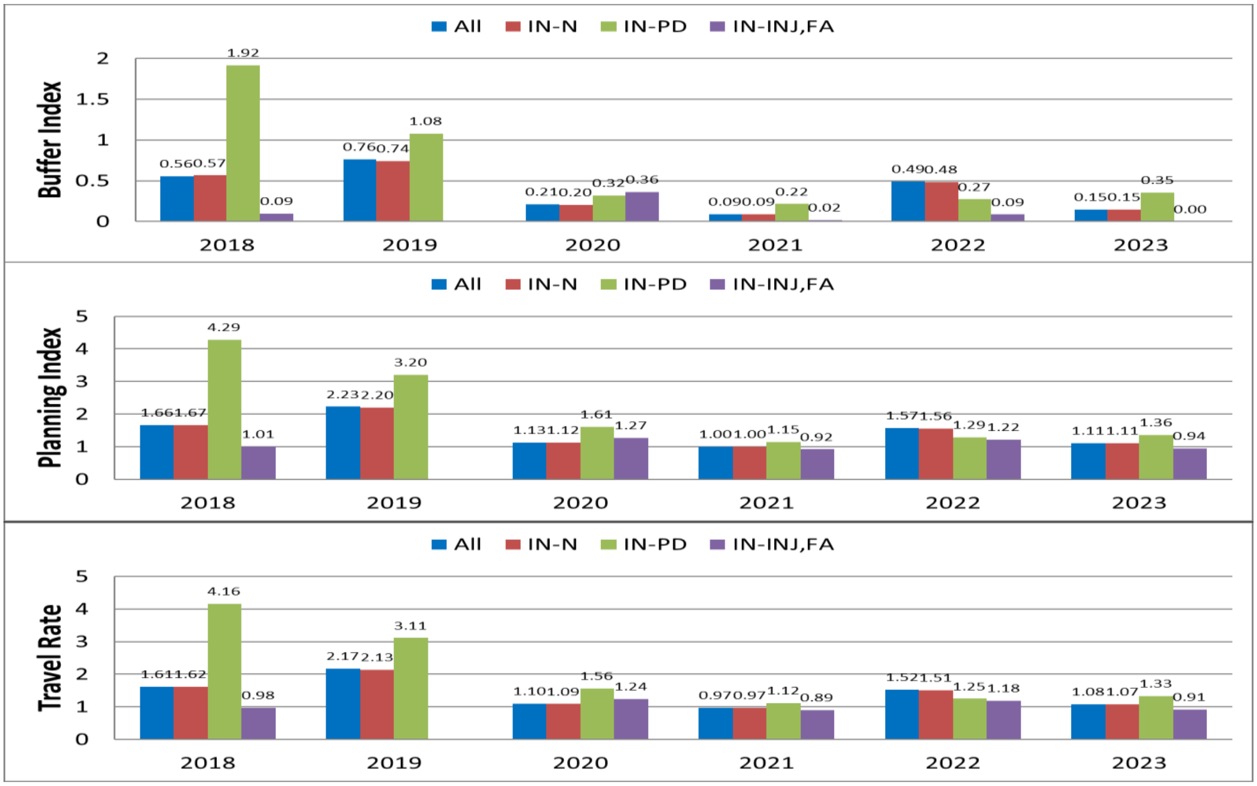
Effects of Work Zones



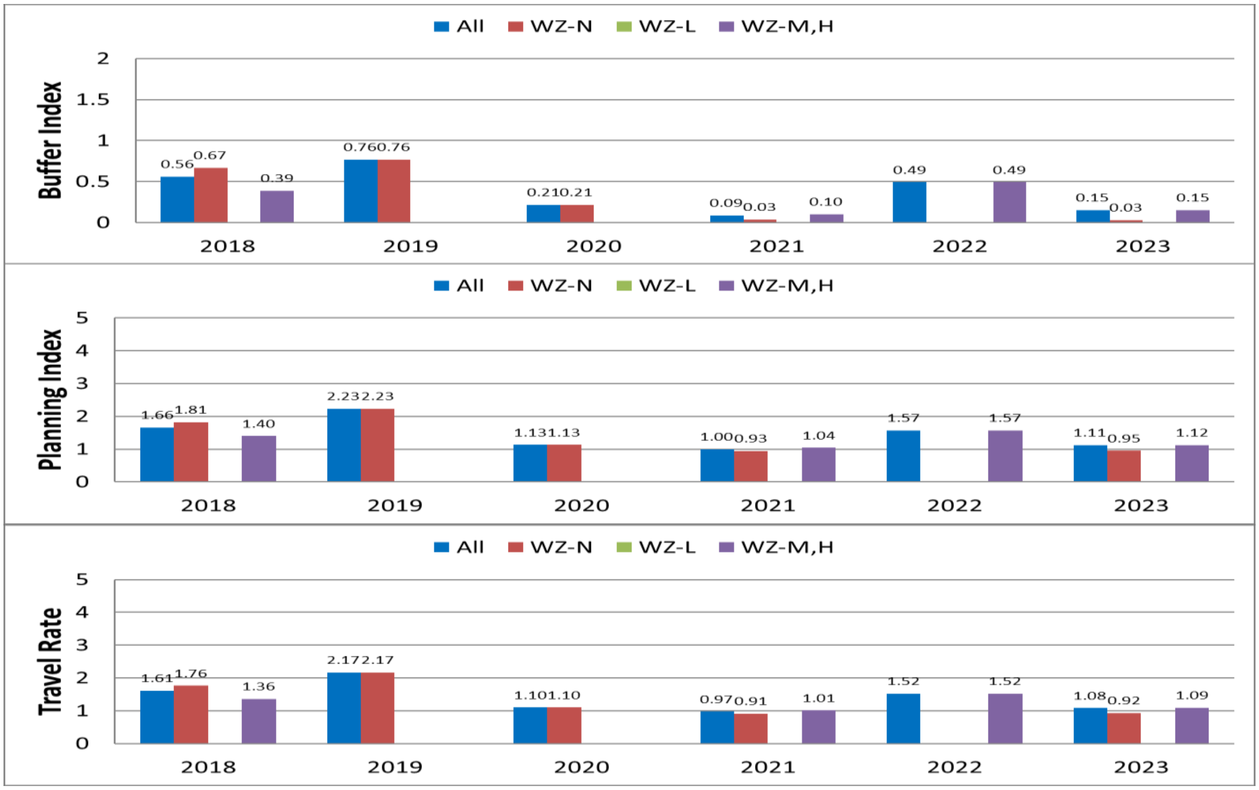
Yearly Variations - ***Weather Effects***



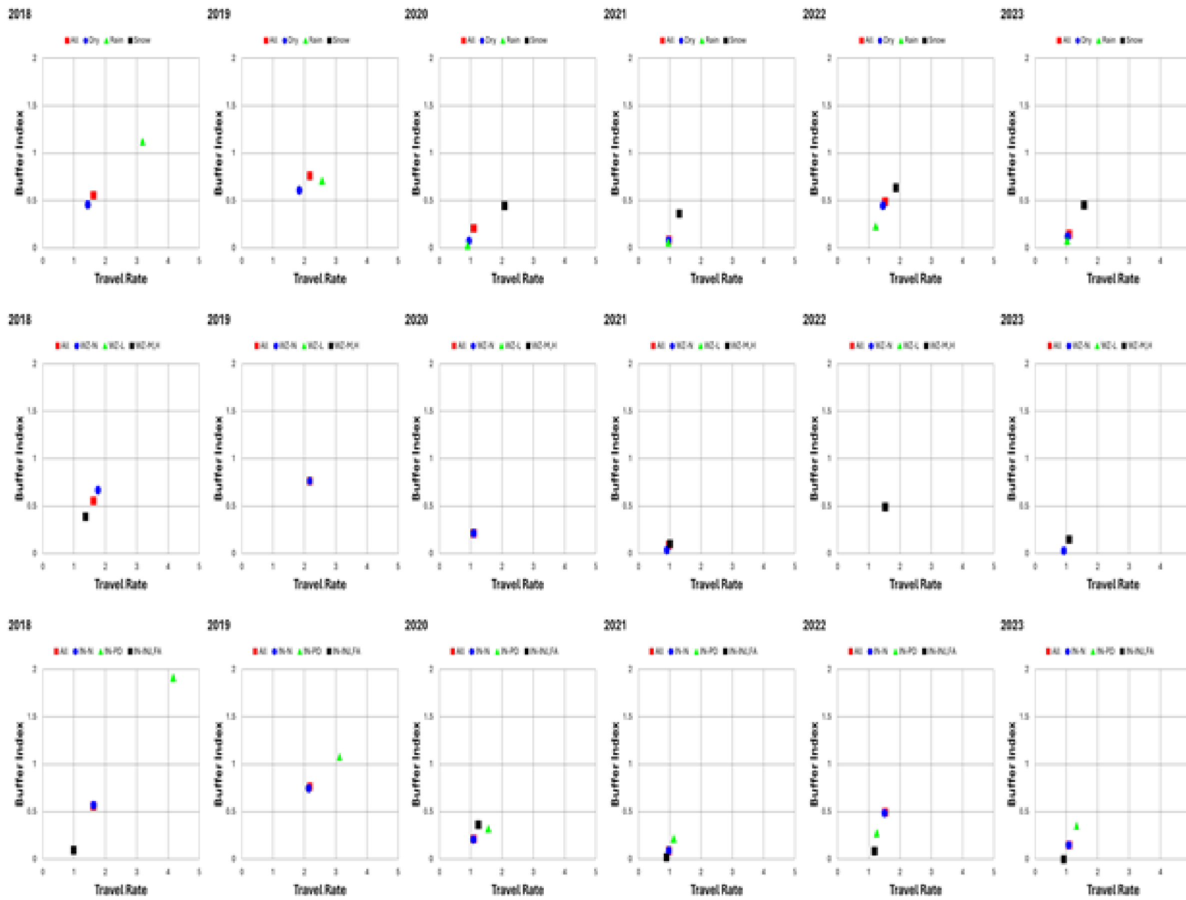
Incident Effects



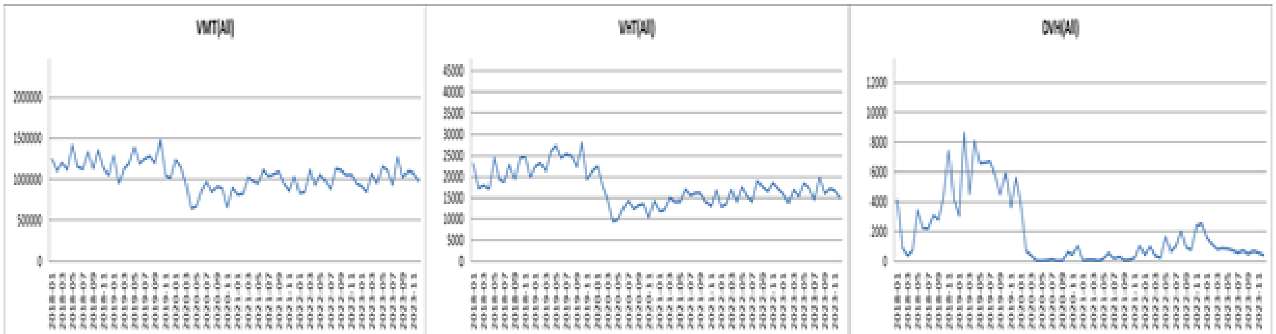
Work-Zone Effects

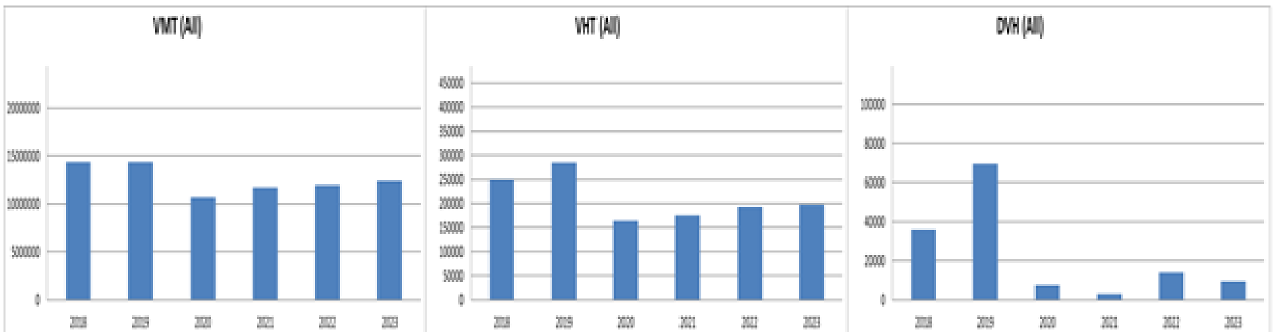


Yearly Variations of Buffer Index - Travel Rate Relationships



Variations of Traffic-Flow Measures

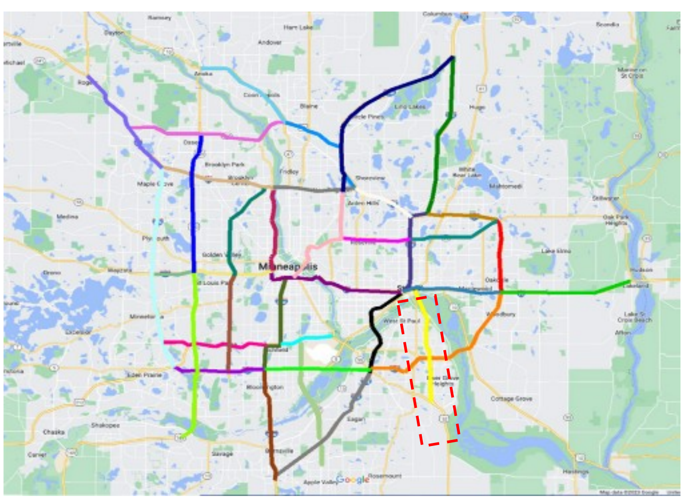




A.3. Effects of Special Events on TTR for Directional Routes with Afternoon Peak Periods

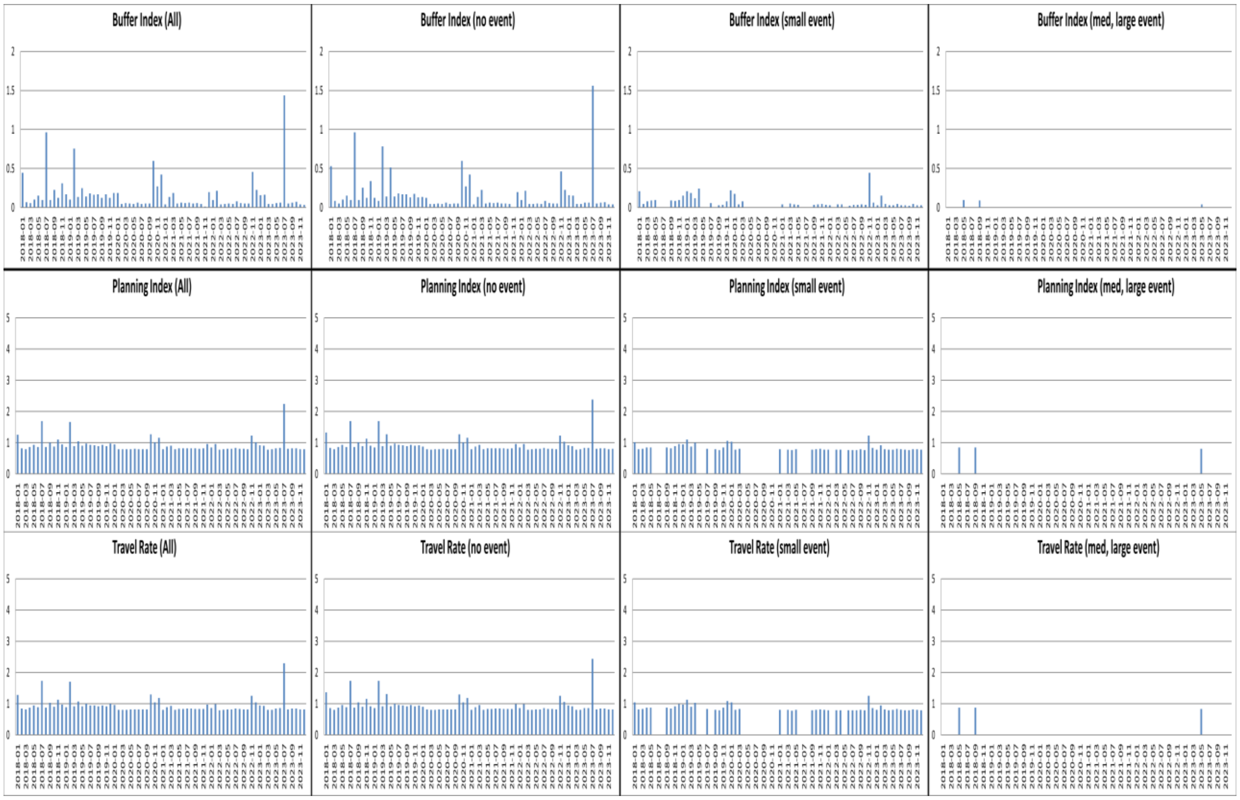
This section presents the monthly and yearly TTR variations of the individual routes, whose TTR values are affected by the special events during the afternoon peak periods. In this study, the TTR values under the following 'special event' conditions are estimated using TeTRES: *'Near (within 3 miles of a given route)', 'No Event', 'Small Event (Attendance < 20,000)' and 'Medium/Large Event (Attendance > 20,000)'.*

1) TH-52 Corridor Southbound (STPL to TH55)

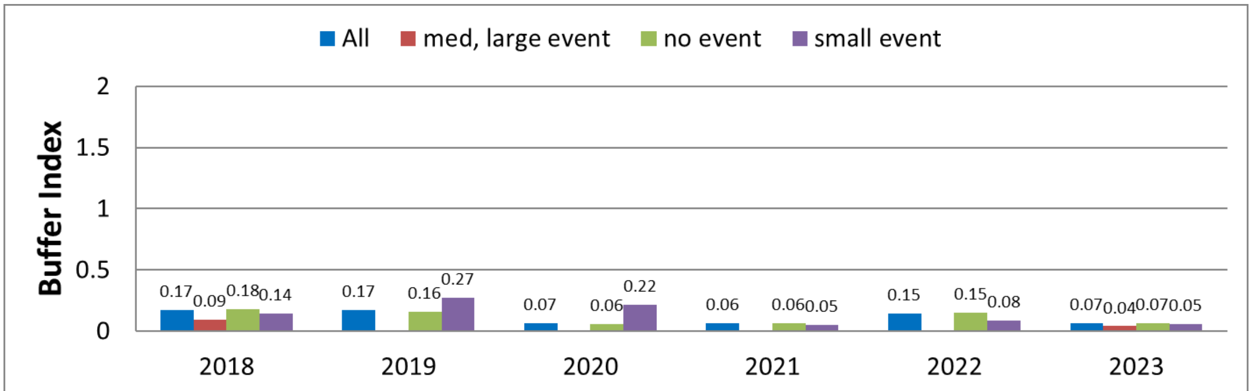
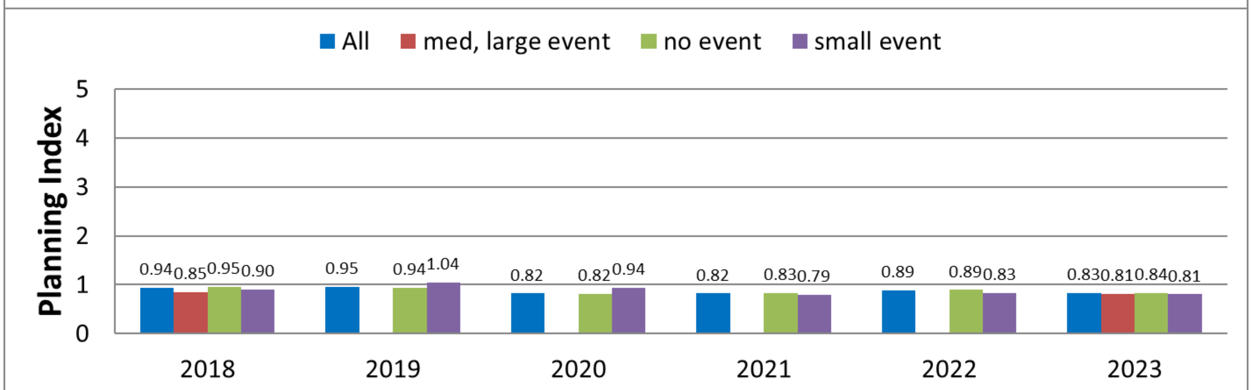
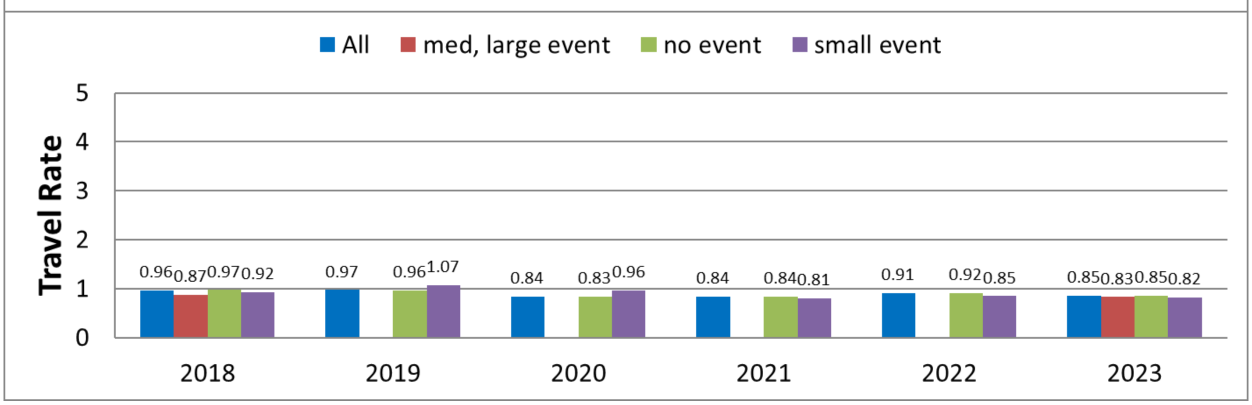


i) TH-52 SB Corridor (STPL to TH55)

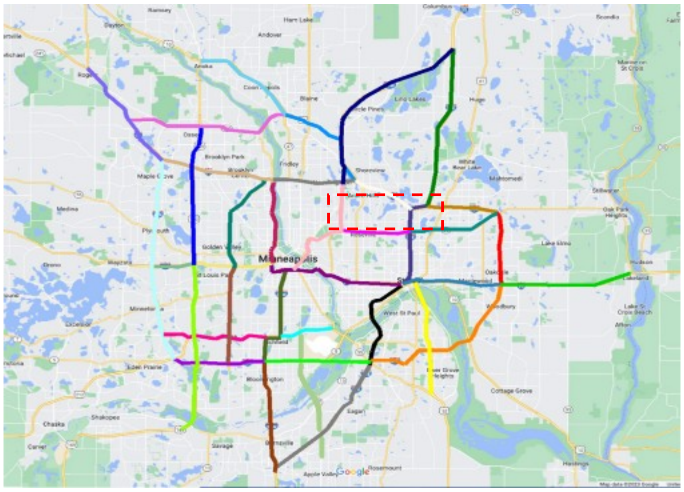
Monthly variations



Yearly variations


All
med, large event
no event
small event
Buffer Index
2
1.5
1
0.5
0
0.17
0.09
0.18
0.14
0.17
0.16
0.27
0.07
0.06
0.22
0.06
0.06
0.05
0.15
0.15
0.08
0.07
0.04
0.07
0.05
2018
2019
2020
2021
2022
2023

All
med, large event
no event
small event
Planning Index
5
4
3
2
1
0
0.94
0.85
0.95
0.90
0.95
0.94
1.04
0.82
0.82
0.94
0.82
0.83
0.79
0.89
0.89
0.83
0.83
0.81
0.84
0.81
2018
2019
2020
2021
2022
2023

All
med, large event
no event
small event
Travel Rate
5
4
3
2
1
0
0.96
0.87
0.97
0.92
0.97
0.96
1.07
0.84
0.83
0.96
0.84
0.84
0.81
0.91
0.92
0.85
0.85
0.83
0.85
0.82
2018
2019
2020
2021
2022
2023

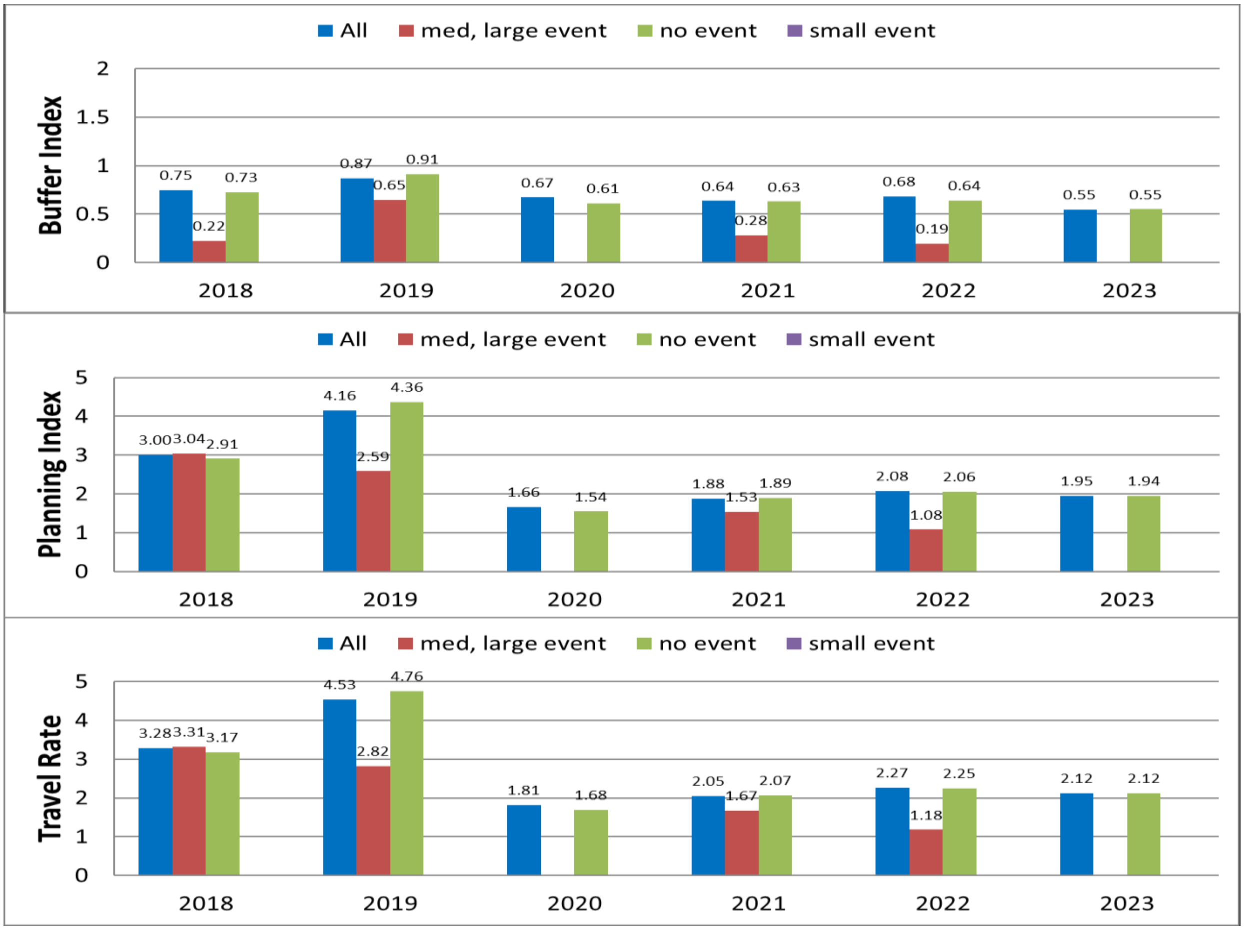
2) TH-36 Corridor B (I-35W to I-35E, Eastbound)



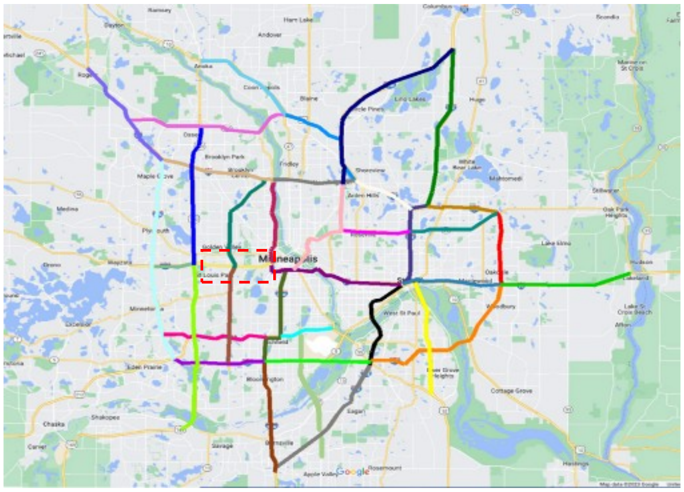
i) TH-36 Corridor B -- EB for I-35W to I-35E

Monthly variations

Yearly variations

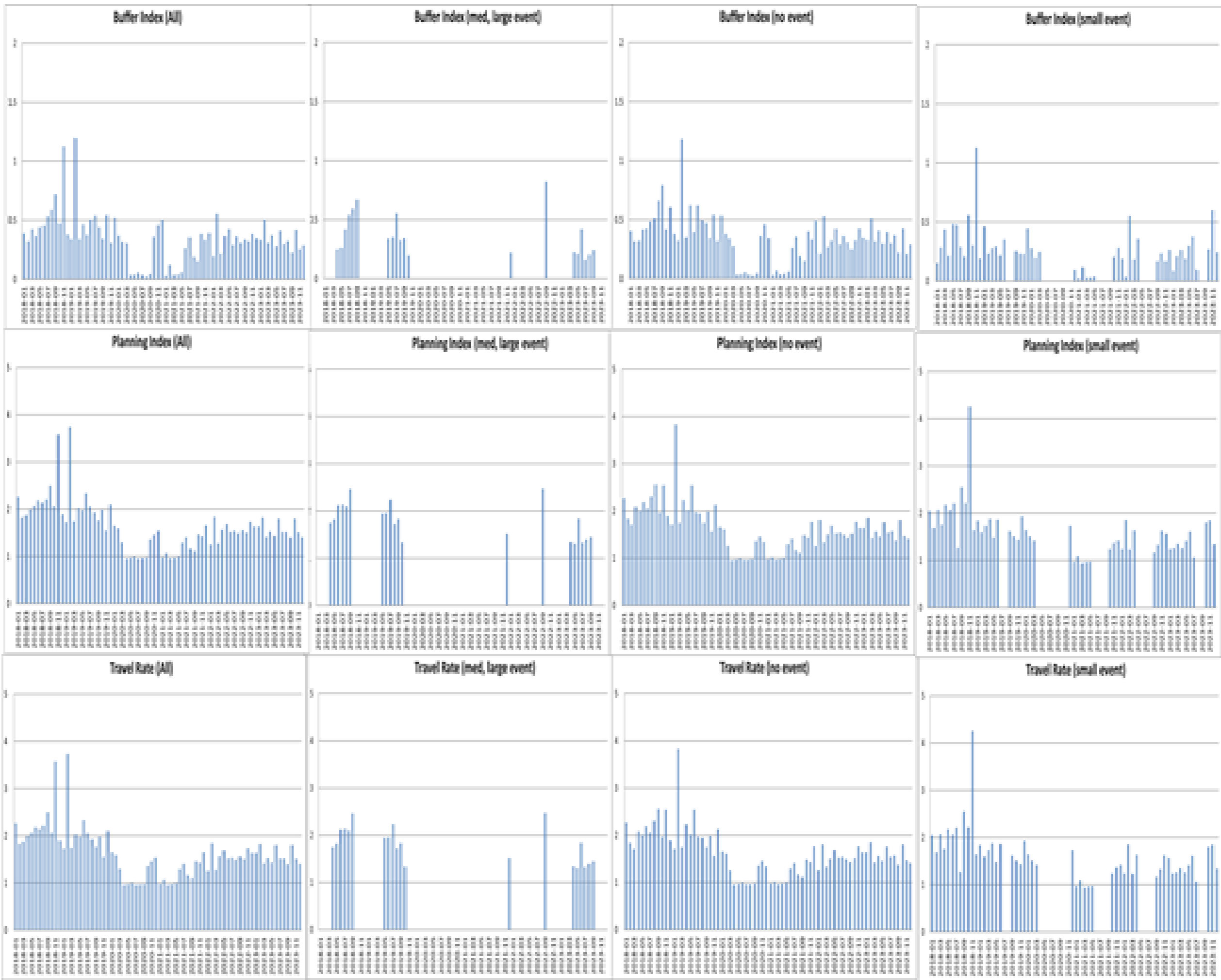

All
med, large event
no event
small event
Buffer Index
0.75
0.22
0.73
0.87
0.65
0.91
0.67
0.61
0.64
0.28
0.63
0.68
0.19
0.64
0.55
0.55
2018
2019
2020
2021
2022
2023
Planning Index
3.00
3.04
2.91
4.16
2.59
4.36
1.66
1.54
1.88
1.53
1.89
2.08
1.08
2.06
1.95
1.94
Travel Rate
3.28
3.31
3.17
4.53
2.82
4.76
1.81
1.68
2.05
1.67
2.07
2.27
1.18
2.25
2.12
2.12

3) I-394 Corridor B (MPLS to US169, Westbound)

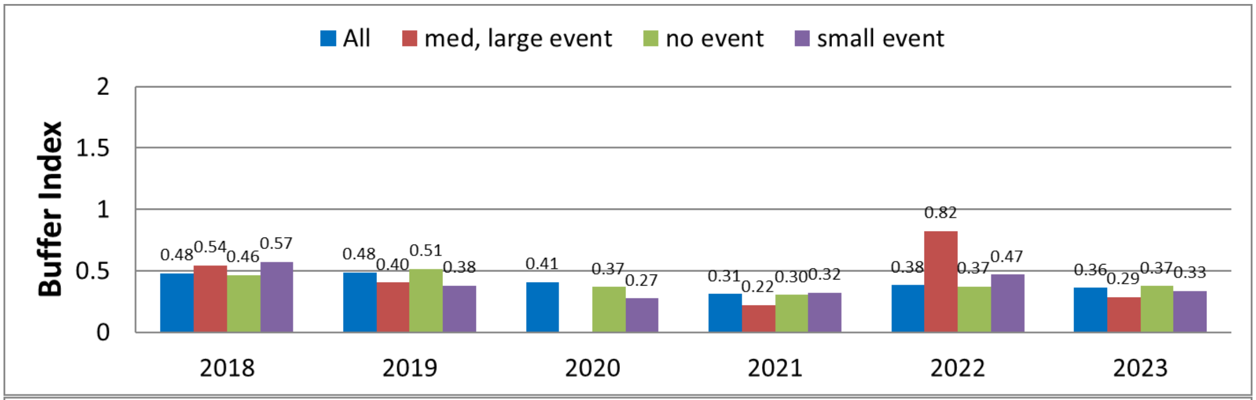


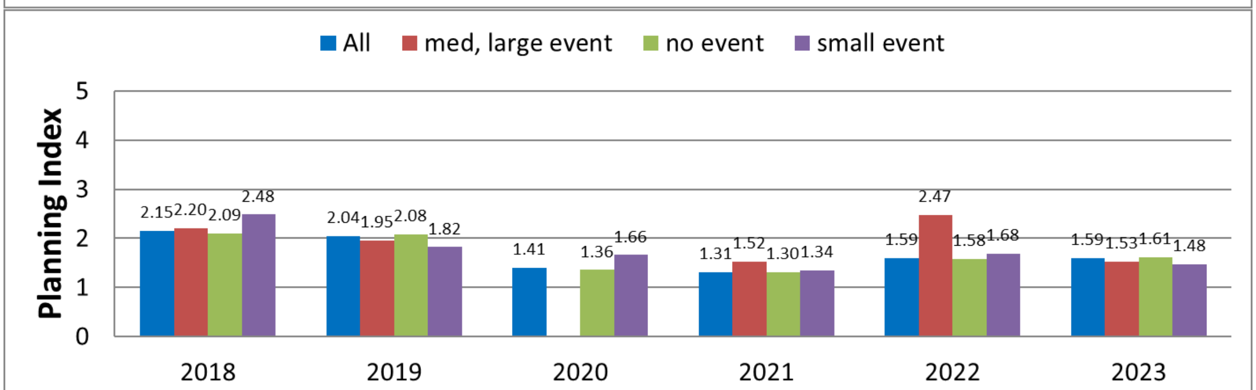
i) I-394 Corridor B-- WB for MPLS to US169

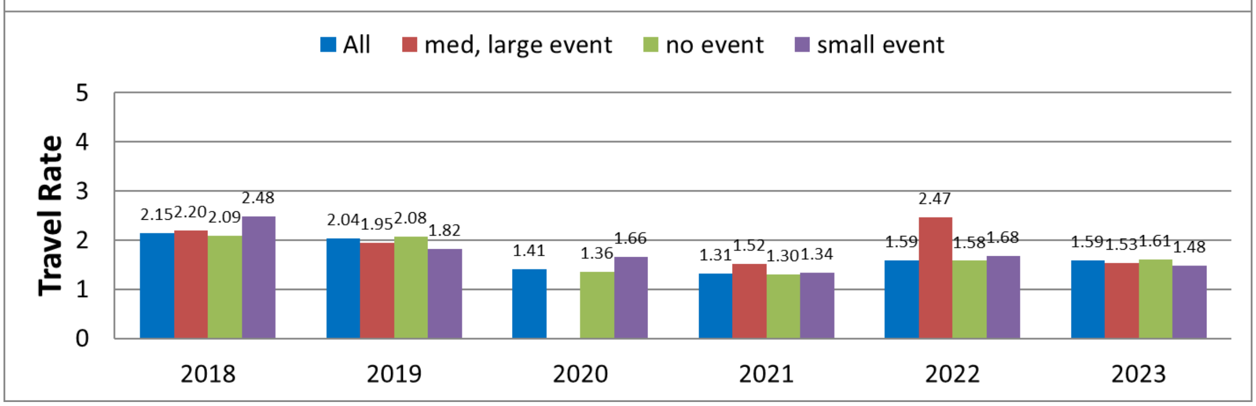
Monthly variations



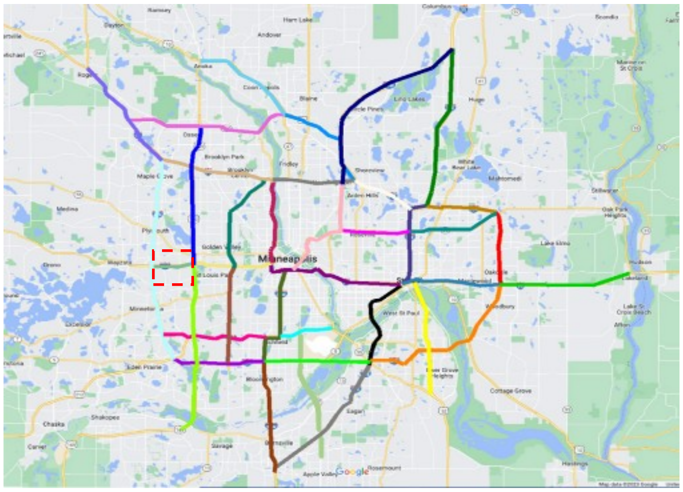
Yearly variations


All
med, large event
no event
small event
Buffer Index
2
1.5
1
0.5
0
0.48 0.54 0.46 0.57
0.48 0.40 0.51 0.38
0.41 0.37 0.27
0.31 0.22 0.30 0.32
0.38 0.82 0.37 0.47
0.36 0.29 0.37 0.33
2018
2019
2020
2021
2022
2023


All
med, large event
no event
small event
Planning Index
5
4
3
2
1
0
2.15 2.20 2.09 2.48
2.04 1.95 2.08 1.82
1.41 1.36 1.66
1.31 1.52 1.30 1.34
1.59 2.47 1.58 1.68
1.59 1.53 1.61 1.48
2018
2019
2020
2021
2022
2023

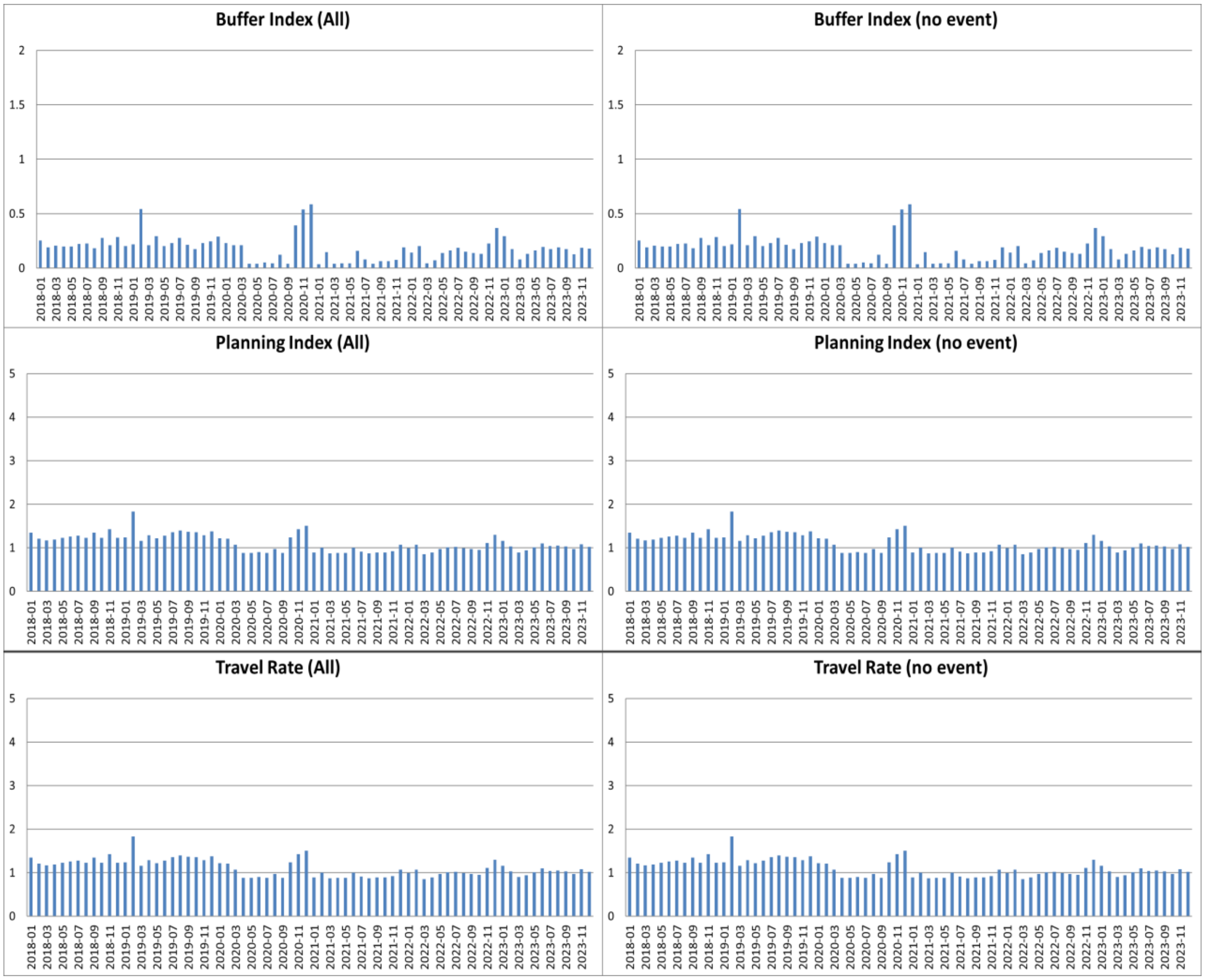

All
med, large event
no event
small event
Travel Rate
5
4
3
2
1
0
2.15 2.20 2.09 2.48
2.04 1.95 2.08 1.82
1.41 1.36 1.66
1.31 1.52 1.30 1.34
1.59 2.47 1.58 1.68
1.59 1.53 1.61 1.48
2018
2019
2020
2021
2022
2023

4) I-394 Corridor A (169 to I494, Westbound)

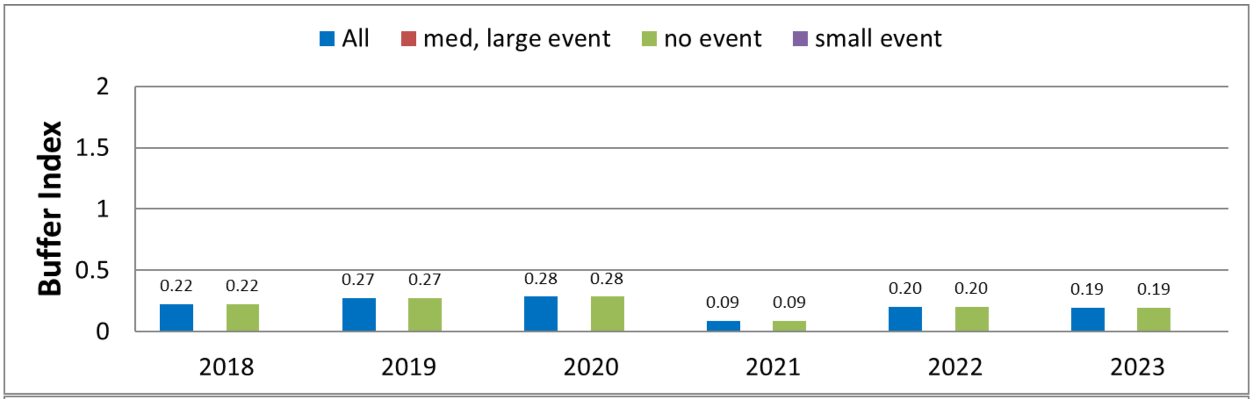


i) I-394 Corridor A -- WB for L2 - 169 to I494

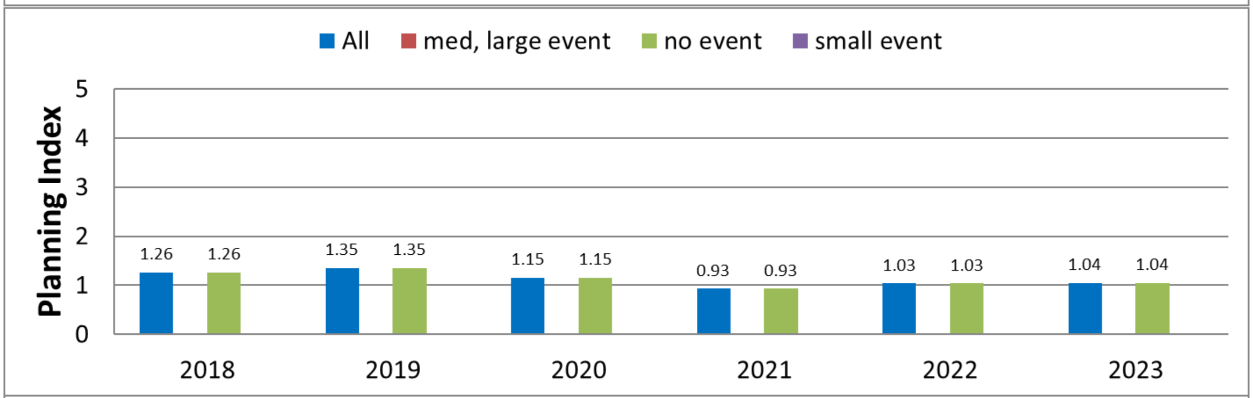
Monthly variations



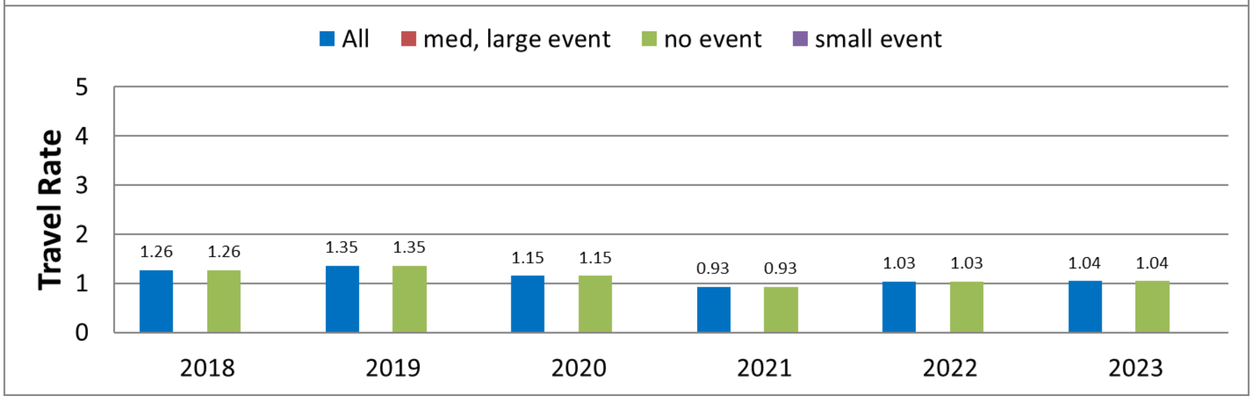
Yearly variations



All
med, large event
no event
small event
Buffer Index
2
1.5
1
0.5
0
0.22
0.22
0.27
0.27
0.28
0.28
0.09
0.09
0.20
0.20
0.19
0.19
2018
2019
2020
2021
2022
2023

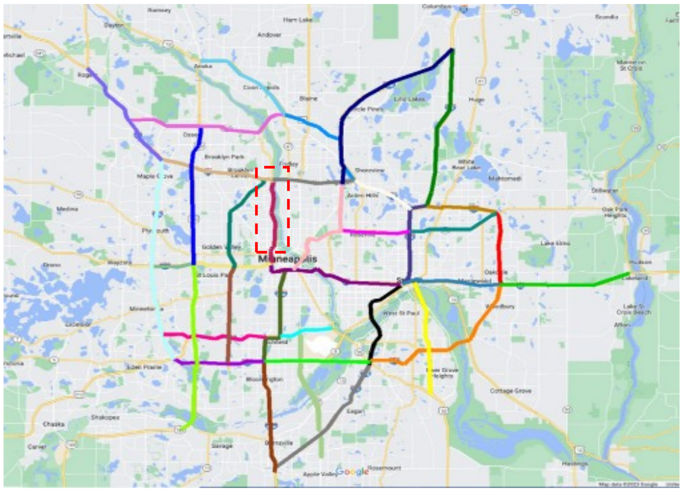


All
med, large event
no event
small event
Planning Index
5
4
3
2
1
0
1.26
1.26
1.35
1.35
1.15
1.15
0.93
0.93
1.03
1.03
1.04
1.04
2018
2019
2020
2021
2022
2023



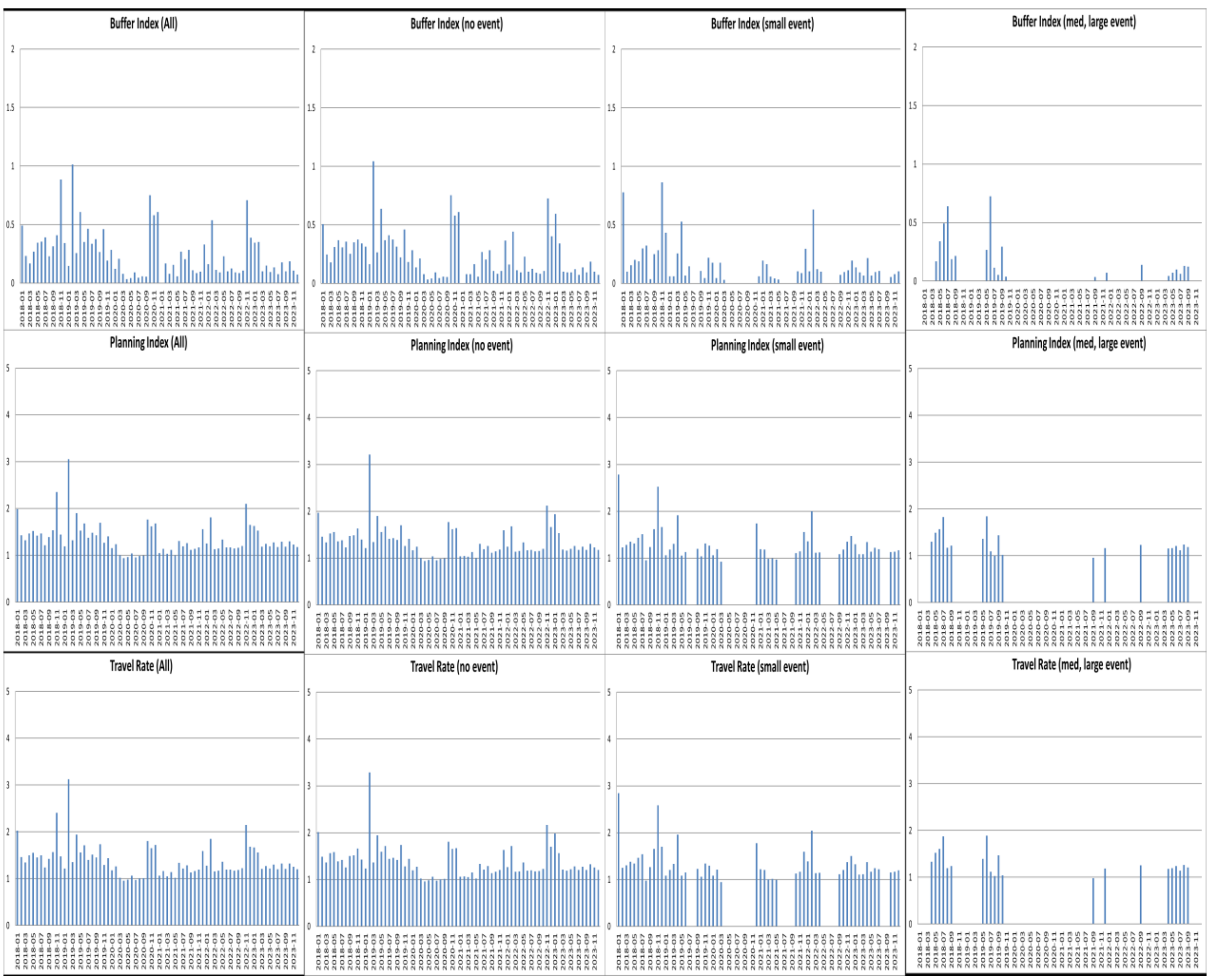
All
med, large event
no event
small event
Travel Rate
5
4
3
2
1
0
1.26
1.26
1.35
1.35
1.15
1.15
0.93
0.93
1.03
1.03
1.04
1.04
2018
2019
2020
2021
2022
2023

5) I-94 Corridor C (MPLS to TH252, Westbound)

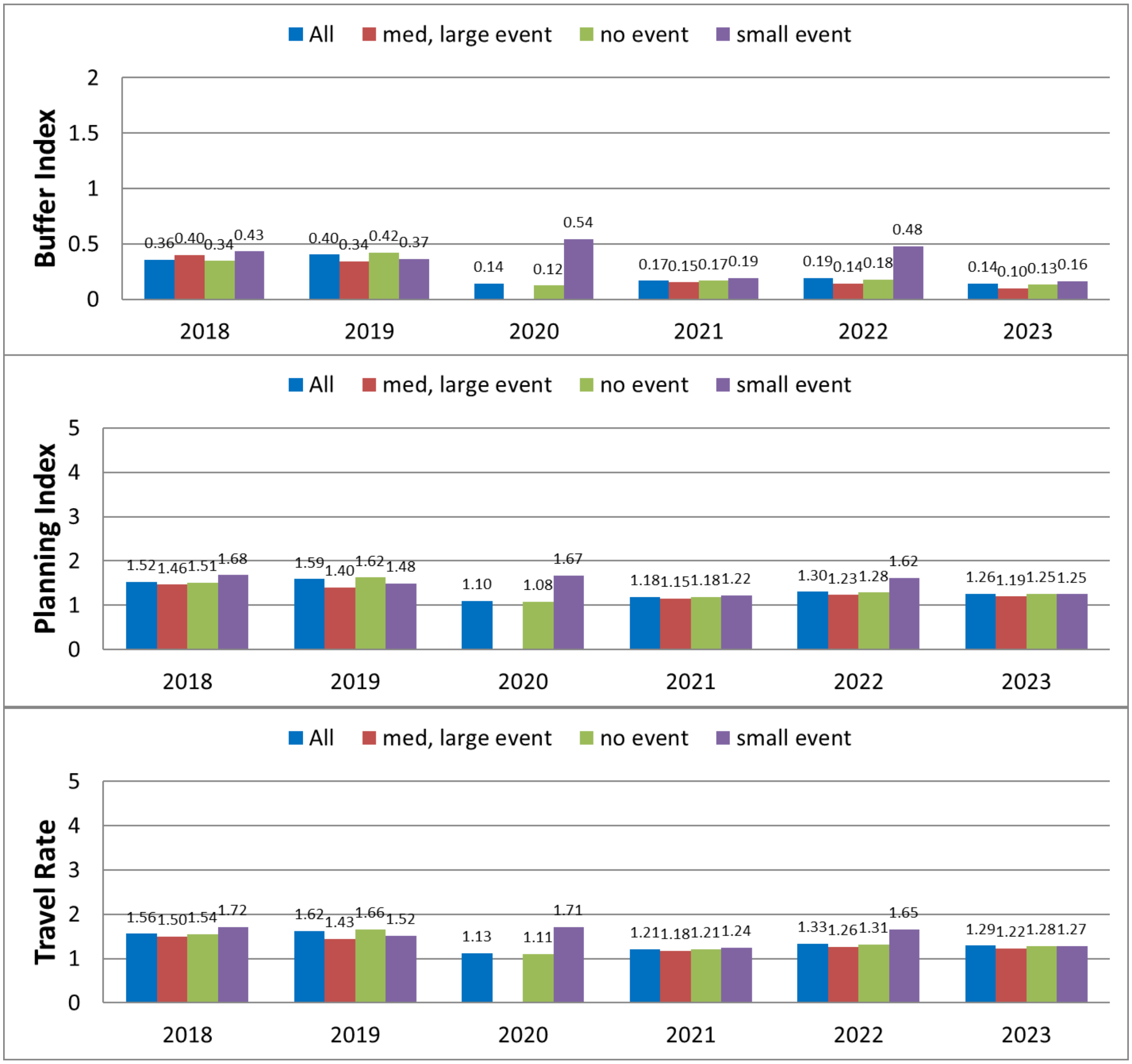


i) I-94 Corridor C -- WB for L2 - MPLS to TH252

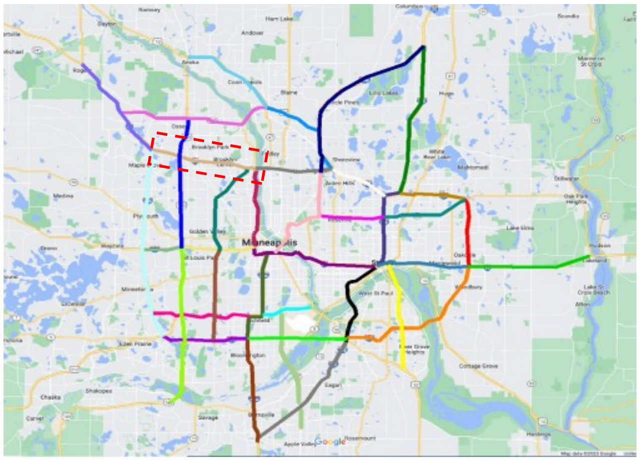
Monthly variations



Yearly variations

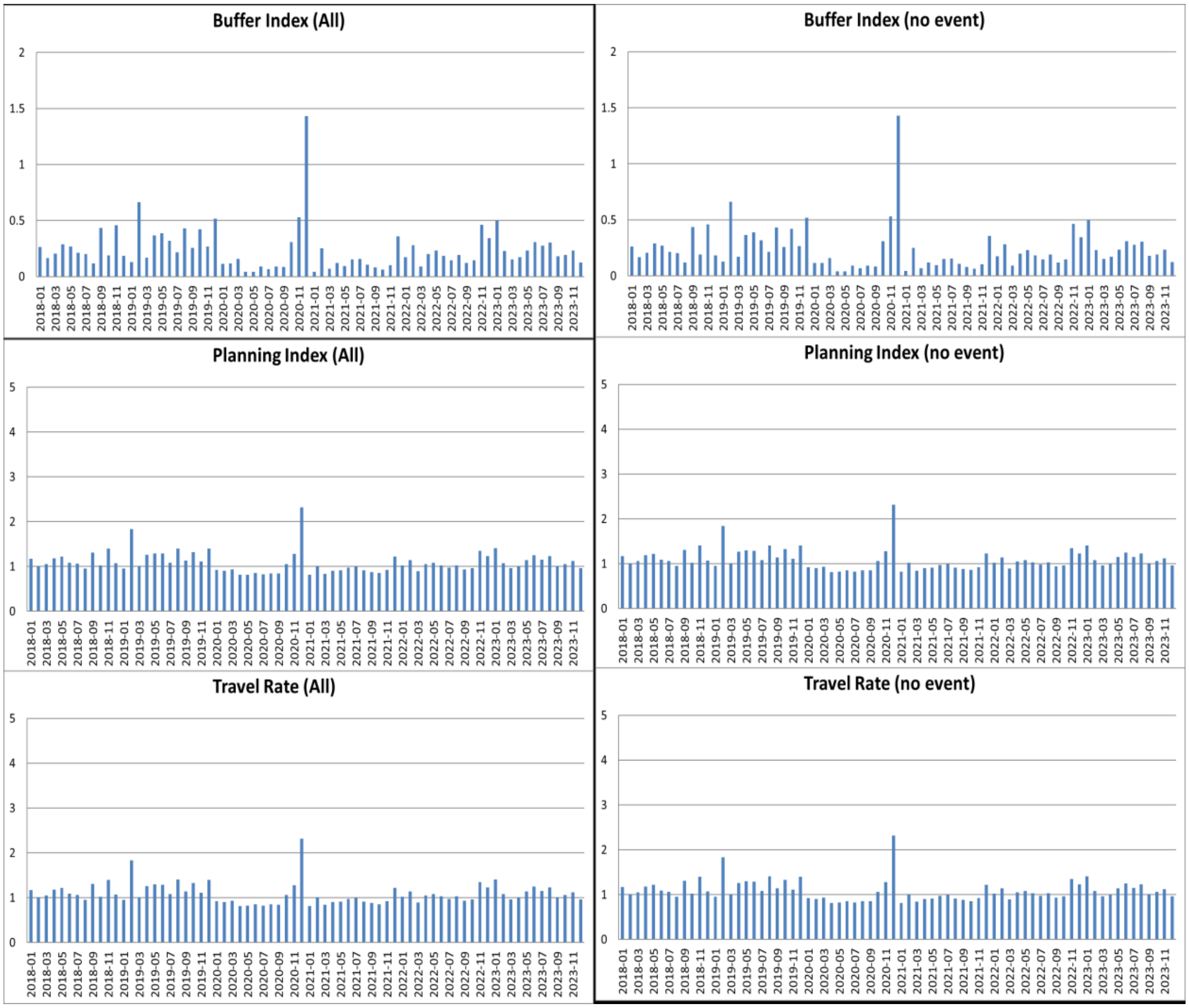


6) I-94 Corridor B (TH252 to I494, Westbound)

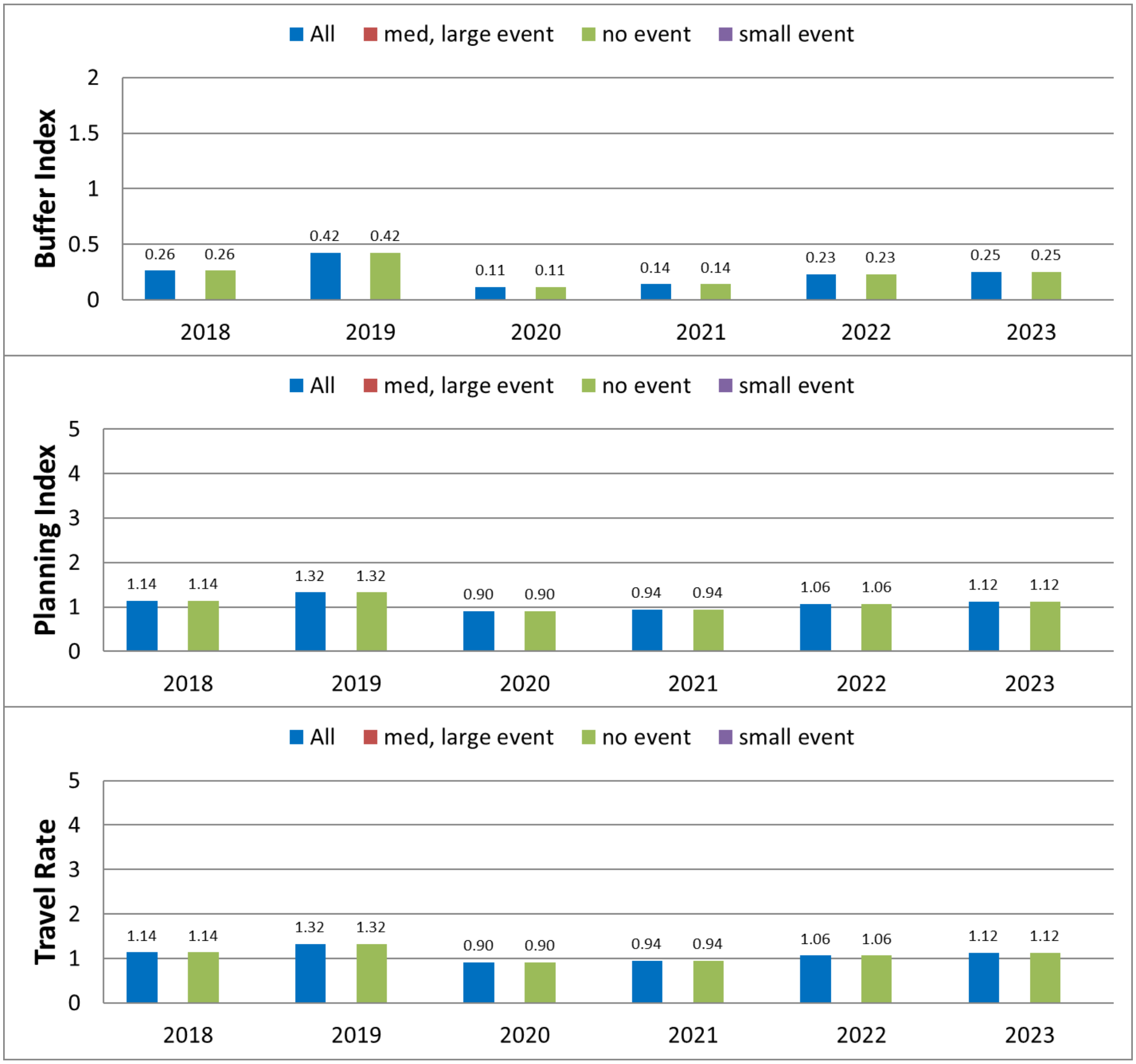


i)I-94 Corridor B -- WB for L2 - TH252 to I494

Monthly variations

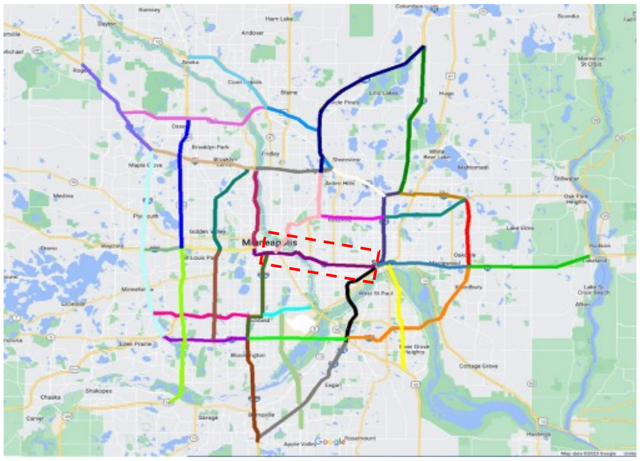


Yearly variations



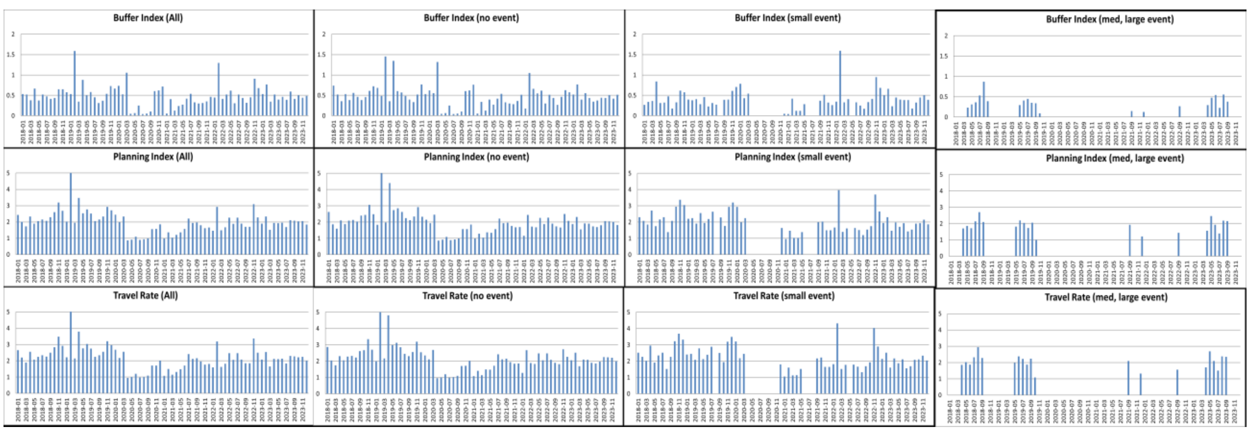
All
med, large event
no event
small event
Buffer Index
2
1.5
1
0.5
0
0.26
0.26
0.42
0.42
0.11
0.11
0.14
0.14
0.23
0.23
0.25
0.25
2018
2019
2020
2021
2022
2023
All
med, large event
no event
small event
Planning Index
5
4
3
2
1
0
1.14
1.14
1.32
1.32
0.90
0.90
0.94
0.94
1.06
1.06
1.12
1.12
2018
2019
2020
2021
2022
2023
All
med, large event
no event
small event
Travel Rate
5
4
3
2
1
0
1.14
1.14
1.32
1.32
0.90
0.90
0.94
0.94
1.06
1.06
1.12
1.12
2018
2019
2020
2021
2022
2023

7) I-94 Corridor D (MPLS <–> STPL, Eastbound/Westbound)

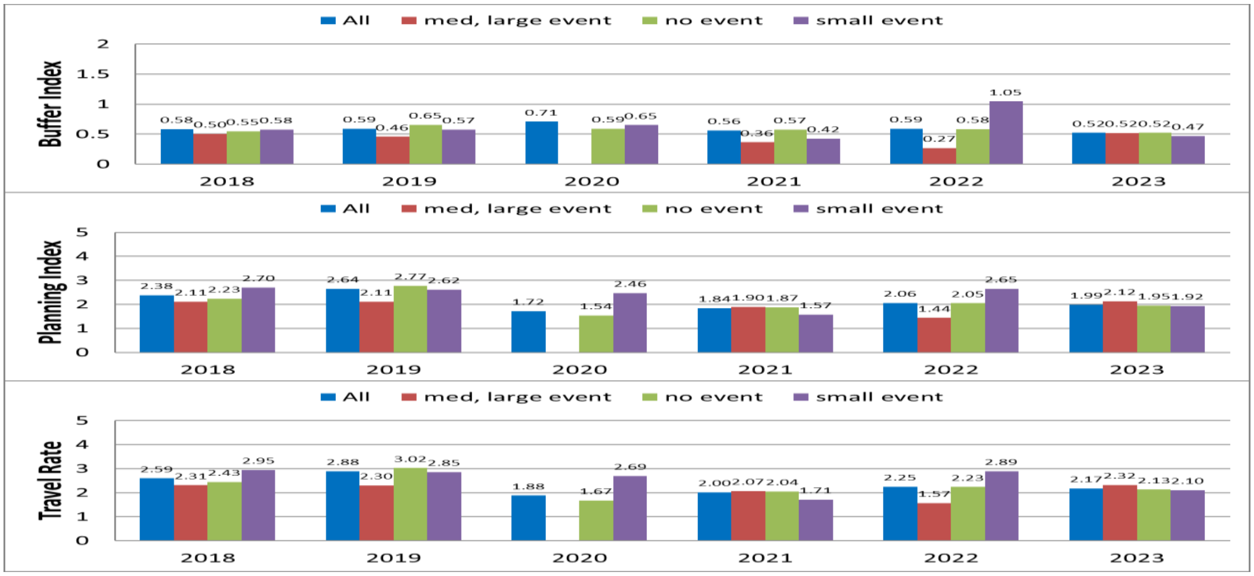


i) I-94 Corridor D -- EB for MPLS to STPL

Monthly variations



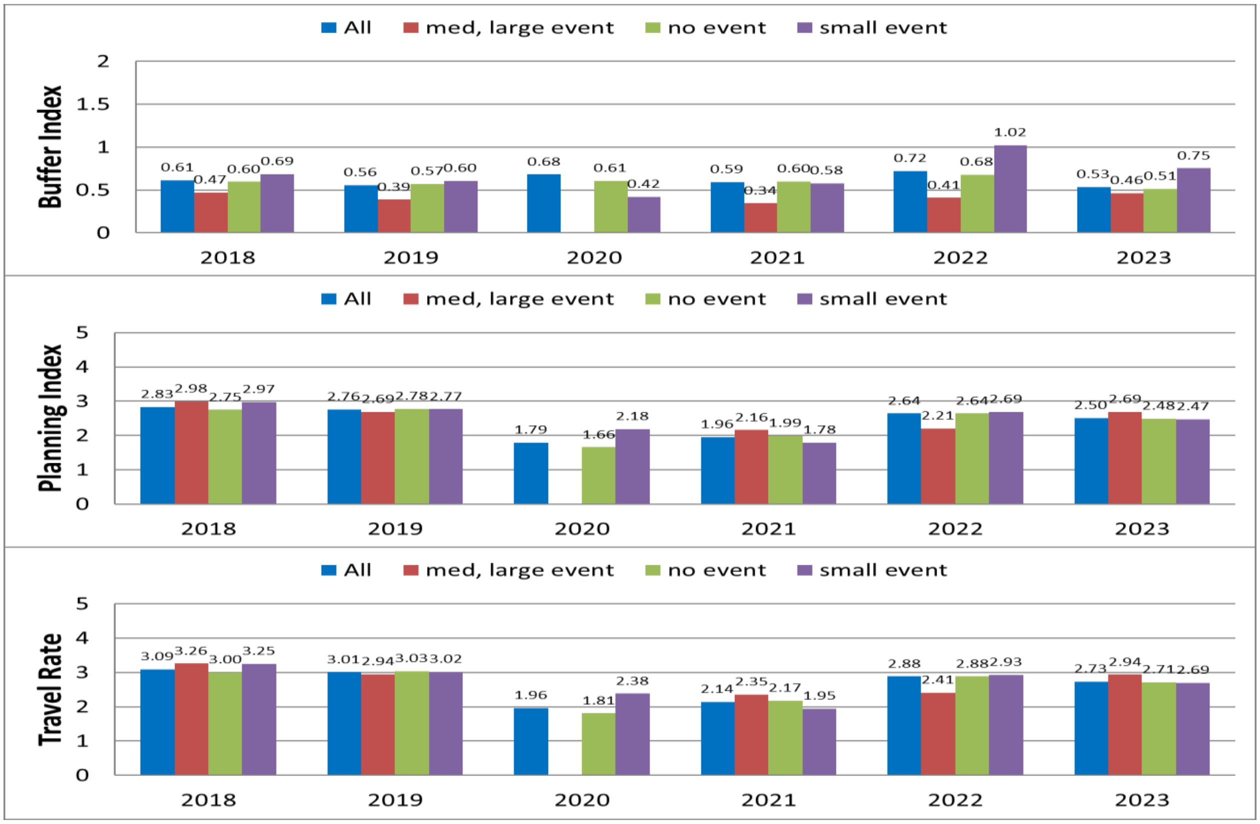
Yearly variations



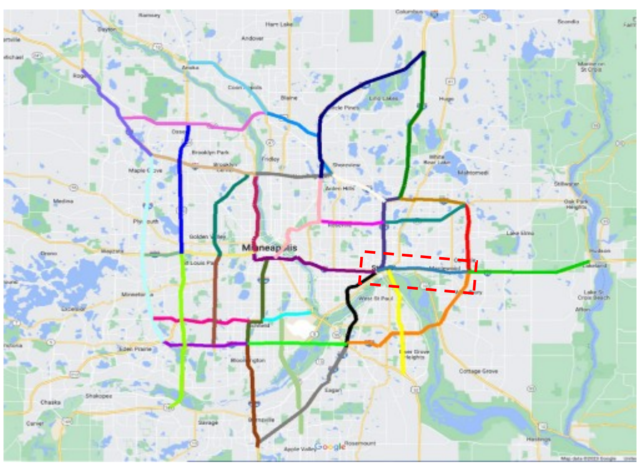
ii) I-94 Corridor D -- WB for STPL to MPLS

Monthly variations

Yearly variations

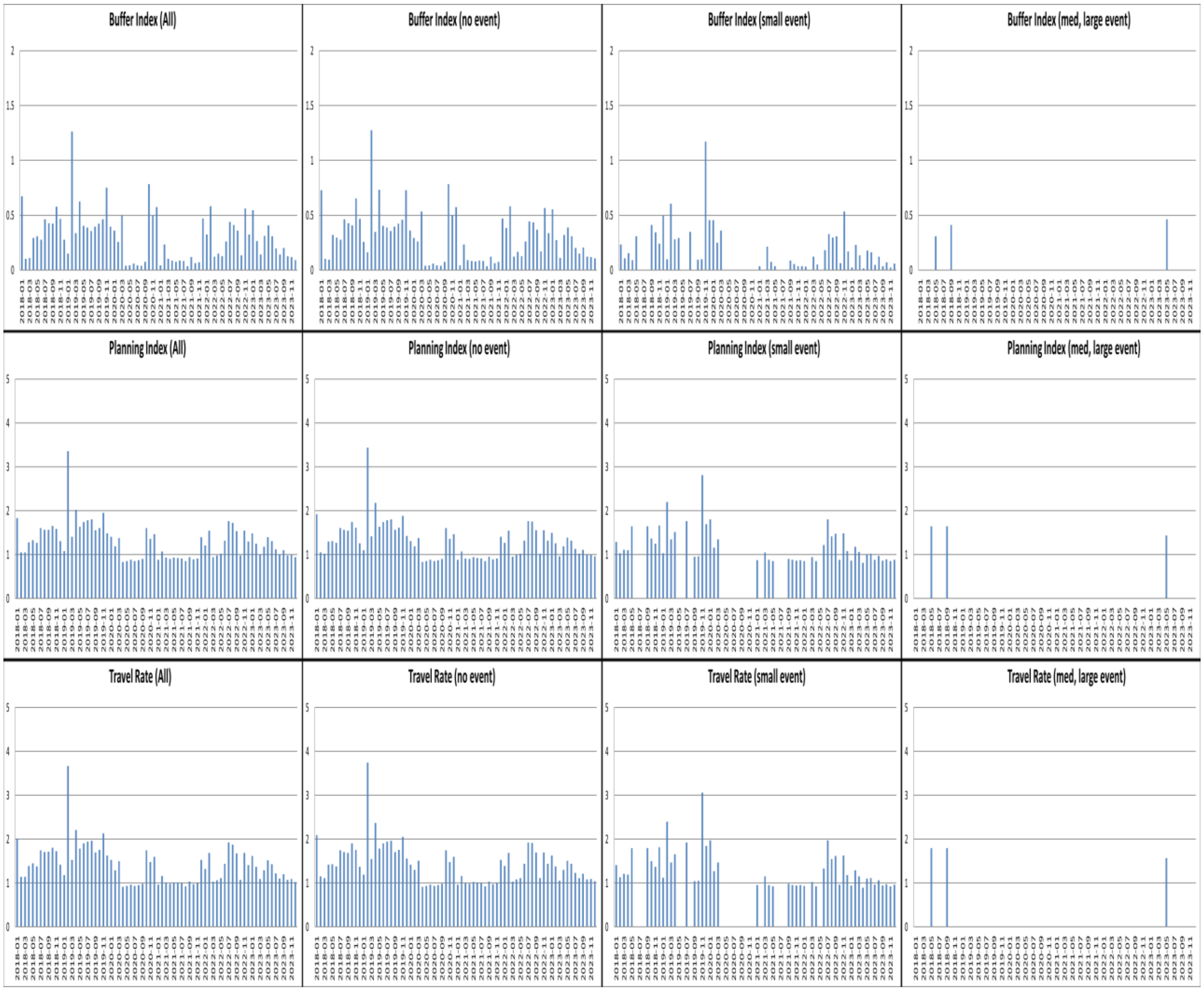


8) I-94 Corridor E (STPL to I694, Eastbound)

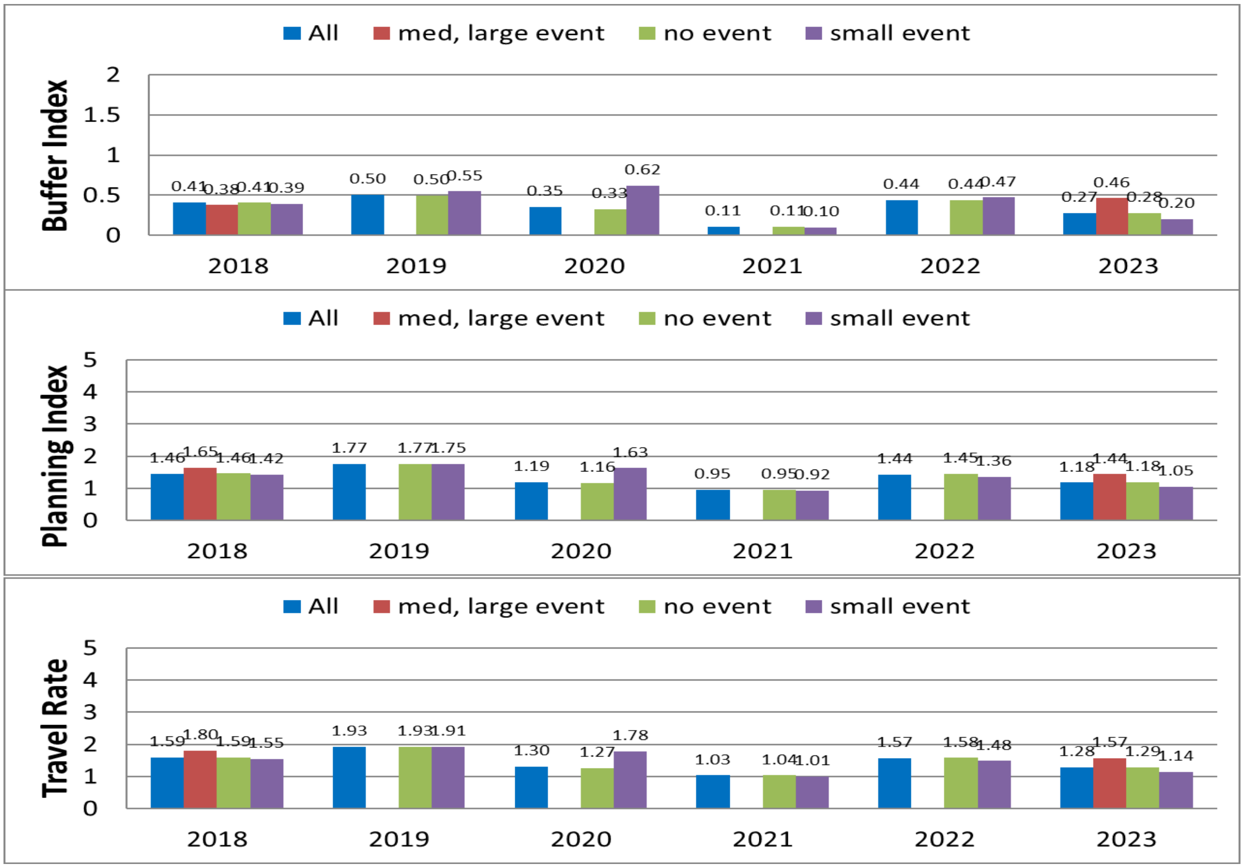


i) I-94 Corridor E -- EB for STPL to I694

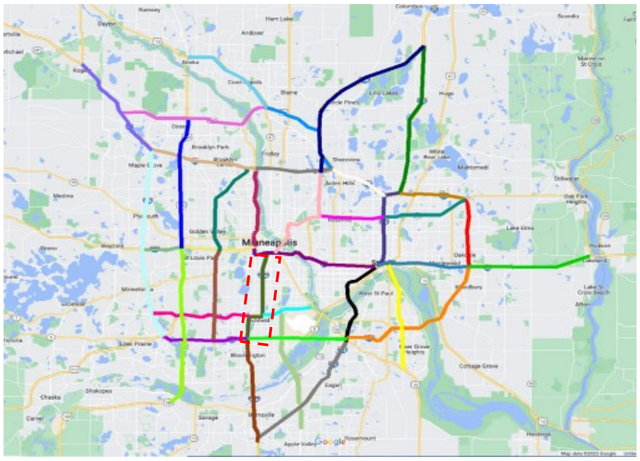
Monthly variations



Yearly variations

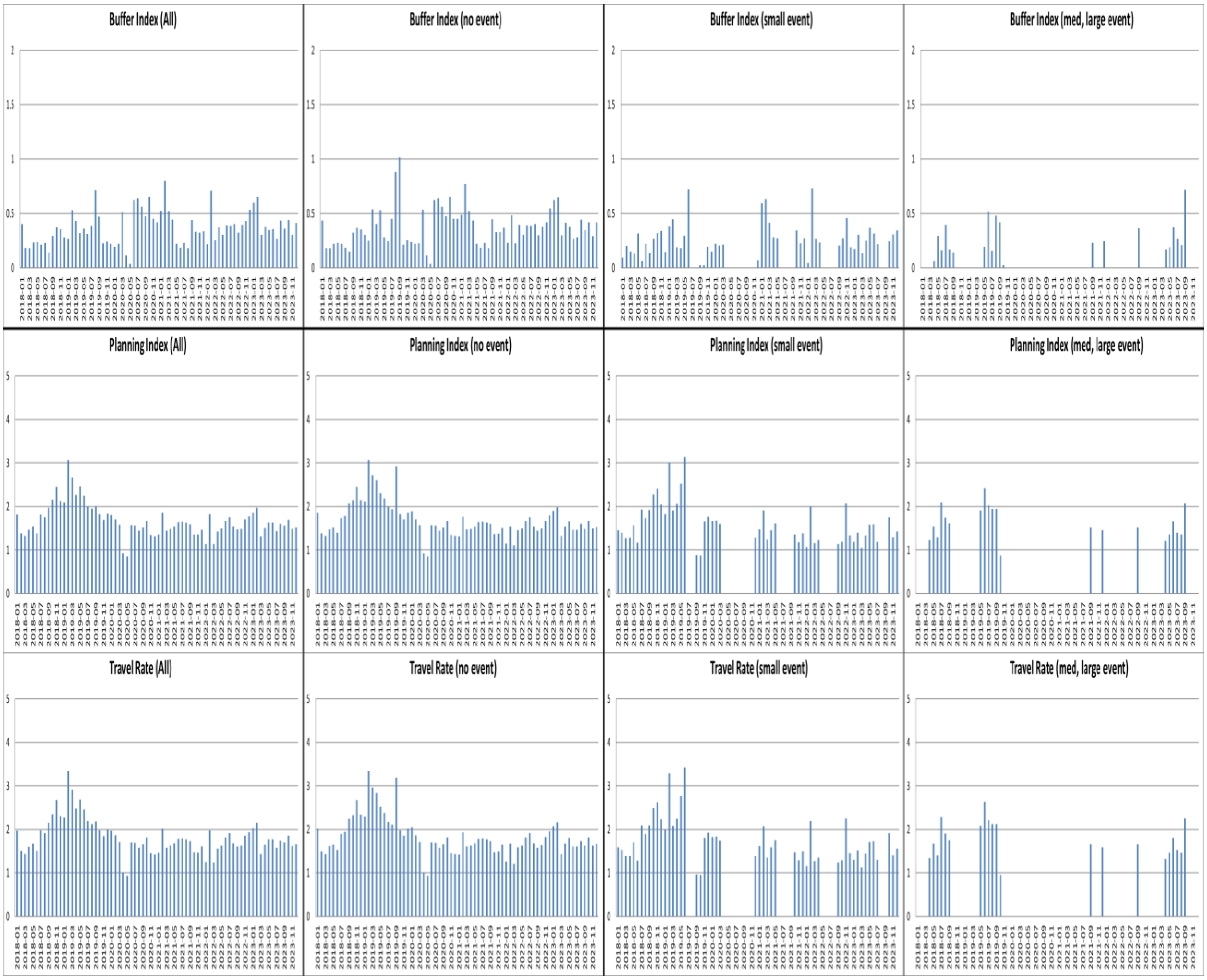

All
med, large event
no event
small event
Buffer Index
2
1.5
1
0.5
0
0.41
0.38
0.41
0.39
0.50
0.50
0.55
0.35
0.33
0.62
0.11
0.11
0.10
0.44
0.44
0.47
0.27
0.46
0.28
0.20
2018
2019
2020
2021
2022
2023
All
med, large event
no event
small event
Planning Index
5
4
3
2
1
0
1.46
1.65
1.46
1.42
1.77
1.77
1.75
1.19
1.16
1.63
0.95
0.95
0.92
1.44
1.45
1.36
1.18
1.44
1.18
1.05
2018
2019
2020
2021
2022
2023
All
med, large event
no event
small event
Travel Rate
5
4
3
2
1
0
1.59
1.80
1.59
1.55
1.93
1.93
1.91
1.30
1.27
1.78
1.03
1.04
1.01
1.57
1.58
1.48
1.28
1.57
1.29
1.14
2018
2019
2020
2021
2022
2023

9) I-35W Corridor B (MPLS to I494, Southbound)

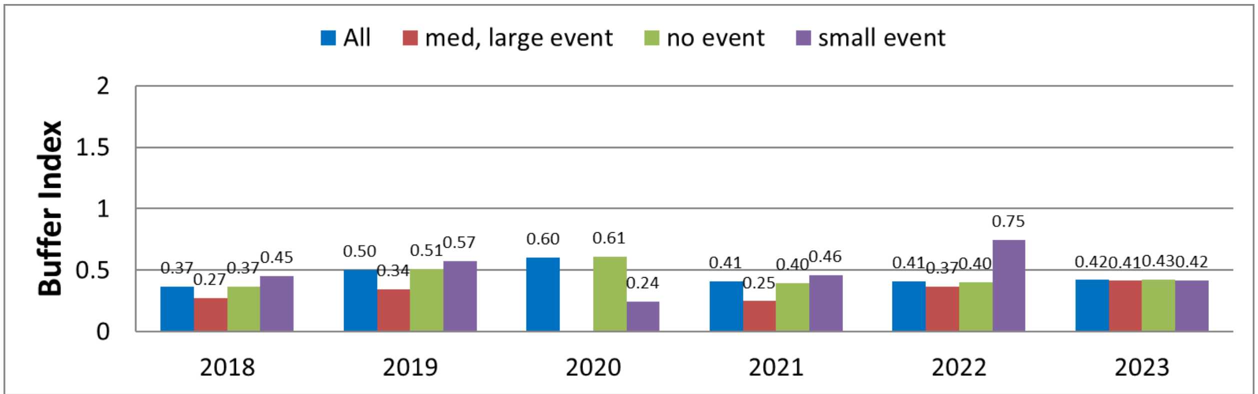


i) I-35W Corridor B -- SB for MPLS to I494

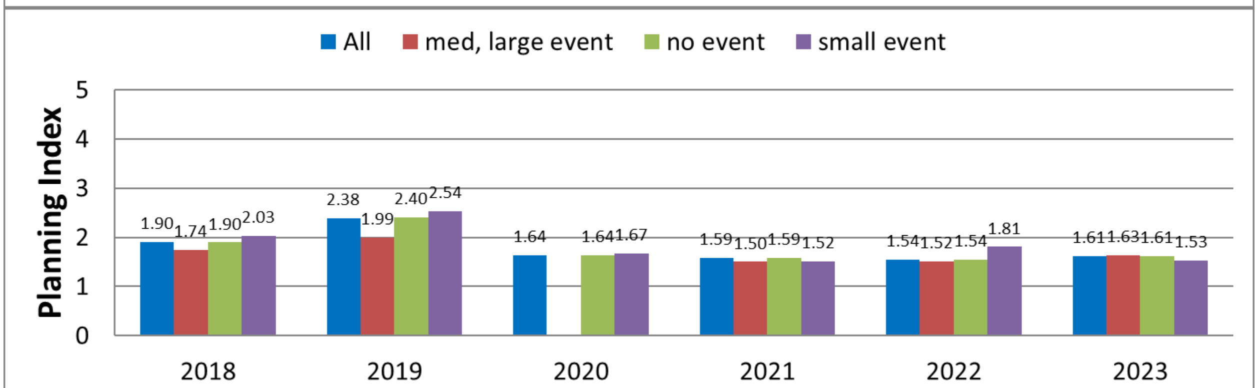
Monthly variations



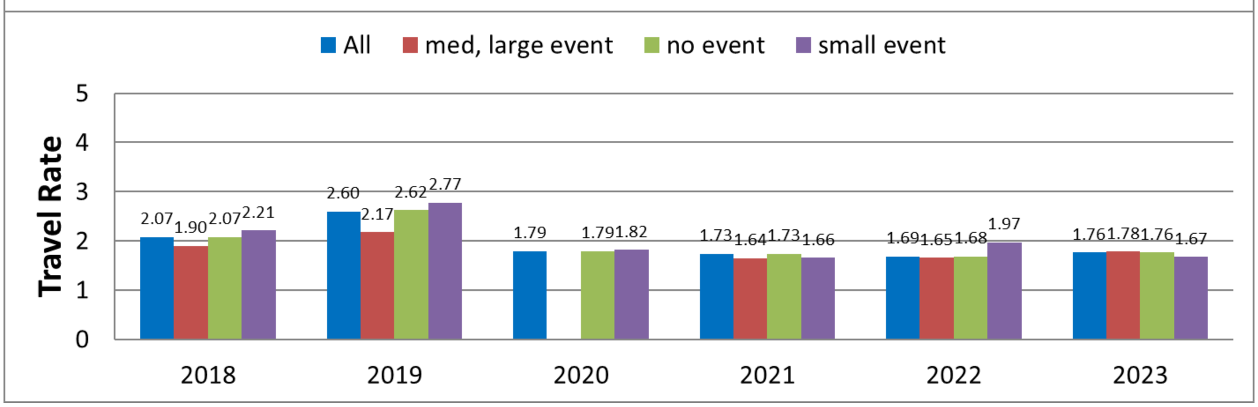
Yearly variations



All
med, large event
no event
small event
Buffer Index
2
1.5
1
0.5
0
0.37
0.27
0.37
0.45
0.50
0.34
0.51
0.57
0.60
0.61
0.24
0.41
0.25
0.40
0.46
0.41
0.37
0.40
0.75
0.42
0.41
0.43
0.42
2018
2019
2020
2021
2022
2023

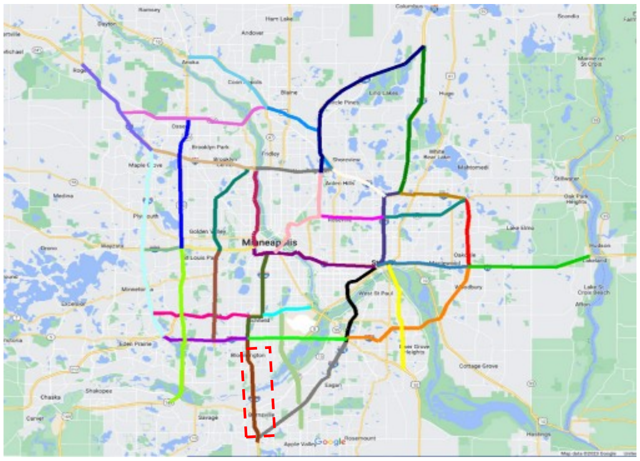


All
med, large event
no event
small event
Planning Index
5
4
3
2
1
0
1.90
1.74
1.90
2.03
2.38
1.99
2.40
2.54
1.64
1.64
1.67
1.59
1.50
1.59
1.52
1.54
1.52
1.54
1.81
1.61
1.63
1.61
1.53
2018
2019
2020
2021
2022
2023



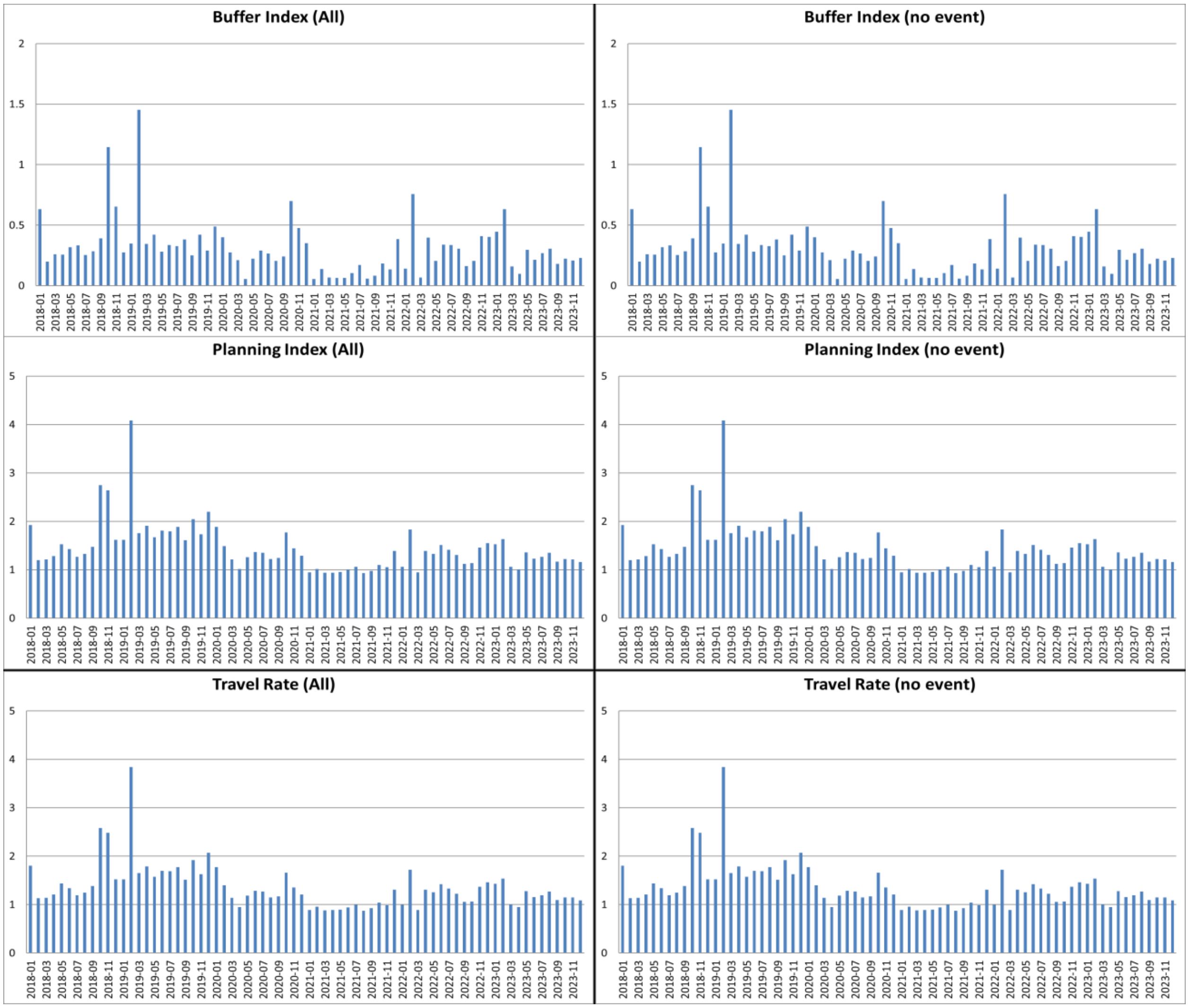
All
med, large event
no event
small event
Travel Rate
5
4
3
2
1
0
2.07
1.90
2.07
2.21
2.60
2.17
2.62
2.77
1.79
1.79
1.82
1.73
1.64
1.73
1.66
1.69
1.65
1.68
1.97
1.76
1.78
1.76
1.67
2018
2019
2020
2021
2022
2023

10) I-35W Corridor A (I494 to I35, Southbound)

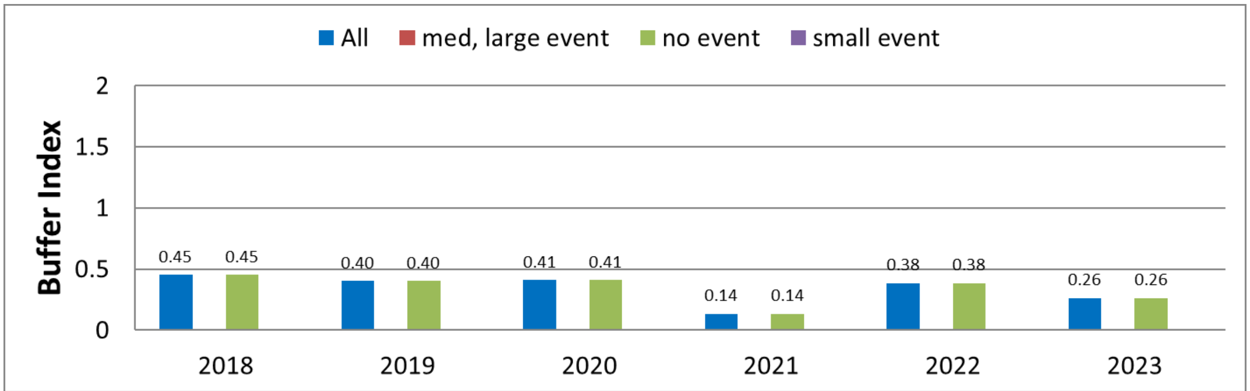


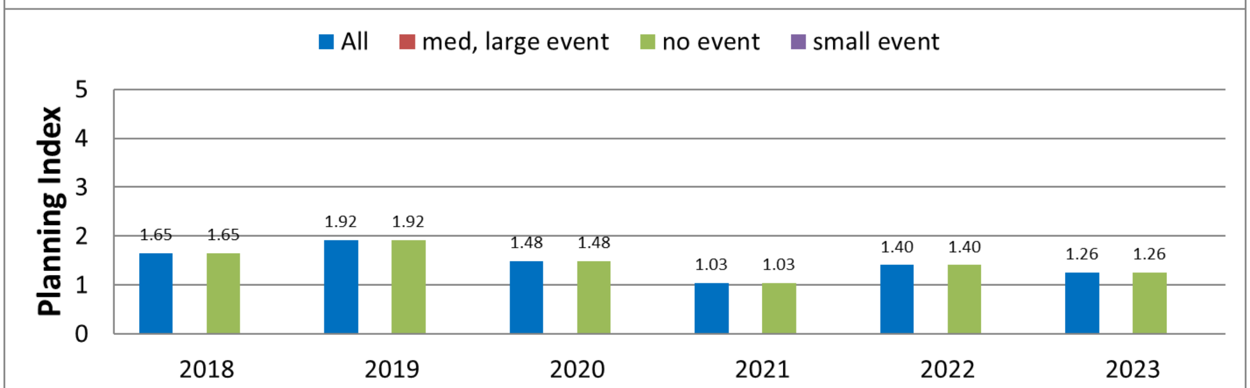
i) I-35W Corridor A-- SB for I494 to I35

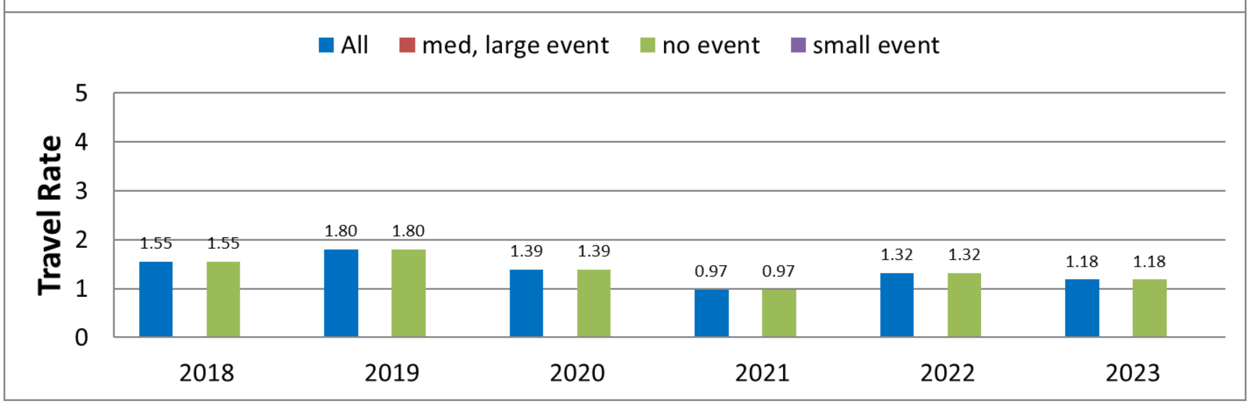
Monthly variations



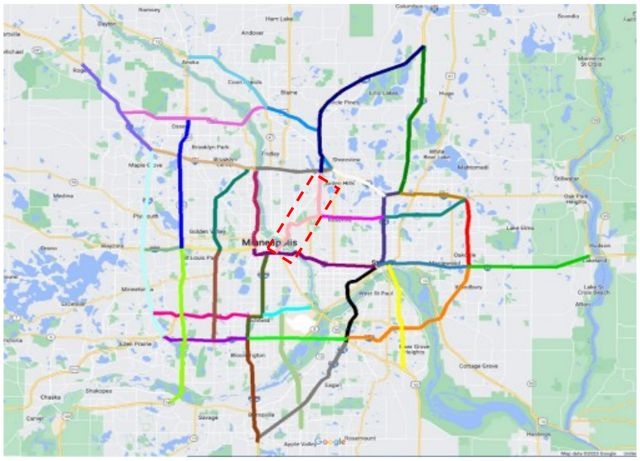
Yearly variations


All
med, large event
no event
small event
Buffer Index
2
1.5
1
0.5
0
0.45
0.45
0.40
0.40
0.41
0.41
0.14
0.14
0.38
0.38
0.26
0.26
2018
2019
2020
2021
2022
2023


All
med, large event
no event
small event
Planning Index
5
4
3
2
1
0
1.65
1.65
1.92
1.92
1.48
1.48
1.03
1.03
1.40
1.40
1.26
1.26
2018
2019
2020
2021
2022
2023


All
med, large event
no event
small event
Travel Rate
5
4
3
2
1
0
1.55
1.55
1.80
1.80
1.39
1.39
0.97
0.97
1.32
1.32
1.18
1.18
2018
2019
2020
2021
2022
2023

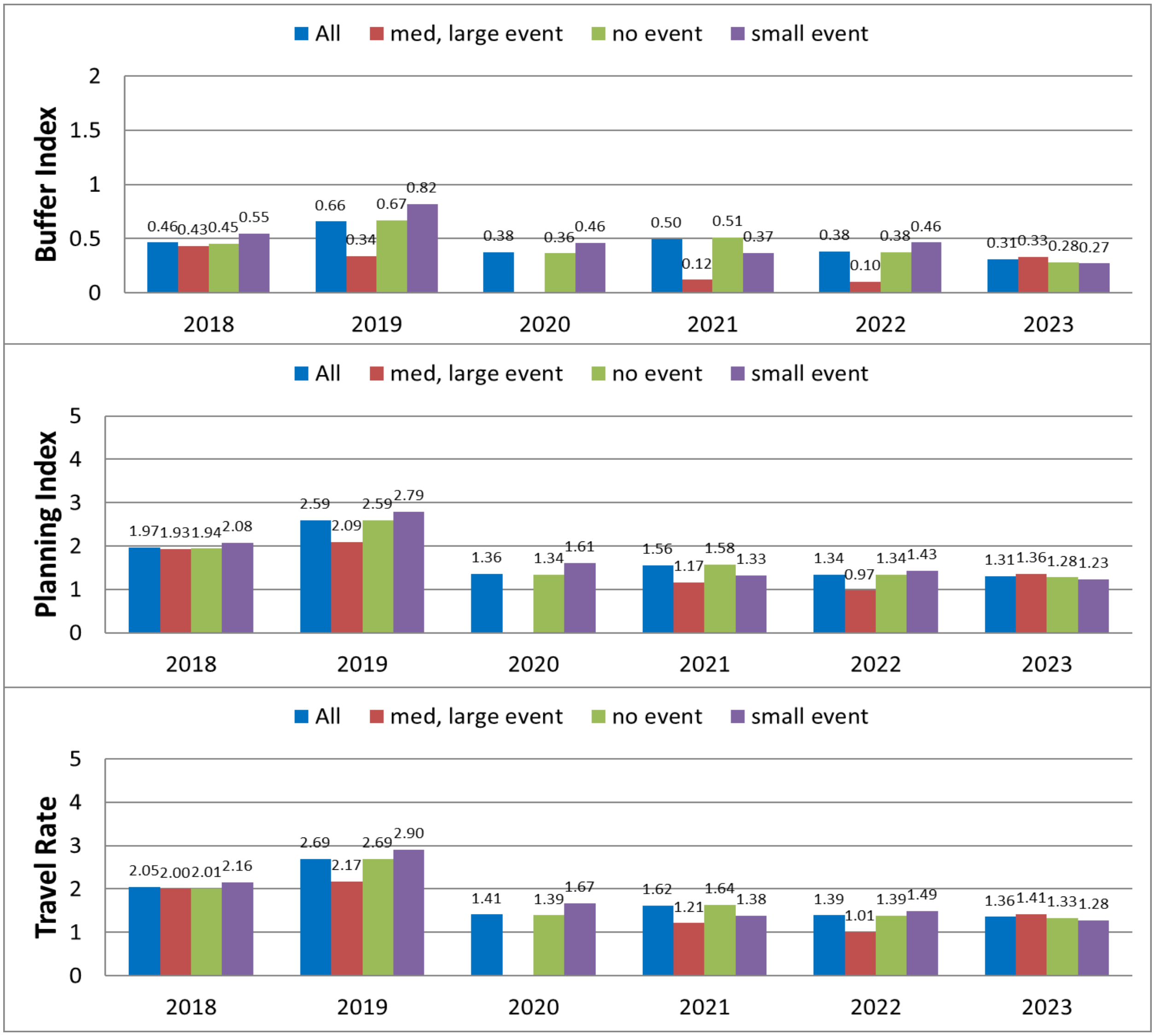
11) I-35W Corridor C (MPLS to I694, Northbound)



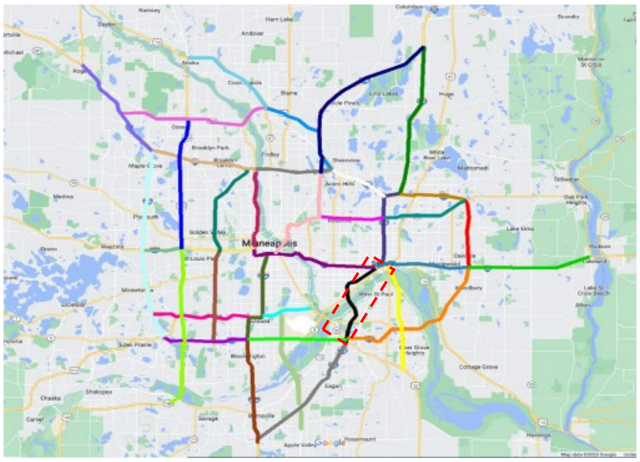
i) I-35W Corridor C -- NB MPLS to I694

Monthly variations

Yearly variations

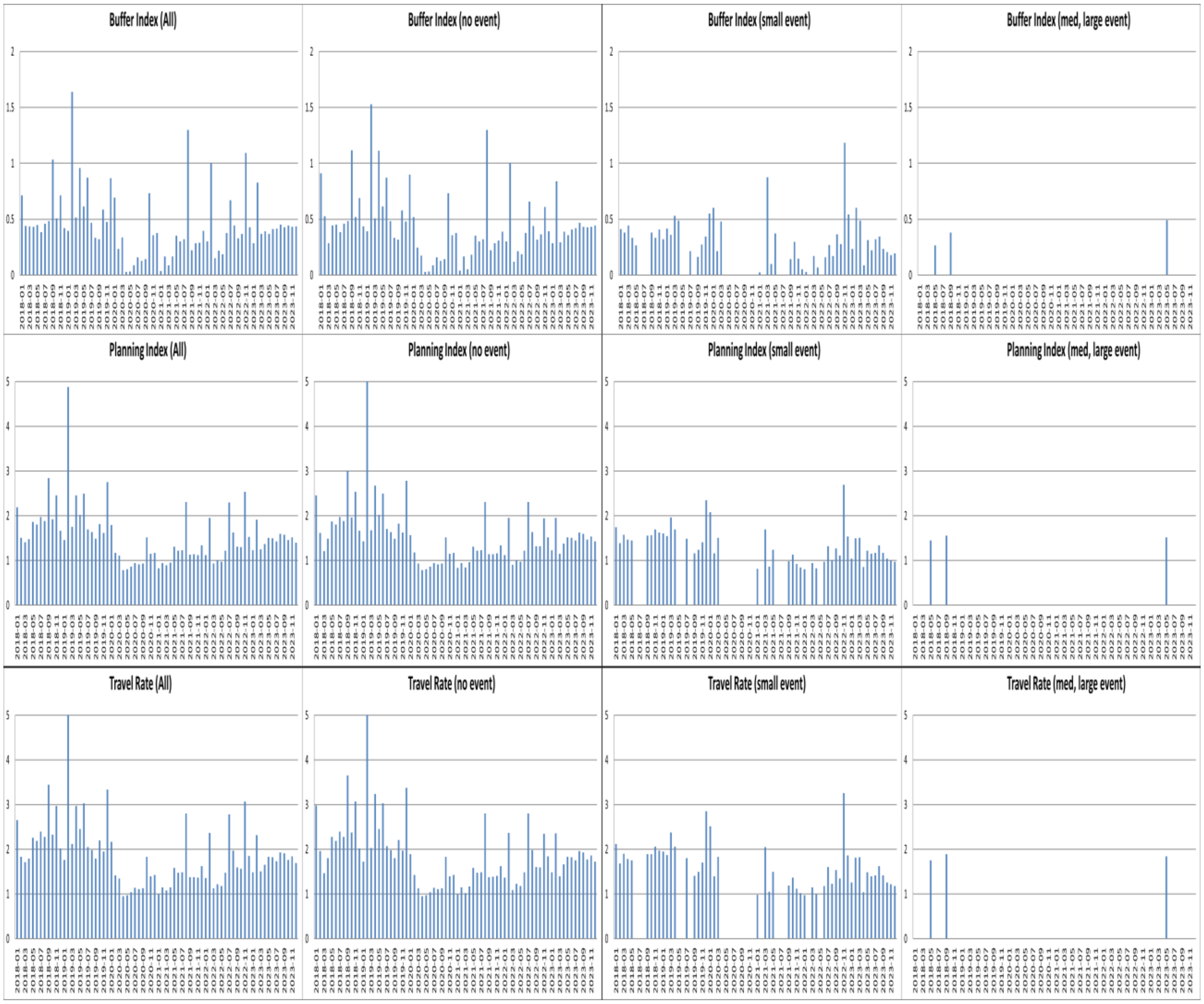


12) I-35E Corridor B (STPL to I494, Southbound)

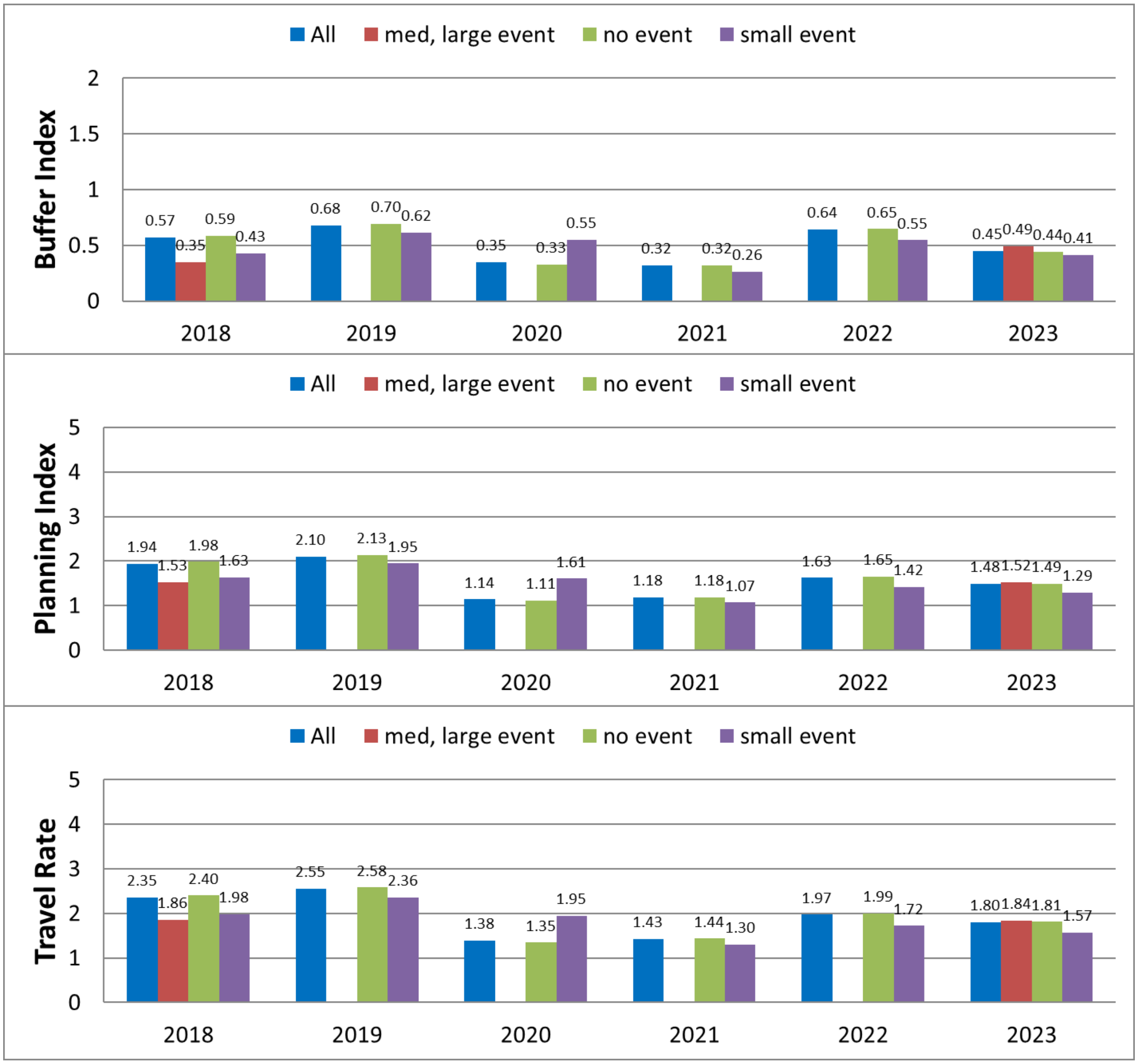


i) I-35E Corridor B -- SB for STPL to I494

Monthly variations

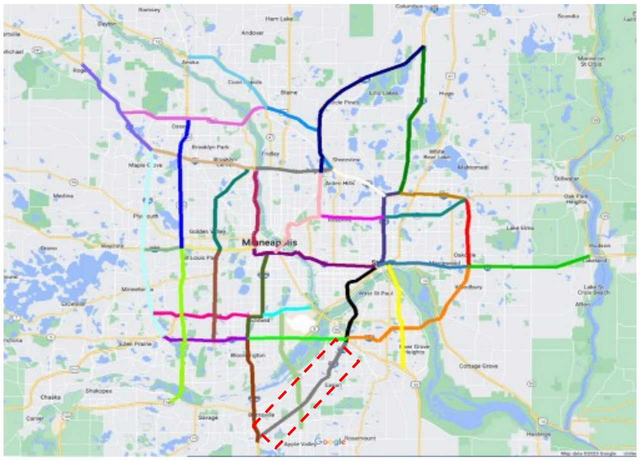


Yearly variations



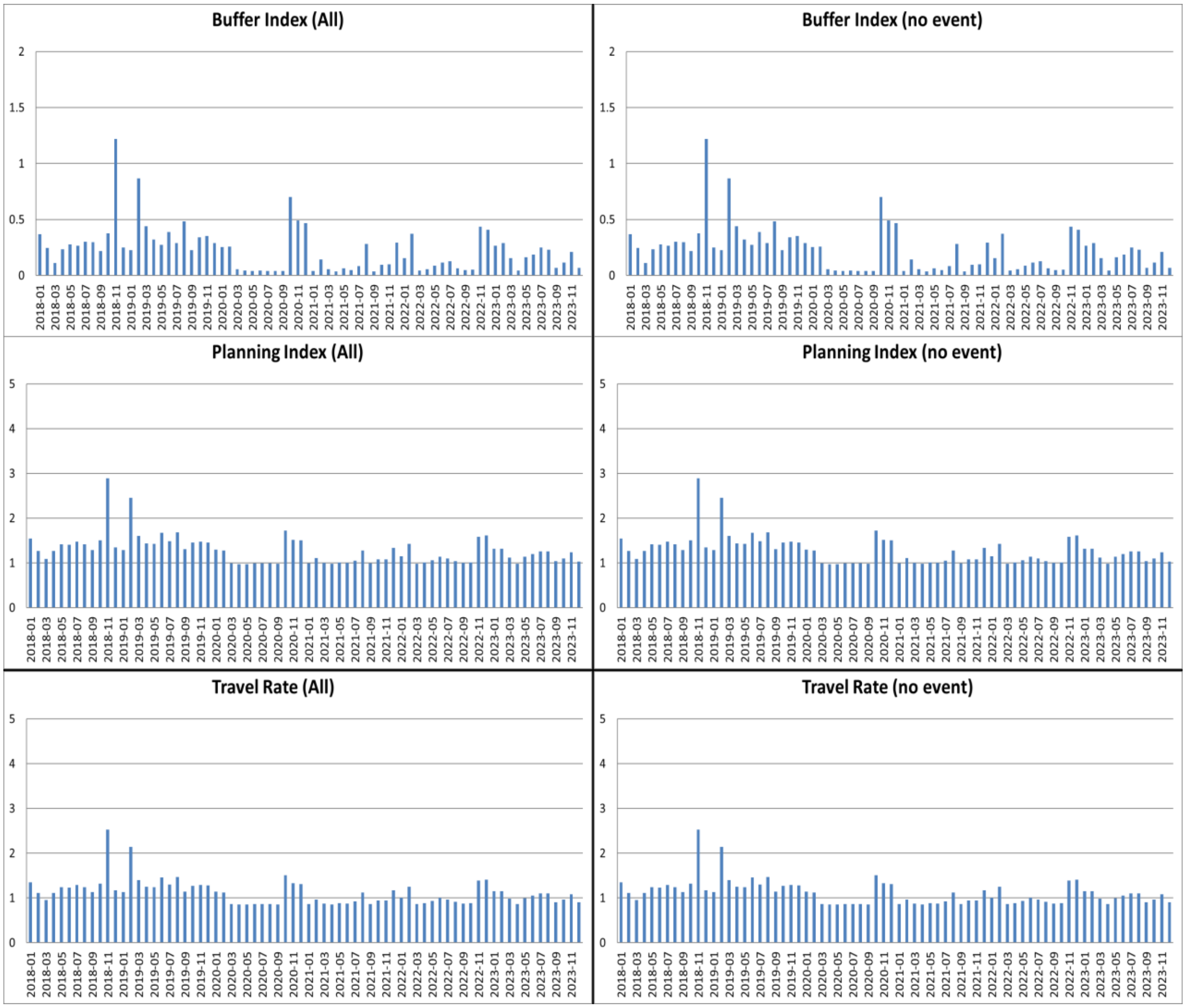
All
med, large event
no event
small event
Buffer Index
2
1.5
1
0.5
0
0.57
0.35
0.59
0.43
0.68
0.70
0.62
0.35
0.33
0.55
0.32
0.32
0.26
0.64
0.65
0.55
0.45
0.49
0.44
0.41
2018
2019
2020
2021
2022
2023
All
med, large event
no event
small event
Planning Index
5
4
3
2
1
0
1.94
1.53
1.98
1.63
2.10
2.13
1.95
1.14
1.11
1.61
1.18
1.18
1.07
1.63
1.65
1.42
1.48
1.52
1.49
1.29
2018
2019
2020
2021
2022
2023
All
med, large event
no event
small event
Travel Rate
5
4
3
2
1
0
2.35
1.86
2.40
1.98
2.55
2.58
2.36
1.38
1.35
1.95
1.43
1.44
1.30
1.97
1.99
1.72
1.80
1.84
1.81
1.57
2018
2019
2020
2021
2022
2023

13) I-35E Corridor A (I494 to I35, Southbound)

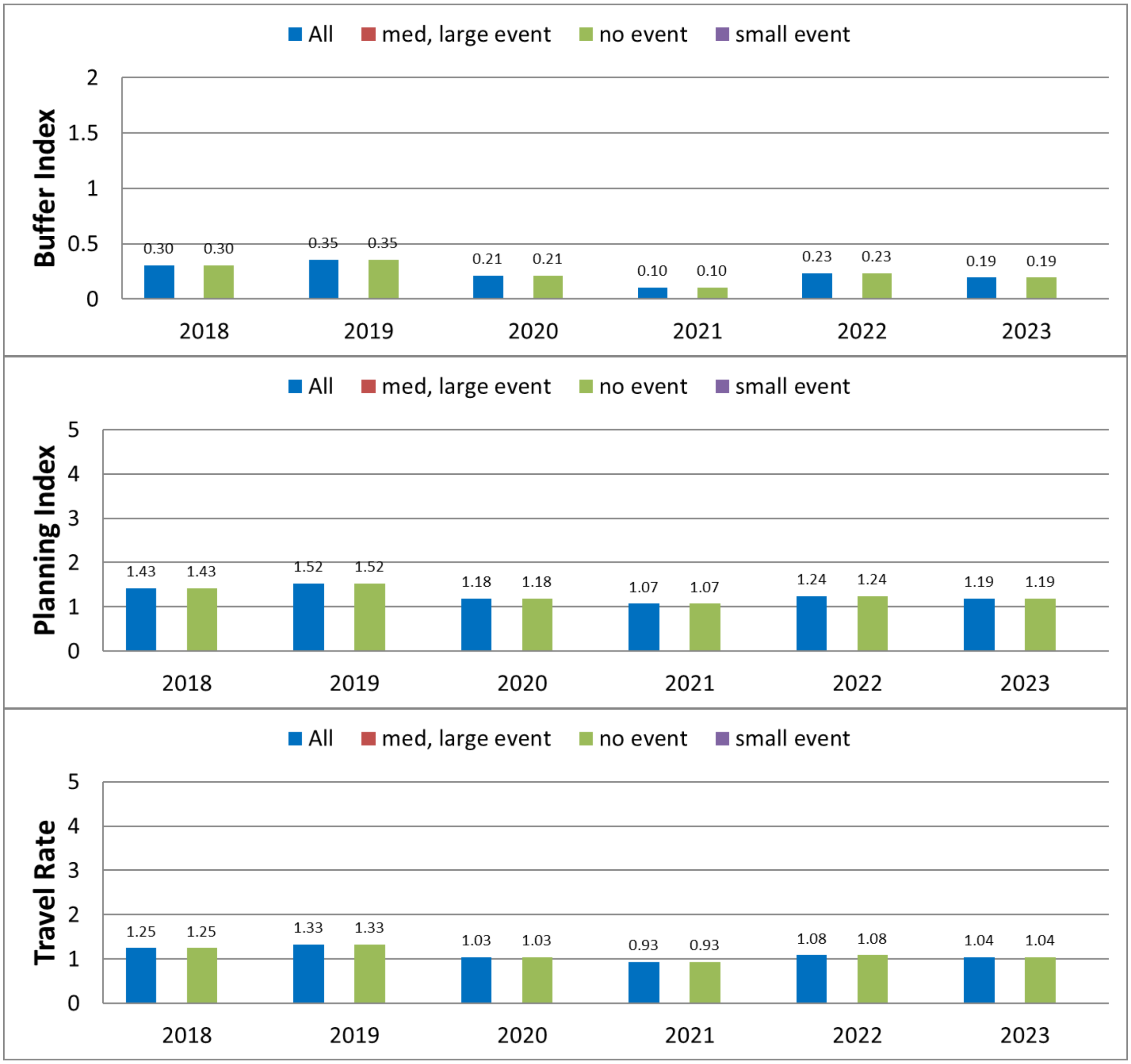


i) I-35E Corridor A -- SB for I494 to I35

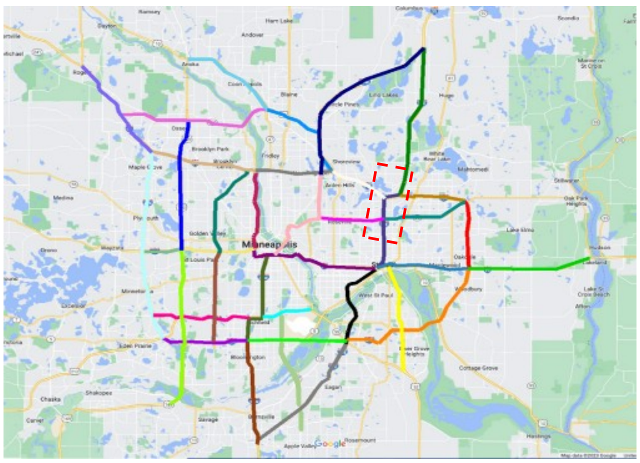
Monthly variations



Yearly variations


All
med, large event
no event
small event
Buffer Index
2
1.5
1
0.5
0
0.30
0.30
0.35
0.35
0.21
0.21
0.10
0.10
0.23
0.23
0.19
0.19
2018
2019
2020
2021
2022
2023
All
med, large event
no event
small event
Planning Index
5
4
3
2
1
0
1.43
1.43
1.52
1.52
1.18
1.18
1.07
1.07
1.24
1.24
1.19
1.19
2018
2019
2020
2021
2022
2023
All
med, large event
no event
small event
Travel Rate
5
4
3
2
1
0
1.25
1.25
1.33
1.33
1.03
1.03
0.93
0.93
1.08
1.08
1.04
1.04
2018
2019
2020
2021
2022
2023

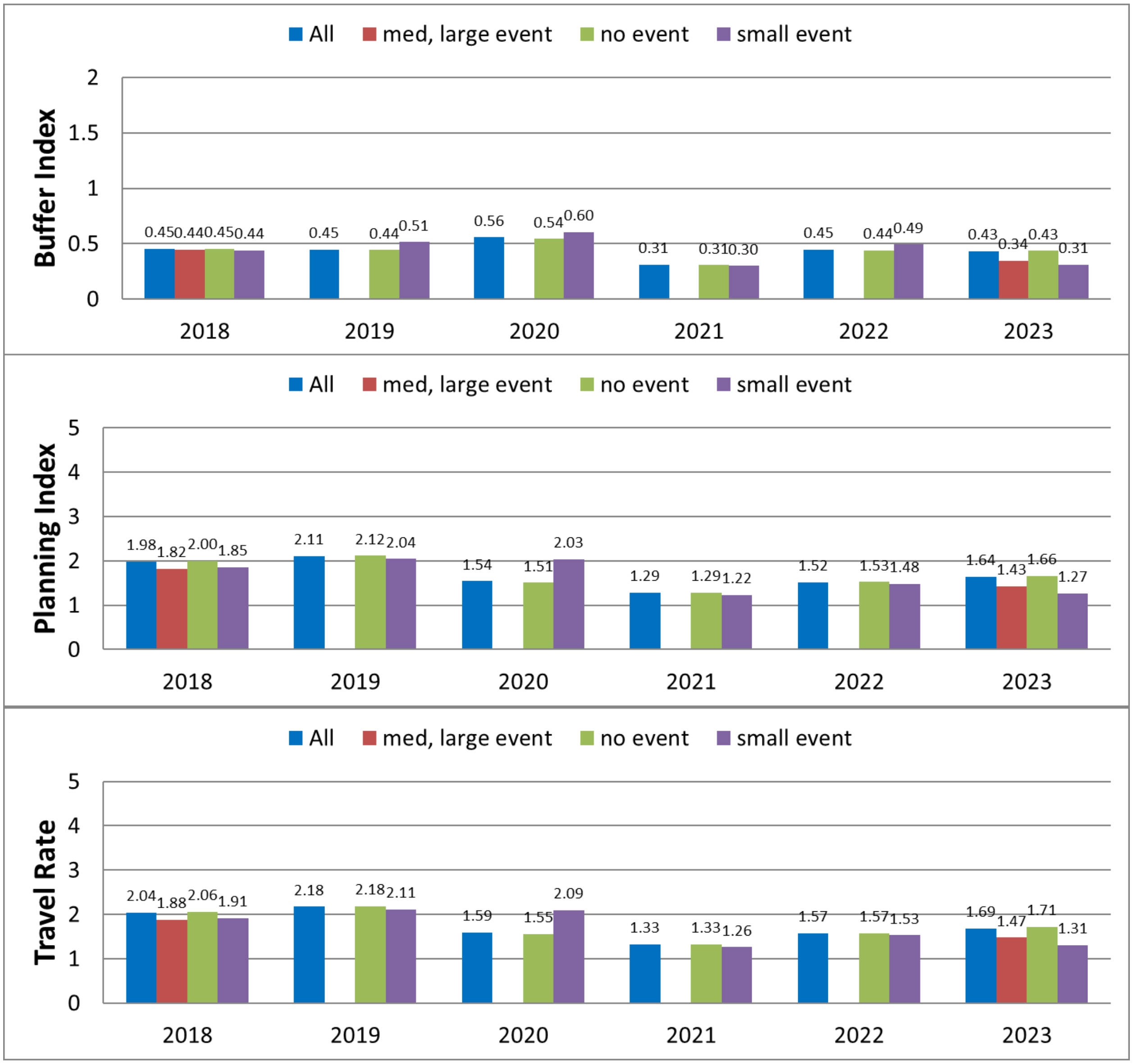
14) I-35E Corridor C (STPL – I694, Northbound)



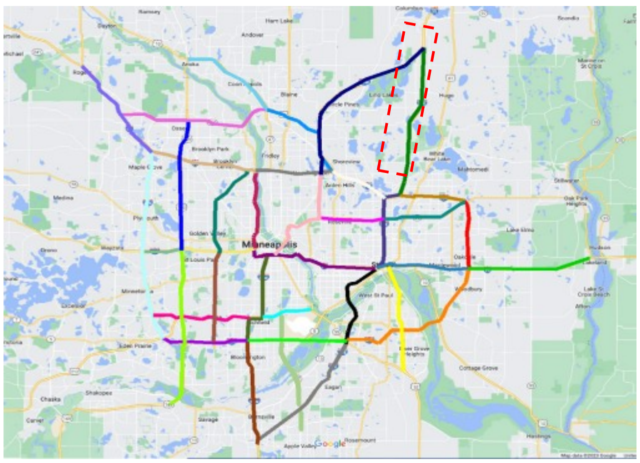
i) I-35E Corridor C NB for STPL to I694

Monthly variations

Yearly variations

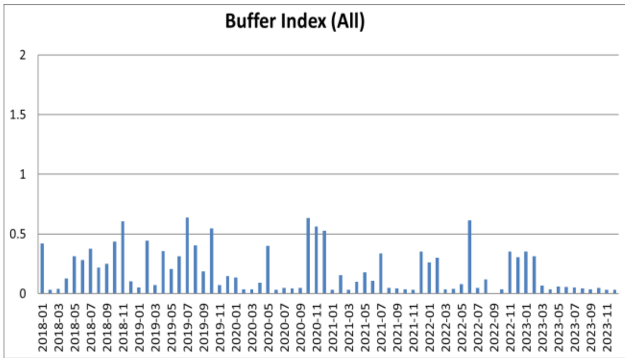

All
med, large event
no event
small event
Buffer Index
0.45
0.44
0.45
0.44
0.45
0.44
0.51
0.56
0.54
0.60
0.31
0.31
0.30
0.45
0.44
0.49
0.43
0.34
0.43
0.31
2018
2019
2020
2021
2022
2023
Planning Index
1.98
1.82
2.00
1.85
2.11
2.12
2.04
1.54
1.51
2.03
1.29
1.29
1.22
1.52
1.53
1.48
1.64
1.43
1.66
1.27
Travel Rate
2.04
1.88
2.06
1.91
2.18
2.18
2.11
1.59
1.55
2.09
1.33
1.33
1.26
1.57
1.57
1.53
1.69
1.47
1.71
1.31

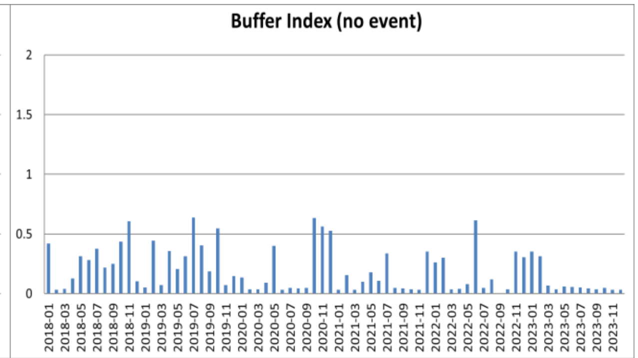
15) I-35E Corridor D (I694 to I35, Northbound)

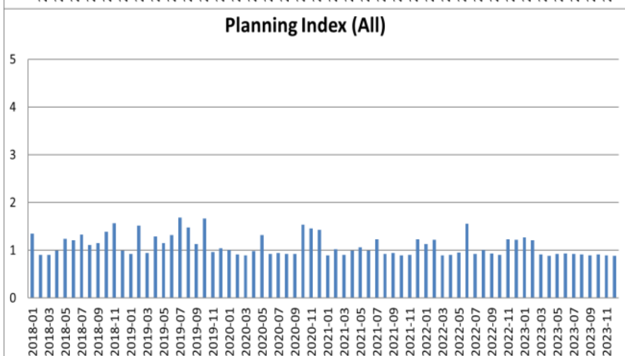


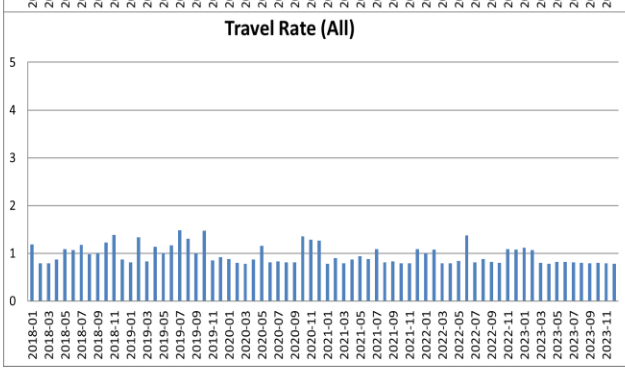
i) I-35E Corridor D -- NB I694 to I35

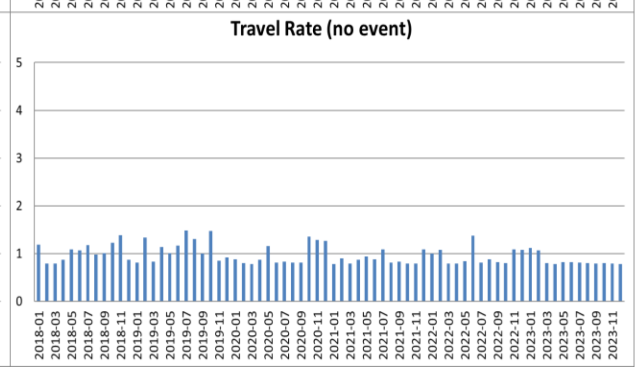
Monthly variations



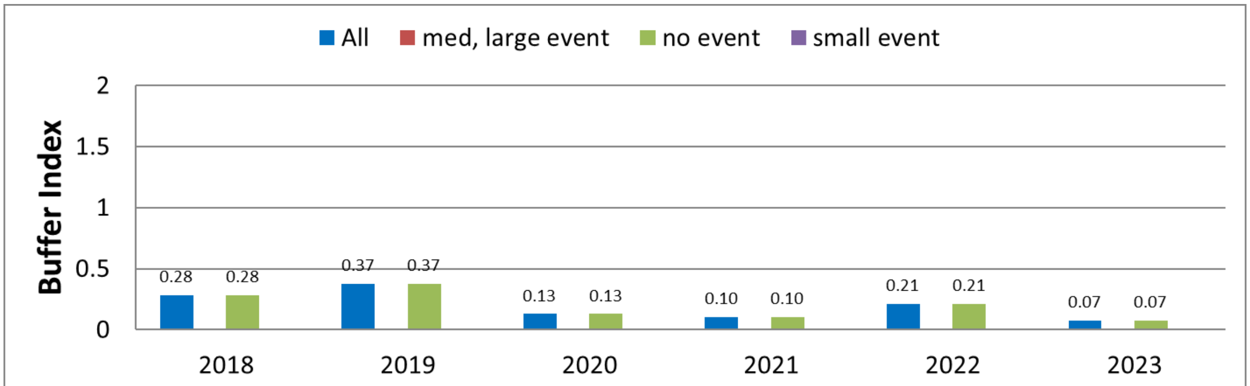


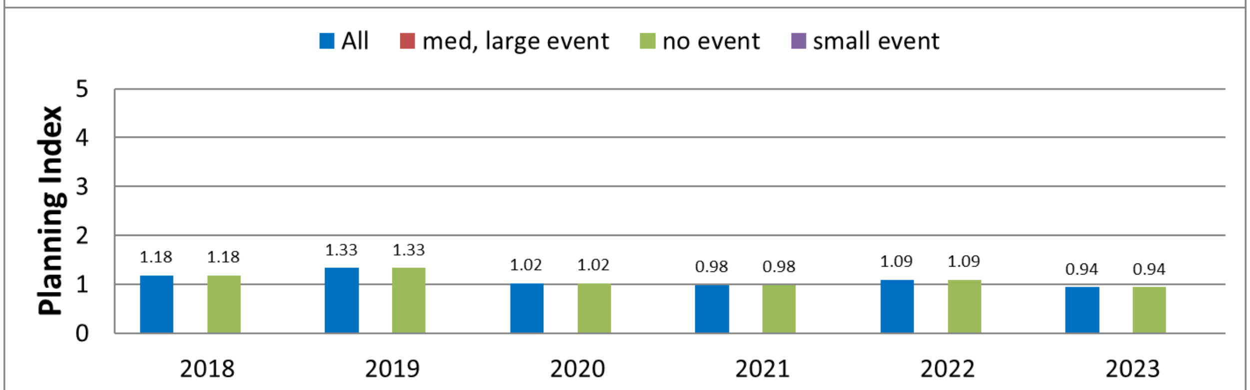


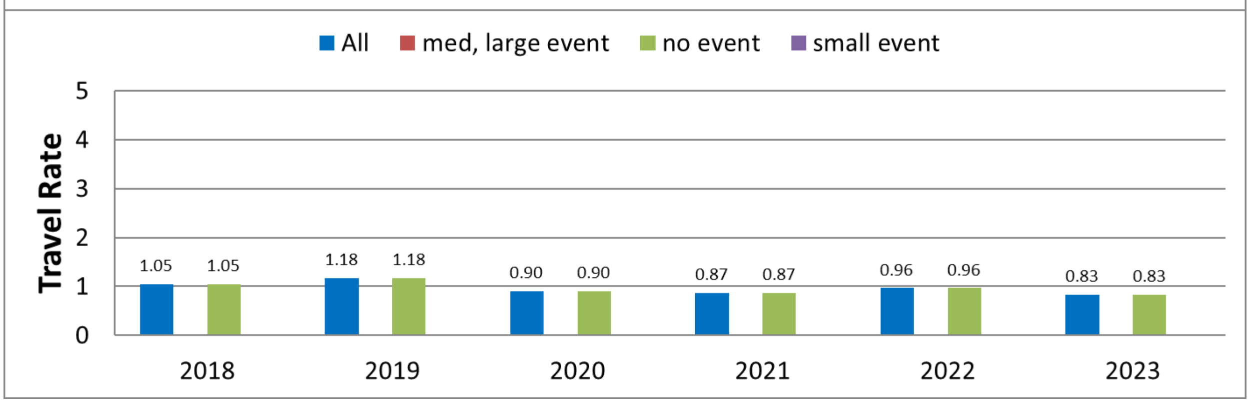




Yearly variations


All
med, large event
no event
small event
Buffer Index
2
1.5
1
0.5
0
0.28 0.28
0.37 0.37
0.13 0.13
0.10 0.10
0.21 0.21
0.07 0.07
2018
2019
2020
2021
2022
2023


All
med, large event
no event
small event
Planning Index
5
4
3
2
1
0
1.18 1.18
1.33 1.33
1.02 1.02
0.98 0.98
1.09 1.09
0.94 0.94
2018
2019
2020
2021
2022
2023


All
med, large event
no event
small event
Travel Rate
5
4
3
2
1
0
1.05 1.05
1.18 1.18
0.90 0.90
0.87 0.87
0.96 0.96
0.83 0.83
2018
2019
2020
2021
2022
2023