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I-25 North Metro Managed Lanes Road Safety Audit (RSA) Report

December 2017

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Table of Contents

List of Figures

List of Tables

List of Appendices

1 BACKGROUND

In the latter half of 2016, the Colorado Department of Transportation (CDOT) implemented managed lanes along Interstate 25 from US Route 36 to 120th Avenue. This reconstruction was in response to relatively sharp population growth and subsequent traffic increase in the greater Denver area. CDOT considers this reconstruction as an interim project and is currently examining the need for additional expansion of the I-25 corridor, including the construction of additional lanes as necessary. In general, properly functioning managed lanes, also referred to as high-occupancy toll (HOT) lanes, toll lanes or express lanes, are intended to reduce traffic congestion thus improving mobility. In the relatively short period of time since construction of the managed lanes was completed, an increase in crash frequency along this newly reconstructed corridor was observed by the City of Thornton and communicated to CDOT. An analysis by CDOT, seen in Figure 1, confirmed that there had been an increase in crash frequency once the managed lanes were in operation. To proactively address this observation, CDOT decided to conduct a formal road safety audit (RSA) on this segment of Interstate 25.

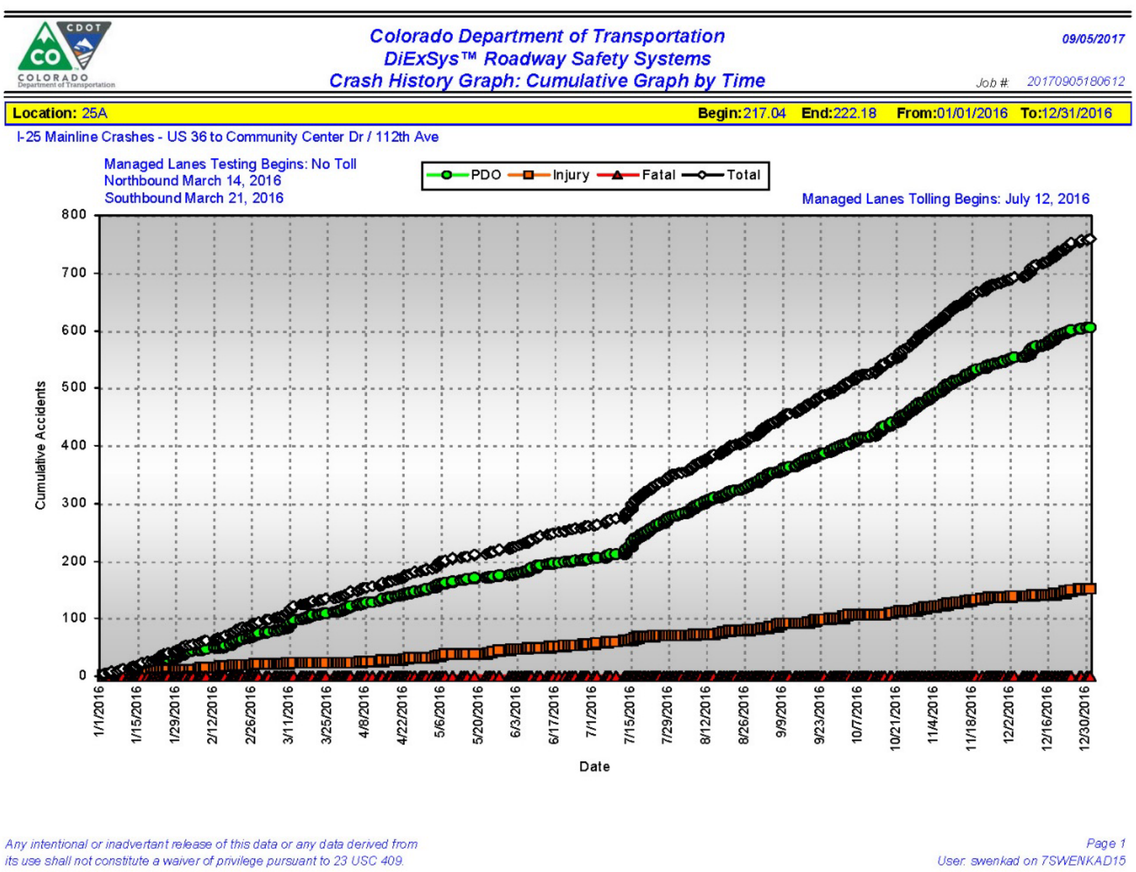

Figure 1 - I-25 2016 Crash Data with Tolling Timeline

1.1 ROAD SAFETY AUDIT PROCESS

A Road Safety Audit (RSA) is the formal safety performance examination of an existing or future road or intersection by an independent, multidisciplinary team. It qualitatively estimates and reports on potential road safety issues and identifies opportunities for improvements in safety for all road users [1]. Typically, mitigation strategies identified through an RSA include short-term, medium-term, and long-term improvements. Ultimately, the goal of this and all RSAs is to reduce traffic-related death, injury, and property damage resulting from crashes as well as provide valuable information for consideration during planning of future or proposed similar facility types.

Figure 2 depicts the eight-step process of any RSA. Step 1 has been completed as previously mentioned by CDOT officials. Step 2 was cooperatively completed by the City of Thornton, CDOT, and the Federal Highway Administration (FHWA) wherein several stakeholders from various backgrounds in engineering and enforcement were invited to take part in the start-up meeting. The complete Road Safety Audit Team, comprised of those that accepted the invitation and participated in this RSA process, is listed in Table 1.

Figure 2 - RSA Process

Table 1 - I-25 North Metro Managed Lanes RSA Team Members

NAME	AGENCY AFFILIATION
KYLE KAMMERMEIER	City of Northglenn
JOEL BROWN	City of Northglenn Police Department
KENT MOORMAN	City of Thornton
MARTA BENAVENTE	City of Thornton
PAT LONG	City of Thornton Police Department
WILLIAM FARR	City of Thornton Police Department
ANDY STRATTON	Colorado Department of Transportation
ALAZAR TESFAYE	Colorado Department of Transportation
LEELA RAJASEKAR	Colorado Department of Transportation
TONY BRINDISI	Colorado Department of Transportation
CHARLES MEYER	Colorado Department of Transportation
CLARK ROBERTS	Colorado Department of Transportation
DAVID SWENKA	Colorado Department of Transportation
ANGIE DRUMM	Colorado Department of Transportation
STEPHANIE ALANIS	Colorado Department of Transportation
CHRISTIANA LACOMBE	Colorado Department of Transportation
BEN KIENE	Colorado Department of Transportation
DAHIR EGAL	FHWA Colorado Division
CHRIS HORN	FHWA Colorado Division
GEORGE MERRITT	FHWA Resource Center - Safety/RSA
JOSH SENDER	Stolfus & Associates, Inc.
MATT BROWN	Stolfus & Associates, Inc.

Prior to the start-up meeting, CDOT compiled crash data for January 1, 2012 to December 31, 2016 located on I-25 from milepost 217.04 (US 36 / I-270) to milepost 222.18 (Community Center Dr). Analysis of this crash data is presented and discussed in subsequent sections of this report. Other information sources used for this RSA include CDOT Traffic Volume Maps, aerial photography from various sources, photographs from CDOT's traffic management center, and historic planning documents.

Step 3 of the RSA, the start-up meeting, was conducted on July 11, 2017. Minutes for this meeting can be found in Appendix A. Formal geographical limits for this RSA were also determined during this start-up meeting and are depicted in Figure 3.

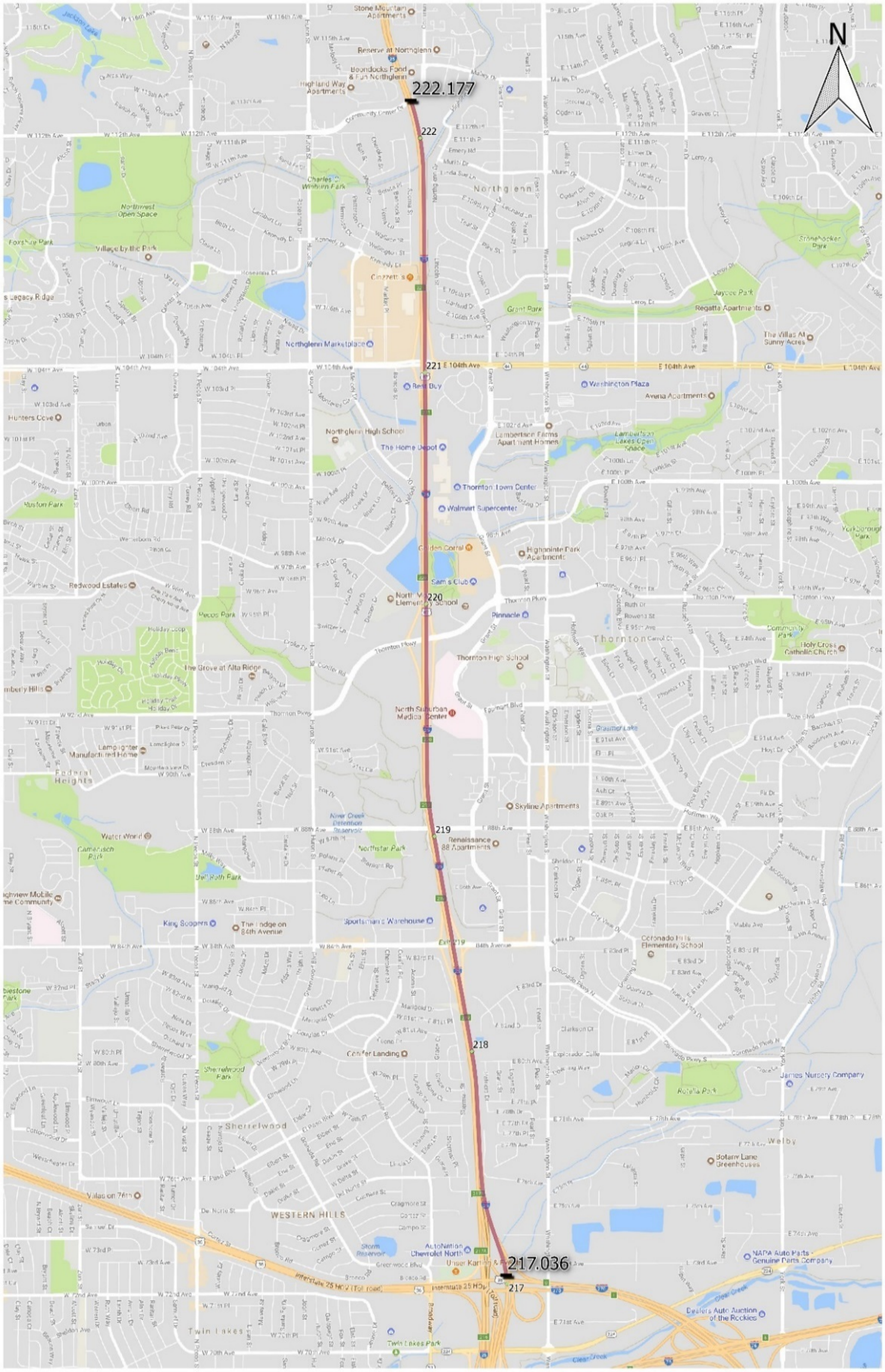

Figure 3 - I-25 North Metro Managed Lanes RSA Limits

The RSA team conducted a field visit (Step 4 of the RSA) on September 7, 2017. During this field visit, team members initially met at the City of Thornton offices, then dispersed into groups to visit four predetermined locations as seen in Figure 4 during the hours of 6:30am-8:30am and 3:15pm-5:30pm. These locations and times were selected based on crash history, traffic counts, and anecdotal evidence from team members who frequently travel and/or work on this section of Interstate 25. The combination of this data indicated that these particular locations and times would have the highest probability for the RSA team members to observe potential highway safety issues from safe, undisturbed, and unobstructed locations while not impeding or affecting the traffic flow. A summary of field audit observations and group discussions which occurred directly after the morning and evening field visits is presented in Section 4.

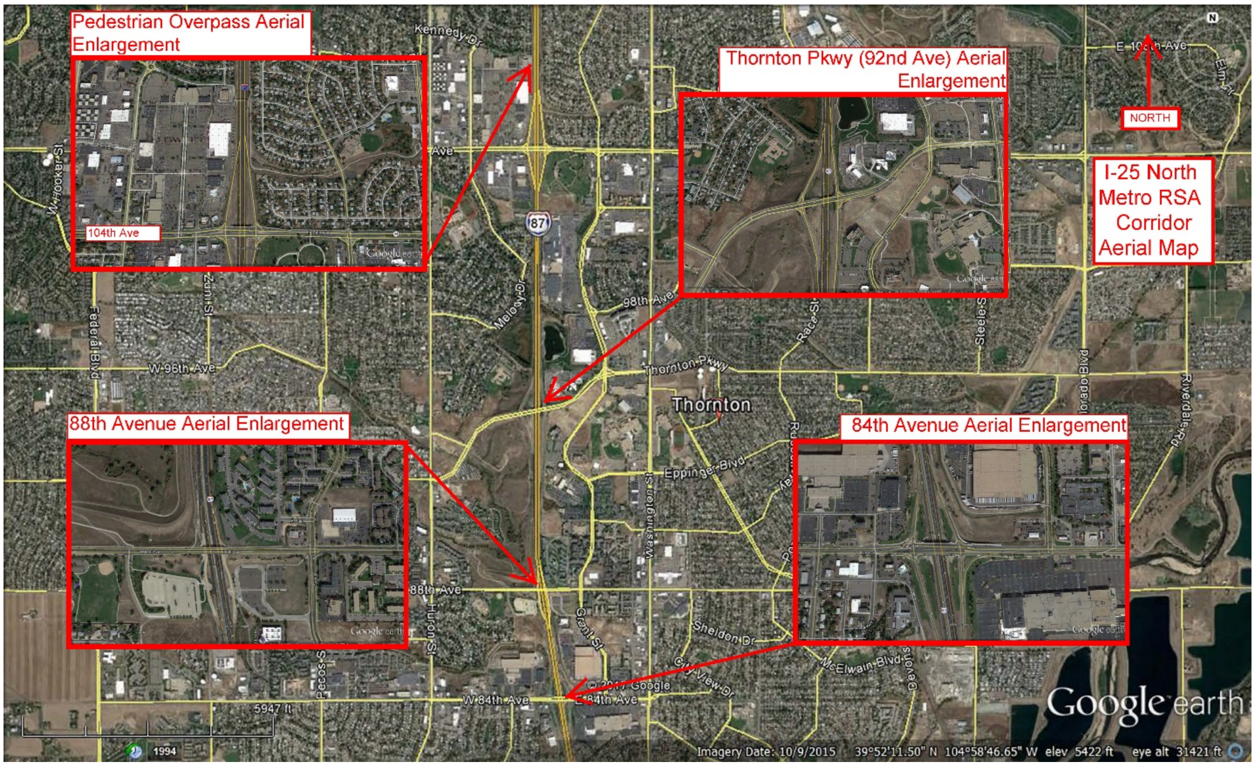

Figure 4 - Field Visit Locations

This report, representative of Step 5 of the RSA process, is a detailed record of all analyses, findings, and potential improvement strategies for the Interstate 25 corridor of interest. All RSA team members have been presented with this report and have had the opportunity to contribute and comment throughout the RSA process. This RSA report will serve as a guidance document for future discussion and for formulating an action plan with respect to the safety related issues discussed herein.

2 PROJECT DESCRIPTION

Interstate 25 runs north-south spanning the entire longitudinal distance of the state of Colorado. Colorado jurisdiction of Interstate 25 begins just south of Trinidad, running north through the major cities of Pueblo, Colorado Springs, Denver, and Fort Collins, then proceeding north into Cheyenne, Wyoming. The focus limits of the Interstate 25 corridor for this road safety audit spans from US Route 36 (milepost 217.04) north to East 112th Avenue (milepost 222.18). This corridor is located just north of the City of Denver and runs primarily through the City of Thornton and extends north into the City of Northglenn beginning at 104th Avenue.

In 1994, managed lanes used for High Occupancy Vehicles (HOV) and/or vehicle tolling, also known as “Express” lanes, were constructed along Interstate 25 from 20th Street in downtown Denver north to US Route 36 (Figure 5 and Figure 6). Managed lanes are primarily used to alleviate traffic congestion by offering motorists the opportunity to use lanes with reduced access and conflict points, frequently in exchange for toll collection and/or the requirement of traveling with 3 or more passengers per vehicle. The managed lanes from 20th Street to US Route 36 are two reversible 12-foot lanes bounded by a 4-foot shoulder on one side and a 10-foot shoulder on the other side. These lanes are situated between the northbound and southbound Interstate 25 general purpose lanes and are separated by permanent concrete barriers on both sides.

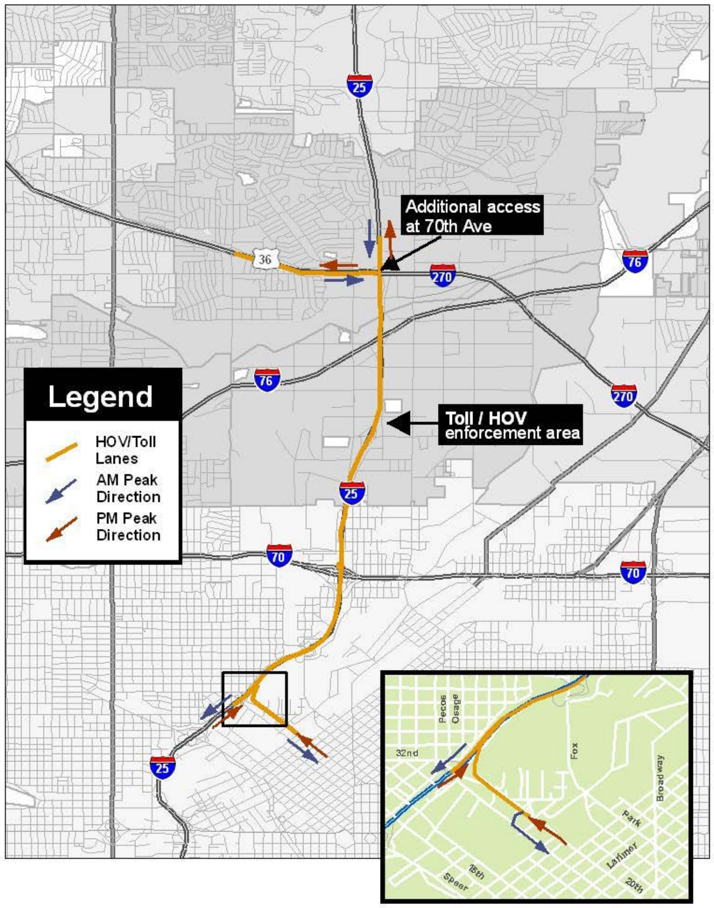

Figure 5 - I-25 HOV/Tolled Express Lane Corridor Map

Figure 6 - Example Street View of I-25 HOV/Toll Lanes near 50th Avenue (Metro)

In fiscal year 2012, CDOT successfully acquired TIGER Grant funding to reconfigure the existing infrastructure along Interstate 25 from US Route 36 to 120th Avenue to include one managed lane each for both northbound and southbound traffic. Construction on this project began in October of 2013 and was completed in the spring of 2016. The new configuration is depicted in Figure 7 and Figure 8 and yields a 4-foot inside shoulder, an 11.5-foot managed lane, a nominal 2-foot double white line striped buffer space, an 11.5-foot general purpose lane, two 12-foot general purpose lanes, and an 8-foot outside shoulder. Before and after street level photos are shown in Figure 9 and Figure 10. New signage and striping was also installed with this project and a detailed plan set can be found in Appendix B.

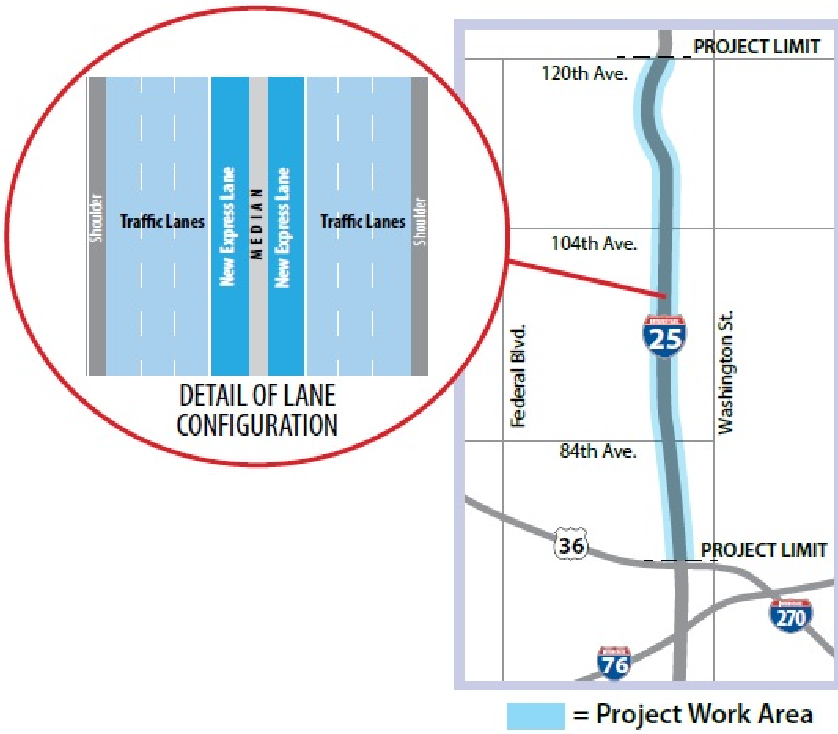

Figure 7 - I-25 North Metro Managed Lanes Configuration

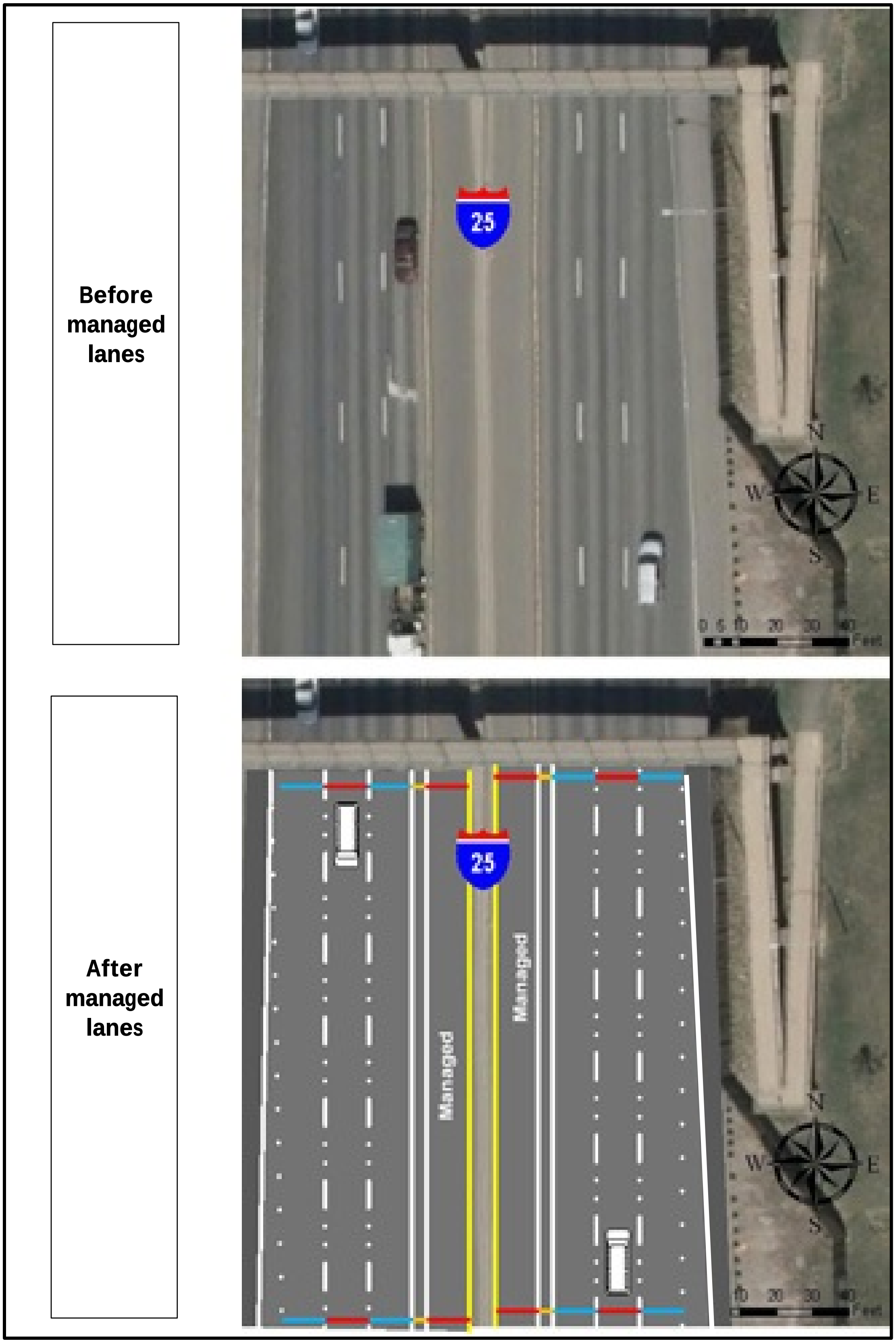

Figure 8 - I-25 North Metro Managed Lanes Configuration

Figure 9 - On Thornton Pkwy overpass looking south (2012 Street View)

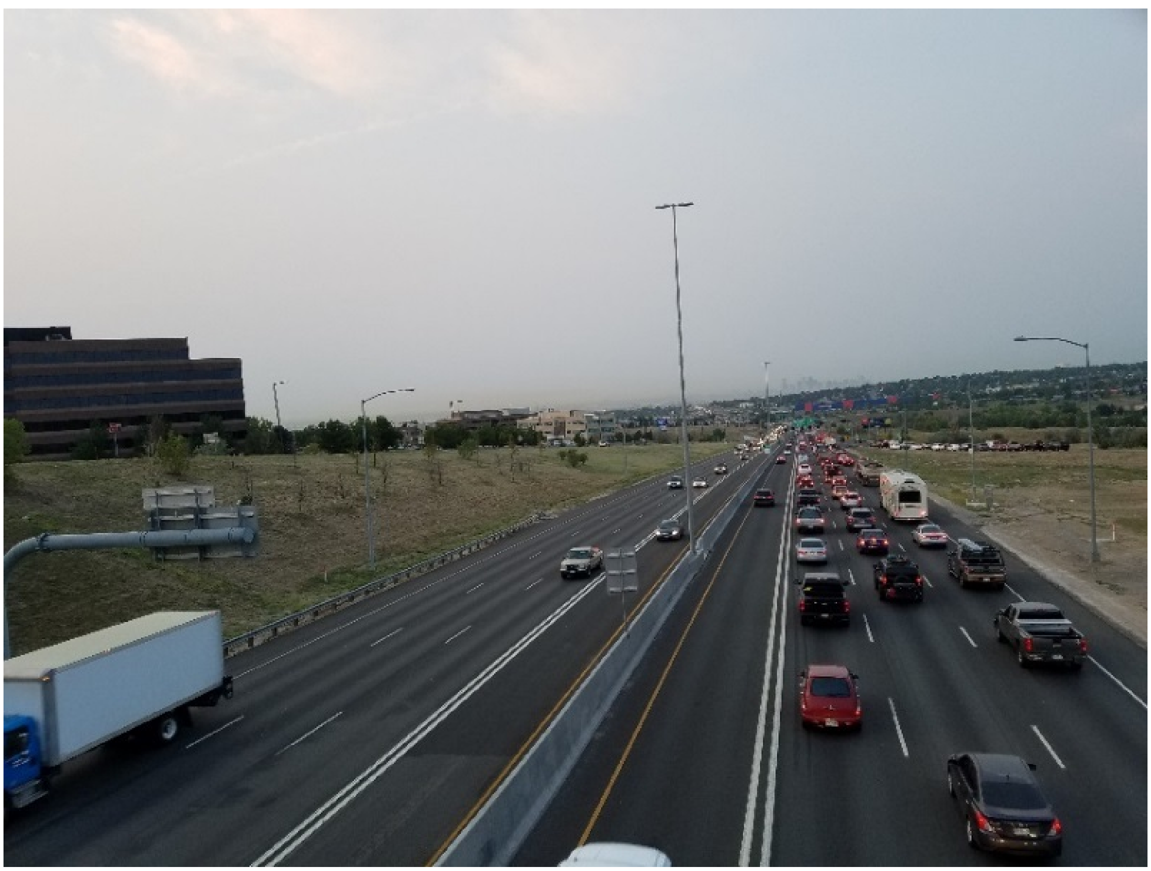

Figure 10 - On Thornton Pkwy overpass looking south (9/7/17 at 6:45am)

3 Crash Data Review

The crash history for the period of January 1, 2012 through December 31, 2016 was examined to locate crash clusters and identify collision causes. Within the study period, 2,739 crashes were reported along I- 25 between MP 217.04 (US 36 / I-270) and MP 222.18 (Community Center Dr). Of these, there were 525 injury collisions and 2 fatal collisions; 714 injured and 2 killed overall. Table 2 summarizes the crash totals for mainline I-25 over the five-year study period. A detailed summary of crashes report can be found in Appendix C.

Table 2 - Crash History of I-25 from US 36 to Community Center Dr by Year

Year	Property Damage Only (PDO) Crashes	Injury (INJ) Crashes	Injuries	Fatal (FAT) Crashes	Fatalities	Total Crashes
2012	253	67	95	0	0	320
2013	334	60	70	0	0	394
2014	505	123	172	0	0	628
2015	514	123	175	1	1	638
2016	606	152	202	1	1	759
Total	**2212**	**525**	**714**	**2**	**2**	**2739**
Average/Yr	**442.4**	**105.0**	**142.8**	**0.4**	**0.4**	**547.8**

Figure 11 shows crash data from this time frame broken down by severity. The majority of the crashes along the corridor are Property Damage Only (PDO) crashes.

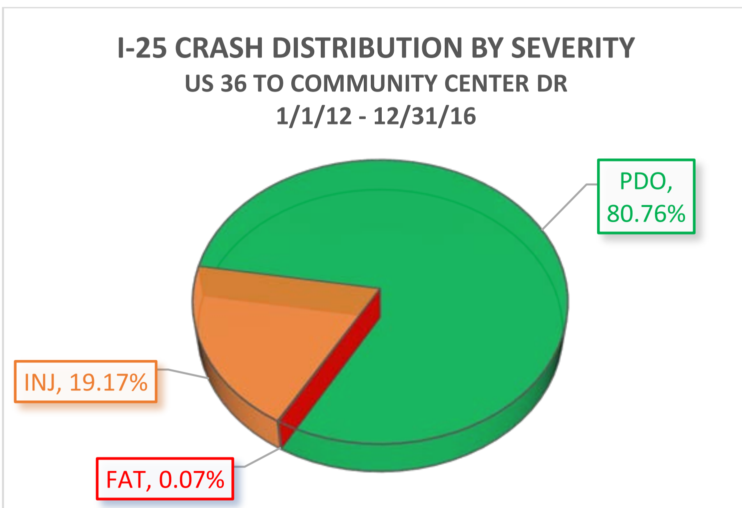

Figure 11 - I-25 Crash Distribution by Severity

Crash data was also analyzed by type as seen in Figure 12. Rear-end crashes account for the majority of all crashes, followed by sideswipe same direction crashes.

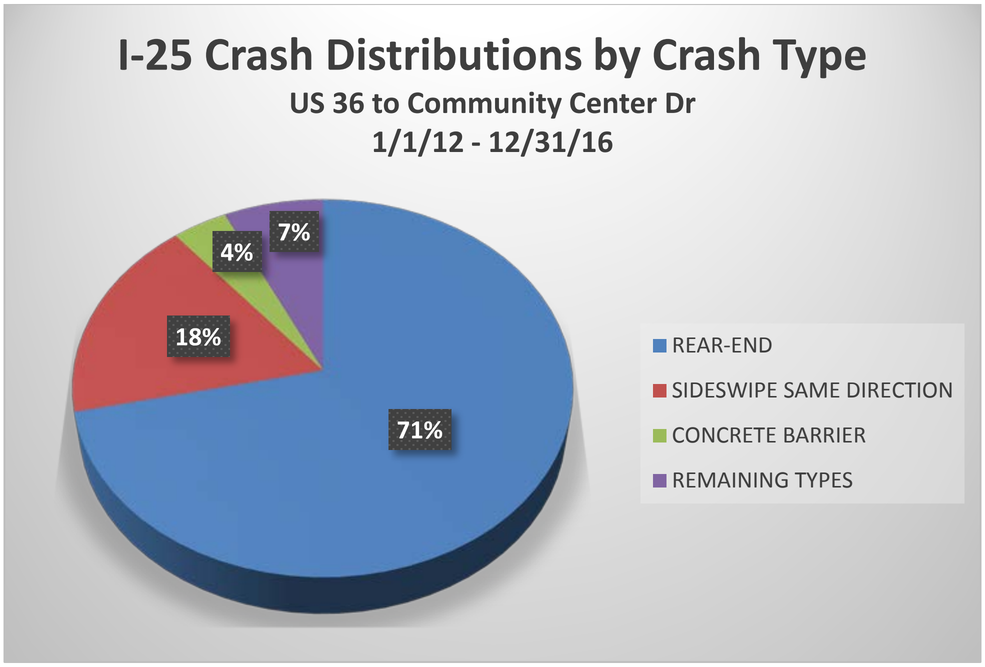

Figure 12 - I-25 Crash Distribution by Crash Type

Similarly, crash data was analyzed by direction. For this analysis, the I-25 corridor was broken into four sections as seen in Table 3 and Figure 13. Table 4 displays that a greater proportion of crashes occur in the southbound direction in Sections 2, 3, and 4 while the reverse is true (more crashes northbound than southbound) in Section 1.

Table 3 - I-25 Sections

Section	Begin Mile Post	Begin Reference	End Mile Post	End Reference	Length (miles)
1	217.036	I-270 and US-36 Junction	218.463	84th Avenue	1.451
2	218.463	84th Avenue	219.859	Thornton Parkway	1.318
3	219.859	Thornton Parkway	221.027	104th Avenue	1.182
4	221.027	104th Avenue	222.177	Community Center Drive	1.135

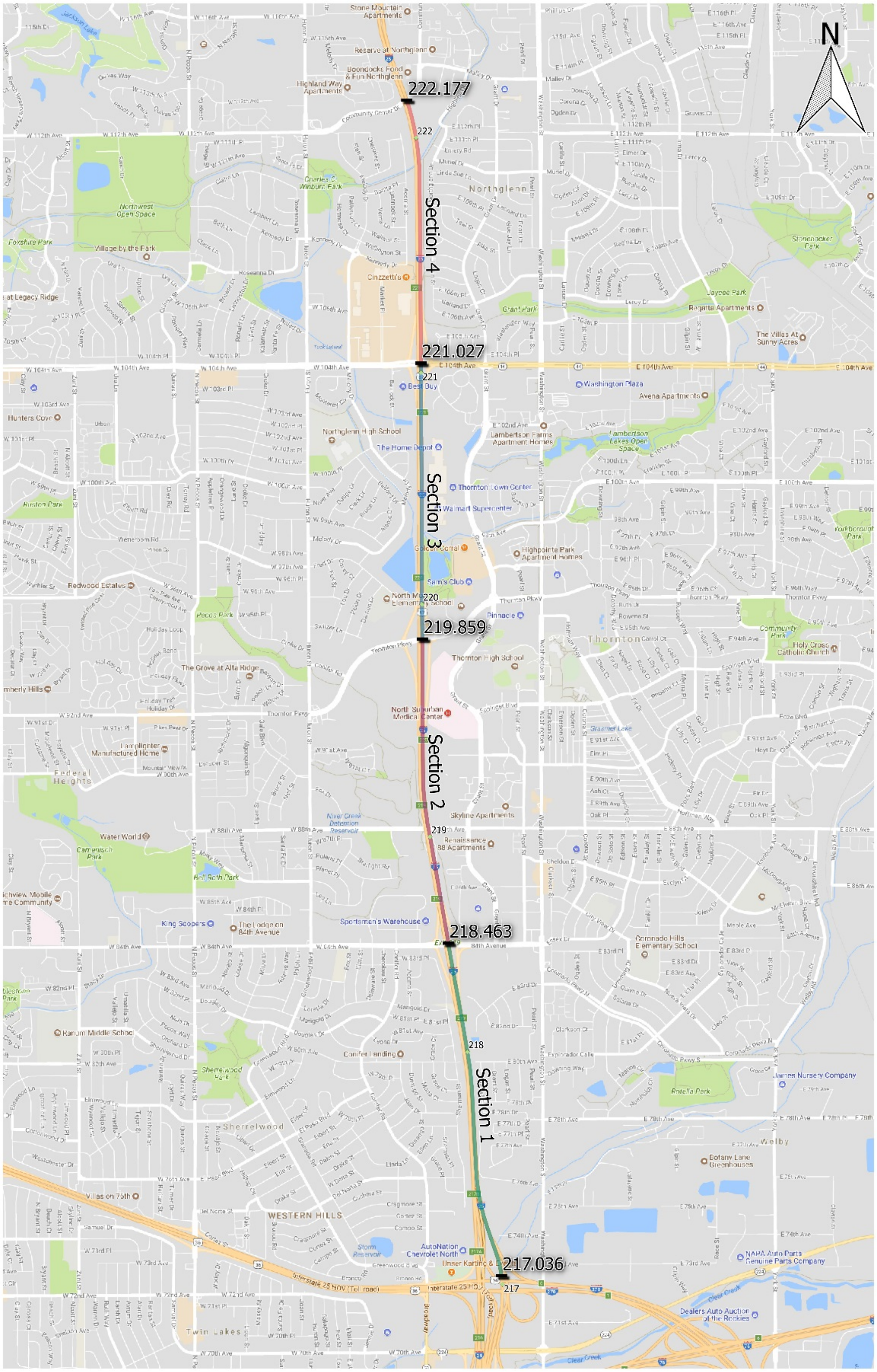

Figure 13 - I-25 Section Map

Table 4 - I-25 crash distribution by section and direction

Direction	Section 1			Section 2			Section 3			Section 4		
	Veh 1	*Veh 2*	*Veh 3*	*Veh 1*	*Veh 2*	*Veh 3*	*Veh 1*	*Veh 2*	*Veh 3*	*Veh 1*	*Veh 2*	*Veh 3*
N	61.8%	62.7%	56.1%	33.3%	32.7%	27.1%	32.0%	28.7%	26.6%	21.3%	18.4%	9.4%
NE	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
E	0.2%	0.2%	0.9%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%	0.6%	0.0%
SE	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%	0.0%	0.0%
S	38.1%	37.1%	41.1%	66.3%	67.0%	72.9%	67.8%	71.1%	71.9%	77.9%	80.4%	89.8%
SW	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	0.2%	0.8%
W	0.0%	0.0%	0.9%	0.1%	0.1%	0.0%	0.2%	0.0%	0.0%	0.2%	0.2%	0.0%
UK	0.0%	0.0%	0.9%	0.2%	0.2%	0.0%	0.0%	0.0%	1.6%	0.0%	0.2%	0.0%

Corridor wide crash data was further analyzed by time of day and is displayed in Figure 14. A similar analysis by time of day was also performed for sectioned crash data and can be found in Appendix D.

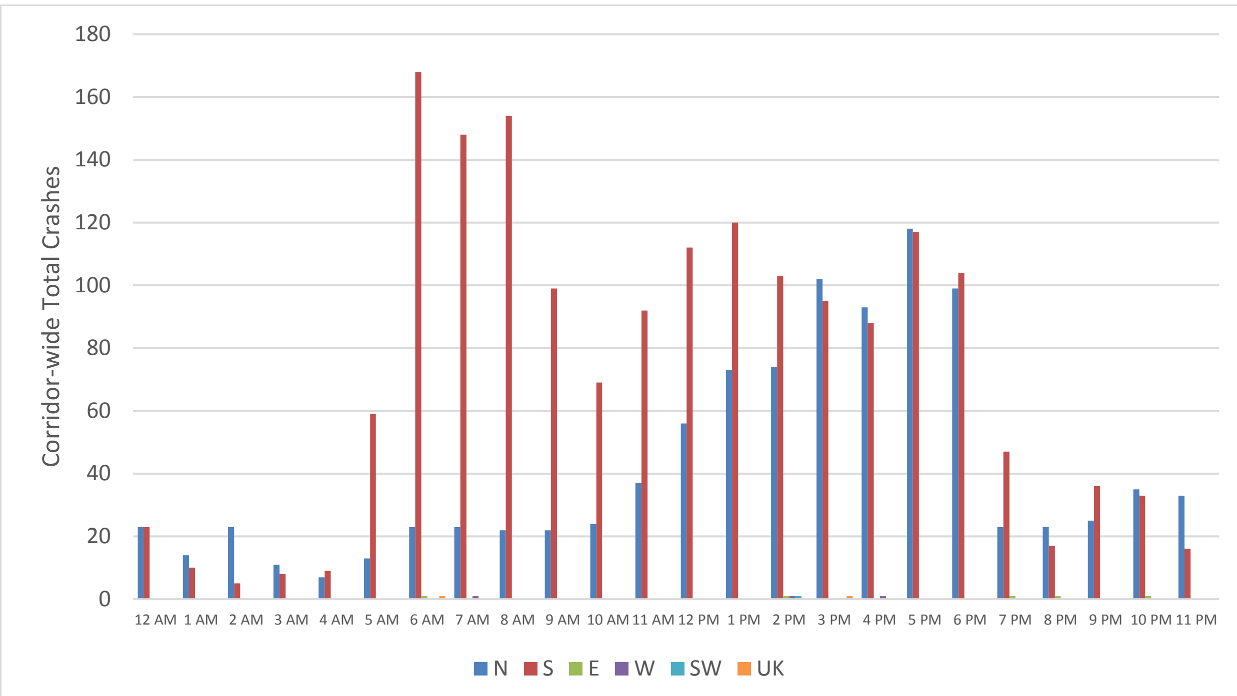

Figure 14 - I-25 Total Crashes by Time of Day

Figure 14 shows that northbound crashes along the entire corridor generally occur at one peak period, evenings between 3pm to 6pm. However, southbound crashes along the corridor appear to occur in several peak periods. The highest peak period for southbound crashes appears to be in the mornings from 6am to 8am. Lesser, secondary peaks then occur from 12pm to 1pm and from 5pm to 6pm. An examination of the crashes for each section along this corridor indicates that these patterns in northbound and southbound crashes are consistent within each section. The data also reveals that more crashes occur in Section 2 than any other section. These multiple peaks in southbound crashes are apparent but less pronounced when examining only injury crashes along the entire corridor as seen in Figure 15.

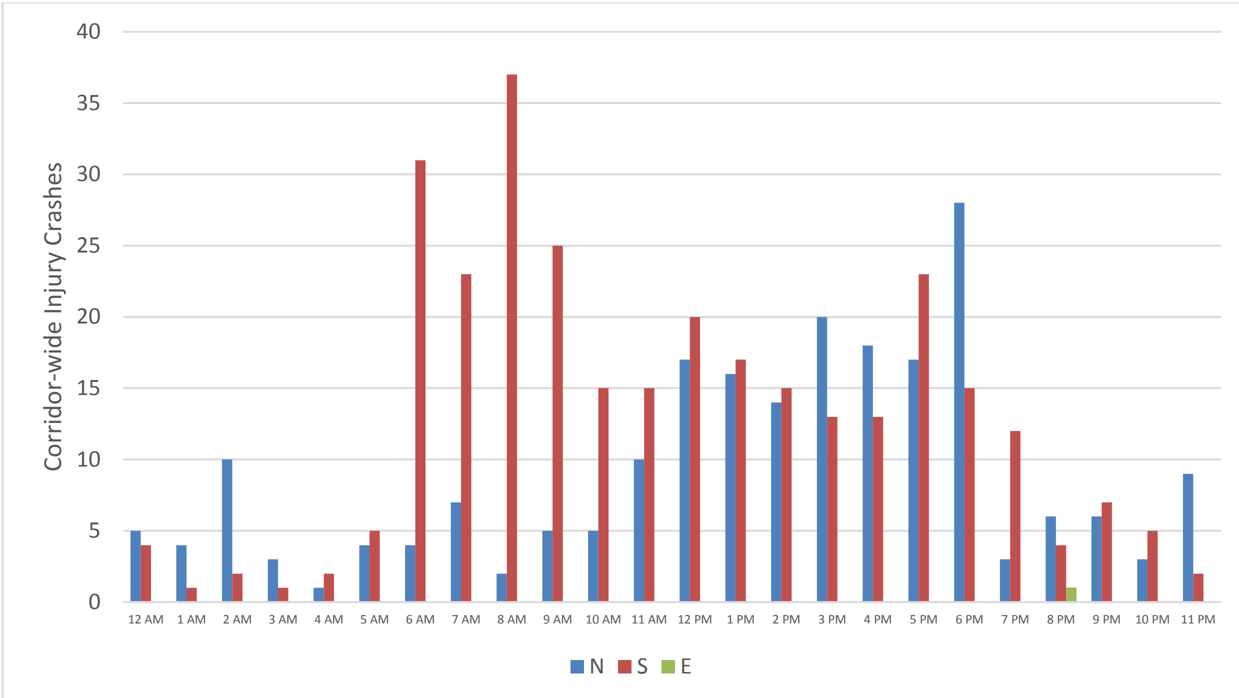

Figure 15 - I-25 Injury Crashes by Time of Day

Section 2 appears to stand out as the largest contributor to total crashes in this corridor of I-25. This is also true when examining crashes by severity as seen in Figure 16. Again, more Property Damage Only (PDO) and Injury (INJ) crashes occur in Section 2 than in any other section. The fewest number of PDO crashes occurs in Section 1, but the relative severity of those crashes tends to be higher as shown in the INJ portion of the graph.

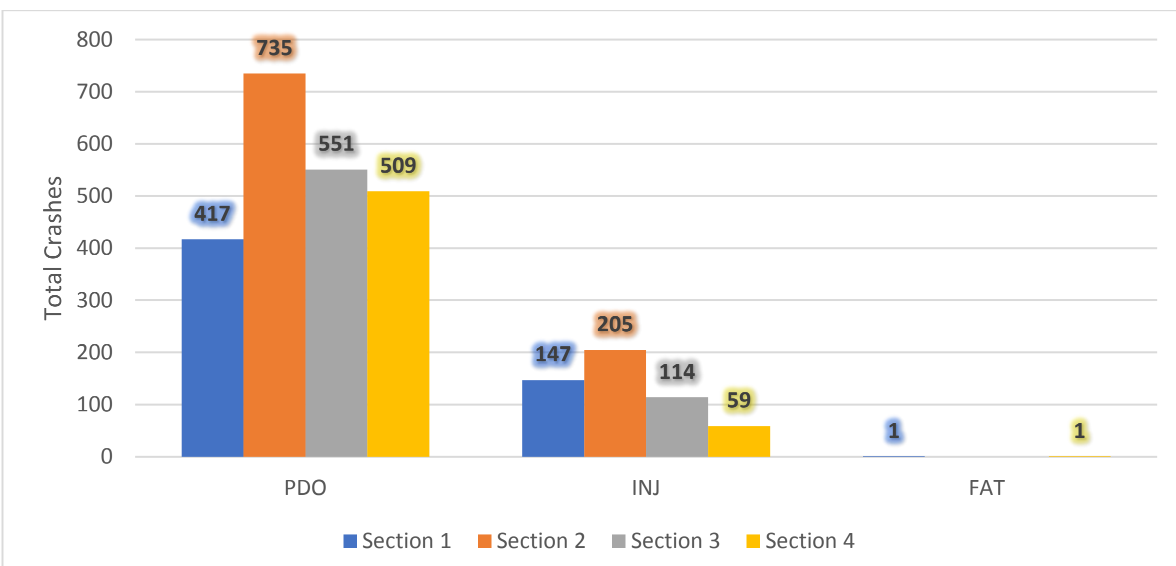

Figure 16 - I-25 Total Crashes by Section and Severity

More patterns appear when directional sectioned crash data is analyzed by day of week as seen in Figure 17 and Figure 18. The number of northbound crashes remains relatively constant in all sections from Sunday to Thursday. Friday and Saturday then show an increase in the number of crashes in Sections 1, 3, and 4 but remain fairly constant in Section 2. These trends also occur when analyzing northbound Injury crashes. Meanwhile, the total number of southbound crashes generally displays an increasing trend from Sunday to Saturday across all Sections. Southbound Injury crashes display this same trend with the exception of Section 2 shown in Figure 19. It appears that there is a peak in southbound Injury crashes in Section 2 on Tuesdays and then again on Fridays to a slightly lesser extent.

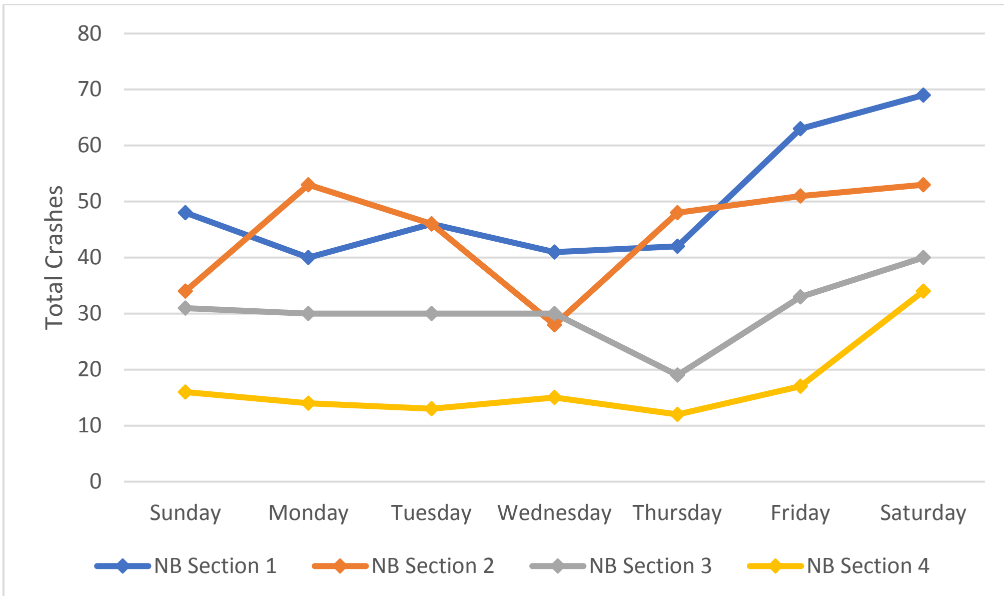

Figure 17 - Northbound I-25 Total Crashes by Section and Day of Week

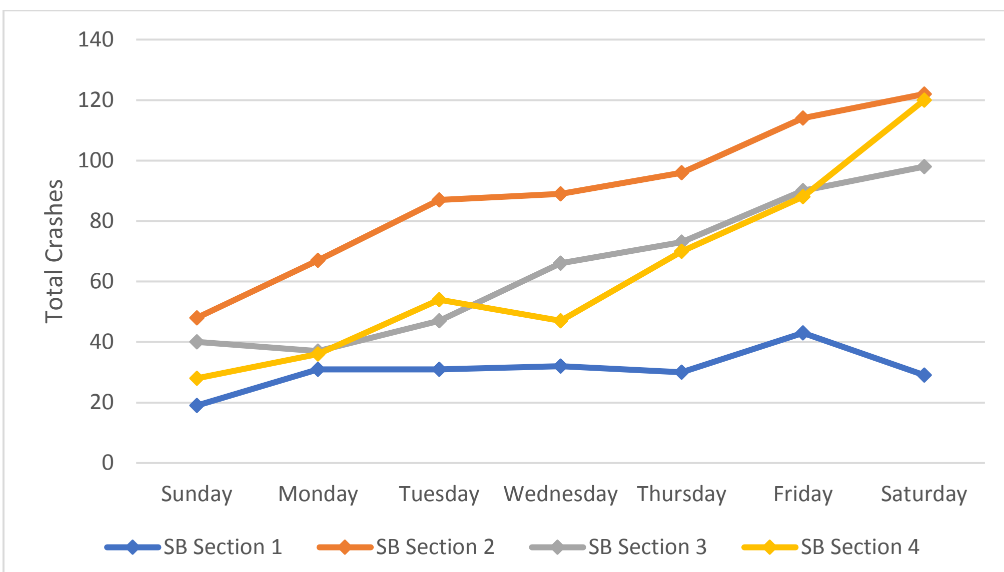

Figure 18 - Southbound I-25 Total Crashes by Section and Day of Week

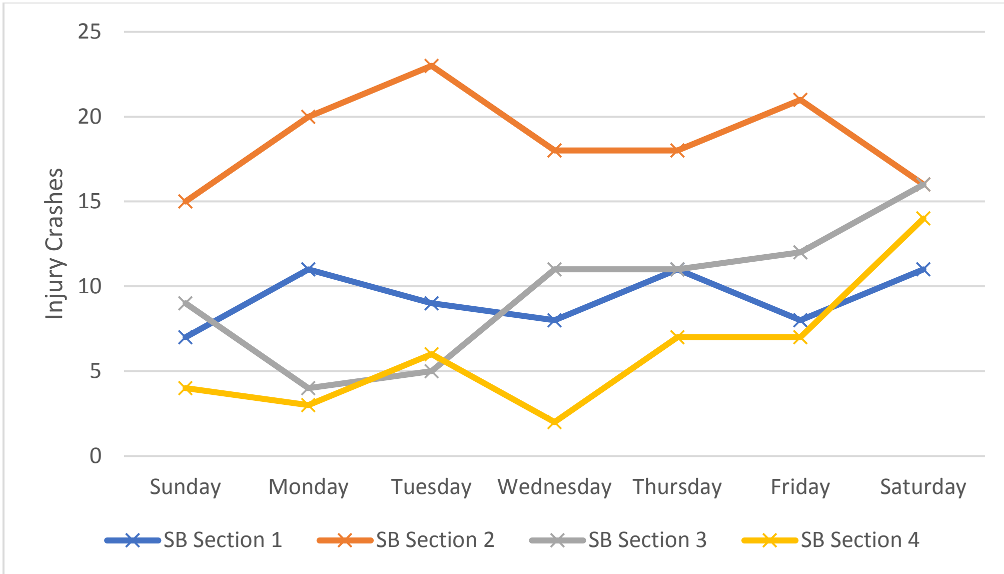

Figure 19 - Southbound I-25 Injury Crashes by Section and Day of Week

It was also noticed that there is a distinct increase in annual crash rate from 2012 to 2016. A typical analysis of highway crash rates in Colorado would usually contain comparisons to a Safety Performance Function (SPF) and subsequent Level of Service of Safety (LOSS) ratings. However, Colorado does not currently have such an SPF developed for highways with managed lanes. Therefore, crash rates were solely used to identify relative patterns for this corridor of I-25.

The aforementioned crash rate observation is best seen when examining the cumulative number of each type for each year, as seen in Figure 20. An increased slope in a data plot line for any given year shown in this figure indicates a rise in the annual crash rate for that year. In general, the plot line for each year trends on a linear path, indicating a consistent crash rate within that year. However, March to April of 2015 and June to July of 2016 both indicate a sharp increase in slope, suggesting perhaps some event occurred which resulted in the increased crash rate. The increase in slope from March to April of 2015 may perhaps be due to construction along I-25 and the related traffic pattern shift. Meanwhile, the increase from June to July of 2016 coincides with the beginning of toll collection on this corridor of I-25.

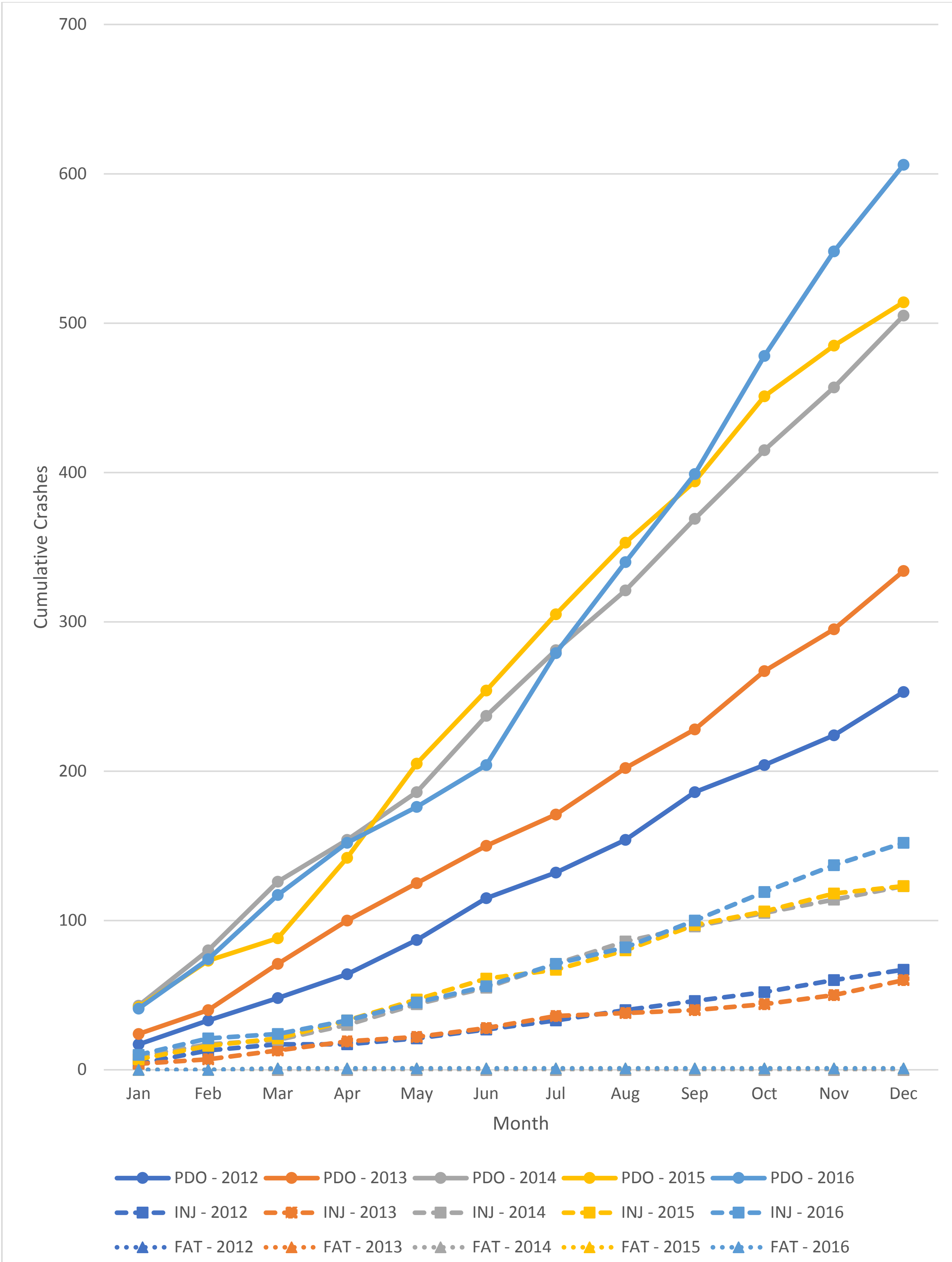

Figure 20 - Cumulative Crashes Both Direction on I-25

Figure 21 displays the total crash rate per Million Vehicle Miles Traveled (MVMT) for this corridor of I-25 for each year analyzed. The total crash rates for three specific timeframes in the year 2016 are also shown in Figure 21. The timeframe of January 1 to March 20 corresponds with the portion of 2016 in which the managed lanes were still under construction. Construction was completed and the managed lanes were opened to traffic on March 21 and operated without toll collection until July 11. Toll collection began on July 12, 2016 and continues to present day.

The total annual crash rate has indeed been increasing since 2012. However, it is clear that there are large deviations from this trend when examining the 2016 timeframes without toll collection and with toll collection. Notably, once the managed lane construction was completed and this new lane functionally operated as a general purpose lane, that is without toll collection, the total crash rate appears to decrease. In contrast, once the managed lane functionally operated as intended, with toll collection, the crash rate appears to increase. These shifts in total crash rate may be evidence of underlying highway capacity related issues.

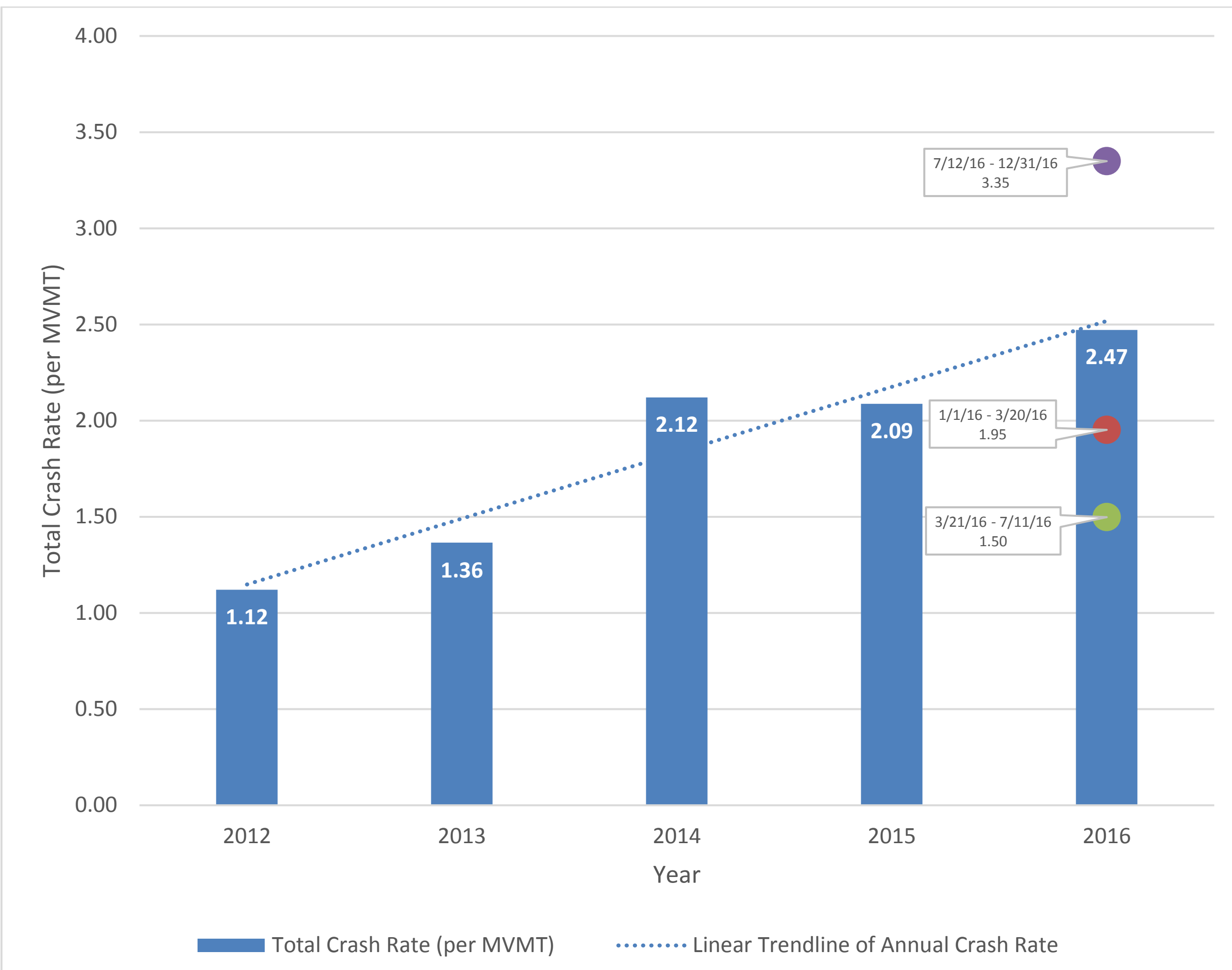

Figure 21 - Total Crash Rates by Year

In contrast, the Average Annual Daily Traffic (AADT) in the study area has shown only a moderate increase from 2012 to 2016. Crash frequency has clearly outpaced volume as displayed in Figure 22 and Table 5. A pattern such as this may be further evidence that the highway is approaching or has surpassed its capacity.

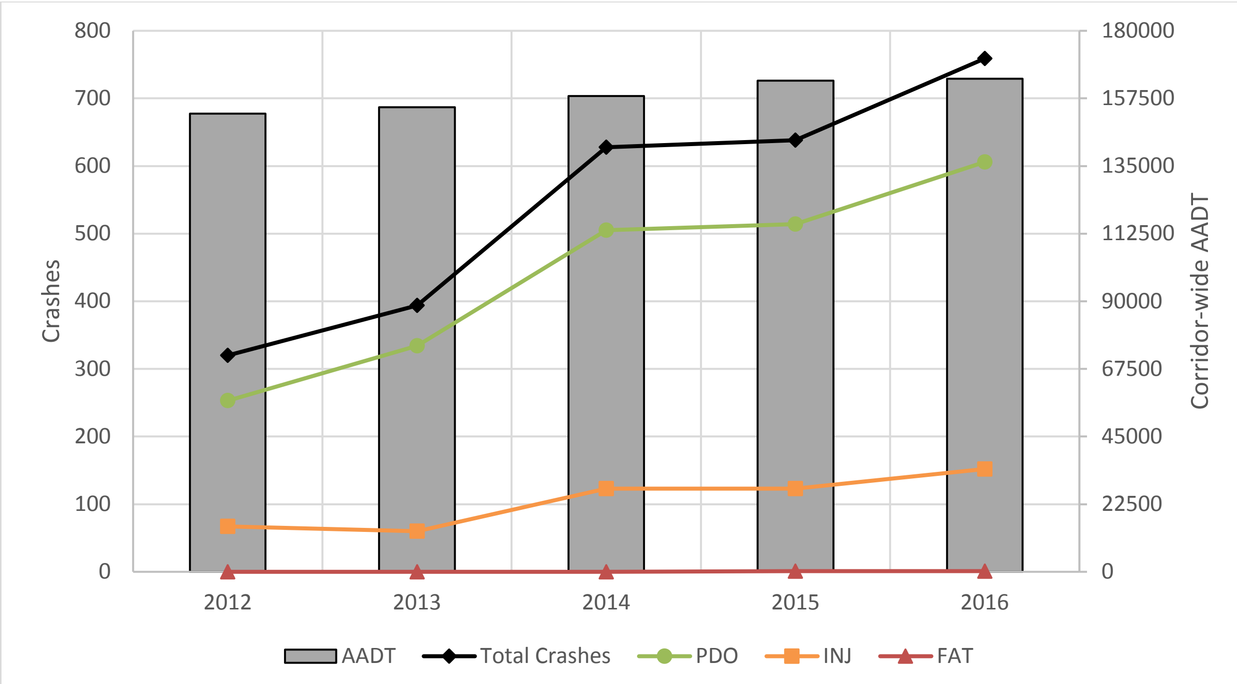

Figure 22 - I-25 Total Crash Distribution Both Directions Compared to AADT

Table 5 - 2012 to 2016 Comparison

	2012 Data	2016 Data	Percent Increase from 2012 to 2016
Total Crashes	320	759	137.2%
AADT	152,406	164,012	7.6%

A more detailed analysis of the crash data based on particular time frames associated with this corridor of I-25 can be found in Appendix E.

4 AUDIT OBSERVATIONS

Field reviews, along with subsequent debriefing and group discussion sessions were performed in the morning and in the evening of September 7, 2017. A list of meeting attendees and the meeting agenda can be found in Appendix F. Excerpts from these group discussion sessions are seen below. In general, the discussions were structured around 4 field observation locations (Pedestrian bridge north of 104th Avenue, 92nd Avenue (Thornton Pkwy), 88th Avenue, and 84th Avenue) as well as general field observations.

Figure 23 - RSA Team Members meeting after field visit on 9/7/17

4.1 MORNING GROUP DISCUSSION

4.1.1 General Observations

- The question was asked "was today a typical day"? Thornton Police Department observed that the morning appeared to be somewhat lighter than typical; perhaps a result of the Labor Day holiday. There were three crashes during the period of observations. All three were in the southbound direction (see Figure 25 and Figure 24 below). Two crashes were located just beyond the southbound on-ramp from Thornton Parkway (between Thornton Parkway and 88th Avenue). This is also the location of geometric concerns that will be discussed in more detail in this report. The 3rd location was located between 104th Avenue and Thornton Parkway. This crash involved closure of Lanes 1 and 2 (managed lane and inside general-purpose lane) for an extended period of time to facilitate potential medical attention and clearance of the crash by local first responders.

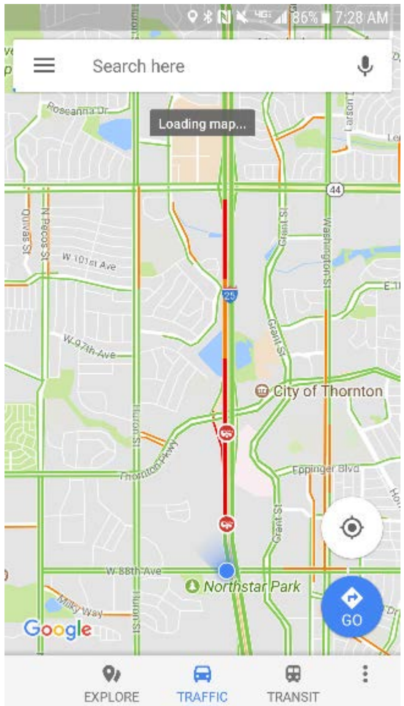

Figure 25 - Crashes on I-25 on 9/7/17 around 7:30am

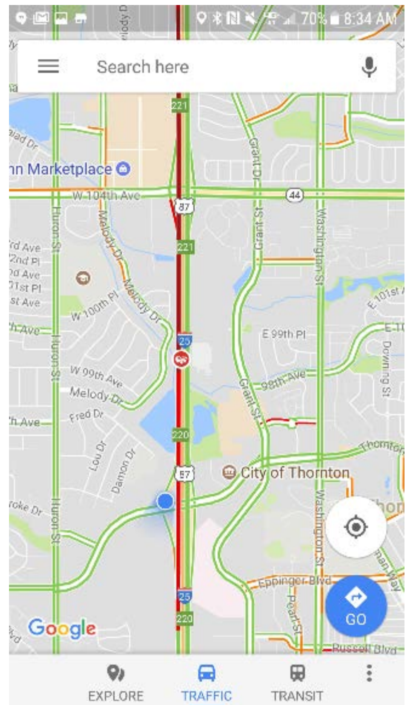

Figure 24 - Crash on I-25 on 9/7/17 around 8:30am

- Some speed measurements were collected by the Thornton Police Department prior to the morning peak hours including speeds as high as 80 to 95 MPH in the managed lanes. Typical speeds in the general purposes lanes at that time were estimated at 45 MPH resulting in a speed differential of 40-45 MPH in these cases.
- Northglenn Police Department noted that crashes occurring in the managed lanes typically resulted in a closure of Lanes 1 and 2. This statement was corroborated by observation of the 3rd crash that occurred in the morning.
- There is often a negative reaction from the public when asked by dispatch to clear crashes from traffic. In rare cases, citations have been issued. Additional public outreach / awareness on this topic would be beneficial. CDOT has been working with the Rocky Mountain Insurance Institute on this issue.
- It was noted that there is a lack of visual cues and signage regarding where to enter / exit managed lanes. Improved signing is needed at the entrance to the managed lanes.

- There is also a lack of understanding related to the meaning of the solid double white lines which separate the managed and general-purpose lanes. Concurrently, there is a lack of awareness by motorists that violation of double white lines is an enforceable action, as well as what the penalty could result from such a violation.
- Is there a technology available that would permit automated enforcement of lane violations?
- Does the width of the buffer between the managed lane and the inner most general-purpose lane matter? It should be investigated if research has been performed that indicates level of compliance based upon separation type, distance, etc.
- Regardless of concerns related to toll violations, it is believed that the primary safety concern is related to speed differential (when speeds in the express lanes are higher than those in the general-purpose lanes).
- It was noted that the experience has been different along US Route 36, which also contains managed lanes. However, it is recognized that the facilities have very different characteristics.
- Use of contrasting color in the managed lane and/or buffer area should be considered.
- It was noted that many changes occurred at the same time (including number of lanes, shoulder widths, ramp entrances / exits, and ramp metering). These changes may also influence the crash history.
- 70% of the crashes along the subject segment of I-25 are rear-end crashes which may imply a congestion issue. CDOT ITS has a queue warning system in deployment for southbound traffic that is nearing full function (see Figure 26).

Figure 26 - Southbound I-25 queue warning system 0.5 miles north of Thornton Pkwy

- Use of variable speed limits to help mitigate speed differential between general purpose and express lanes should be evaluated.
- I-70 Peak Period Shoulder Lanes project uses an 8-inch solid yellow line to delineate the shoulder / managed lane versus the general-purpose lanes. The PPSL is only an express

lane for a limited number of hours / days per year. The I-25 express lane is 24/7 and therefore a shoulder stripe treatment may not be appropriate.

- Some of the guide signing is confusing (for example signs at mile marker 217B) and could benefit from improvements. A review of corridor guide signing and relationship (in the cross section) of that signing to the express lanes is needed. Sign 217B reads "LEFT" meaning left exit but can be interpreted as left (managed) lane.
- General comment was also made that the ITS displays on Dynamic Message Signs (DMS) should consist of no more than two panels. Three panel displays are difficult to read at highway speeds. Visual overload may also exist given the lengthy message of signs and DMS in the area.
- Left-lane exits in combination with left-side managed lanes are undesirable. One longer-term objective may be to remove left-hand exits.
- A physical separation between the managed lane and the general-purpose lanes should be considered. Issues installing this physical separation include right-of-way, funding, drainage, snow removal, and other maintenance considerations.
- Consider changing the tolling strategy. This may include dynamic tolling, which would vary the toll price based on congestion, or removing tolls entirely.
- Consider shortening the length of the toll sections.
- Review locations of ingress and egress to managed lanes considering closely spaced interchanges and weaving concerns. This may include consideration of closing some ingress/egress locations to minimize weaving.
- Review location and frequency (coverage) of toll points from the perspective of avoidance. What is the zone of detection for toll purposes (full lane width, more / less?)
- Consider physically shortening the length of the toll corridor from the south so that there is less confusion when approaching the US 36 / I-270 interchange. However, this change may present an issue for HPTE.
- Consider a true express service with no intermediate entrance / egress between start and end.
- Based on the data, there are significantly more crashes in the southbound direction than northbound.
- It was generally observed that the inside through lane (left-most general-purpose lane) experienced higher density of flow than all other lanes.
- Before the managed lanes were installed, this segment of I-25 had a cross-section consisting of a 10 foot outside shoulder, three 12-foot general purpose lanes, and a 15 foot inside shoulder.
- The current cross section of this segment of I-25 consists of an 8 foot outside shoulder, two 12-foot general purpose lanes, one 11.5 left-most general-purpose lane, a nominal 2-foot marked buffer, one 11.5-foot managed lane, and a 4-foot insider shoulder.

- Safety assessments should include a predictive crash analysis in addition to the review of observed crash history.

4.1.2 North of 104th Ave (Pedestrian Bridge)

- Observed significant level of traffic volume ebb and flow.
- Lane violations were more frequent when brake lights were visible ahead (see Figure 27).

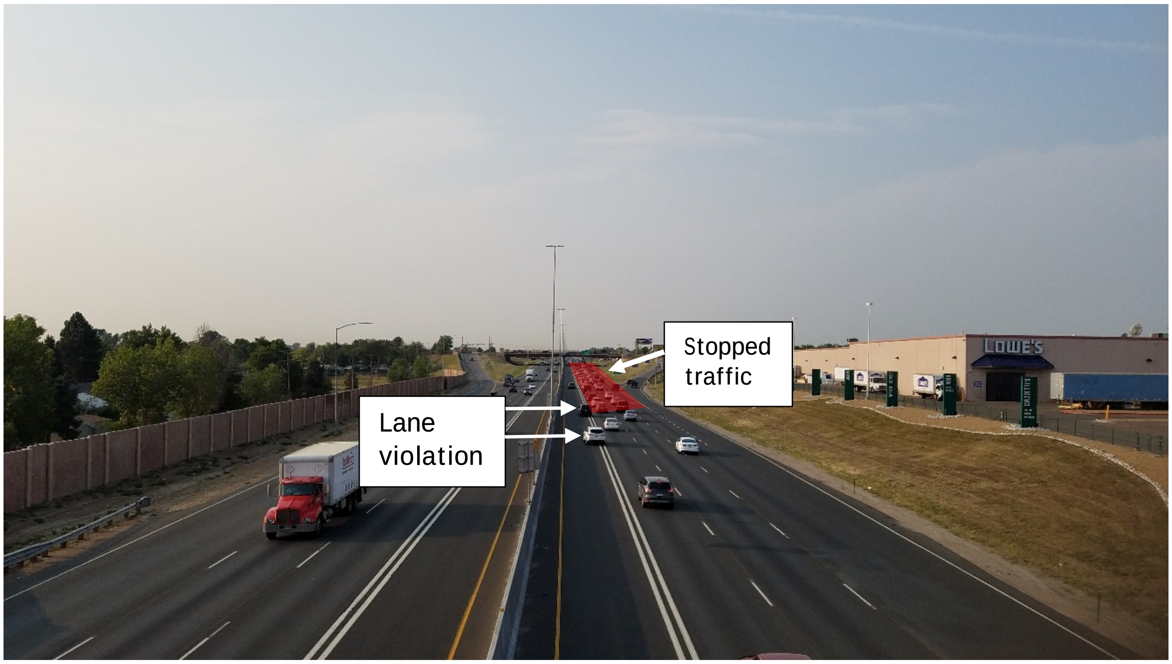

Figure 27 - North of 104th Ave looking south on 9/7/17 at 8:15am

- Traveling southbound, there is a downgrade at approximately MP 221.3 at which motorists have a good view of the roadway ahead and/or any brake lights ahead. However, there are bridges and other structures within this downgrade that tend to obstruct sight lines.
- Lack of shoulders combined with high volumes and speeds makes enforcement dangerous and runs the risk of secondary crashes as a result of lane violations.

4.1.3 Thornton Pkwy (92nd Ave)

- Observed lane violations at this location. Modifications to the southbound on-ramp are suggested for consideration. Rather than having 2 lanes beyond the meter, a better alternative may be to merge the lanes together quicker, thereby avoiding a "three lanes to one" merge condition downstream. Figure 28 shows an aerial view of this conceptual layout. Other options may include lengthening the gore for the same reason.

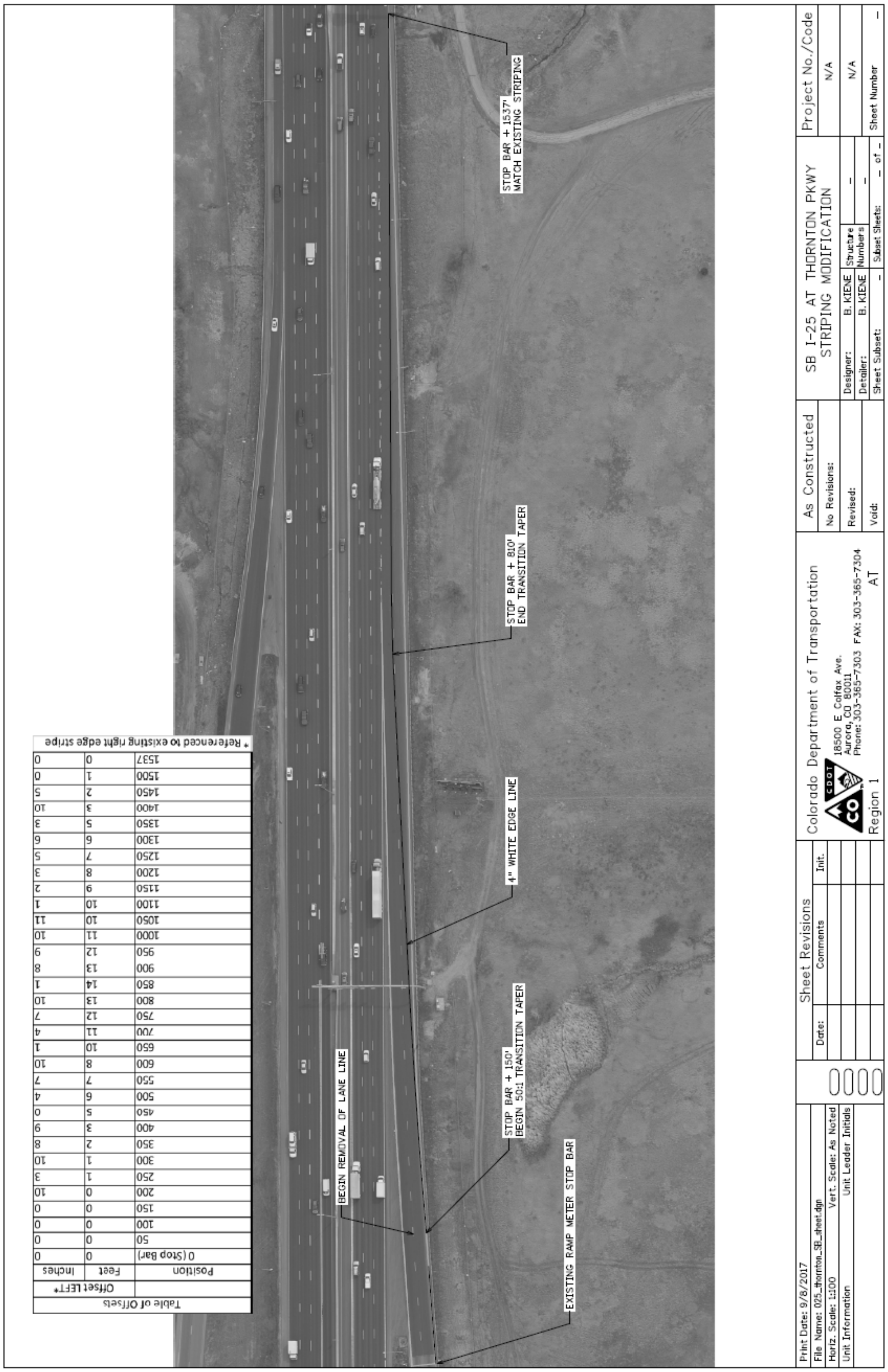

Figure 28 - Conceptual layout of proposed merge pattern at southbound on ramp to I-25 from eastbound Thornton Ave

4.1.4 88th Avenue

- Buses at the RTD pull-out were seen stopping / staging along the highway at near the off ramp (see Figure 29, Figure 30, and Figure 31). The buses are rapidly decelerating upon exit which presents a hazard for the following traffic along the outside lanes of southbound I-25. There is currently no separate deceleration lane for this movement. Also, there appears to be room to widen the off-ramp to store buses further off the freeway (see Figure 32).

Figure 29 - On 88th Ave looking north on 8/23/17 around 10:30am

Figure 30 - On 88th Ave looking north on 9/7/17 at 7:30am

Figure 31 - On southbound I-25 just north of 88th Ave looking south on 9/7/17 at 7:20am

Figure 32 - RTD station on west side of I-25 just south of 88th Ave

- CDOT has a PEL and 30% NEPA at 88th / I-25. The current plan is to have a median station for buses in the future to better serve transit via the managed lane. This plan is also trying to incorporate a 4-foot buffer for the managed lanes.
- Buses exiting the station are creating queues / slowing traffic along I-25 when merging / weaving into the managed lanes from the bus-only on-ramp. If a median station cannot be provided, buses will have to use 84th Avenue.
- Coordinate with RTD on potential solutions for this area.
- FHWA is not inclined to approve transit only access in the future if the shoulders are going to be used as storage and staging of the transit vehicles or if they have any other negative impacts on the safety or operations of the Interstate System.

4.1.5 84th Avenue

- It was discussed that there may be some safety and operational benefits to revising the "add" lane from 84th Avenue to be a through lane at that location and making the 84th Avenue on-ramp a merge movement. A sketch of preliminary reconfiguration ideas was drawn during the field meeting debrief and is seen in Figure 33. Additional downstream (southbound) changes at the I-76, I-270 and US Route 36 interchange may also help to limit weaving. An operational analysis of the segment from 84th Avenue through 58th Avenue is recommended. Stacking along the southbound on-ramp from 84th Avenue may be of concern.

Figure 33 - 84th Ave add lane sketches

4.2 EVENING GROUP DISCUSSION

4.2.1 General Observations

- The northbound queues that were observed just south of 120th Avenue may be due to ongoing construction on I-25 north of 120th Avenue (to extend the managed lanes north) and difficulties that heavy vehicles experience while negotiating the uphill grade.
- The term "Express Lane" as used in many public relation pieces, which is referring to the managed lane, may attribute to increased speeding violations as motorists expect this lane to travel at a higher speed.
- There is confusion regarding toll collection and cost based on where a vehicle enters the managed lane.
- Thornton Police Department noted that left lane crashes occur at a ratio of 4:1 when compared to right lane crash frequency.
- The evening traffic observed on this date seemed unusually low.
- CDOT noted that crashes on southbound I-25 occur most frequently on Saturdays.
- It was noted that there is a lack of understanding regarding exactly what the toll revenue is funding.
- Enforcement issues were observed as seen in Figure 34. It is clear that there is very limited space in which law enforcement can operate.

Figure 34 - On 84th Ave looking north on 9/7/17 at 3:45pm

5 POTENTIAL SAFETY ENHANCEMENTS

The RSA team proposed the following short, intermediate, and long-term potential safety enhancements for the Interstate 25 corridor from US Route 36 north to Community Center Drive. Enhancements are grouped by type (Engineering, Enforcement, and Education) and category (overall enhancement goal). The Time Frame column seen in Table 8 reflects how long the particular enhancement may take to deploy, as described in Table 6 below.

Table 6 - Time Frame

Time Frame	
Short	Less than 1 year
Medium	1-3 years
Long	Greater than 3 years

The Cost column seen in Table 8 reflects the costs of each potential safety enhancement including both direct capital costs and indirect (such as environmental, policy alteration, tolling revenue alteration, time required, etc.) costs. The matrix seen in Table 7 was used to determine the overall cost ranking reflected in Table 8.

Table 7 - Potential Safety Enhancement Cost

Direct Capital Cost				
	High	High	High	High
	Medium	Medium	Medium	High
	Low	Low	Medium	High
		Low	**Medium**	**High**
		Indirect Cost		

Table 8 - Potential Safety Enhancements

	Category	Potential Safety Enhancement	Safety Benefit	Time Frame	Cost	Responsible Agency	Most Recent Action
Engineering	**Improve signage**	Dynamic message signs are too long and should be limited to 2 panels only	Low	Short	Low	CDOT	
		Additional and/or more concise signage at the entrances to the managed lane	Low	Short	Low	CDOT	Signage review and recommendation documentation currently in progress as of 11/20/17
		Additional signage informing motorists of lane violation regulations	Low	Short	Low	CDOT	Signage review and recommendation documentation currently in progress as of 11/20/17
		Additional tolling cost structure signage (see Appendix G for draft signage proposed on 10/23/17)	Low	Short	Low	CDOT	
		Conduct a thorough review of all regulatory, warning, and guide signs along the entire corridor (see Appendix G for draft signage improvements proposed on 10/23/17)	Low	Short	Low	CDOT	Signage review and recommendation documentation currently in progress as of 11/20/17
	Improve pavement visuals	Research contrasting color to the pavement in the buffer zones	Low	Short	Low	CDOT	
		Research contrasting color to the pavement in the managed lanes	Low	Short	Low	CDOT	
	Mitigate speed differential	Continue to improve the queue warning system currently used for southbound traffic	Low-Medium	Short	Low	CDOT	
		Investigate the use of variable speed limits in both the managed and general-purpose lanes	Low-Medium	Short-Medium	Medium	CDOT	

	Category	Potential Safety Enhancement	Safety Benefit	Time Frame	Cost	Responsible Agency	Most Recent Action
Engineering	**Modify tolling strategy**	Modify the toll lanes access points such that there is one ingress and one egress point for each direction	Medium	Medium	Low-Medium	CDOT / HPTE	
		Consider changing the tolling cost structure from time-of-day and day-of-week to dynamic, congestion based pricing	Unknown	Medium	Medium	CDOT / HPTE	
		Enhance zone of toll collection detection to incorporate more than only toll point (if current technology allows)	Unknown	Long	High	CDOT / HPTE	
		Convert the managed lanes to peak period shoulder lanes	Medium	Long	High	CDOT / HPTE	
		Consider removing or adjusting the toll facilities or toll zones	Medium	Long	High	CDOT / HPTE	
	Modify corridor geometry and/or cross section	Modify on-ramp configurations such that vehicles merge to one lane before entering mainline traffic	Low-Medium	Short	Low	CDOT	Modification to southbound on ramp to I-25 from Thornton Pkwy completed on 9/17/17
		Review current managed lane standards and develop new standards as necessary	Low	Medium	Low	CDOT	
		Review lane geometry for the entire corridor	Low	Short	Low	CDOT	
		Install a rumble strip or other warning device within the buffer zone	Low	Short	Low	CDOT	

	Category	Potential Safety Enhancement	Safety Benefit	Time Frame	Cost	Responsible Agency	Most Recent Action
Engineering	**Modify corridor geometry and/or cross section**	Coordinate with RTD and the City of Thornton on bus stop operations along the corridor	Low	Medium	Medium	CDOT	CDOT initiated communications with RTD regarding this potential safety enhancement on 11/1/17
		Conduct an operational analysis of the segment from 84th Ave to 58th Ave to determine optimal lane assignment	Low	Medium	Medium	CDOT	
		Review and/or modify the managed lane ingress/egress points and weaving segments (managed lane access control)	Medium	Medium	Medium	CDOT	
		Shorten the length of toll sections (i.e. shorten the length of the double white stripe pavement markings)	Medium	Medium	Medium	CDOT	
		Remove visual obstructions (bridges and structures) on vertical curve near 104th Ave	Low	Long	High	CDOT	
		Remove left-hand exits that conflict with the left-hand managed lane	Medium	Long	High	CDOT	
		Increase the buffer width	Low-Medium	Long	High	CDOT	
		Increase the inside shoulder width	High	Long	High	CDOT	
		Increase outside shoulder width	High	Long	High	CDOT	
		Reconstruct I-25 corridor to full build out plan	High	Long	High	CDOT	

	Category	Potential Safety Enhancement	Safety Benefit	Time Frame	Cost	Responsible Agency	Most Recent Action
Enforcement	**Improve incident responses**	Create a Traffic Incident Management Plan (TIMP) for the corridor which reflects managed lane conditions	Medium	Short-Medium	Medium	CDOT / Local Agencies	
	Decrease lane violations	Investigate currently available technology (and any necessary corresponding legislation) which may aid in or automate enforcement of managed lane regulations including lane violations.	Low	Long	Unknown	CDOT / Local Agencies	
Education	**Improve education and outreach efforts**	Educate motorists on proper incident management procedures	Low-Medium	Short-Medium	Low	CDOT / Local Agencies	
		Educate motorists on the proper and legal use of the managed lanes	Low-Medium	Short-Medium	Low	CDOT / Local Agencies	
		Consider ways to change the culture behind the terminology of "Express" lane. "Express" may evoke undesirable driver behavior and styles.	Low	Short-Medium	Low	CDOT	
		Educate motorists on the tolling cost structure	Low	Short-Medium	Low	CDOT	

6 NEXT STEPS

This road safety audit consisted of a great deal of discussion among panel members and stakeholders, equipped with field observations and limited crash data, wherein a bevy of potential safety enhancements for Interstate 25 between US 36 / I-270 and Community Center Drive were suggested. This report has been presented to the owner, CDOT, as well as to the RSA team, completing Step 6 of the RSA Process seen in Figure 35. CDOT Region 1 will review all available information, including this report, and take the lead on any further actions deemed appropriate. These actions complete Step 7 and Step 8 of the RSA process. Additionally, CDOT Region 1 will continue to monitor the safety of this corridor and will elicit further stakeholder participation as necessary.

Figure 35 - RSA Process

7 WORKS CITED

[1] Federal Highway Administration, "Road Safety Audits (RSA)," 15 October 2014. [Online]. Available: https://safety.fhwa.dot.gov/rsa/.

[2] K. Fitzpatrick, M. A. Brewer, S. Chrysler, N. Wood, B. Kuhn, G. Goodin, C. Fuhs, D. Ungemah, B. Perez, V. Dewey, N. Thompson, C. Swenson, D. Henderson and H. Levinson, "Guidelines for Implementing Managed Lanes," Transportation Research Board, Washington, DC, 2016.

[3] K. Fitzpatrick, M. Brewer, T. Lindheimer, S. Chrysler, R. Avelar, N. Wood, D. Ungemah, C. Swenson and C. Fuhs, "Research Supporting the Development of Guidelines for Implementing Managed Lanes," Transportation Research Board, Washington, DC, 2016.

[4] M. E. Hallenbeck, J. Ishimaru and D. Zyuzin, "Evaluation of the Effects of Changing to Continuous Access HOT Lanes on SR 167," The State of Washington Department of Transportation, Seatlle, 2016.

[5] K. Jang, K. Chung, D. Ragland and C.-Y. Chan, "Comparison of Collisions on HOV Facilities with Limited and Continuous Access During Peak Hours," University of California Berkeley Traffic Safety Center, Berkeley, 2008.

[6] S. Srinivasan, P. Haas, P. Alluri, A. Gan, J. Bonneson and P. Hiers, "Crash Prediction Method for Freeway Facilities with High Occupancy Vehicle (HOV) and High Occupancy Toll (HOT) Lanes," Transportation Research Board, Washington, DC, 2015.

List of Appendices

APPENDIX A

COLORADO Department of Transportation Transportation Systems Management & Operations	**Traffic Safety & Engineering** **Road Safety Audit (RSA) Kick-Off Meeting** Tuesday, July 11, 2017 – 1:00pm to 3:00pm HQ Blue Spruce Conference Room 4201 East Arkansas, Denver, CO 80222

I-25 North
Road Safety Audit (RSA)

Kick-off Meeting
CDOT HQ
Tuesday, July 11, 2017
1:00 pm 3:00 pm

Agenda Items – Minutes & Action Items

1. Welcome and Introductions

- HQ – Charles Meyer: Welcome & Problem Statement / Meeting Intent
  - Round table & phone for attendee introductions.
    - Meeting sign-in sheet – *Attachment 1*
    - *Phone-in remote attendees*
      - *George Merritt george.merritt@dot.gov (FHWA)*
      - *Scott Rees scott.rees@state.co.us (CDOT)*
      - *Rich Christy Richard.christy@state.co.us (CDOT)*
      - *Cpt. Rocco Domenico rocco.domenico@state.co.us (CSP)*
      - *Kyle Kammermeier kkammermeier@northglenn.org (Northglenn)*
  - Altering agenda to cover Item 3 first – 8 step RSA Process.

- Region 1 – Angie Drumm: Welcome & conveyance of need for all involved to respect the process, keep internal to attendee group and appropriate staff to enable a thorough and successful process.
  - All potential media inquiries should be directed to Region 1 Angie Drumm's office.

- FHWA – Dahir Egal: Appreciation for all attendees and agency involvement.
  - Focus of meeting: developing this RSA process, not final solutions today.

CDOT HQ Point of Contact: David Swenka – david.swenka@state.co.us P: 303-512-5103

FHWA Area Engineer Point of Contact: Chris Horn – chris.horn@dot.gov P: 720-963-3017

2. Brief overview of the I-25 North safety issues (what is the problem?)

- Proposed RSA team member additions to augment multidisciplinary RSA team.
  - CDOT Intelligent Transportation Systems (ITS)
  - CDOT Maintenance
  - CDOT Traffic Incident Mgmt (TIM)
  - City of Northglenn Police Department
  - CDOT Courtesy Patrol
  - FHWA Resource Center
  - Regional Transportation District (RTD)

- Impetus for initiation of CDOT review and subsequent RSA on this segment:
  - Thornton traffic analysis and subsequent provision to CDOT for further review.
  - Thornton findings indicate safety decline possibly as a result of managed lane.
    - Thornton analysis findings indicate significant crash rate increase NB & SB
    - Thornton PD states that they observe drivers weaving in/out of managed lane during periods of high volume and are resulting in collisions associated with high speed differential between managed lane and GP1 lane. Managed lane is being used as a bypass/passing lane due to the absence of a physical barrier between managed lane and GP1.
    - Law enforcement to mitigate this circumstance is extremely dangerous to officers due to minimal shoulder width – thus currently not enforced.
    - Law enforcement states that traffic incidents often require the closure of more than one lane for first responders and PD to effectively and safely process the crash scene due to limited shoulder widths.
    - Thornton believes that too many lane drops occur at Southern limit of study area which contribute to NB incidents (SH270, US 36, 58th Ave).
    - Thornton believes that I-25SB to SH270 left hand on-ramp and associated signage/VMS potentially cause driver confusion and vehicle conflict.
    - Majority of crash types are Rear End (RE) & Side Swipe Same Direction (SSSD), which is consistent both pre and post managed lane operation.
    - Directional imbalance of crashes is increasing between SB & NB lanes with SB crashes being more frequent.

- Lane (Striping) Geometry:
  - 4’ shoulder, 11.5’ managed lane, 2’ buffer, 11.5’ GP1, 2x12’ GP2&3, 8’ shoulder.

- Original segment analysis:
  - I-25 between 84th Avenue (MP: 218.44) & 104th Avenue (MP: 221.00) – 2.6mi
  - 2013-2015 (+preliminary CDOT 2016 data)

- Proposed increased segment length for RSA analysis (RSA team concurrence secured):
  - Southern limit: US36 overpass
  - Northern limit: 112th Avenue overpass

- Short term mitigation efforts while RSA process is underway:
  - CDOT Region 1 has applied thermoplastic markings clearly indicating “Express”.
    - Attendees found this effort favorable.

- Concrete barrier coring to eliminate water ponding near 112th Ave:
  - Attendees found this effort favorable.
- Future project under development:
  - Plan to widen to standard shoulders (84th → 92nd) @ 30% CD presently.
  - 2040 long term plan to widen entire segment in planning phase(s).

3. Brief overview of the 8 step RSA process – Dahir Egal

(Paraphrasing FHWA PowerPoint presentation – *Attachment 2)*

- RSA Purpose
  - Safety concerns & mitigation opportunities.

- Review of FHWA 8 Step RSA Process
  - Identify project
  - Team selection – Independent / Multidisciplinary
  - Start-up / Info Exchange (today's meeting)
  - Field reviews
  - RSA analysis & findings
  - Presentation of RSA findings to direct stakeholders
  - Formal response preparation
  - Incorporate findings into projects when appropriate

- Field Review
- Post field review meeting(s)
- Report Findings / Preliminary Recommendations
  - Example/Draft: RSA Report - *Attachment 3*
  - Potential safety enhancement summary

4. Availability/assembly/distribution of the site-specific materials

– As built plans, maps, pictures, existing conditions, crash history, ADTs/turning movements, managed lane roadway info, …

- Additional RSA Analysis Research / Query Considerations:
  - Driver considerations:
    - Commuters, unfamiliar drivers (tourists), inexperience (age), etc.

  - Roadway geometry / condition considerations:
    - Lane geometry, signage, striping, markings, ADT, environmental, sight distance, grade, SB/NB differences, VMS messaging, on/off ramps, etc.

  - Vehicular considerations:
    - Buses, commercial trucks, RTD Park n' Ride access, etc.

  - Technological considerations:
    - ITS technology that exists, TIM operations, VMS messaging, ATM, Cue Warning, Ramp Metering, advisory speed communication, tolling, etc.

- Documents to consider:
  - Layout of the corridor (plan/aerial view).
  - Current signing plan.
  - Current striping plan.
  - Traffic Incident Management Plan (TIMP)

- Additional potential sources of crash / roadway data:
  - Local PD/CSP narratives and crash diagrams – potential review of sampling.
  - Municipal mainline crash data if available.
  - OTIS, DTD, CDOT, etc.

- Law enforcement delineation of response zones for the subject segment (Informational if becomes applicable for data collection)
  - 58th Ave → 84th Ave - CSP response zone.
  - 84th Ave → 92nd Ave - Thornton PD response zone.
  - 92nd Ave → 104th Ave - Thornton PD / Northglenn PD split response zone.
  - 104th Ave → 120th Ave - Northglenn PD response zone
  - 120th Ave → North – Westminster PD response zone

- Early stage initial improvement suggestions:
  (Informational Only – RSA to provide recommendations upon completion of process)
  - Advisory speeds (enforceability considerations).
  - Automated toll enforcement.
  - Intermediate toll locations.
  - Dynamic re-routing.

5. Site visit planning/ logistics

– Date confirmation

- CDOT HQ to develop proposed field visit dates.
  - Completion of field AM & PM visits are preferred to occur on the same day.
  - Group suggestions - AM: 05:30-07:00 | PM: 15:30-18:00

– Transportation/site meeting/parking spaces

- CDOT HQ to coordinate with City of Thornton to establish locations and access logistics.
  - Will work with Thornton & Thornton PD regarding PED access & potential bridge lane closures.
  - Will work with Thornton & Thornton PD to secure post meeting space & parking.

6. Post visit discussions/completion plan

- Review agenda item 7 below for schedule going forward. The four items listed directly below will be incorporated into the post-field review de-briefing meeting(s) agenda.

– Discussion of the observations
– Finalization of findings
– Discussion of potential improvements
– Finalization of the recommendations/report

7. Roles and responsibilities/schedule

- CDOT HQ & Region 1
  - Overall RSA Coordination
  - Safety Analysis (HQ)
  - Project Details / Specifications, Traffic Incident Management Plan (TIMP)
- FHWA
  - Provide Technical Assistance
  - RSA Process Guidelines
- City of Thornton
  - Field Visit Accommodations
  - Crash Data Assistance
- Stolfus & Associates
  - Analysis Support & Logistics as Needed
  - Draft & Final Report Generation
- All Team Members
  - Review & Input
  - Implement Recommendations

8. Pre-audit meeting/agenda

- To be developed by CDOT (HQ? / Region1?) prior to field reviews.

9. Next steps – **Most immediate action items**

- Thornton PD/CDOT to compile local current crash data for review.

- CDOT Region 1 to research current Traffic Incident Management Plan (TIMP).
  - Review status & update as necessary (time frame for update not determined).

- CDOT Region 1 to research design waivers / design variances.
  - Includes discussion/communication with construction project engineer(s).

- CDOT Region 1 to obtain current documents for RSA analysis use as needed.
  - Current signing plan / strip maps.
  - Most recent construction drawings /as-builts of the subject corridor.

- Add proposed stakeholder entities / persons described herein to RSA team.
  - Please provide contact info to David.Swenka@state.co.us if you have it.

- Field review coordination (schedule / locations & post-meetings / locations).

- Develop field review & post-field review debrief agenda.

- Perform / complete field review process.

I-25 North Road Safety Audit
Kick-off Meeting
July 11, 2017

4201 E Arkansas Ave, Denver CO 80222

SIGN IN SHEET

Name	Agency	Email Address	Phone Number
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Attachment 1
Page 2 of 2

I-25 North Road Safety Audit
Kick-off Meeting
July 11, 2017

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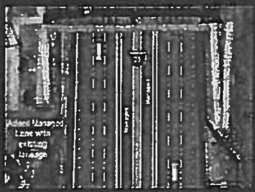
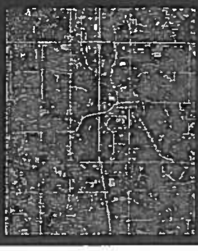
Attachment 2
Page 1 of 4

I-25 North
Road Safety Audit (RSA)

July 11, 2017
Denver, Colorado





Purpose of the RSA

The purpose of the RSA is to answer the following questions:

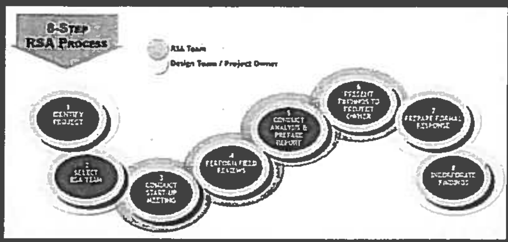
- What elements of the road may present a safety concern: to what extent, to which road users, and under what circumstances?
- What opportunities exist to eliminate or mitigate identified safety concerns?

Location/Existing Conditions

RSA Limits
84th to 104th

RSA Limits
84th to 104th

The 8-step RSA process



The 8-step RSA process

1. Identify Project or Existing Road for RSA
2. Select Independent and Multidisciplinary RSA Team
3. Conduct Start-up Meeting to Exchange Information
4. Perform Field Reviews under Various Conditions
5. Conduct RSA Analysis and Prepare Report Findings
6. Present RSA Findings to Owner/Design Team
7. Prepare Formal Response
8. Incorporate Findings into the project when Appropriate

Field Review – What to expect

- Pre-audit meeting
- Review crash data – (previously studied)
- Walk /Drive through –Daytime
- Walk/Drive through- Nighttime
- Capture your observations and share
- Take or request photo notes to be taken
- List observations /recommendations before leaving field
- More than one visit maybe necessary
- Traffic control by CDOT MTCE?

Post Field Review Team Meeting

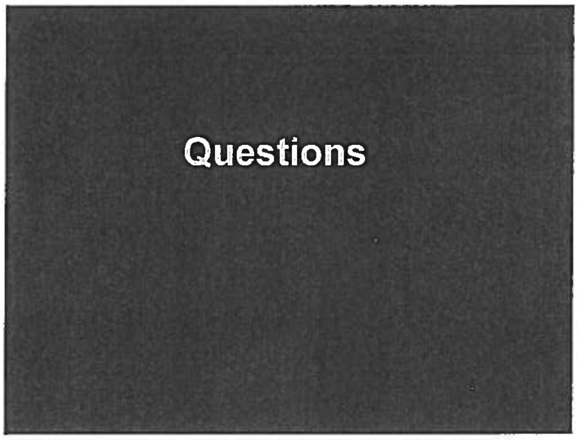
- Discuss nature of the field safety issue/problem observed
  - Road
  - Driver
- Conduct additional analysis if necessary
- Discuss Risk associated with the problem (low, moderate, high)
- Discuss Potential solution to mitigate the risk/correct hazard

Report/ Preliminary Findings/Recommendations

- A formal report
  - A formal response
    - Frequency rating
    - Severity rating
    - Risk assessment
  - Prioritization of Issues
  - Potential Safety Enhancement Summary
  - Short Term Recommendations
  - Long Term Recommendations

Potential Safety Enhancement Summary

Potential Safety Enhancement Summary Safety Issue	Safety Enhancement	Responsibility	Safety Payoff (High –Low)	Time Frame	Cost


Questions

I-25 North Managed Lanes

Road Safety Audit (RSA) Report

Outline (typical)

Title Page

Disclaimer

Table of Contents

Background- purpose of RSA

Project Description- includes graphics

Audit Observations

- Bullet points of observations

Potential Safety Enhancements

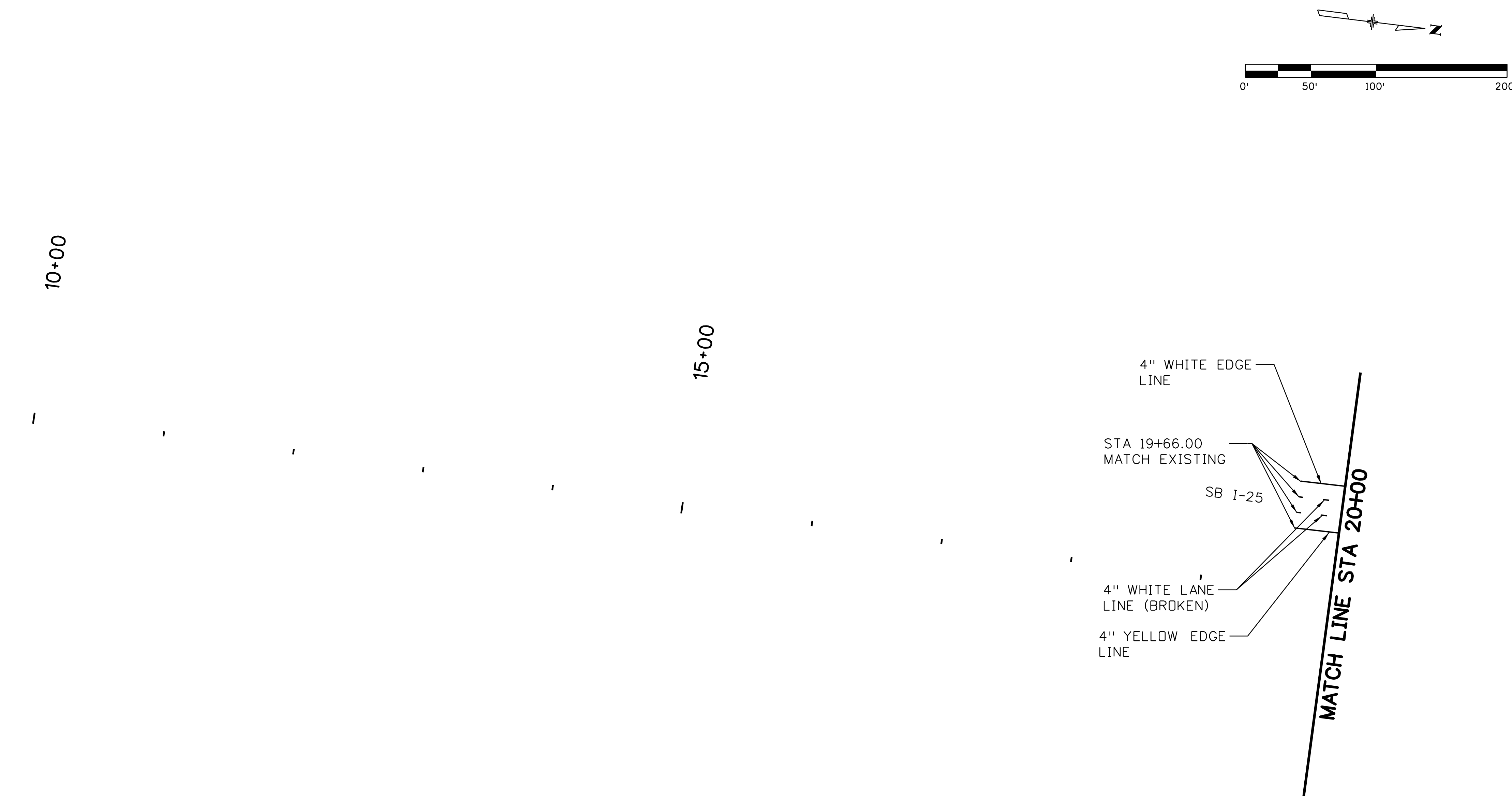
- Bullet points of recommendations

Summary of Road Safety Audit

- Summarize the potential Engineering recommendations

Safety Issue	Safety Enhancement	Responsibility (CDOT, maintenance, local)	Safety Payoff High, Med, low	Time Frame	Cost

APPENDIX B



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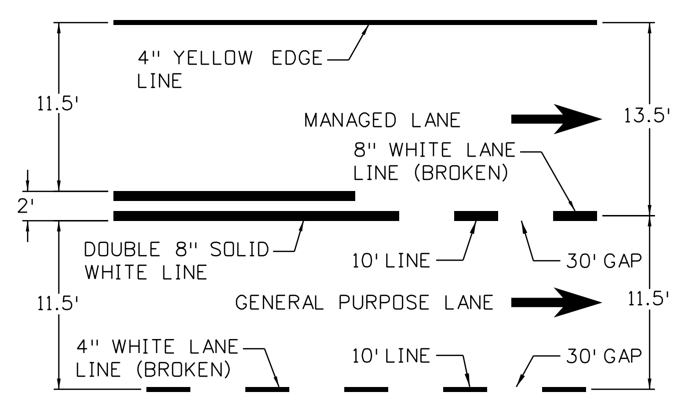

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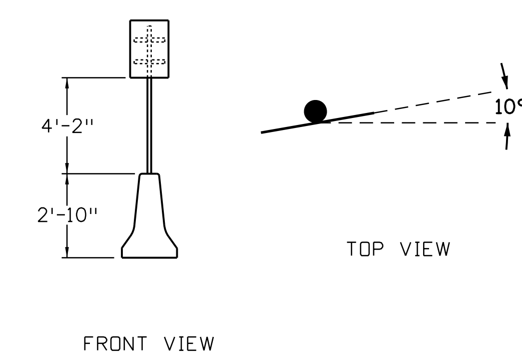

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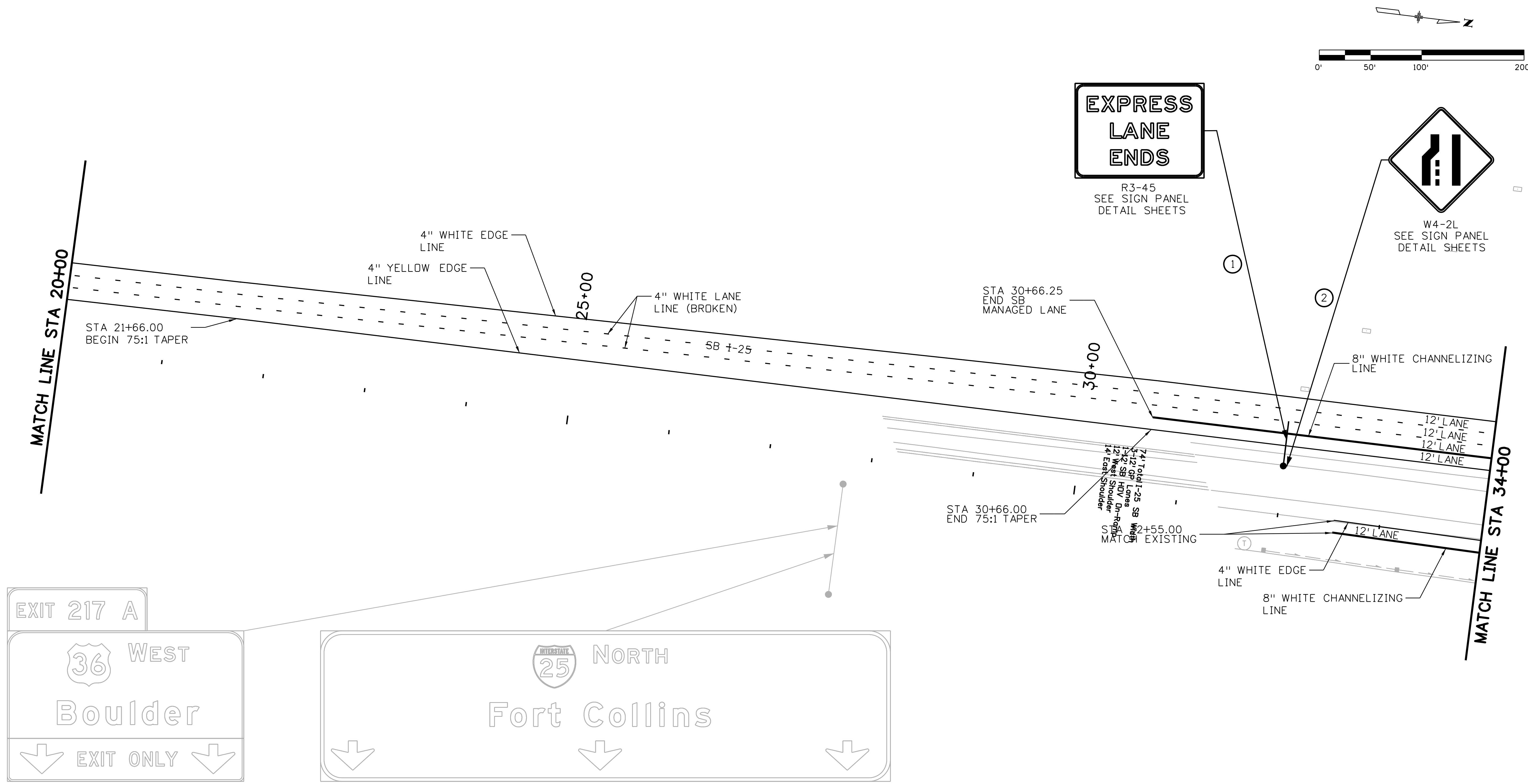

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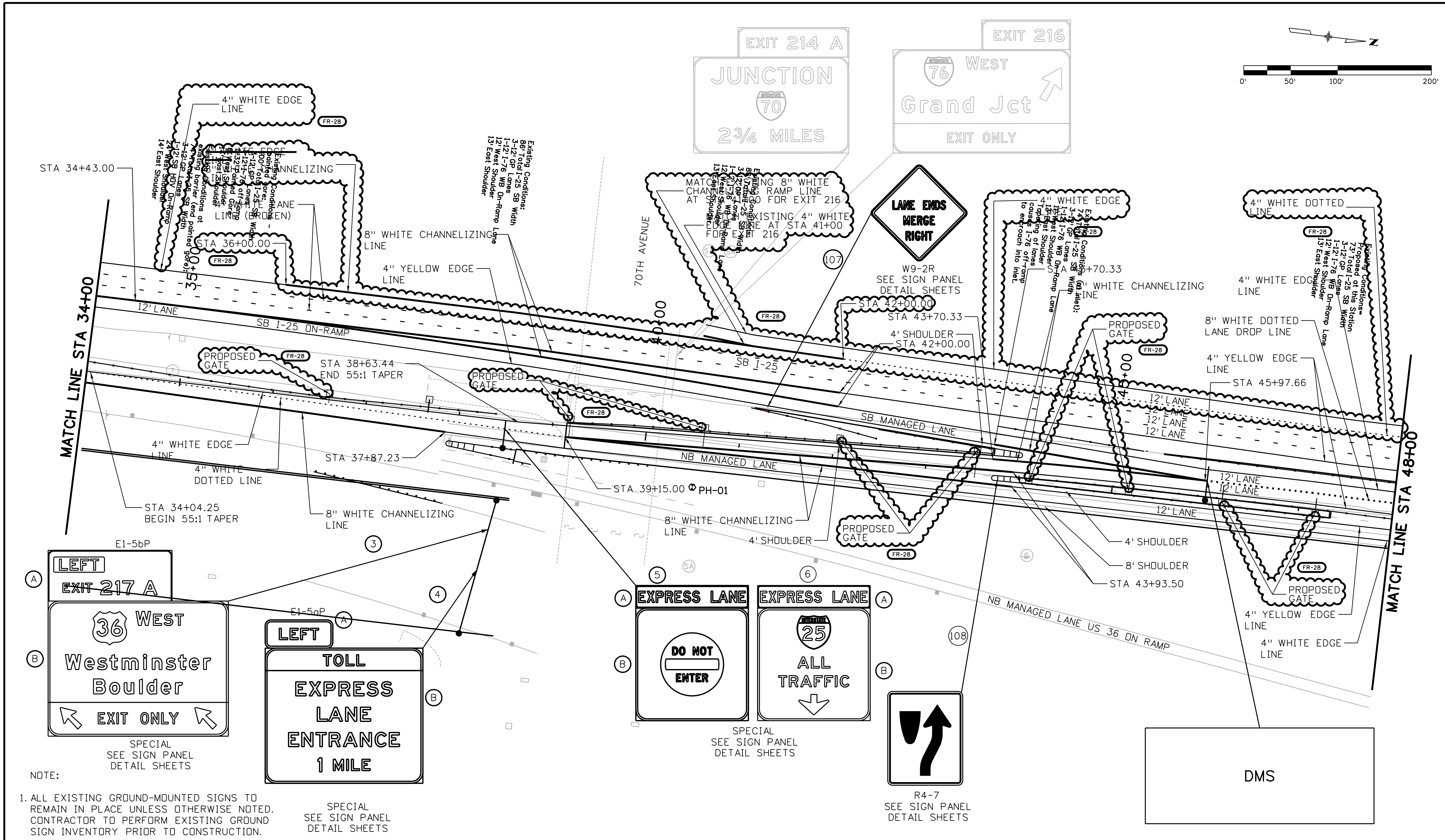

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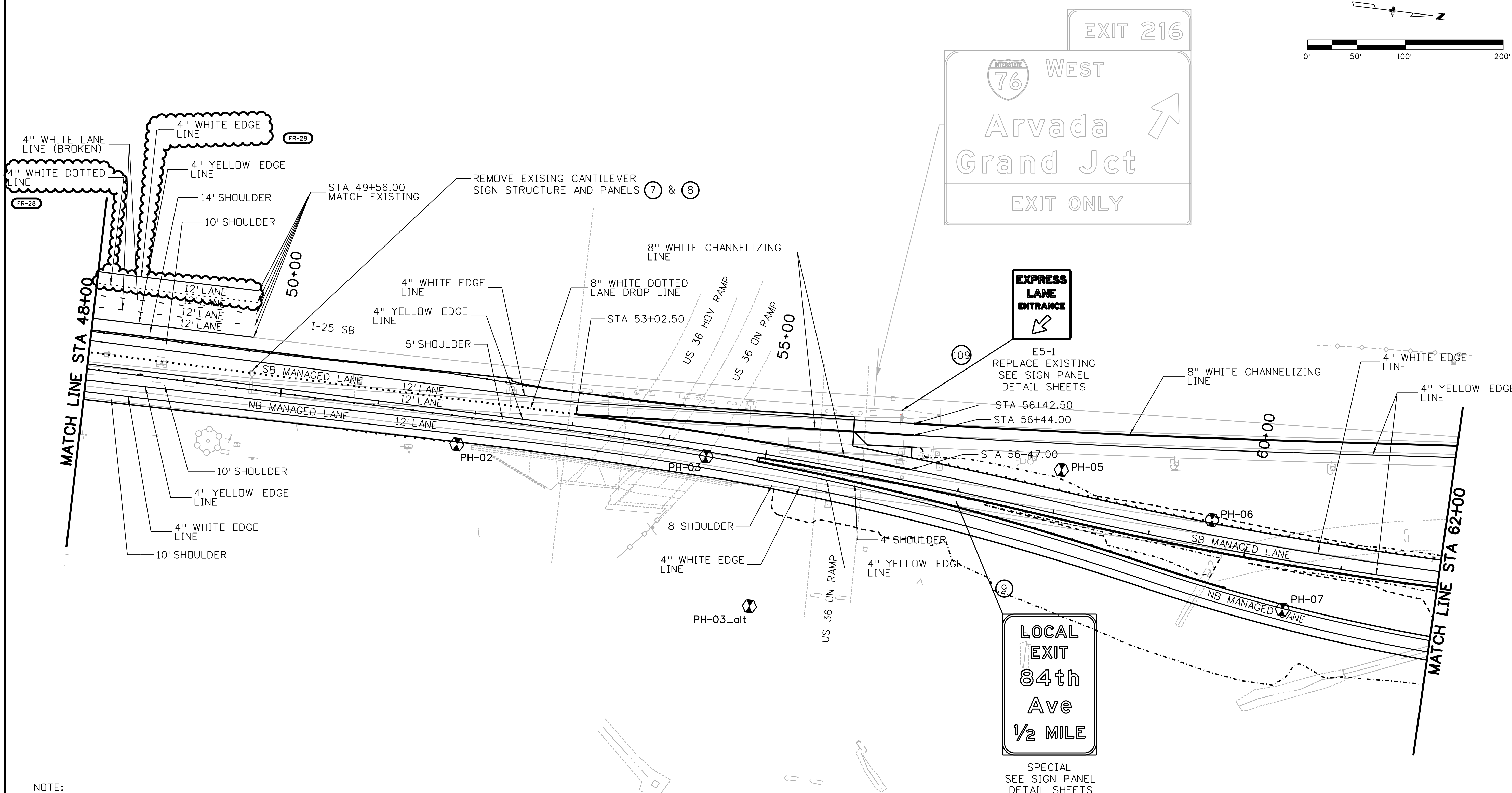

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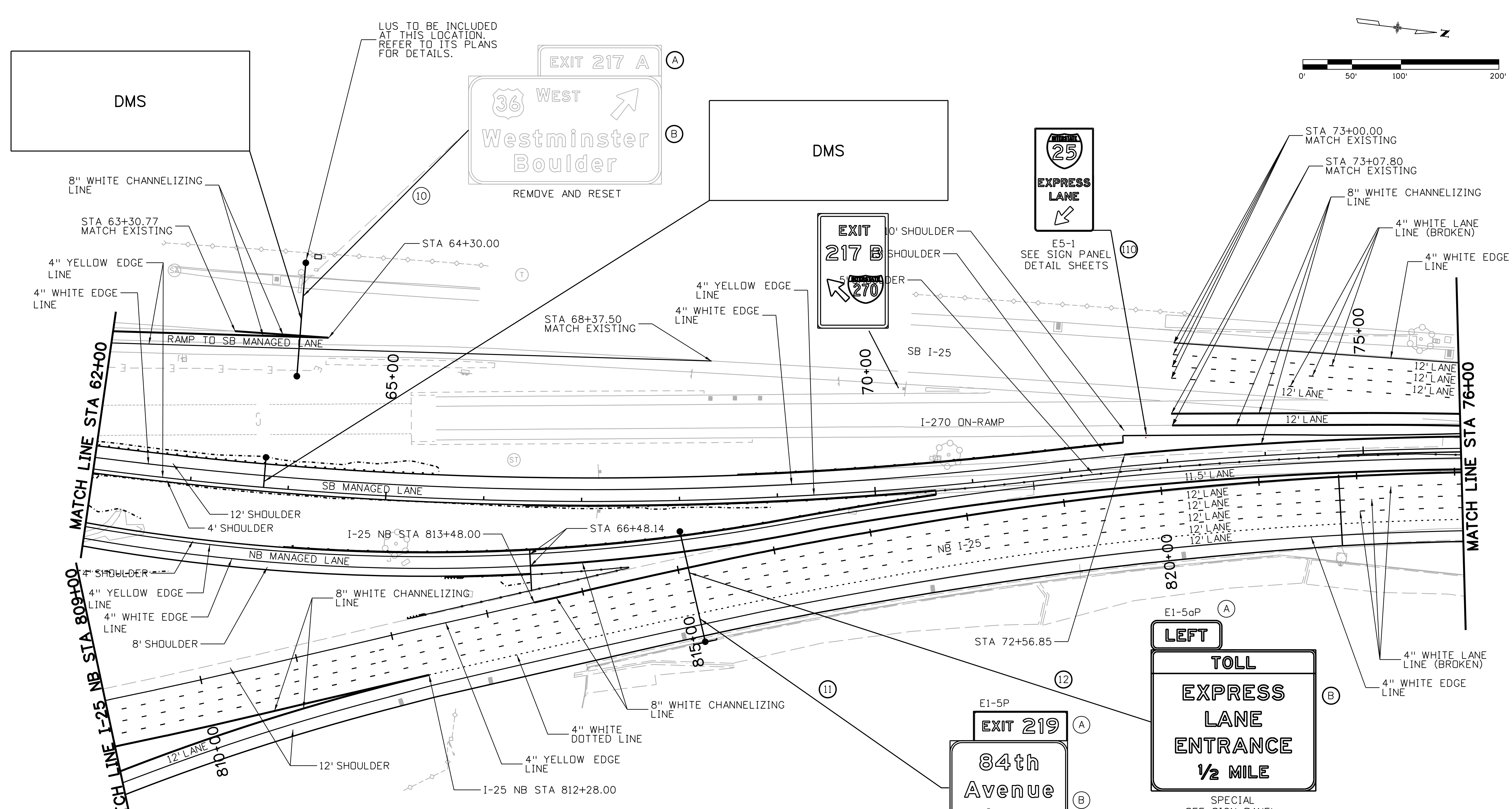

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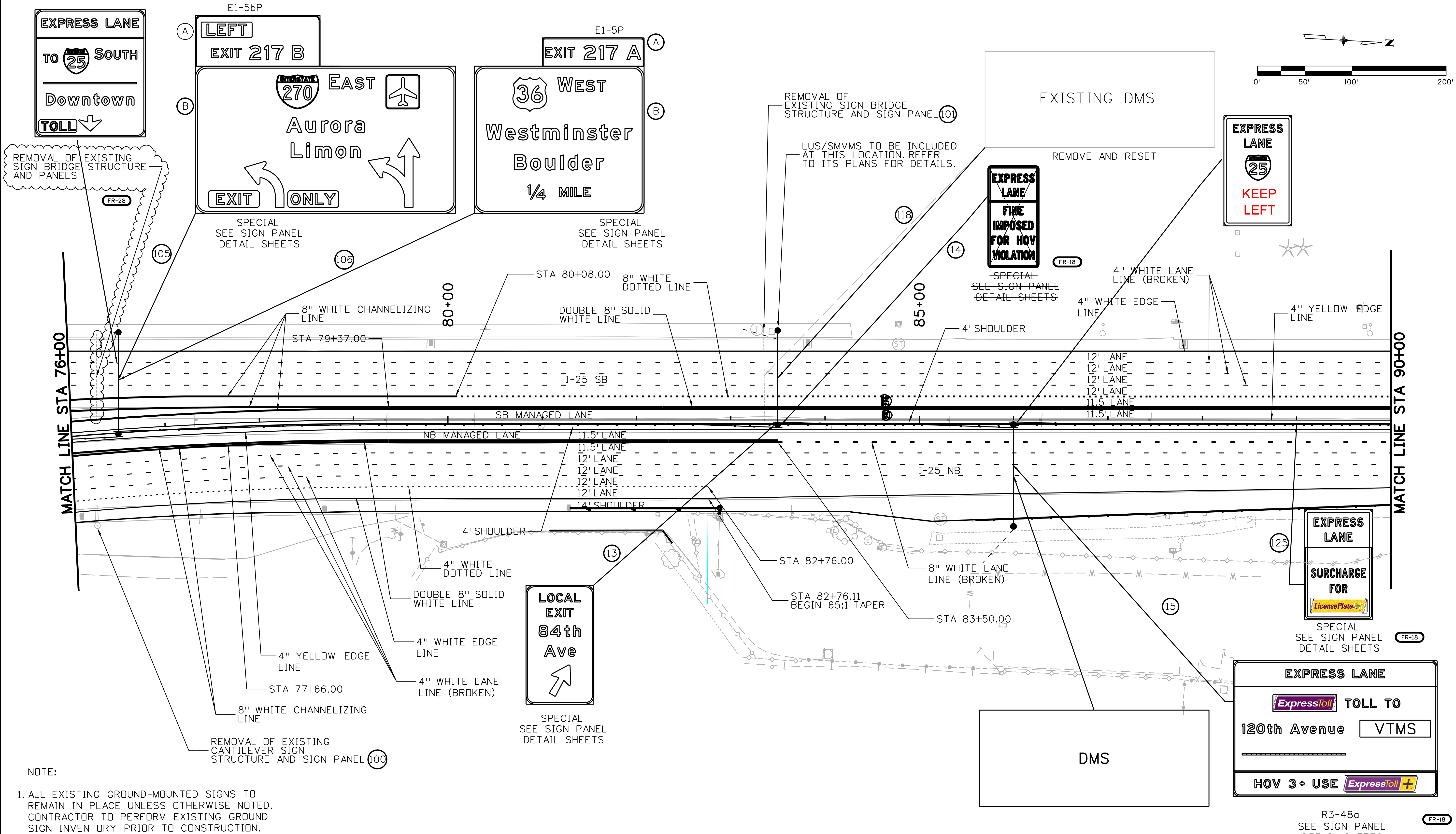

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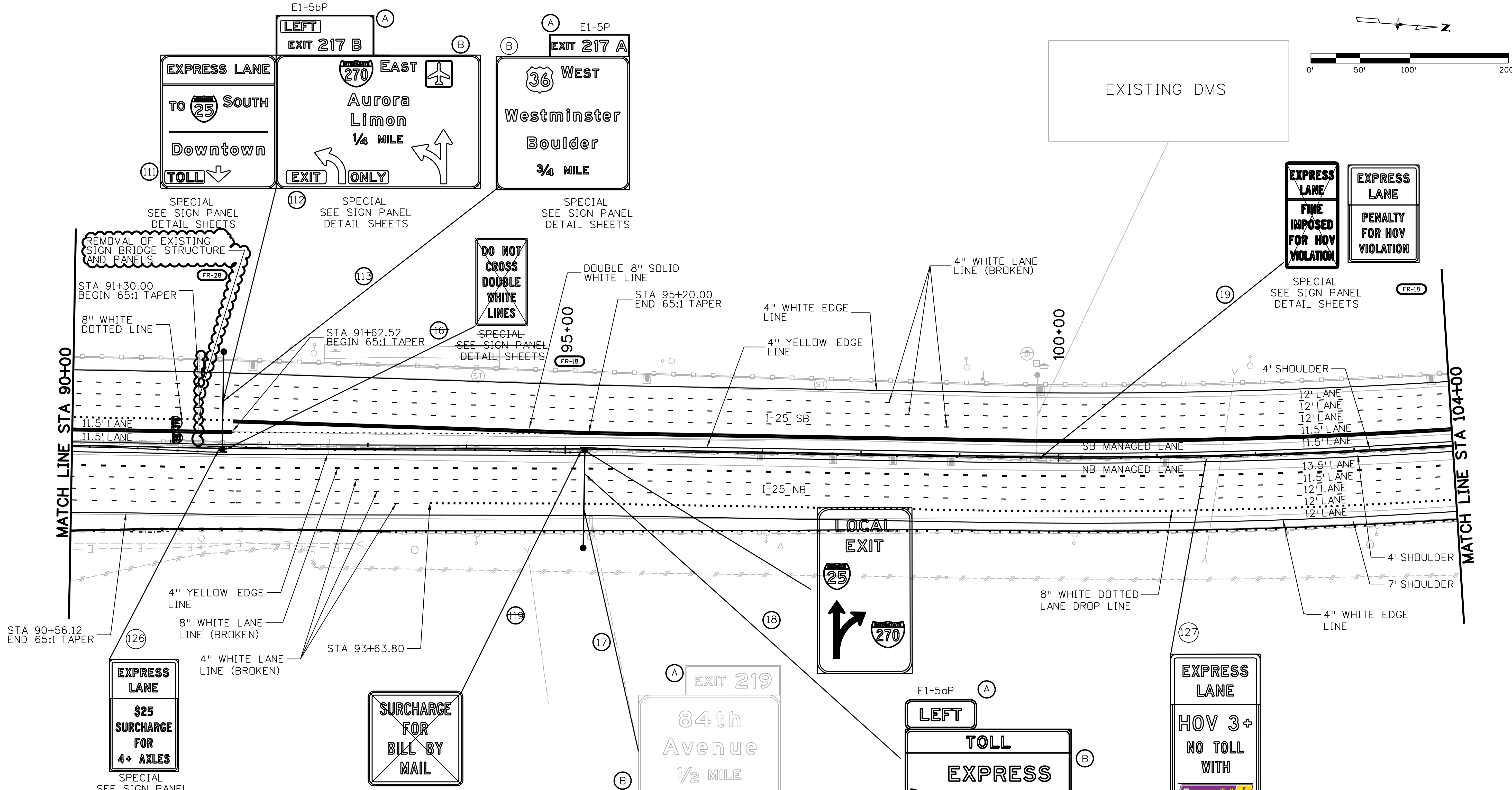

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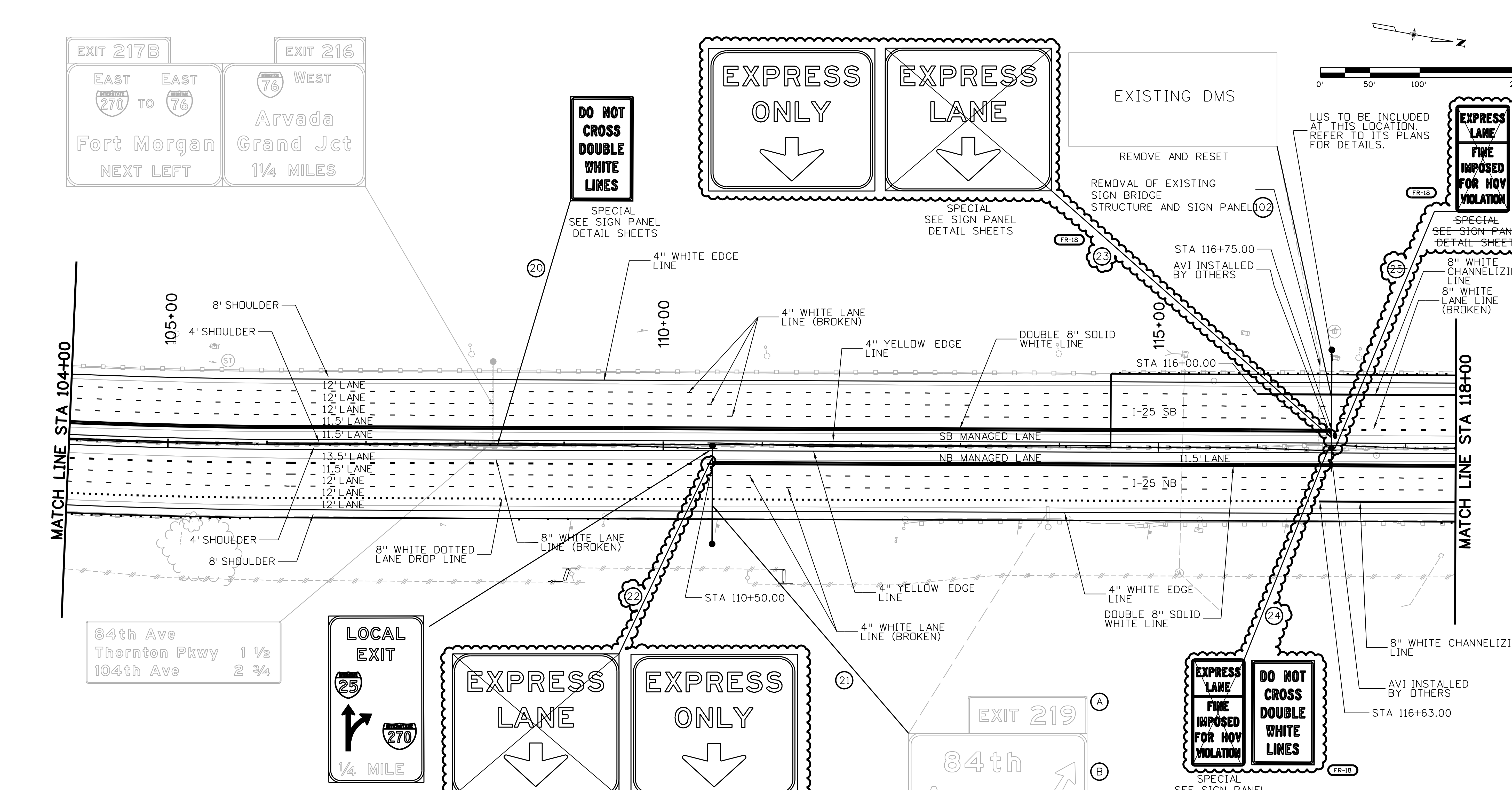

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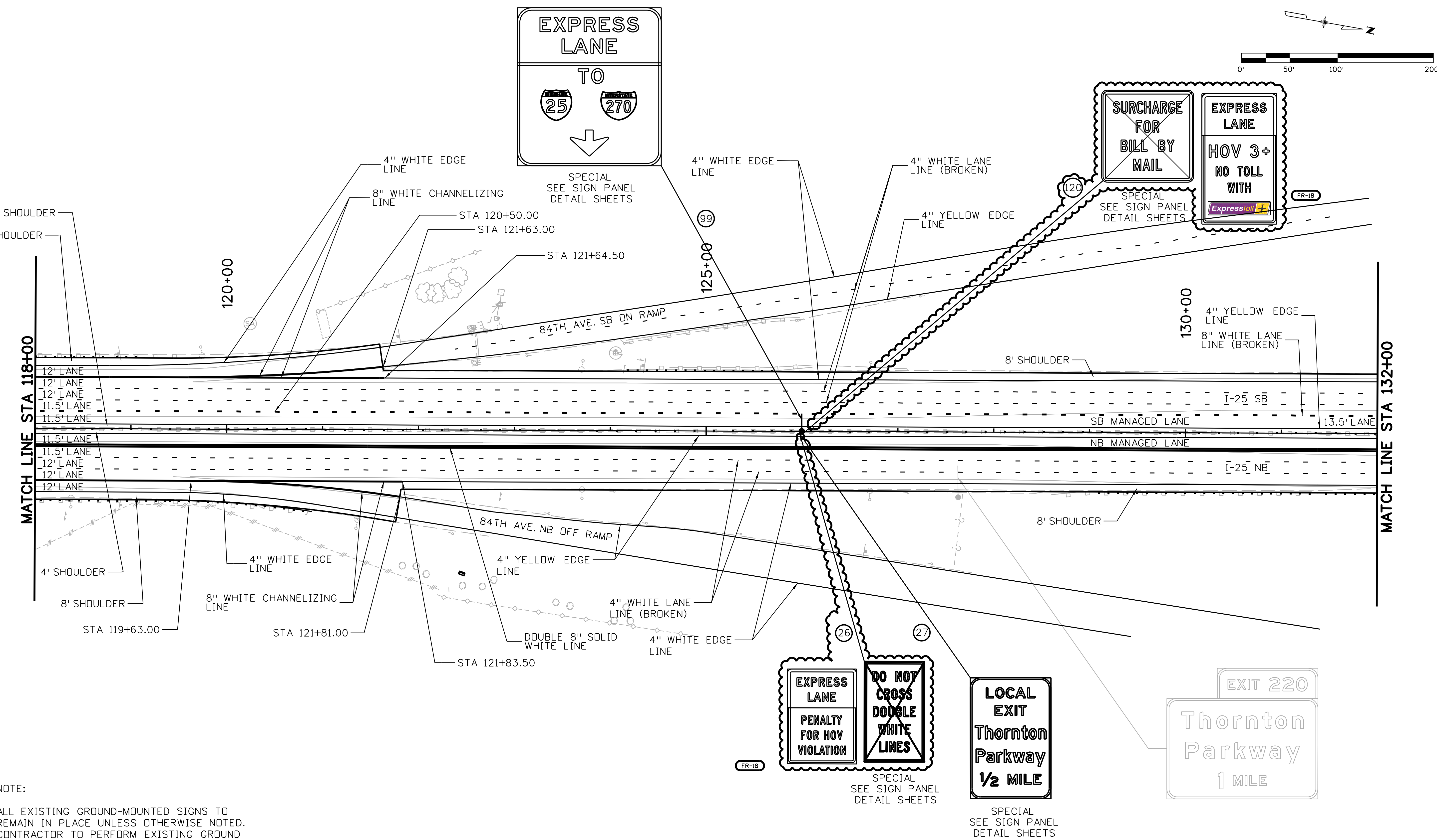

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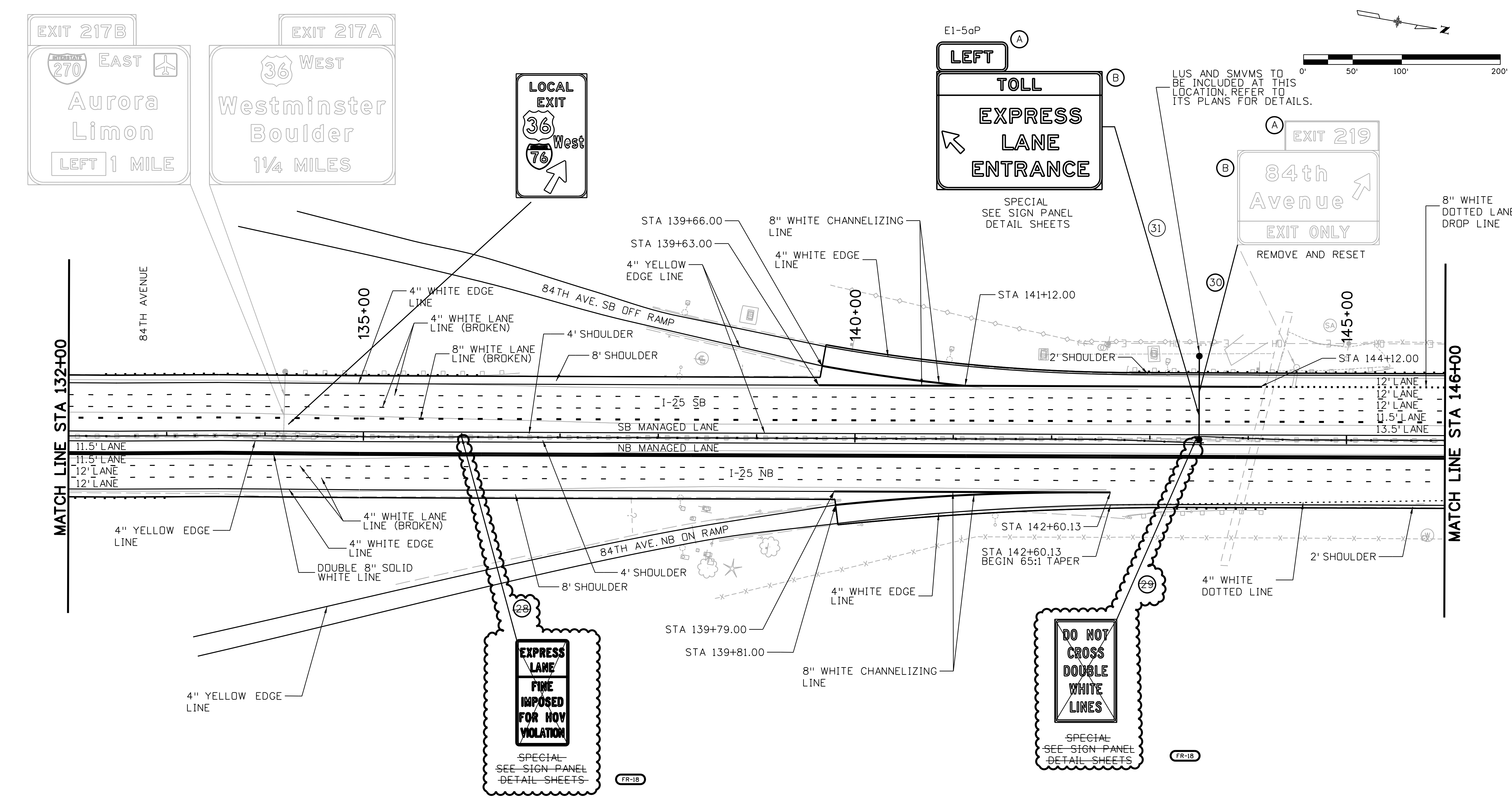

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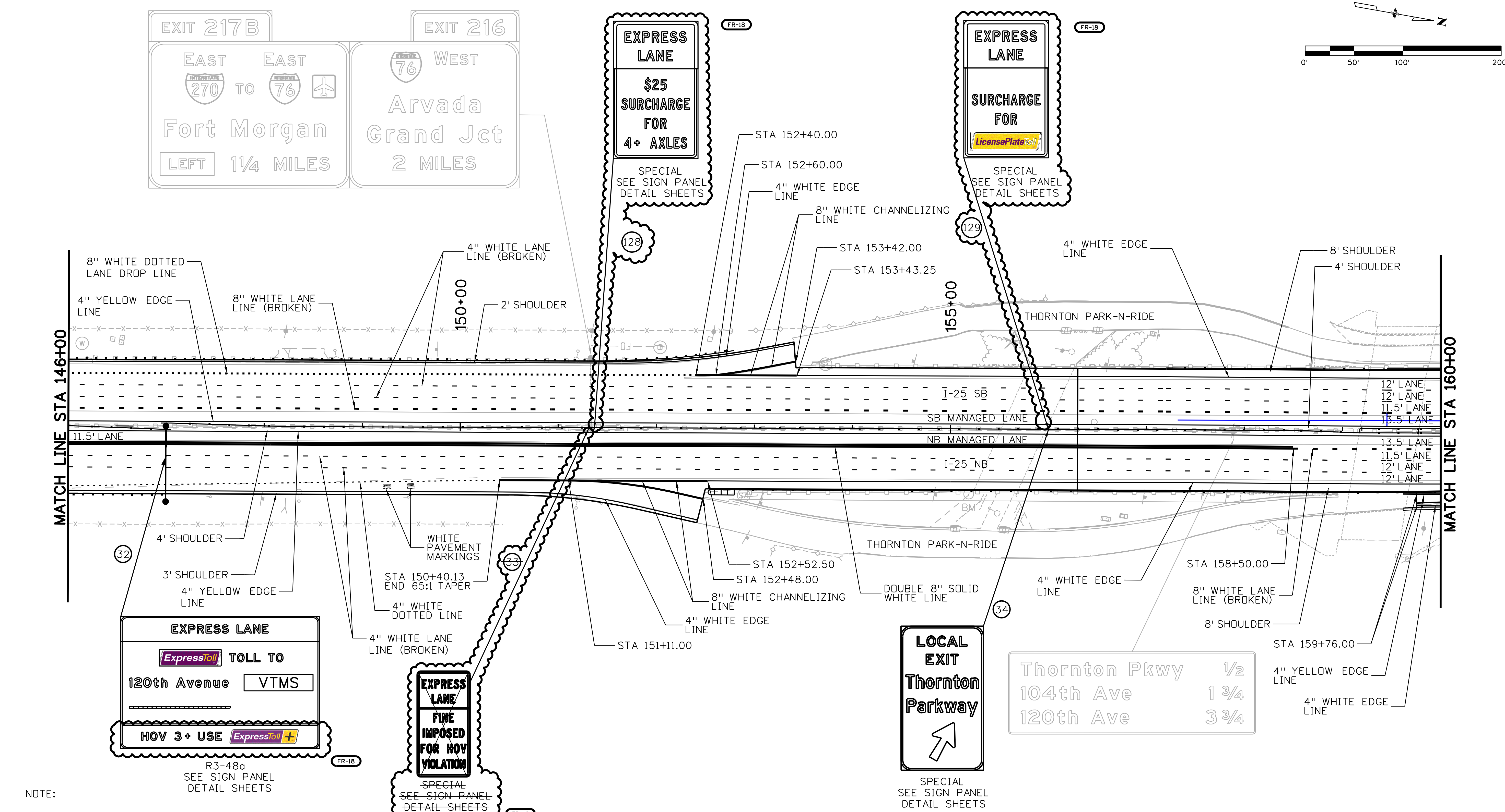

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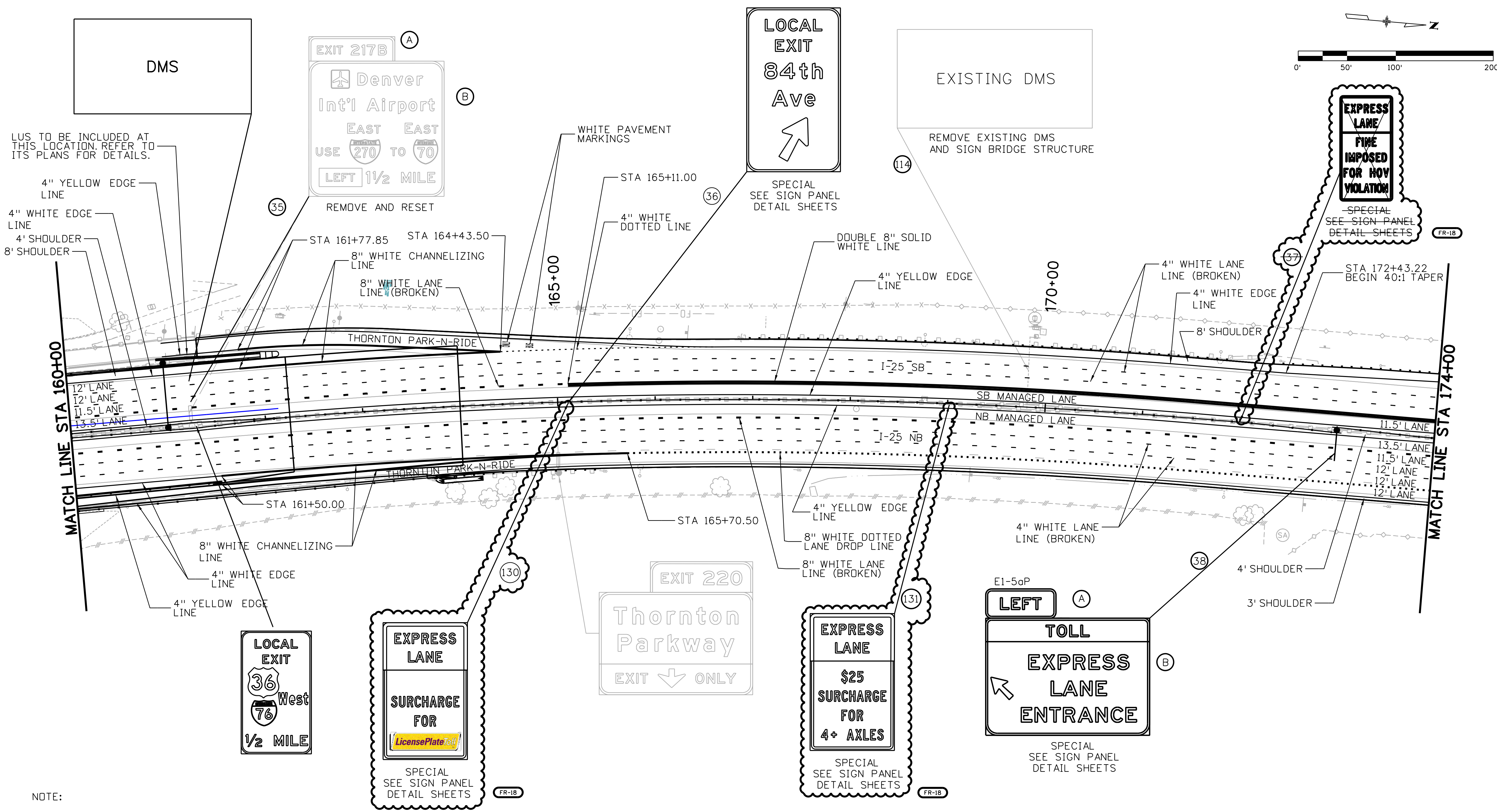

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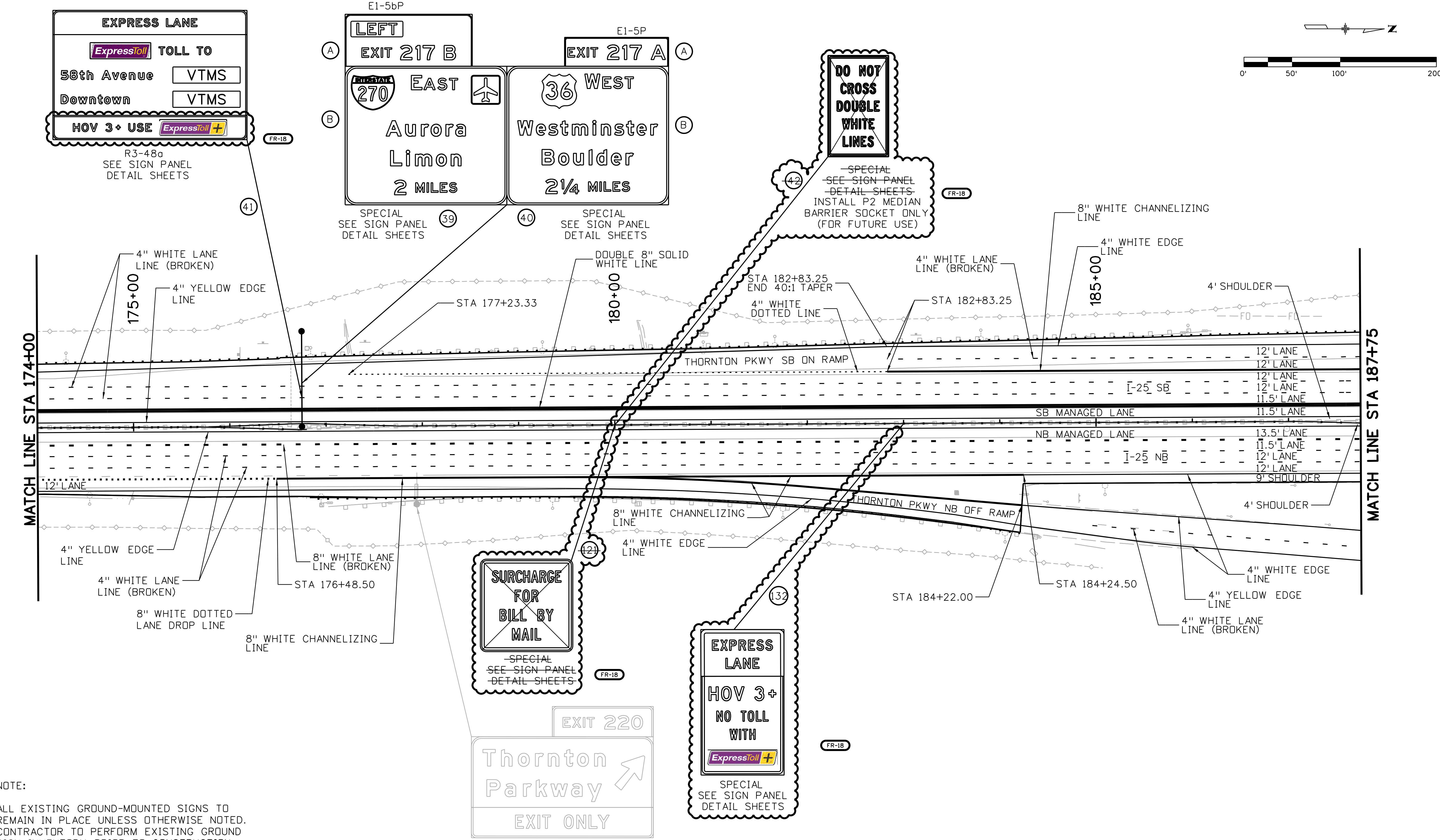

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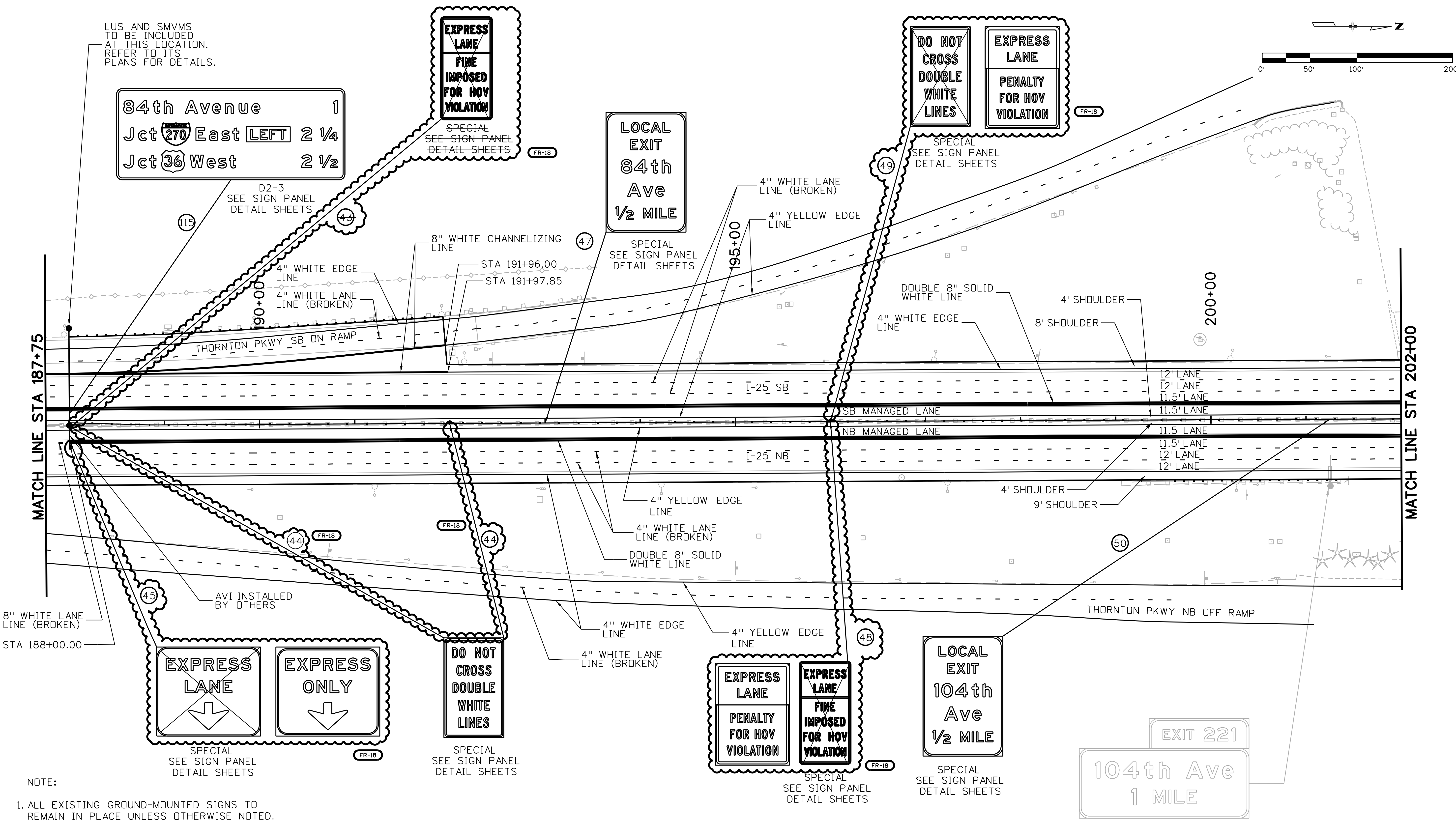

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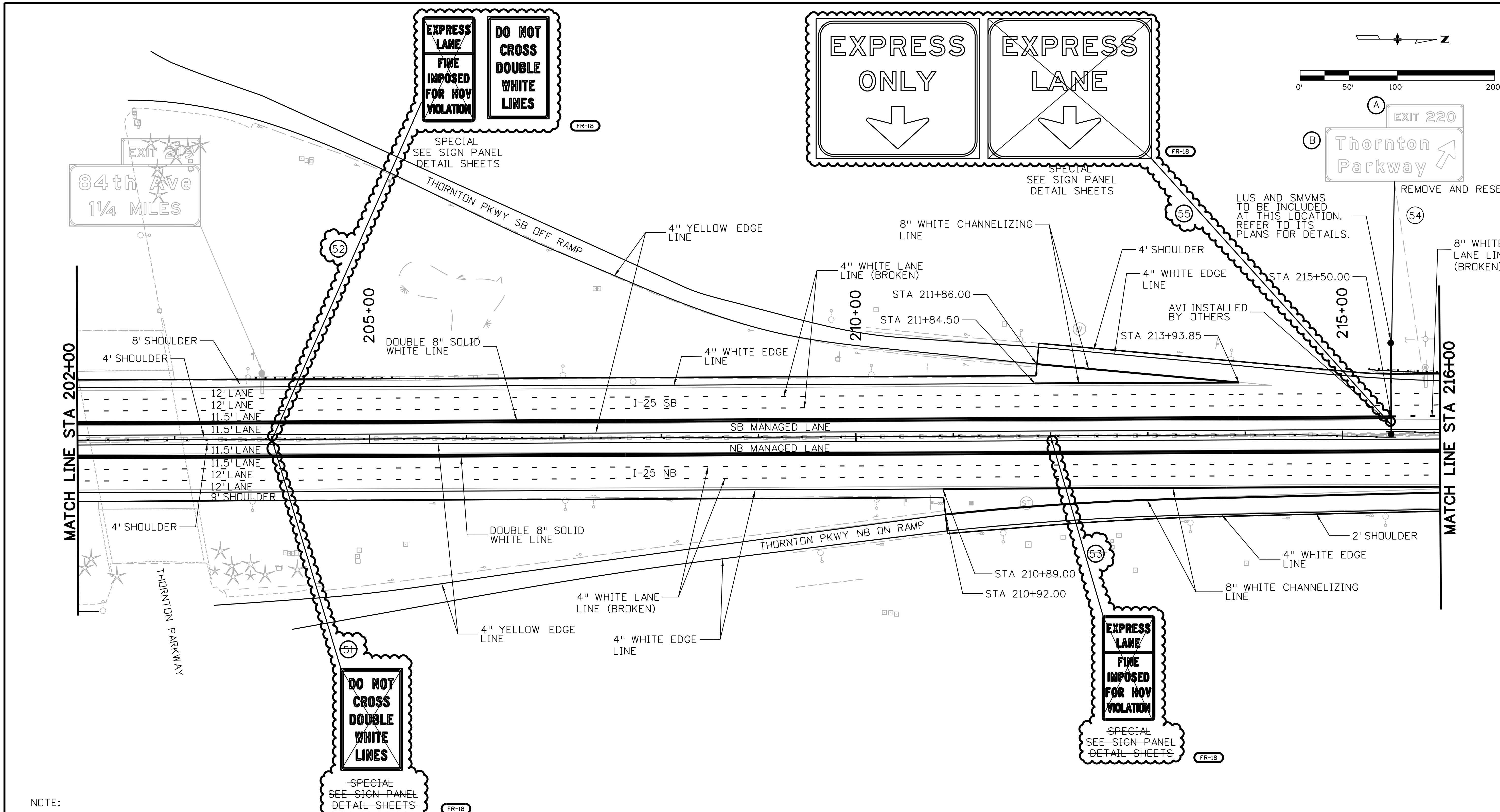

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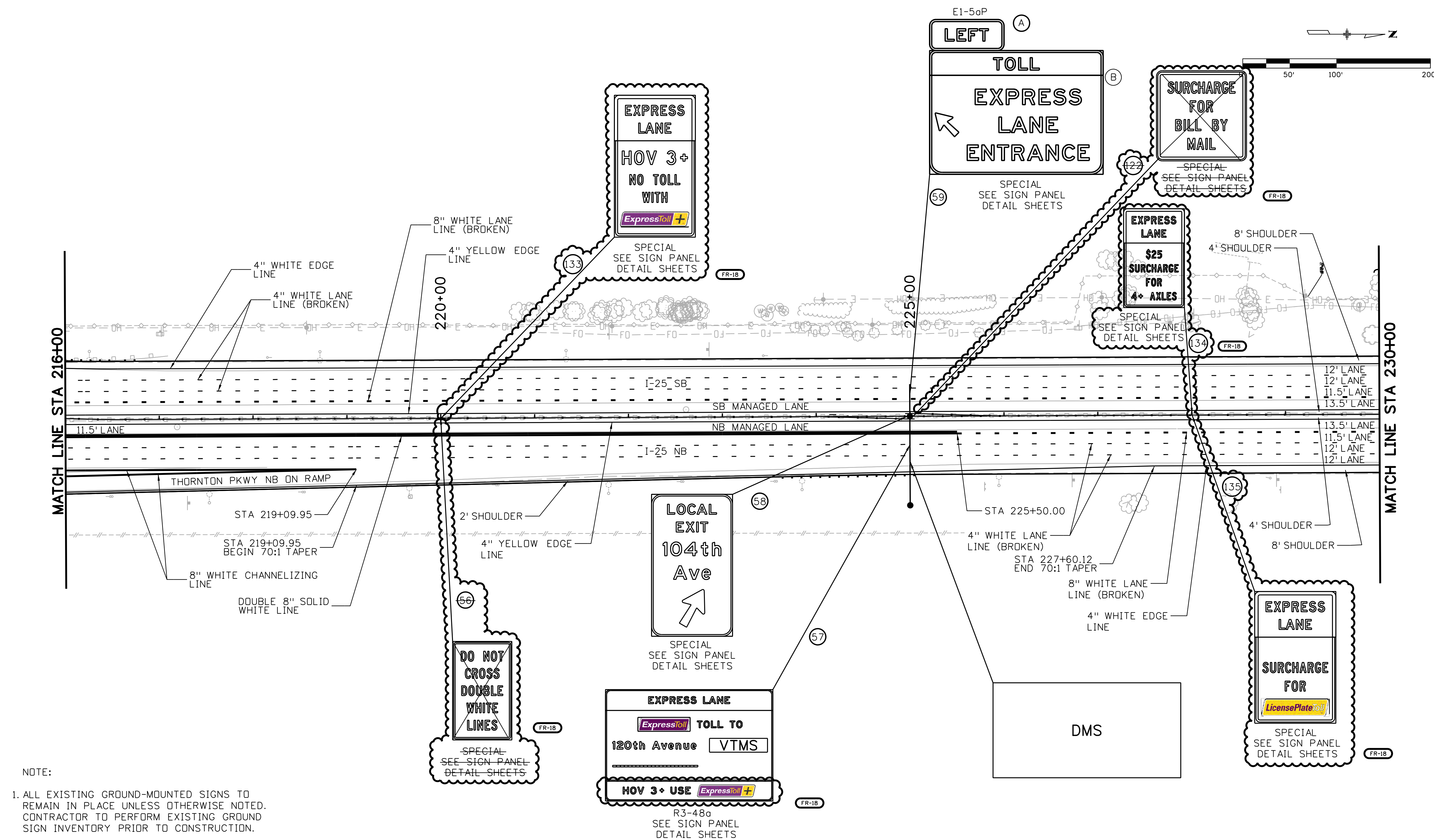

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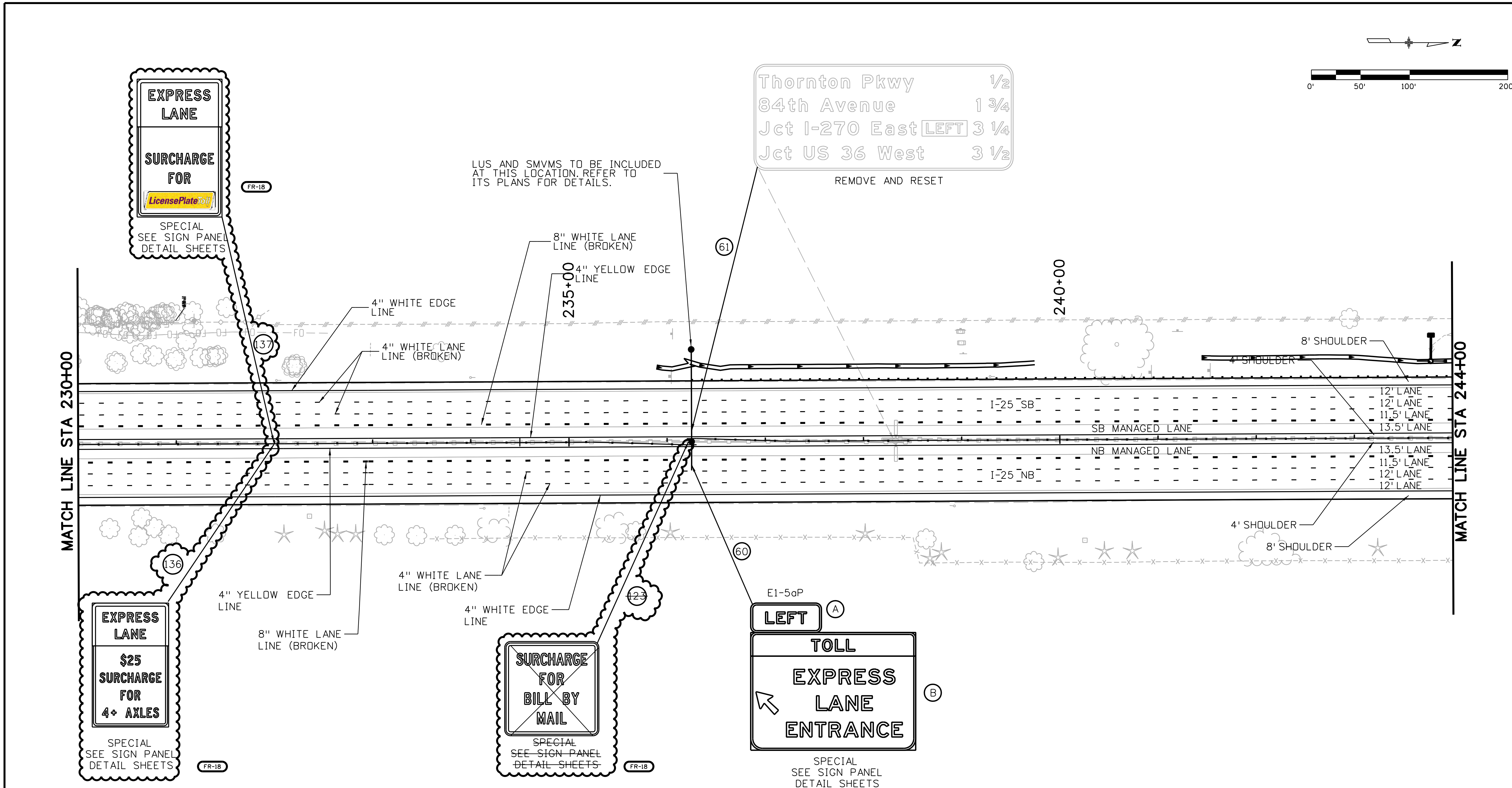

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Unit Information	Unit Leader Initials

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Designer: KAM	Structure Numbers	
Detailer: AJR		
Sheet Subset: TRAFFIC	Subset Sheets: 17 of 29	

Project No./Code
18695
IM 0253-222
Sheet Number 488

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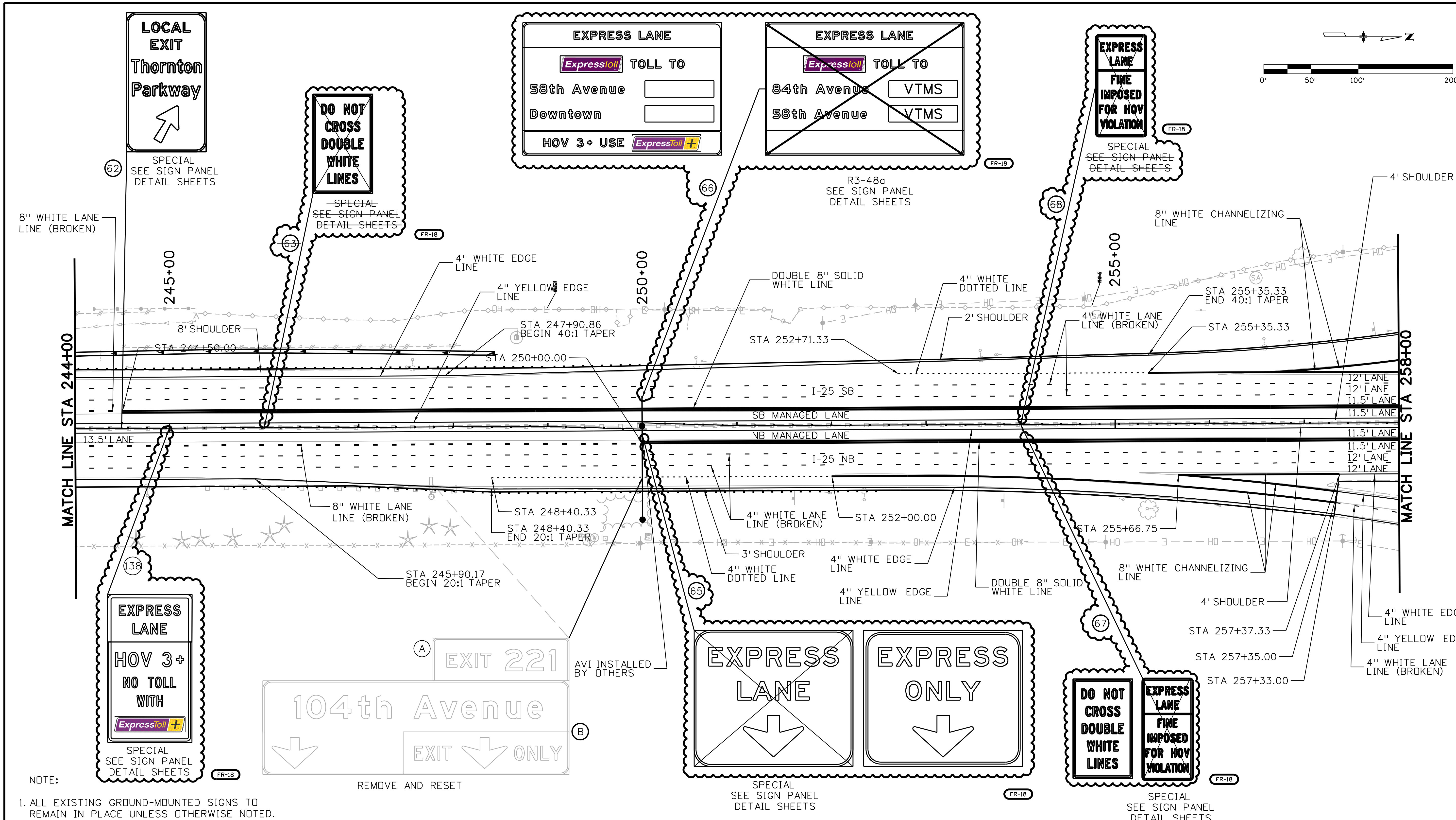

NOTE:

1. ALL EXISTING GROUND-MOUNTED SIGNS TO REMAIN IN PLACE UNLESS OTHERWISE NOTED. CONTRACTOR TO PERFORM EXISTING GROUND SIGN INVENTORY PRIOR TO CONSTRUCTION.

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Detailer:	AJR		
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Project No./Code
18695
IM 0253-222
Sheet Number 489

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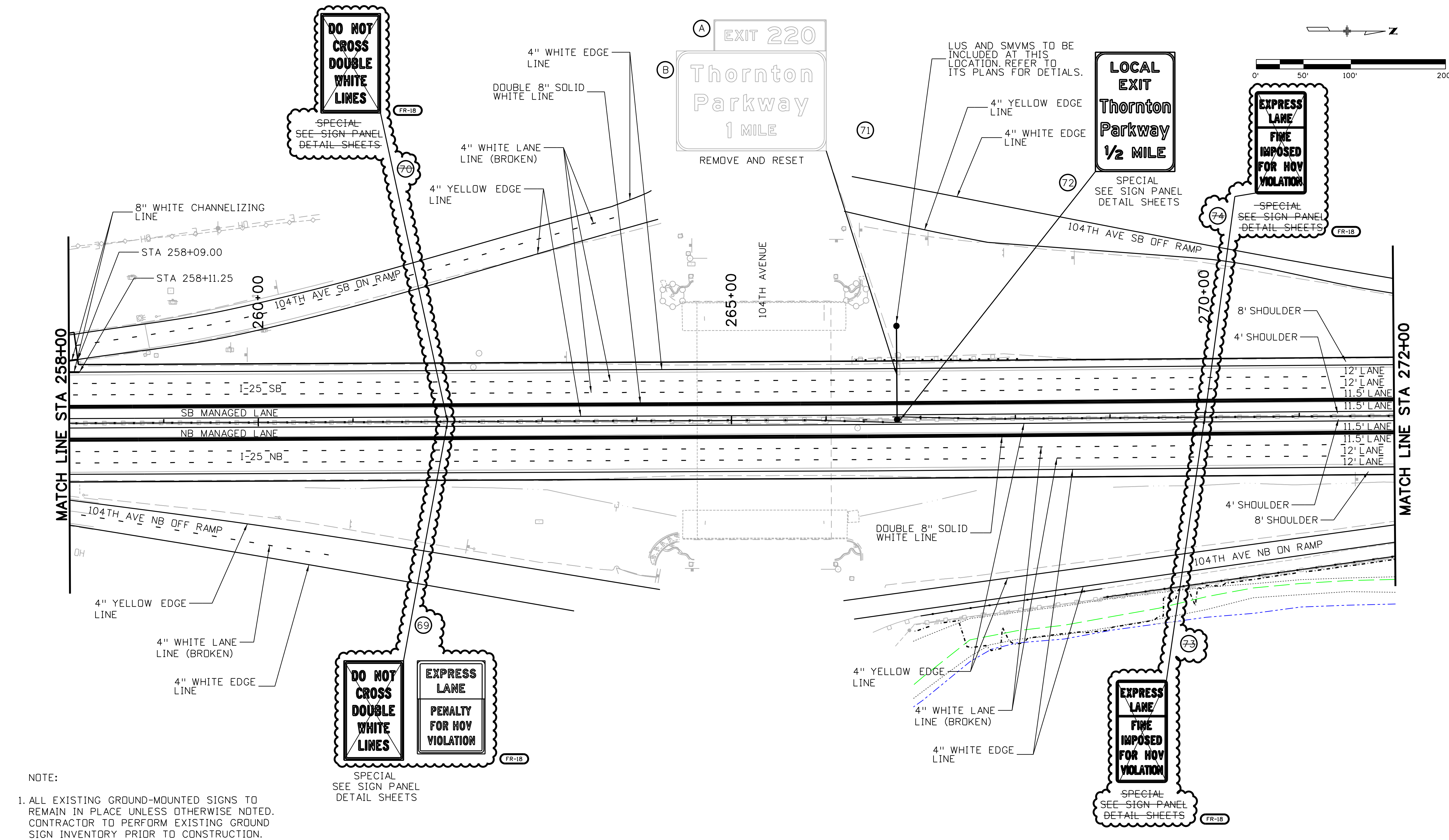

NOTE:

1. ALL EXISTING GROUND-MOUNTED SIGNS TO REMAIN IN PLACE UNLESS OTHERWISE NOTED. CONTRACTOR TO PERFORM EXISTING GROUND SIGN INVENTORY PRIOR TO CONSTRUCTION.

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Unit Information Unit Leader Initials				
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No Revisions:			18695
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	Detailer: AJR		
Void:	Sheet Subset: TRAFFIC	Subset Sheets: 19 of 29	Sheet Number 490

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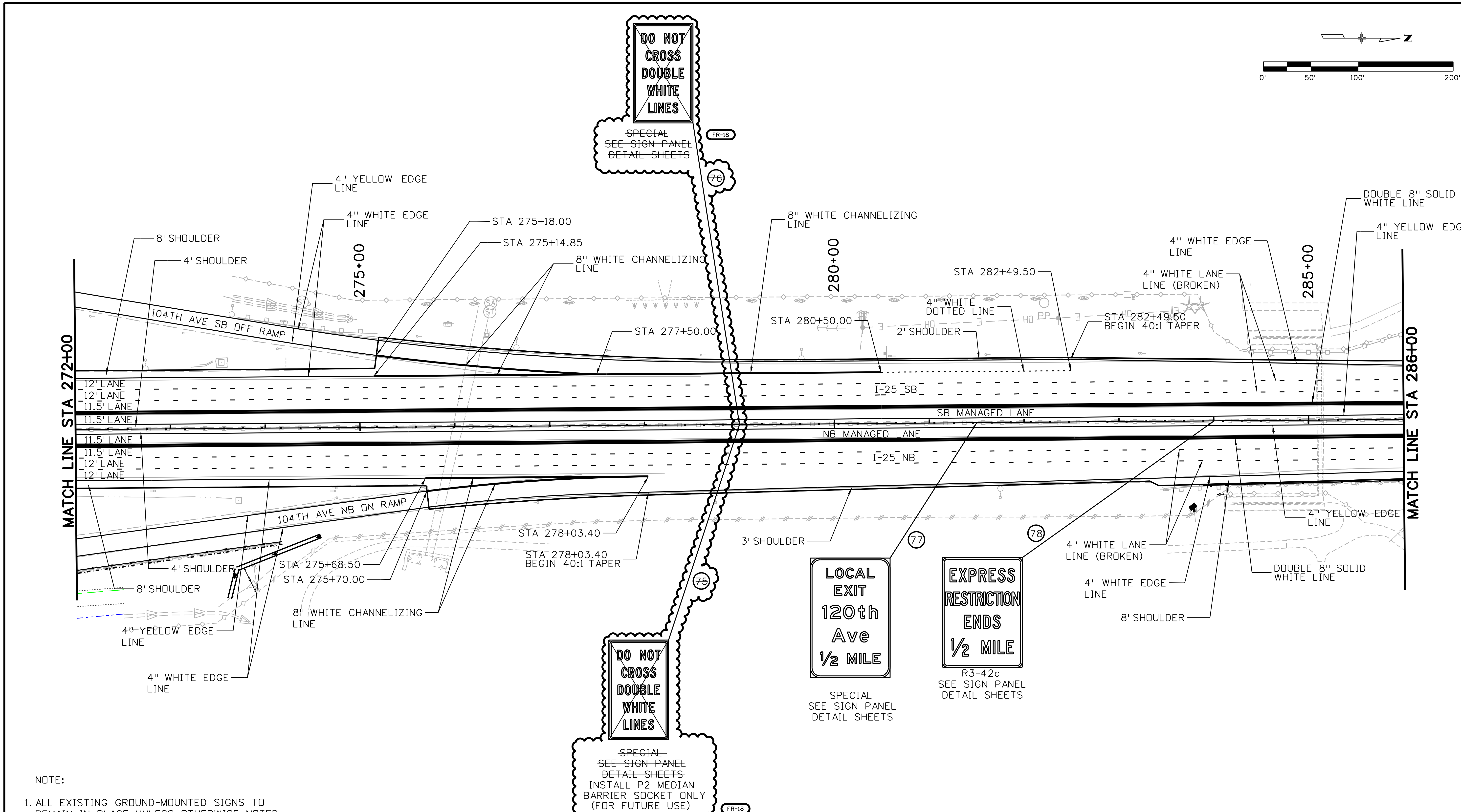

NOTE:

1. ALL EXISTING GROUND-MOUNTED SIGNS TO REMAIN IN PLACE UNLESS OTHERWISE NOTED. CONTRACTOR TO PERFORM EXISTING GROUND SIGN INVENTORY PRIOR TO CONSTRUCTION.

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Unit Information Unit Leader Initials			
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Detailer: AJR			
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Project No./Code	
18695	
IM 0253-222	
Sheet Number	491

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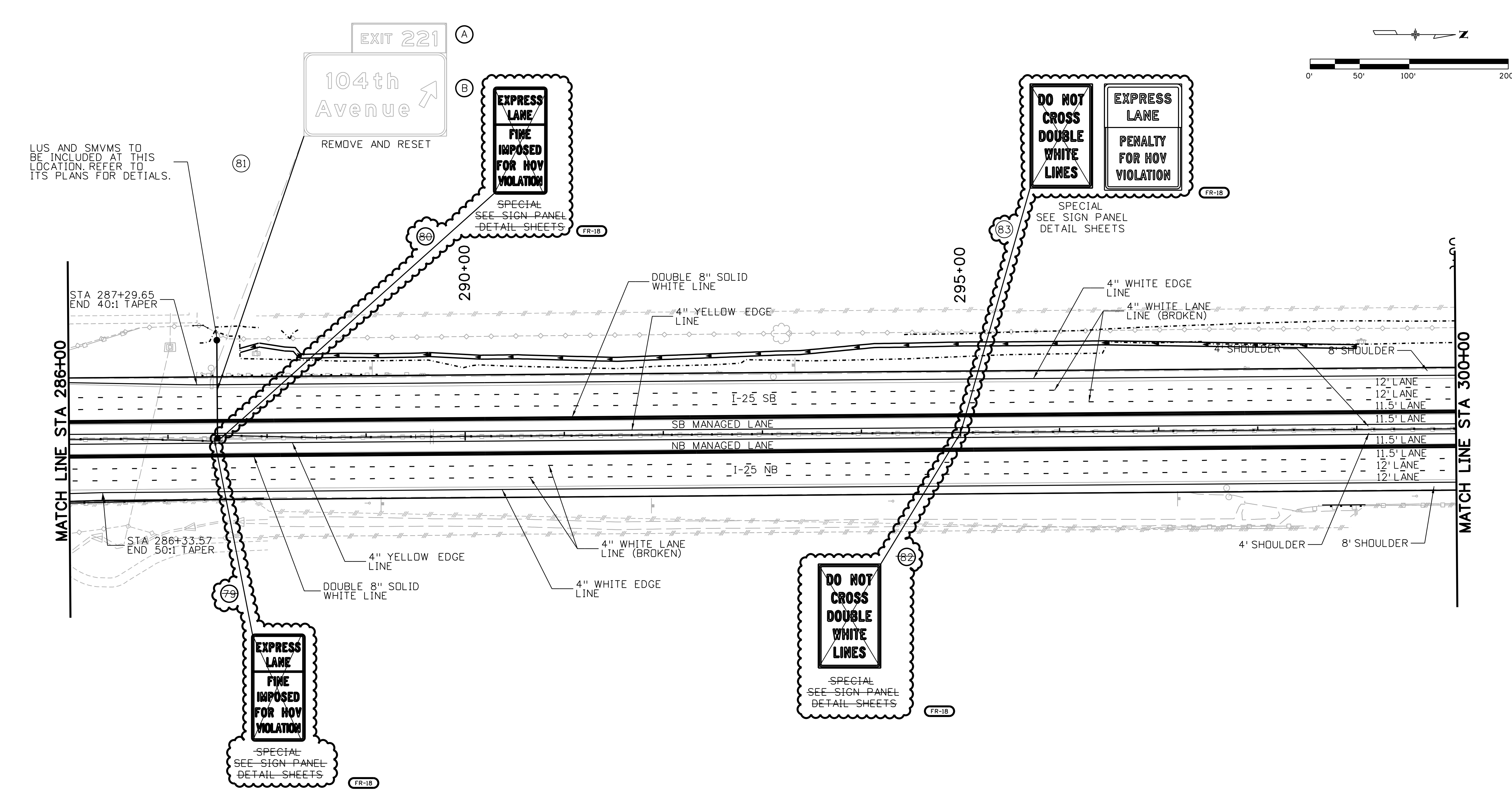

NOTE:

1. ALL EXISTING GROUND-MOUNTED SIGNS TO REMAIN IN PLACE UNLESS OTHERWISE NOTED. CONTRACTOR TO PERFORM EXISTING GROUND SIGN INVENTORY PRIOR TO CONSTRUCTION.

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No Revisions:					18695
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	Detailer: AJR				
Void:	Sheet Subset: TRAFFIC	Subset Sheets: 21 of29			Sheet Number 492

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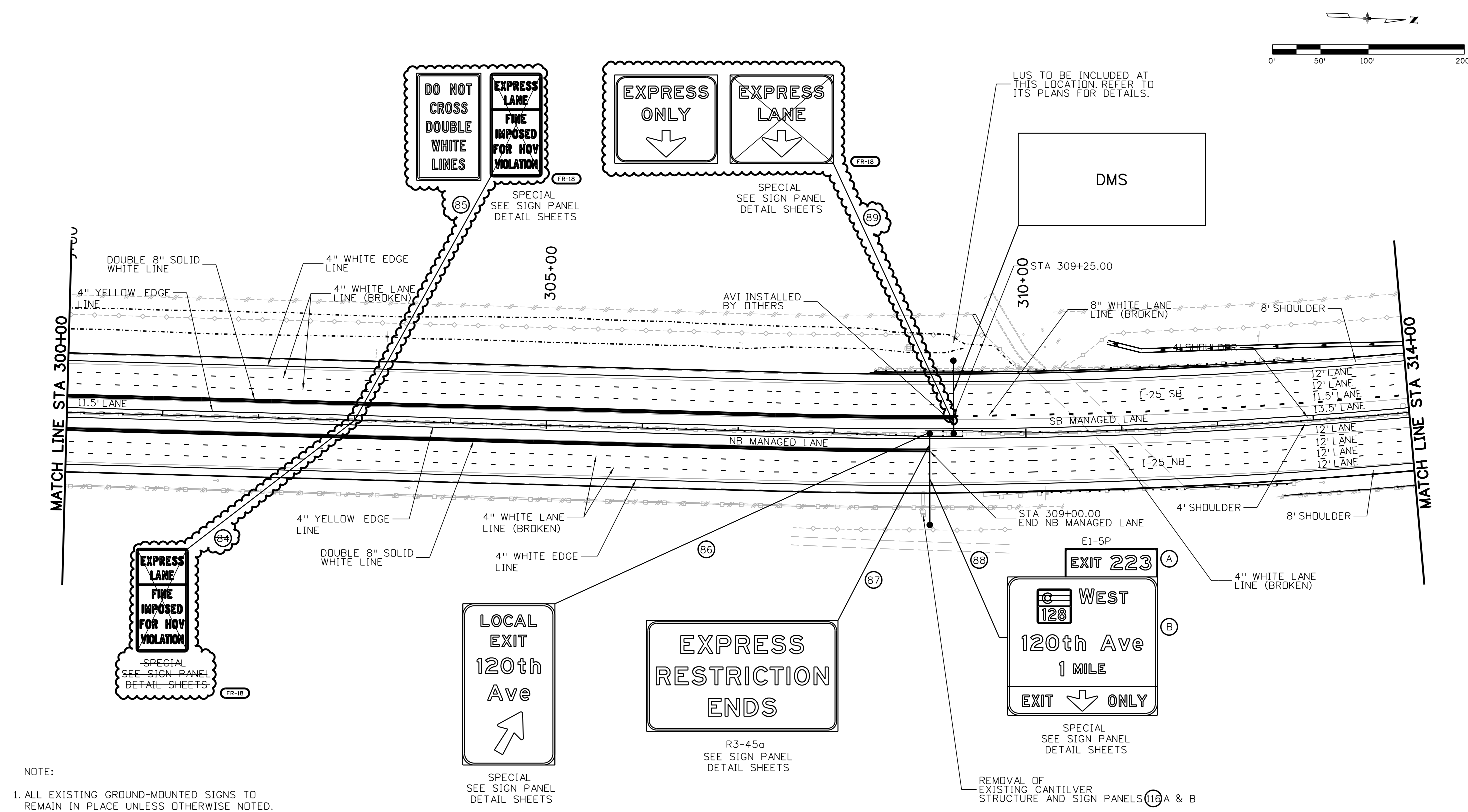

NOTE:

1. ALL EXISTING GROUND-MOUNTED SIGNS TO REMAIN IN PLACE UNLESS OTHERWISE NOTED. CONTRACTOR TO PERFORM EXISTING GROUND SIGN INVENTORY PRIOR TO CONSTRUCTION.

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File Name: 18695_Traffic_Plan22.dgn
Horiz. Scale: 1:100 Vert. Scale: N/A
Unit Information Unit Leader Initials

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Designer: KAM
Detailer: AJR
Structure Numbers
Sheet Subset: TRAFFIC Subset Sheets: 22 of 29

Project No./Code
18695
IM 0253-222
Sheet Number 493

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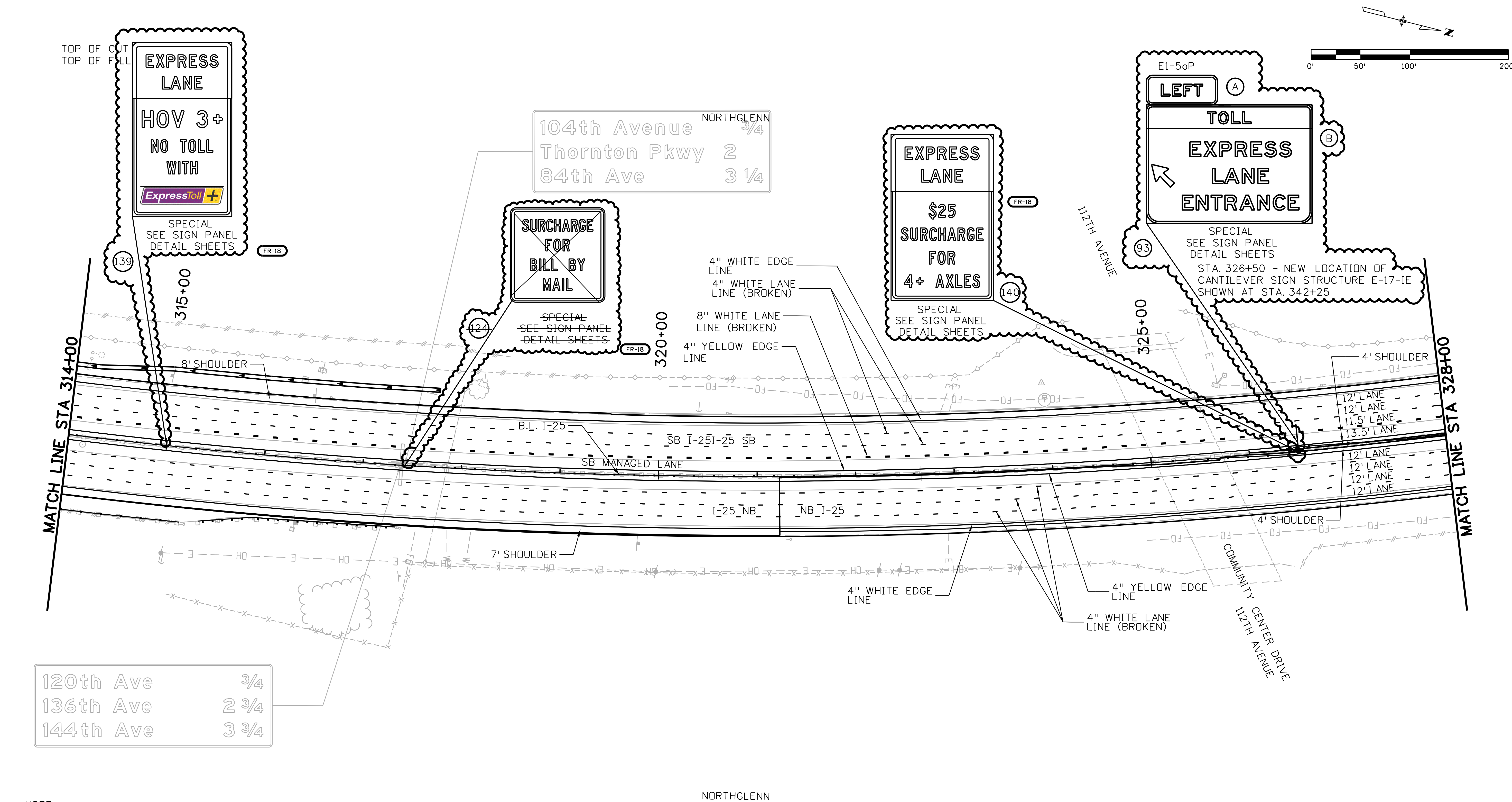

NOTE:

1. ALL EXISTING GROUND-MOUNTED SIGNS TO REMAIN IN PLACE UNLESS OTHERWISE NOTED. CONTRACTOR TO PERFORM EXISTING GROUND SIGN INVENTORY PRIOR TO CONSTRUCTION.

Print Date: 9/14/2017	
File Name: 18695_Traffic_Plan23.dgn	
Horiz. Scale: 1:100	Vert. Scale: N/A
Unit Information	Unit Leader Initials

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Designer:	KAM	Structure Numbers	
Detailer:	AJR		
Sheet Subset:	TRAFFIC	Subset Sheets:	23 of 29

Project No./Code
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IM 0253-222
Sheet Number 494

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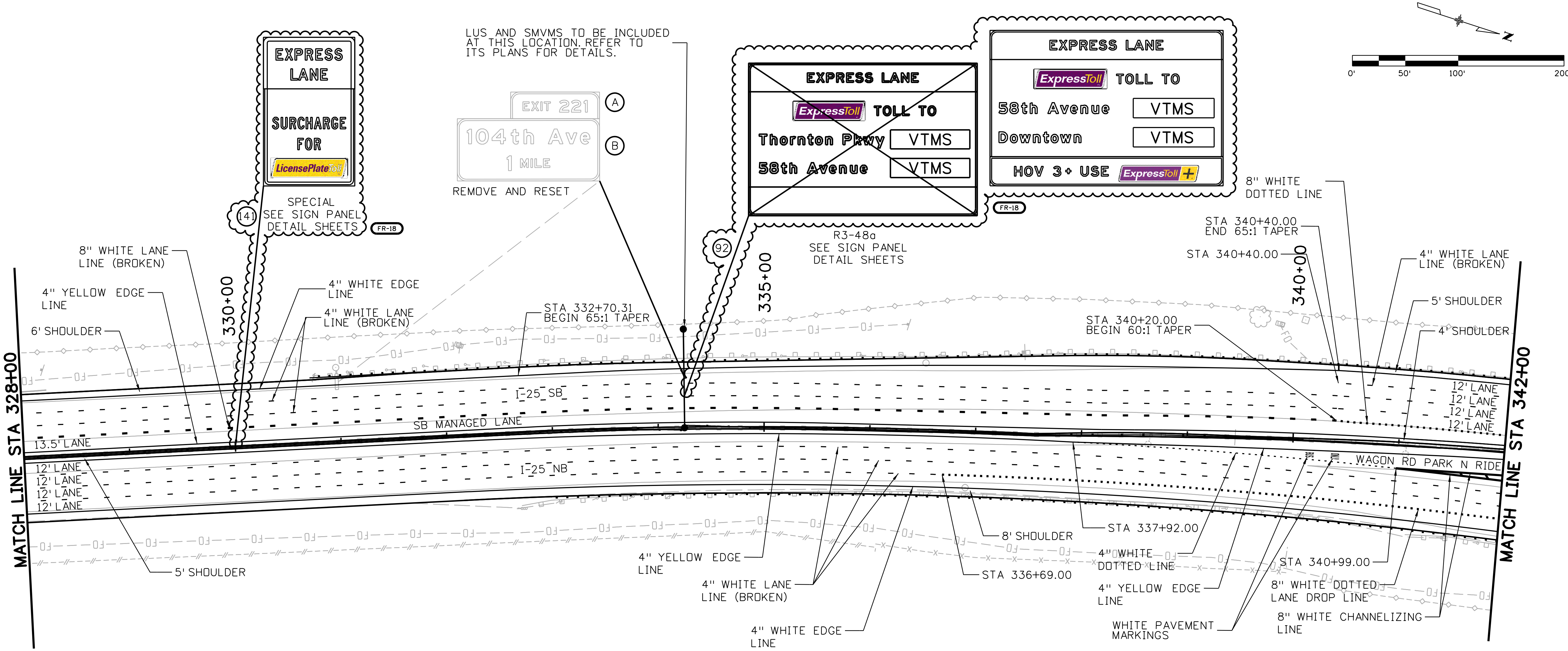

NOTE:

1. ALL EXISTING GROUND-MOUNTED SIGNS TO REMAIN IN PLACE UNLESS OTHERWISE NOTED. CONTRACTOR TO PERFORM EXISTING GROUND SIGN INVENTORY PRIOR TO CONSTRUCTION.

Print Date: 9/14/2017	Sheet Revisions	Colorado Department of Transportation	As Constructed	Project No./Code
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Horiz. Scale: 1:100 Vert. Scale: N/A	FR-18 01-29-15 SIGN REVISIONS AAA		Revised:	IM 0253-222
Unit Information / Unit Leader Initials		Region 6 DJH	Void:	Sheet Number 495
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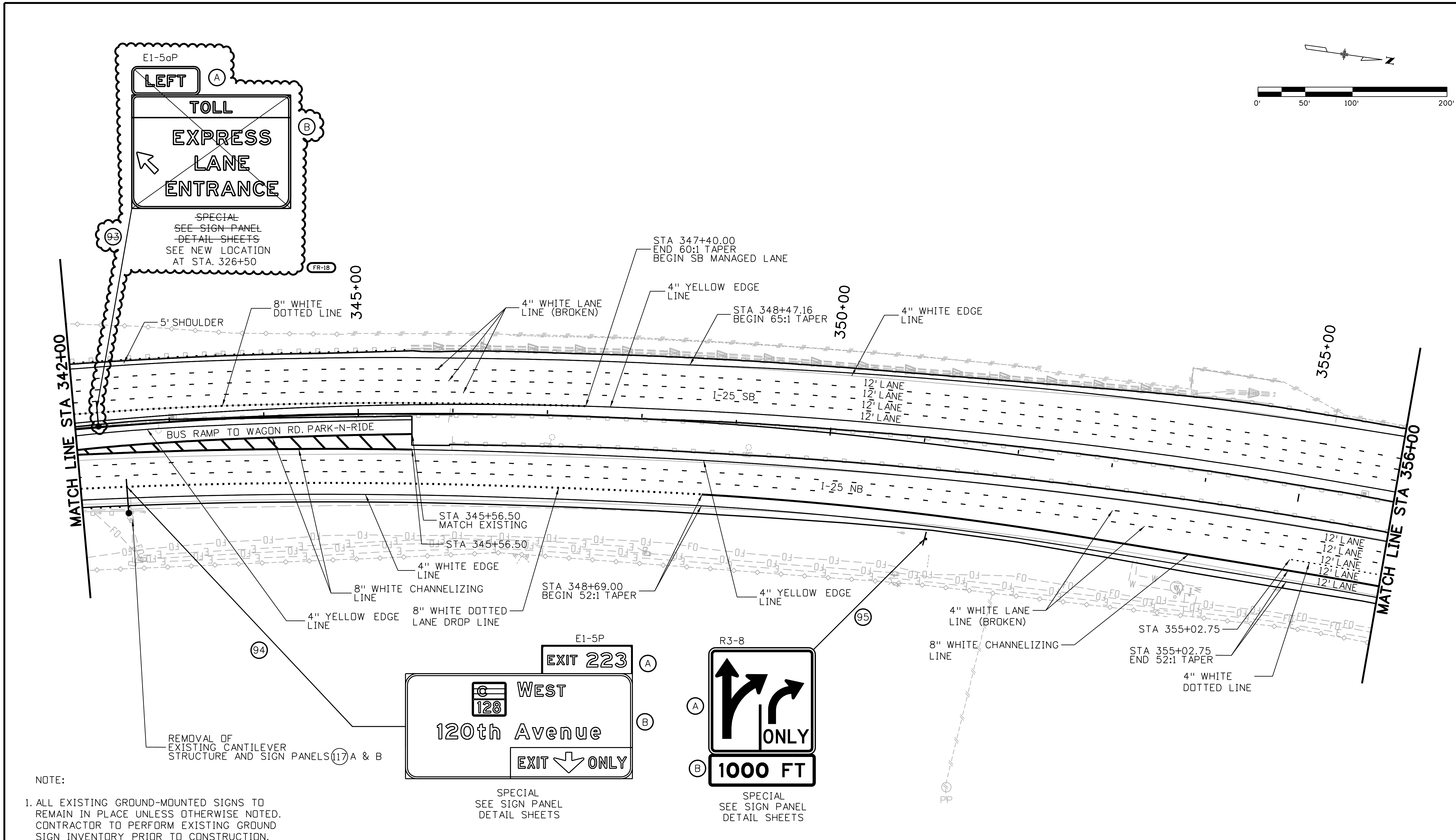
Designer:	KAM	Structure Numbers	
Detailer:	AJR		
Sheet Subset:	TRAFFIC	Subset Sheets:	24 of 29



NOTE:

1. ALL EXISTING GROUND-MOUNTED SIGNS TO REMAIN IN PLACE UNLESS OTHERWISE NOTED. CONTRACTOR TO PERFORM EXISTING GROUND SIGN INVENTORY PRIOR TO CONSTRUCTION.

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Horiz. Scale: 1:100 Vert. Scale: N/A	01-29-15	SIGN REVISIONS	AAA	FR-18
Unit Information Unit Leader Initials				

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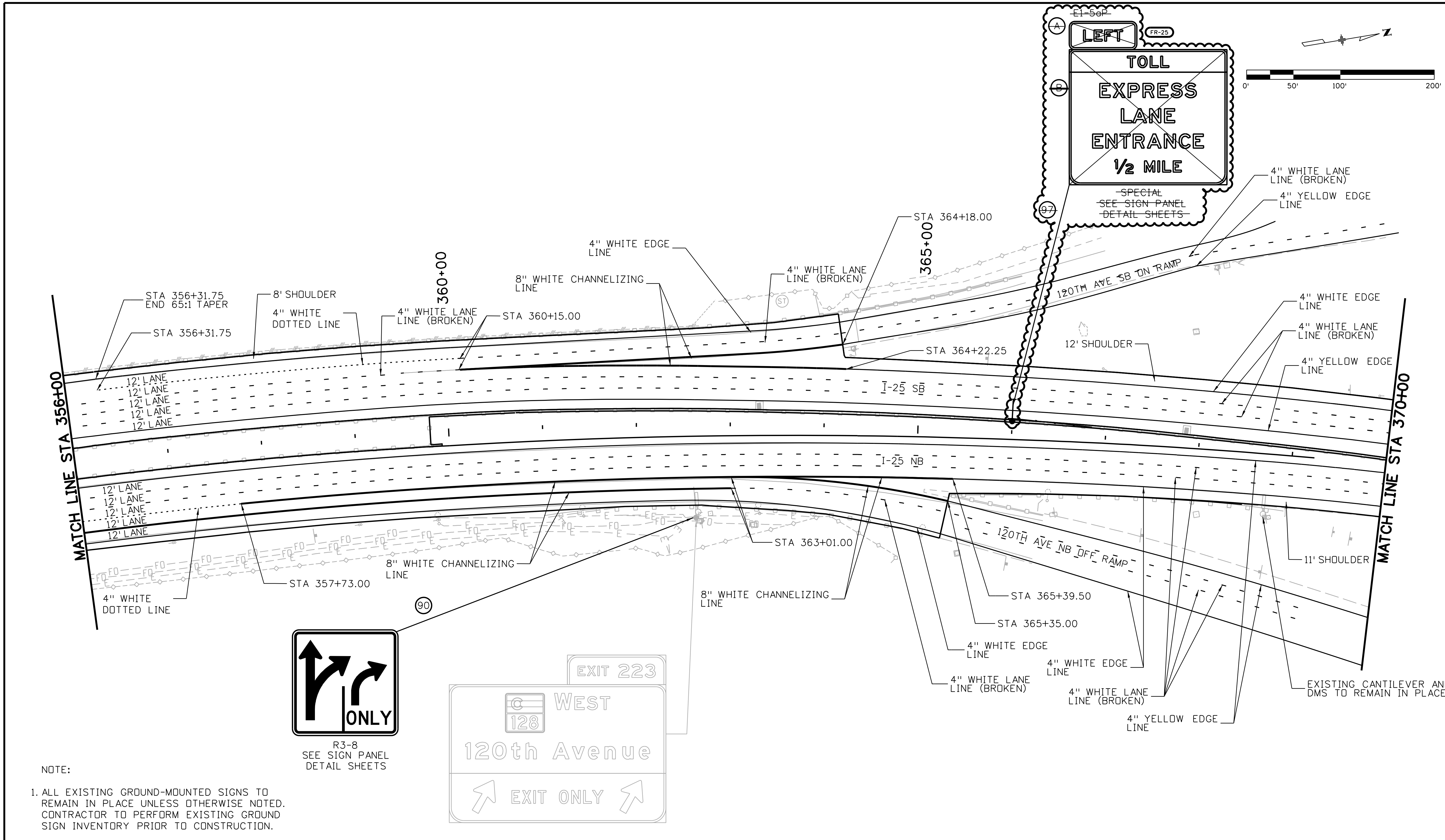
Designer: KAM
Detailer: AJR
Structure Numbers
Sheet Subset: TRAFFIC
Subset Sheets: 25 of 29

Project No./Code
18695
IM 0253-222
Sheet Number 496



NOTE:

1. ALL EXISTING GROUND-MOUNTED SIGNS TO REMAIN IN PLACE UNLESS OTHERWISE NOTED. CONTRACTOR TO PERFORM EXISTING GROUND SIGN INVENTORY PRIOR TO CONSTRUCTION.

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Print Date: 9/14/2017		
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Unit Information	Unit Leader Initials	
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	Date:	Comments	Init.
FR-25	04-21-15	SIGN REVISIONS	AAA

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Revised:
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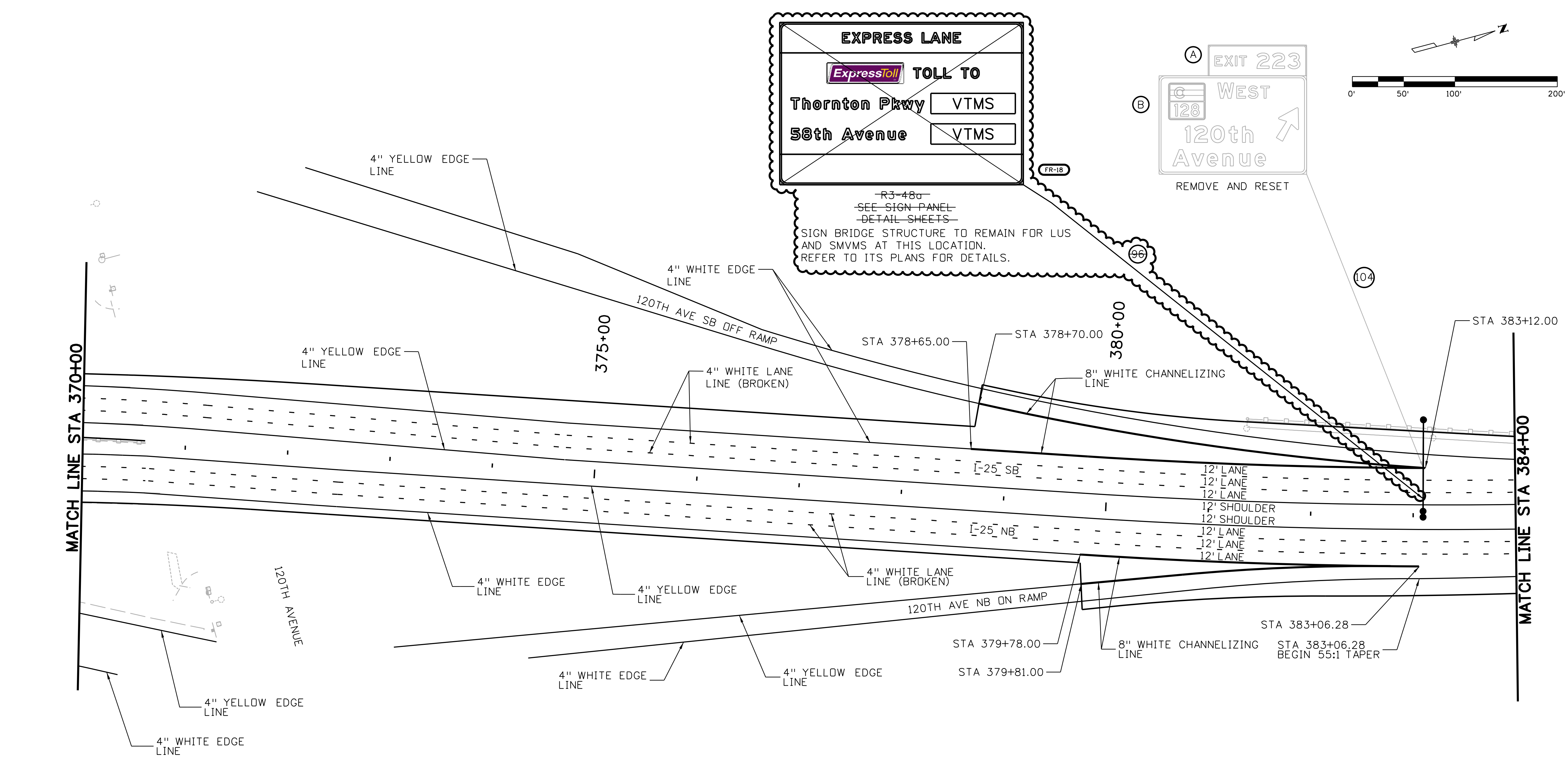
Designer: KAM	Structure Numbers		
Detailer: AJR			
Sheet Subset: TRAFFIC	Subset Sheets: 26 of 29		

Project No./Code
18695
IM 0253-222
Sheet Number 497



NOTE:

1. ALL EXISTING GROUND-MOUNTED SIGNS TO REMAIN IN PLACE UNLESS OTHERWISE NOTED. CONTRACTOR TO PERFORM EXISTING GROUND SIGN INVENTORY PRIOR TO CONSTRUCTION.

Print Date: 9/14/2017				
File Name: 18695_Traffic_Plan27.dgn				
Horiz. Scale: 1:100	Vert. Scale: N/A			
Unit Information	Unit Leader Initials			

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Designer: KAM	Structure Numbers		
Detailer: AJR			
Sheet Subset: TRAFFIC	Subset Sheets: 27 of 29		

Project No./Code
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IM 0253-222
Sheet Number 498

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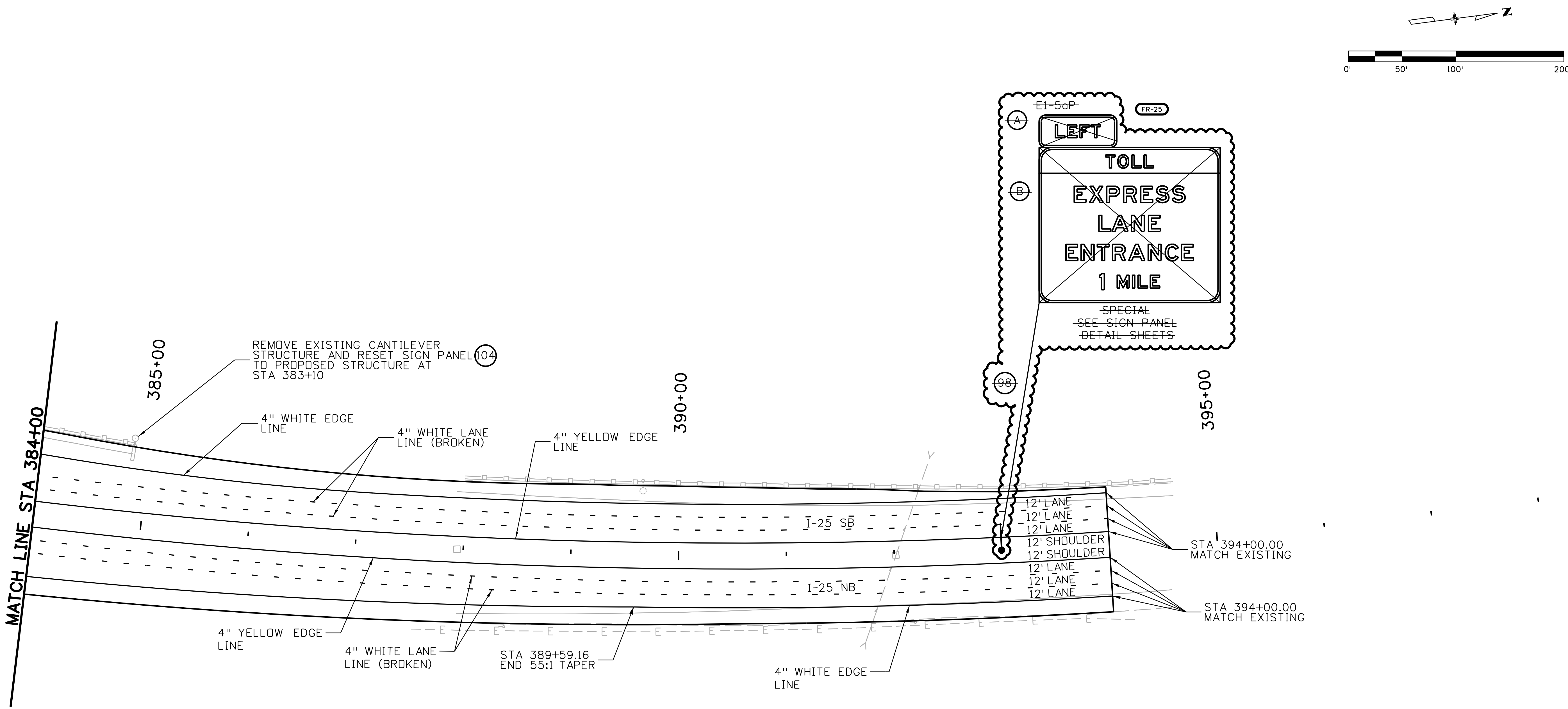

NOTE:

1. ALL EXISTING GROUND-MOUNTED SIGNS TO REMAIN IN PLACE UNLESS OTHERWISE NOTED. CONTRACTOR TO PERFORM EXISTING GROUND SIGN INVENTORY PRIOR TO CONSTRUCTION.

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Unit Information Unit Leader Initials				

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No Revisions:		18695
Revised:	Designer: KAM / Detailer: AJR / Structure Numbers	IM 0253-222
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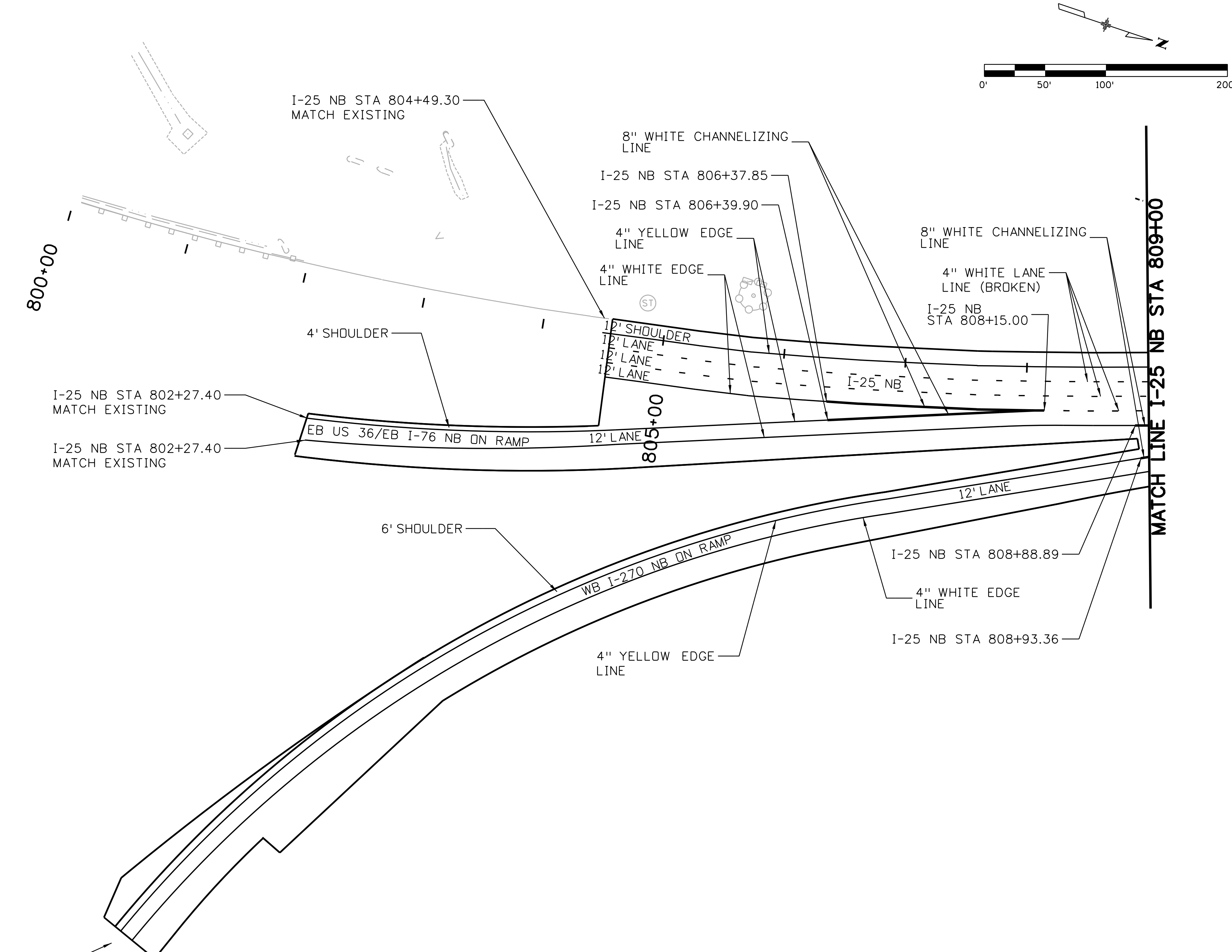

NOTE:

1. ALL EXISTING GROUND-MOUNTED SIGNS TO REMAIN IN PLACE UNLESS OTHERWISE NOTED. CONTRACTOR TO PERFORM EXISTING GROUND SIGN INVENTORY PRIOR TO CONSTRUCTION.

Print Date: 9/14/2017	Sheet Revisions	Colorado Department of Transportation	As Constructed	SIGNING AND STRIPING PLANS
File Name: 18695_Traffic_Plan29.dgn	Date: / Comments / Init.	4670 Holly Street Denver, CO 80216-6408 Phone: 303-398-6749 FAX: 720-945-1028	No Revisions:	Project No./Code: 18695
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Unit Information Unit Leader Initials		Region 6 DJH	Void:	Designer: KAM; Detailer: AJR; Structure Numbers
ATKINS 4601 DTC Boulevard, Suite 700, Denver, CO 80237, Phone: (303) 221-7275 Fax: (303) 221-7276				Sheet Subset: TRAFFIC; Subset Sheets: 29 of 29; Sheet Number

APPENDIX C

Location: 25A **Begin:** 217.04 **End:** 222.18 **From:** 01/01/2012 **To:** 12/31/2016

I-25 Mainline Crashes - US 36 to Community Center Dr / 112th Ave

Severity

PDO:	2212		
INJ:	525	714	:Injured
FAT:	2	2	:Killed
Total:	**2739**		

Number of Vehicles

One Vehicle:	222
Two Vehicles:	1955
Three or More:	562
Unknown:	0
Total:	**2739**

Location

On Road:	2526
Off Road Left:	97
Off Road Right:	116
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**2739**

Lighting Conditions

Daylight:	1979
Dawn or Dusk:	116
Dark - Lighted:	548
Dark - Unlighted:	93
Unknown:	3
Total:	**2739**

Weather Conditions

None:	2528
Rain:	83
Snow/Sleet/Hail:	108
Fog:	2
Dust:	0
Wind:	3
Unknown:	15
Total:	**2739**

Crash Rates

PDO:	1.49	*
INJ:	0.35	*
FAT:	0.13	**
Total:	**1.84**	*

* MVMT
** 100 MVMT

Crash Type

Overturning:	24	Bridge Abutment:	0
Other Non Collision:	14	Column/Pier:	0
Pedestrians:	3	Culvert/Headwall:	2
Broadside:	0	Embankment:	9
Head On:	1	Curb:	0
Rear End:	1959	Delineator Post:	0
Sideswipe (Same):	480	Fence:	3
Sideswipe (Opposite):	0	Tree:	2
Approach Turn:	0	Large Boulders or Rocks:	0
Overtaking Turn:	0	Barricade:	2
Parked Motor Vehicle:	15	Wall/Building:	0
Railway Vehicle:	1	Crash Cushion:	22
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	3
Domestic Animal:	1	Total Fixed Objects:	205
Wild Animal:	1	Rocks in Roadway:	0
Light/Utility Pole:	9	Vehicle Cargo/Debris:	18
Traffic Signal Pole:	1	Road Maintenance Equipment:	1
Sign:	12	Involving Other Object:	16
Bridge Rail:	3	Total Other Objects:	35
Guard Rail:	29	Unknown:	0
Cable Rail:	1	**Total:**	**2739**
Concrete Barrier:	107		

Mainline/Ramps/Frontage Roads

Mainline:	2739
Crossroad (A):	0

Frontage/Ramp Intersections

M:	0	N:	0	O:	0	P:	0

Ramps

B:	0	F:	0	J:	0
C:	0	G:	0	K:	0
D:	0	H:	0	T:	0
E:	0	I:	0		

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**2739**

Road Description

At Intersection:	0
At Driveway Access:	0
Intersection Related:	0
Non Intersection:	2739
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**2739**

Road Conditions

Dry:	2454
Wet:	148
Muddy:	0
Snowy:	39
Icy:	52
Slushy:	20
Foreign Material:	1
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	4
Snowy w/Icy Road Treatment:	2
Icy w/Icy Road Treatment:	3
Slushy w/Icy Road Treatment:	0
Unknown:	16
Total:	**2739**

ADT: 160,106 **Length:** 5.08

Location: 25A **Begin:** 217.04 **End:** 222.18 **From:** 01/01/2012 **To:** 12/31/2016

I-25 Mainline Crashes - US 36 to Community Center Dr / 112th Ave

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	1417	1176	276
Passenger Car/Van w/Trl:	2	3	0
Pickup Truck/Utility Van:	441	466	91
Pickup Truck/Utility Van w/Trl:	20	13	2
SUV:	571	718	160
SUV w/Trl:	2	1	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	97	98	12
School Bus < 15 People:	0	1	0
Non School Bus < 15 People:	3	7	1
Motorhome:	4	0	0
Motorcycle:	26	7	1
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	154	19	18
Other:	2	7	0
Unknown:	0	1	1
Total:	**2739**	**2517**	**562**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	1800	756	110
Slowing:	251	827	140
Stopped in Traffic:	13	850	307
Making Right Turn:	0	0	0
Making Left Turn:	0	2	0
Making U-Turn:	0	0	0
Passing:	21	1	1
Backing:	10	0	0
Enter/Leave Parked Position:	3	0	0
Starting in Traffic:	0	0	0
Parked:	1	14	0
Changing Lanes:	394	28	1
Avoiding Object/Veh in Road:	29	18	0
Weaving:	38	0	0
Wrong Way:	2	0	0
Other:	177	20	1
Unknown:	0	1	2
Total:	**2739**	**2517**	**562**

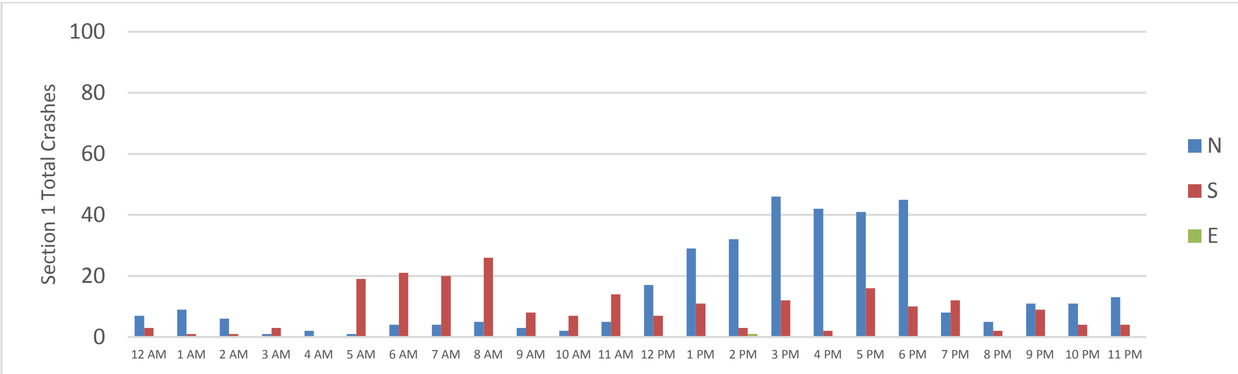
Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	983	2229	500
Asleep at the Wheel:	29	2	1
Illness:	17	1	1
Distracted by Passenger:	25	1	0
Driver Inexperience:	180	6	2
Driver Fatigue:	17	0	0
Driver Preoccupied:	414	3	4
Driver Unfamilar with Area:	29	1	1
Driver Emotionally Upset:	5	0	0
Evading Law Enforcement Officier:	2	0	0
Physical Disability:	1	0	0
Unknown:	1037	274	53
Total:	**2739**	**2517**	**562**

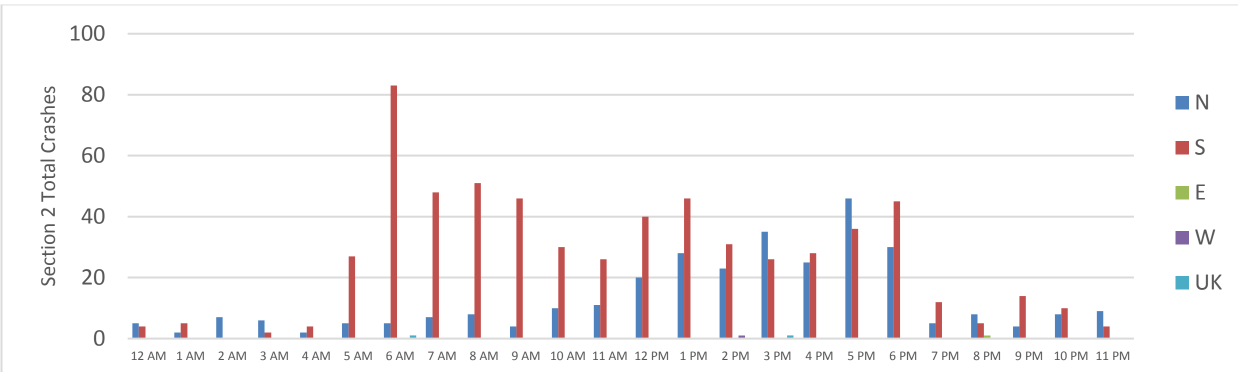
Direction	Veh 1	Veh 2	Veh 3
North:	996	879	160
Northeast:	0	0	0
East:	5	4	1
Southeast:	0	1	0
South:	1732	1627	396
Southwest:	1	1	1
West:	3	2	1
Northwest:	0	0	0
Unknown:	2	3	3
Total:	**2739**	**2517**	**562**

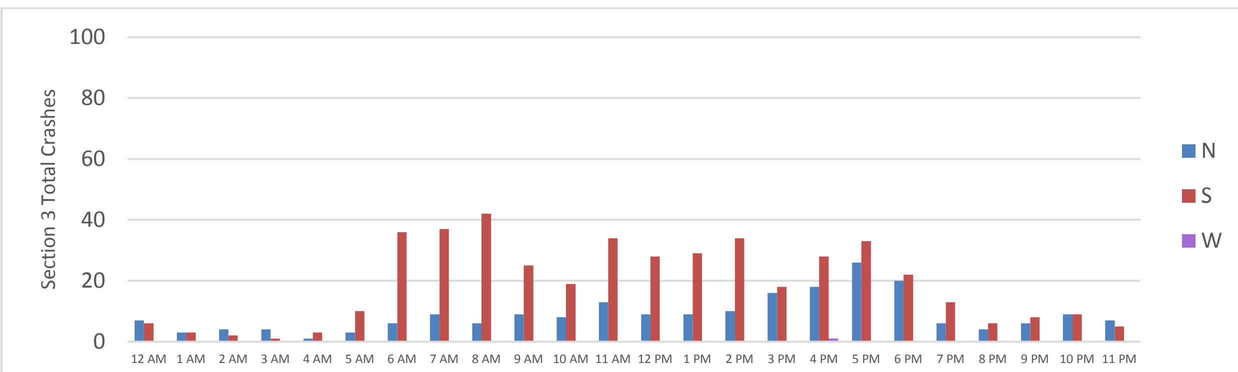
Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	2661	2509	562
Alcohol Involved:	49	8	0
RX, Medication, or Drugs Involved:	15	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	14	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**2739**	**2517**	**562**

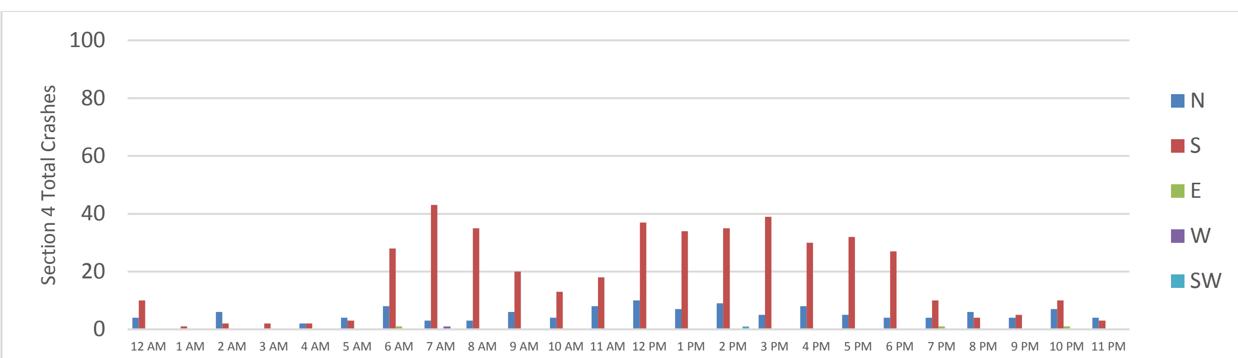
ADT: 160,106 **Length:** 5.08

Appendix D – Crash Data by Time of Day and Section









APPENDIX E – DETAILED CRASH DATA REVIEW

JANUARY 2012 TO SEPTEMBER 2013 CRASH DATA (BEFORE CONSTRUCTION)

Crash data from January 1, 2012 to September 30, 2013 was examined from milepost 217.00 to 222.18. Construction along this segment of I-25 began in October of 2013, therefore January 1, 2012 to September 30, 2013 will be considered as the "before" time frame.

During this 639-day time frame, there was a total of 481 Property Damage Only (PDO) crashes, 107 Injury crashes, and 0 fatal crashes. Rear-end crashes accounted for approximately 70% of all crashes, followed by Sideswipe Same Direction crashes at 15%, and Concrete Barrier at 5.4% of all crashes.

The crash data indicates that a typical crash during this time frame would occur on a Saturday (20%) and involve two (69%) southbound (62%) vehicles, going straight (71%) with zero speed differential (22%). The At-Fault Violation sited by the officer would likely be "Careless Driving" (52%), "Following Too Close" (30%), or "Unsafe Lane Change" (5%).

OCTOBER 2013 TO MARCH 20, 2016 CRASH DATA (DURING CONSTRUCTION)

As previously mentioned, construction along this segment of I-25 began in October of 2013. All records and periodicals indicate that construction ended in the first quarter of 2016 coinciding with opening the newly constructed managed lanes to all traffic. Therefore, construction period crash data was analyzed from October 1, 2013 to March 20, 2016 from milepost 217.00 to 222.18.

During this 902-day time frame, there was a total of 1,230 Property Damage Only (PDO) crashes, 290 Injury crashes, and 1 fatal crash. Rear-end crashes accounted for approximately 71% of all crashes, followed by Sideswipe Same Direction crashes at 18%, and Concrete Barrier at 3.5% of all crashes.

The crash data indicates that a typical crash during this time frame would occur on a Saturday (22%) and involve two (73%) southbound (64%) vehicles, going straight (64%) with zero speed differential (20%). The At-Fault Violation sited by the officer would likely be "Following Too Close" (44%), "Careless Driving" (29%), or "Unsafe Lane Change" (10%).

MARCH 21, 2016 TO JULY 11, 2016 CRASH DATA (AFTER CONSTRUCTION, WITHOUT TOLLS)

All records and periodicals indicate that construction on this segment of I-25 was completed in the first quarter of 2016. Records also indicate that the newly constructed managed lanes opened for testing, with no toll collections, on March 14, 2016 in the northbound direction and on March 21, 2016 in the southbound direction. Toll collection began on July 12, 2016. Therefore, crash data from March 21, 2016 to July 11, 2016 was examined from milepost 217.00 to 222.18.

During this 113-day time frame, there was a total of 107 Property Damage Only (PDO) crashes, 36 Injury crashes, and 1 fatal crash. Rear-end crashes accounted for approximately 65% of all crashes, followed by Sideswipe Same Direction crashes at 19%, and Concrete Barrier at 7.6% of all crashes.

The crash data indicates that a typical crash during this time frame would occur on a Wednesday (22%) and involve two (68%) southbound (65%) vehicles, going straight (63%) with zero speed differential (23%). The At-Fault Violation sited by the officer would likely be "Following Too Close" (42%), "Careless Driving" (37%), or "Unsafe Lane Change" (7%).

July 12, 2016 to December 31, 2016 Crash Data (After Construction, With Tolls)

Toll collection along this segment of I-25 began on July 12, 2016. Any crash data from 2017 might not yet be reliable as it has not yet undergone quality control. Therefore, crash data from July 12, 2016 to December 31, 2016 will be the last time frame analyzed for this report.

During this 173-day time frame, there was a total of 394 Property Damage Only (PDO) crashes, 92 Injury crashes, and zero fatal crashes. Rear-end crashes accounted for approximately 76% of all crashes, followed by Sideswipe Same Direction crashes at 17%, and Concrete Barrier at 2.3% of all crashes.

The crash data indicates that a typical crash during this time frame would occur on a Saturday (20%) or on a Friday (19%) and involve two (70%) southbound (64%) vehicles, going straight (66%) with zero speed differential (24%). The At-Fault Violation sited by the officer would likely be "Careless Driving" (41%), "Following Too Close" (36%), or "Unsafe Lane Change" (7%).

Comparison of Before and After Construction Without Tolls

It is common practice to compare the crash data from the "before improvements" condition to the "after improvements" condition. In this RSA, there are two "after improvements" time frames: after construction completion without toll collection and after construction completion with toll collection. A comparison of before construction crash data with after construction without tolls crash data was conducted by highway section and is presented below. This comparison primarily focuses on crash data percentages of wholes as there is 639-days' worth of crash data before construction and 113-days of after construction without tolls crash data.

In Section 1, there are several crash pattern changes of note. First, crashes before construction primarily occurred on a Saturday while crashes after construction without tolls primarily occurred on a Thursday. Also, crashes primarily occurred in the northbound direction before construction, while after construction without tolls, crashes primarily occurred in the southbound direction. Furthermore, the percentage of rear-end crashes reported in this section increased from 57% to 70% while the percentage of sideswipe same direction crashes decreased from 31% to 16% comparing the before construction to after construction, without tolls time frames respectively. Similarly, a reported speed differential of 30 miles per hour or greater between vehicles 1 and 2 increased from 19% to 35%.

Unlike Section 1, crash data from Section 2 occurred primarily in the southbound direction both before construction and after construction without tolls. Also, crash data in Section 2 displayed a decrease in reported rear-end crashes from 75% to 69% while displaying an increase in reported sideswipe same direction crashes from 9% to 15%. However, much like Section 1, crashes before construction primarily occurred on a Friday while crashes after construction without tolls primarily occurred on a Wednesday. Similarly, crash data from Section 2 displayed an increase in crashes reported with a 30 mile per hour or greater speed differential from 30% to 38%.

Crash data from Section 3 displayed a similar pattern shift in crashes primarily occurring on a Friday before construction and on a Tuesday after construction without tolls. The percentage of rear-end crashes decreased from 67% to 56% while sideswipe same direction crashes increased from 13% to 19% comparing before construction to after construction without tolls respectively. Furthermore, crashes involving a lane change were less frequent before construction than after construction without tolls, occurring at 11% and 16% respectively. There was little to no change in the percentage of crashes reported with a speed differential of 30 miles per hour or greater.

Only 11 total crashes occurred in Section 4 during the after construction without tolls time frame. Therefore, percentages of wholes for this section and this time frame may be influenced by the relatively small dataset size. That being said, Section 4 also displayed a crash pattern shift from crashes primarily occurring on a Saturday before construction to crashes primarily occurring on a Tuesday after construction without tolls. The percentage of rear-end crashes decreased from 79% to 55% while sideswipe same direction crashes increased from 12% to 45% comparing before construction to after construction without tolls respectively. Meanwhile, the percentage of crashes involving a lane change increased from 12% before construction to 18% after construction without tolls. Finally, the percentage of crashes reported with a 30 miles per hour or great speed differential between Vehicle 1 (at-fault vehicle) and Vehicle 2 decreased from 24% before construction to 18% after construction without tolls.

It is worthwhile to note that while a change in the percentage of a certain crash data variable may have occurred, this does not necessarily imply that the change is statistically significant. To determine statistical significance, the annualized number of rear-end, sideswipe same direction, 30 miles per hour or greater speed differential, and at-fault vehicle changing lanes crashes were calculated for both time frames and subsequently compared. Only the change in the annualized number of sideswipe same direction crashes was proven statistically significant to a 90% confidence level. The changes in the annualized number of rear-end, 30 miles per hour or greater speed differential, and at-fault vehicle changing lanes crashes were not statistically significant at a 90% confidence level. None of the changes in the annualized count of these crash data variables were statistically significant at a 95% confidence level.

The annualized number of Property Damage Only (PDO) and Injury (INJ) crashes was also calculated and compared for each time frame. This analysis also indicated that the change in annualized number of crashes of each type was not statistically significant at or above a 90% confidence level.

Comparison of After Construction Without and With Tolls

One hypothesis which contributed to the necessity for this RSA was that beginning the toll collections had a direct negative effect on the safety of this section of I-25. To test this hypothesis, crash data from the time frames "after construction without tolls" and "after construction with tolls" was compared by highway section. Again, this comparison primarily focuses on crash data percentages of wholes as there is 113-days worth of crash data after construction without tolls and 173-days of after construction with tolls crash data.

Crash data from Section 1 indicated that crashes primarily occurred on a Thursday after construction without tolls and on a Friday after construction with tolls. The percentage of rear-end crashes decreased from 70% to 67% while the percentage of sideswipe same direction crashes increased from 16% to 26%, comparing the after construction without and with tolls time frames respectively. The percentage of crashes reported involving a lane change increased from 14% after construction without tolls to 21% after construction with tolls. The percentage of crashes with a 30 miles per hour or greater speed differential between Vehicle 1 and Vehicle 2 decreased from 35% after construction without tolls to 30% after construction with tolls.

Section 2 crash data indicated that crashes primarily occurred on a Wednesday after construction without tolls and on a Thursday after construction with tolls. The percentage of rear-end crashes increased from 69% to 82% while the percentage of sideswipe same direction crashes decreased from 16% to 14%, comparing the after construction without and with tolls time frames respectively. The percentage of crashes involving a lane change increased from 10% without tolls to 12% with tolls. Similar to Section 1, the percentage of crashes reported with a 30 miles per hour or greater speed differential in Section 2 decreased from 38% without tolls to 28% with tolls.

Section 3 crash data indicated that crashes primarily occurred on a Tuesday after construction without tolls and on a Saturday after construction with tolls. The percentage of rear-end crashes increased from 56% to 79% while the percentage of sideswipe same direction crashes decreased from 19% to 14%, comparing the after construction without and with tolls time frames respectively. The percentage of crashes involving a lane change decreased from 16% without tolls to 11% with tolls. Unlike Sections 1 and 2, the percentage of crashes with a 30 miles per hour or greater speed differential in Section 3 decreased from to 34% without tolls to 28% with tolls.

Crash data from Section 4 indicated that crashes primarily occurred on a Tuesday after construction without tolls and on a Friday after construction with tolls. The percentage of rear-end crashes increased from 55% to 64% while the percentage of sideswipe same direction crashes decreased from 45% to 19%, comparing the after construction without and with tolls time frames respectively. The percentage of crashes reported involving a lane change decreased from 18% without tolls to 16% with tolls. Similar to Sections 1 and 2, the percentage of crashes with a 30 miles per hour or greater speed differential in Section 4 increased from 18% without tolls to 33% with tolls.

A similar comparison of annualized crash data, as was conducted in the previous Section, was conducted to compare the after construction without tolls and after construction with tolls crash data in order to determine statistical significance. **In this case, the change in**

annualized number of rear-end crashes, sideswipe same direction crashes, and crashes involving lane changing were all proven statistically significant at a 90% confidence level. Meanwhile, the change in annualized number of crashes involving a 30 miles per hour or greater speed differential was proven not statistically significant at a 90% confidence level. **The changes in annualized number of rear-end crashes and crashes involving lane changing were also proven statistically significant at a 95% confidence level, while the changes in annualized number of sideswipe same direction crashes and crashes involving a 30 miles per hour or greater speed differential were proven not statistically significant at a 95% confidence level.**

The annualized number of Property Damage Only (PDO) and Injury (INJ) crashes was also calculated and compared for each time frame. **This analysis indicated that the change in annualized number of PDO crashes was statistically significant at both a 90% and 95% confidence level.** However, the change in annualized number of INJ crashes was proven not statistically significant at both a 90% and 95% confidence level.

Comparison of Before Construction to After Construction With Tolls

A comparison of the change in crash data percentages between the before construction and after construction with tolls time frames can be implicitly drawn from data presented in the previous Sections. Furthermore, this comparison can also be viewed in Figure E1 and Figure E2.

Statistical significance of the change in annualized number of various crash data is not implicit in the preceding sections. These calculations were performed and it was determined that **the change in annualized number of rear-end crashes, sideswipe same direction crashes, crashes involving lane changing, and crashes involving a 30 miles per hour or greater speed differential were all proven statistically significant at a 90% confidence level. The change in annualized number of sideswipe same direction crashes, crashes involving lane changing, and crashes involving a 30 miles per hour or greater speed differential were also proven statistically significant to a 95% confidence level,** while the change in annualize number of rear-end crashes was proven not statistically significant to a 95% confidence level. The annualized number of Property Damage Only (PDO) and Injury (INJ) crashes was also calculated and compared for each time frame. **This analysis indicated that the change in annualized number of PDO crashes was statistically significant at both a 90% and 95% confidence level. The change in annualized number of INJ crashes was proven statistically significant at both a 90% confidence level but was proven not statistically significant at a 95% confidence level.**

Figure E1

		Before Construction to After Without Tolls				After Without Tolls to After With Tolls				Before Construction to After With Tolls			
		Section 1	Section 2	Section 3	Section 4	Section 1	Section 2	Section 3	Section 4	Section 1	Section 2	Section 3	Section 4
Primary Day of Week		Saturday -> Thursday	Friday -> Wednesday	Friday -> Tuesday	Saturday -> Tuesday	Thursday -> Friday	Wednesday -> Thursday	Tuesday -> Saturday	Tuesday -> Friday	Saturday -> Friday	Friday -> Thursday	Friday -> Saturday	Saturday -> Friday
Rear-end Crashes	Change in Proportion	12%	-6%	-11%	-25%	-2%	13%	23%	10%	10%	6%	12%	-15%
	Average change in proportion	-7%				11%				3%			
	Change in Annualized count	55	51	4	-43	42	168	184	76	98	219	189	32
	Average change in annualized count	17				118				134			
	--Statistically significant at 90%?												
	--Statistically significant at 95%?												
Sideswipe Same Direction Crashes	Change in Proportion	-14%	6%	6%	34%	9%	-1%	-5%	-27%	-5%	5%	1%	7%
	Average change in proportion	8%				-6%				2%			
	Change in Annualized count	0	19	9	7	30	24	23	11	30	43	32	18
	Average change in annualized count	9				22				31			
	--Statistically significant at 90%?												
	--Statistically significant at 95%?												
At-Fault Vehicle Changing Lanes Crashes	Change in Proportion	-10%	2%	5%	6%	7%	2%	-5%	-2%	-2%	4%	0%	3%
	Average change in proportion	1%				1%				1%			
	Change in Annualized count	2	11	8	-3	25	25	18	17	27	36	25	13
	Average change in annualized count	4				21				25			
	--Statistically significant at 90%?												
	--Statistically significant at 95%?												
At-Fault Vehicle to Vehicle 2 Speed Differential >=30 Crashes	Change in Proportion	16%	8%	2%	-6%	-5%	-10%	-6%	15%	11%	-2%	-5%	9%
	Average change in proportion	5%				-2%				3%			
	Change in Annualized count	35	40	9	-12	13	32	51	42	47	72	60	30
	Average change in annualized count	18				35				52			
	--Statistically significant at 90%?												
	--Statistically significant at 95%?												
Property Damage Only Crashes	Change in Proportion	-21%	-1%	2%	10%	21%	0%	0%	-11%	0%	-1%	2%	-1%
	Average change in proportion	-2%				2%				0%			
	Change in Annualized count	20	65	22	-36	80	140	170	95	100	206	192	59
	Average change in annualized count	18				121				139			
	--Statistically significant at 90%?												
	--Statistically significant at 95%?												
Injury Crashes	Change in Proportion	19%	1%	-2%	-10%	-19%	0%	0%	11%	0%	1%	-2%	1%
	Average change in proportion	2%				-2%				0%			
	Change in Annualized count	43	18	2	-8	-9	37	32	17	34	55	34	9
	Average change in annualized count	14				19				33			
	--Statistically significant at 90%?												
	--Statistically significant at 95%?												

Statistical significance:

	= Yes
	= No

Figure E2

		Section 1			Section 2			Section 3			Section 4		
		Before Construction to After Without Tolls	*After Without Tolls to After With Tolls*	*Before Construction to After With Tolls*	*Before Construction to After Without Tolls*	*After Without Tolls to After With Tolls*	*Before Construction to After With Tolls*	*Before Construction to After Without Tolls*	*After Without Tolls to After With Tolls*	*Before Construction to After With Tolls*	*Before Construction to After Without Tolls*	*After Without Tolls to After With Tolls*	*Before Construction to After With Tolls*
Primary Day of Week		Saturday -> Thursday	Thursday -> Friday	Saturday -> Friday	Friday -> Wednesday	Wednesday -> Thursday	Friday -> Thursday	Friday -> Tuesday	Tuesday -> Saturday	Friday -> Saturday	Saturday -> Tuesday	Tuesday -> Friday	Saturday -> Friday
Rear-end Crashes	Change in Proportion	12%	-2%	10%	-6%	13%	6%	-11%	23%	12%	-25%	10%	-15%
	Change in Annualized count	55	42	98	51	168	219	4	184	189	-43	76	32
	--Statistically significant at 90%?												
	--Statistically significant at 95%?												
Sideswipe Same Direction Crashes	Change in Proportion	-14%	9%	-5%	6%	-1%	5%	6%	-5%	1%	34%	-27%	7%
	Change in Annualized count	0	30	30	19	24	43	9	23	32	7	11	18
	--Statistically significant at 90%?												
	--Statistically significant at 95%?												
At-Fault Vehicle Changing Lanes Crashes	Change in Proportion	-10%	7%	-2%	2%	2%	4%	5%	-5%	0%	6%	-2%	3%
	Change in Annualized count	2	25	27	11	25	36	8	18	25	-3	17	13
	--Statistically significant at 90%?												
	--Statistically significant at 95%?												
At-Fault Vehicle to Vehicle 2 Speed Differential >=30 Crashes	Change in Proportion	16%	-5%	11%	8%	-10%	-2%	2%	-6%	-5%	-6%	15%	9%
	Change in Annualized count	35	13	47	40	32	72	9	51	60	-12	42	30
	--Statistically significant at 90%?												
	--Statistically significant at 95%?												
Property Damage Only Crashes	Change in Proportion	-21%	21%	0%	-1%	0%	-1%	2%	0%	2%	10%	-11%	-1%
	Change in Annualized count	20	80	100	65	140	206	22	170	192	-36	95	59
	--Statistically significant at 90%?												
	--Statistically significant at 95%?												
Injury Crashes	Change in Proportion	19%	-19%	0%	1%	0%	1%	-2%	0%	-2%	-10%	11%	1%
	Change in Annualized count	43	-9	34	18	37	55	2	32	34	-8	17	9
	--Statistically significant at 90%?												
	--Statistically significant at 95%?												

Statistical significance:

	= Yes
	= No

APPENDIX F

COLORADO
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I-25 North Metro Road Safety Audit (RSA)

Field Review | Thursday, September 7, 2017 | 6am-6pm

Primary Interstate Observation Locations:

- 84th Avenue Bridge
- 88th Avenue Bridge
- Thornton Pkwy (92nd Ave) Bridge
- Pedestrian Bridge North of 104th Avenue

Meeting/Discussion Location:

- City of Thornton Civic Center – 9500 Civic Center Drive, Thornton, CO 80229
  - Visitor Parking Lot – North Side (See Aerial Map Provided)
  - Conference Room – North Side (Enter through Economic Development door)
    - Direction to room will be given by staff at the counter.

Field Review Schedule:

- **6:00am – 6:15am** – Meet at Thornton Civic Center – Prepare/Depart for AM Observation Locations
- **6:15am – 6:30am** – Travel/Arrive at AM Peak Period Observation Locations
  - Please carpool and feel free to visit any or all of the pre-selected locations.
- **6:30am – 8:30am** – AM Peak Period Observations
  - Feel free to roam to any or all of the 4 identified observation locations.

- **8:30am – 8:45am** – Return to Thornton Civic Center – Conference Room
- **8:45am – 11:00am** – Group Discussion of Observations / Comment Period
- **11:00am – 2:30pm** – Break for Lunch / Independent Observation Period
- **2:30pm – 3:00pm** – Reconvene at Thornton Conference Room – Finalize PM Observation Strategy
- **3:00pm – 3:15pm** – Travel/Arrive at PM Peak Period Observation Locations
  - Please carpool and feel free to visit any or all of the pre-selected locations.
  - Please do not leave belongings at this point as we will not be returning to conference room.

- **3:15pm – 5:30pm** – PM Peak Period Observations
- **5:30pm – 5:45pm** – Return to Thornton Civic Center – Visitor Parking Lot
- **5:45pm – 6:15pm** – Brief Discussion / Closing Thoughts
- **6:15pm** – Group Dismissal – We Appreciate Your Involvement in This RSA Effort!

PLEASE REVIEW THE IMPORTANT NOTES ASSOCIATED WITH THIS FIELD REVIEW PORTION OF THIS RSA ON THE FOLLOWING PAGE. ADDITIONALLY, PLEASE REVIEW THE VARIOUS AREA MAPS PROVIDED TO AID IN YOUR TRAVEL TO EACH OF THE PRE-SELECTED OBSERVATION LOCATIONS AND ASSOCIATE DESIGNATED PARKING.

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I-25 North Metro RSA – Field Review Sign-In

Date: Thursday, September 7, 2017
Location: City of Thornton Civic Center & Multiple I-25 Viewing Locations

	Name	Email Address	Company, Agency, or CDOT Region
Am/pm	William Farr	William.Farr@cityofthornton.net	Thornton PD
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AM/PM	KYLE KAMMERMEIER	KKAMMERMEIER@NORTHGLENN.ORG	NG
AM/PM	BEN KIENE	benjamin.kiene@state.co.us	CDOT R1

APPENDIX G

Example supplemental sign for double white line restriction.

Southbound at 88th Ave.

Existing

Proposed

Southbound between 88th and 84th

Existing

Proposed

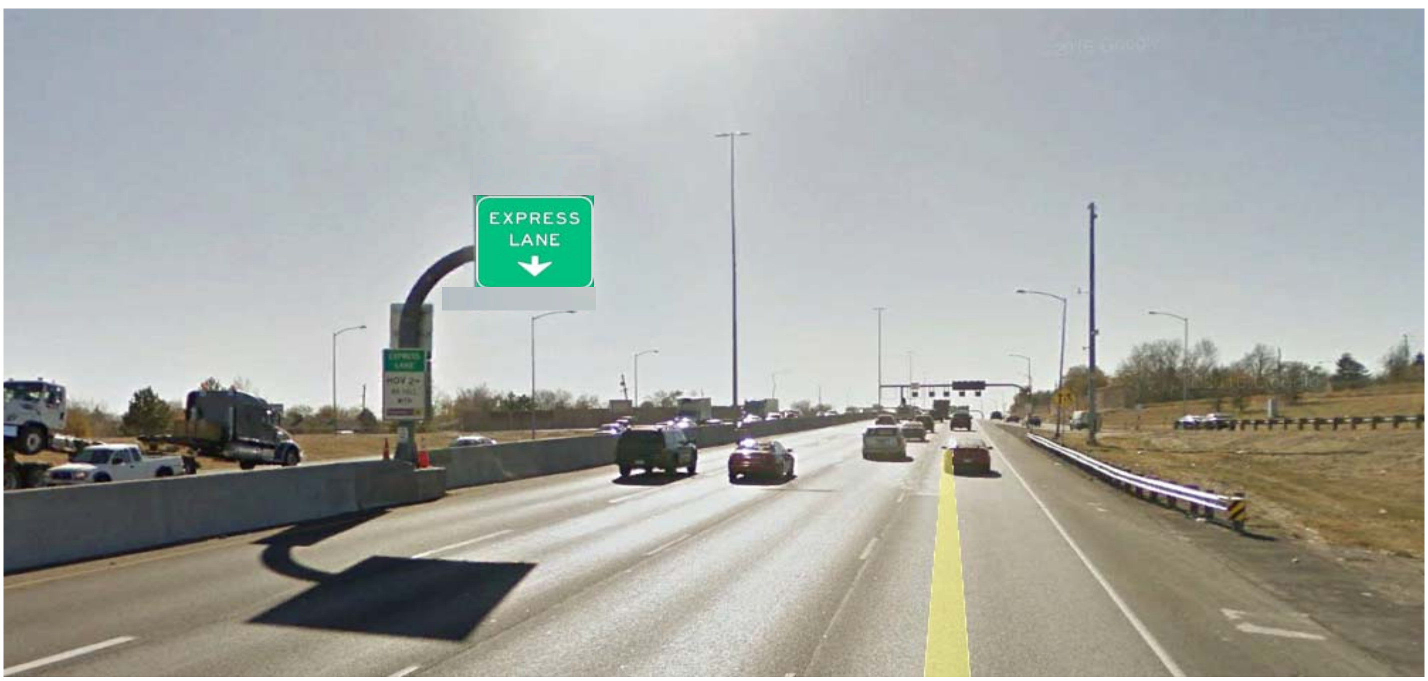
Southbound at 84th Ave.

Existing

Proposed

Southbound south of 84th Ave.

Existing



Proposed

Southbound south of 84th Ave.

Existing

Proposed

APPENDIX H – LITERATURE REVIEW

Several research studies have been conducted on the states of best practices, current implementation, and safety effects of managed lanes on freeway facilities. The Transportation Research Board (TRB) has a host of resources regarding managed lanes which can be found at the following web address:

http://www.trb.org/AHB35/AHB35.aspx

Using these resources as future guidance and as reference for hindsight may prove useful to this RSA. Particularly, there is a publication provided by the TRB titled "Guidelines for Implementing Managed Lanes" which contains applicable and valuable guidance. This publication states,

> *"Numerous domestic and international agencies either have constructed or are planning to implement systems of managed lanes; however, experience has demonstrated that each system is unique, designed in response to issues and challenges that emerge when these projects are implemented in high-demand, congested, or constrained travel corridors. Despite earlier efforts and despite an apparent need, there is currently no comprehensive resource available to assist transportation agencies when planning and implementing managed lanes. Various guides that do exist contain some information about various aspects of the program, but they do not explicitly address the wide range of issues and complexities in sufficient detail to serve as an effective, widely applicable implementation guide.* NCHRP Research Report 835: Guidelines for Implementing Managed Lanes *fills that void with a comprehensive set of guidelines addressing a broad array of issues affecting design, implementation, operation, and maintenance of managed lanes. Steps range from defining initial objectives, outlining the necessary decision-making process, and addressing safety concerns, through the process of detailed design configuration and operation. These guidelines can serve as the primary reference on managed lanes—complementing other national guidelines—and they are applicable to practitioners at all levels of experience when designing and implementing managed lanes on freeways and expressways." [2]*

The aforementioned publication is also supported by a different TRB publication titled "Research Supporting the Development of Guidelines for Implementing Managed Lanes." This publication states,

> *"Numerous domestic and international agencies either have constructed or are planning managed lanes; each facility is unique and presents issues and challenges because these facilities are often implemented in high-demand, congested, or constrained corridors. There has been no singular guidance to assist transportation agencies implementing managed lanes; various guides contain some information on managed lanes, but they do not explicitly address the wide range of issues and complexity associated with managed lanes in*

sufficient detail to serve as a national guide on the subject. The objective of NCHRP Project 15-49 was to develop guidelines for the planning, design, operations, and maintenance of managed lanes. The final product—Guidelines for Implementing Managed Lanes—will become the primary reference on managed lanes and complement other national guidelines. It was designed to be applicable to practitioners at all levels of experience with managed lanes and to be used to support informed decision-making. The scope of this project was limited to managed lanes on freeways and expressways.

In Phase I of this project, the research team compiled existing information from published literature and existing manuals and policy documents, emphasizing sources published in the last 10 years. Researchers also discussed current practices with practitioners in group and individual settings to document guidance needs that the practitioners identified. Using information obtained in these activities, in Phase II, the research team conducted a series of focused studies to fill identified knowledge gaps on design decision-making, trade-offs of geometric design elements, access design, and factors that affect speed on managed lanes. The activities and findings of the research team on those tasks, along with potential research needs and suggested changes to existing reference documents, are documented in this report and its appendices. The final version of the guidelines is published as a stand-alone document to facilitate its dissemination and use within the profession." *[3]*

One potential solution to mitigate sudden or drastic weaving and lane changing behavior while addressing congestion issues implicit in increased AADT, crash rates, and crash type frequencies is to convert the managed lanes to continuous access. Several states have successfully implemented continuous access managed lanes in which there is no buffer between the managed and general-purpose lanes. Vehicles are free to go in and out of the managed lanes as they wish. A study conducted by the Washington State Transportation Center (TRAC) stated the following regarding a similar scenario on a Washington State highway,

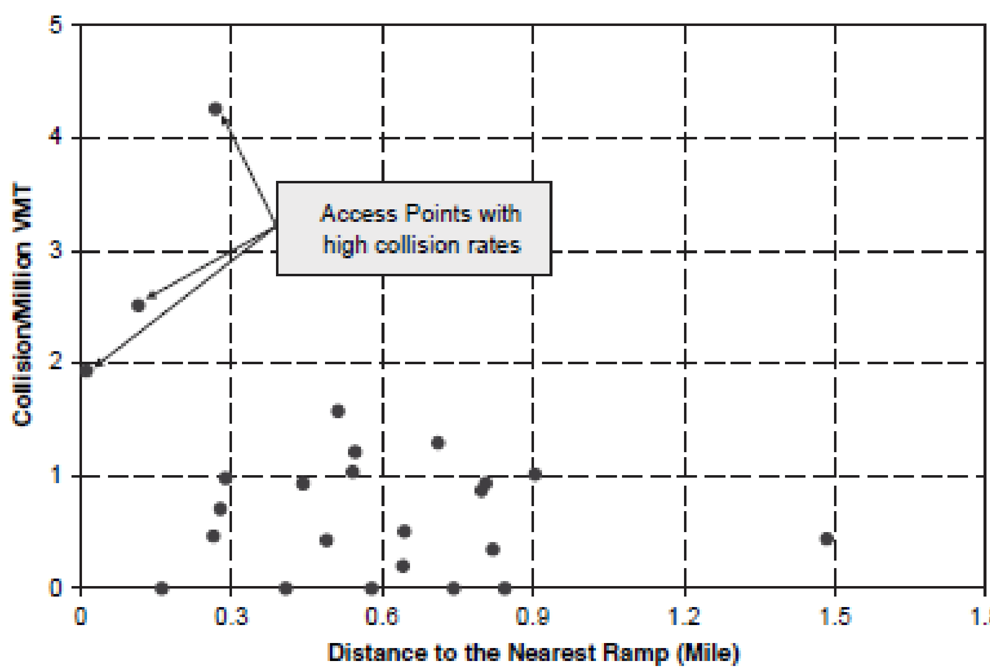
"*In August 2014, The Washington State Department of Transportation (WSDOT) changed the access controls for the HOT (High Occupancy Toll) lanes on State Route (SR) 167. The lanes were initially designed and implemented to allow access at only six points northbound and four points southbound. Since August 23, 2014, free access has been allowed into and out of the HOT lanes. This study was performed to determine the effects of allowing continuous access to the SR 167 HOT lanes. It examined customer attitudes toward the new access rules, the performance of the corridor, including both the HOT lanes and the parallel general purpose (GP) lanes, and the volumes of use and travel times experienced. It also examined the amount of revenue collected, the amount of toll evasion occurring, collision frequency and severity, and the impacts on transit operations.*

The changes in the corridor since the change in access rules have been complex. This report describes that complexity. In general, traffic volumes are increasing in the corridor. Travel times have degraded slightly in both the GP *and HOT lanes in the corridor. Prices and total revenue are up in the HOT lane. Prices increased substantially during the first five months of operation of the new rules, declined somewhat after that, but remain higher than under access control rules. No statistically significant change in safety is apparent. A large fraction of the travelers in the corridor are in favor of the access rule changes, and that includes the transit agencies operating in the corridor.*" *[4]*

Additional research has been conducted which attempted to relate managed lane access frequency with ramp frequency and crash rates. The study concluded with the following guidance,

> "*Significantly higher collision rates… [associate with] ingress-egress segments with the following common features:*
> 1. *Located within 0.3 mi of the nearest on- or off-ramp.*
> 2. *Short access length (0.25 mi), and*
> 3. *High traffic volume in the HOV lane during peak hours.*" *[5]*

The study further summarized this finding as seen in Figure H 1 below.



[5]

Figure H 1 – Relationship between collisions per average hourly vehicle-miles travelled and distance to the nearest ramp

Lastly, the Department of Civil and Coastal Engineering at the University of Florida performed a research study for The Florida Department of Transportation and Research Office titled "Crash Prediction Method for Freeway Facilities with High Occupancy Vehicle (HOV) and High Occupancy Toll (HOT) Lanes" which was published in July of 2015. This report states,

> "*This study developed methods for estimating the expected crash frequency of urban freeway segments with HOV or HOT lanes. The safety impacts of the type of separation between the managed lanes and general purpose lanes were*

examined. Separate models were estimated for fatal and injury (FI) crashes and all crashes. The models for facilities with HOV lanes were estimated using five years' of data from California, Washington, and Florida. All these facilities have one HOV in each direction (included in the count of total number of lanes). The effect of separation type on crash rates is found to be statistically significant only in the models for ten-lane facilities. The models for freeways with HOT lanes were estimated using four years' of data from 27 miles (48 segments) of freeways from the states of California, Texas, and Florida. All these facilities have two HOT lanes in each direction. Facilities with a 1-foot separation are estimated to have more crashes than those that have a 3-foot separation which in turn have more crashes than facilities with a 20-foot separation. All the estimated models have been implemented in a spreadsheet program which will enable analysts to apply these equations for crash prediction. Overall, this study provides procedures that will help FDOT consider safety in decisions about planning and designing freeways with HOV or HOT lanes." *[6]*