

Technical Memorandum #1

FINAL REPORT

Before and After Evaluation of the "Pre-Signal" Control at the Prince Road/I-10 UPRR Railroad Crossing

Prepared For:



Pima Association of Governments
And Member Agencies

Prepared By:

DMJM HARRIS | AECOM

1860 East River Road,
Suite 300

Tucson, Arizona 85718

(520) 299-8700

Project Number 046105594.0002

June 2006

Executive Summary

Several Highway/Railroad crossings in the Tucson Metropolitan Area have experienced drivers stopping on railroad tracks when queued at adjacent traffic signals during red light indications. One notable location was the Union Pacific Railroad Crossing on Prince Road, which is adjacent to the I-10/Prince Road traffic interchange. As an experimental measure, the City of Tucson in coordination with Union Pacific and Pima Association of Governments (PAG) installed a Pre-signal on the approach to this railroad crossing. A simple definition of a “Pre-Signal” is a typical traffic signal that displays red, yellow and green lights and is installed on the approach to a railroad crossing that is located adjacent to a signalized intersection for the purpose of stopping traffic in advance of the railroad tracks.

This Technical Memorandum provides a comprehensive “Before” and “After” evaluation of the Pre-signal control that was installed on Prince Road located just east of the I-10 Traffic Interchange. To accomplish this task, several types of before and after data were collected. These include traffic volume data, train volume data, traffic signal operational data, accident data, delay measurements, conflict, violation and behavior data, and condition diagrams

Based on this evaluation, the following key points were concluded:

- The Pre-signal improved the safety of the Prince Road/UPRR crossing by reducing the occurrence of motorists stopping on the railroad tracks and other undesirable violations and behaviors.
- The Pre-signal improved the operation of traffic at the Prince Road/UPRR crossing in terms of reducing violations and undesirable behaviors; however, it also increased the average stopped delay per vehicle by an amount less than 12 seconds per vehicle.
- The benefits realized with the installation of this Pre-signal are:
 - Reduces the occurrence of motorists stopping on the tracks.
 - Improves visibility of the traffic signals on the approach.
 - Improves compliance (less running of the flashing light indications)
 - Provides clear understandable indication to the motorists.
 - Provides a yellow change interval on a busy, high speed approach.
 - Improves safety – reduces accidents, violations and undesirable behaviors.
 - A benefit-to-cost ratio significantly greater than 1.0.
- The issues and challenges that were encountered with the installation of the Pre-Signal are:
 - The effort to install and operate a Pre-signal requires personnel with signal construction and operation expertise.
 - The cost of the Pre-signal includes design, construction, operation, maintenance and power.
 - Some undesirable behaviors and violations such as drivers proceeding through the Pre-signal red light, and drivers speeding to beat the Pre-signal red light occur.
 - Increase in delay and cycle length.
 - Signal timing adjustments are required. This included signal timing coordination with the interchange signal, clearance intervals, and pre-emption cycling.
- The Pre-Signal control should be considered for other crossings in the region where queuing over the tracks is common and where tracks are in close proximity to a signalized intersection as specified in the MUTCD.

Table of Contents

1.0 INTRODUCTION	1
2.0 CONDITIONS BEFORE PRE-SIGNAL INSTALLATION	1
2.1 Physical Conditions (Before Pre-Signal)	1
2.2 Operation of the Prince Road/UPRR Crossing (Before Pre-Signal)	4
2.3 Accident Experience	6
3.0 INSTALLATION OF THE PRE-SIGNAL	11
3.1 What is a Pre-Signal	11
3.2 Coordination with the Union Pacific Railroad Company	13
4.0 CONDITIONS AFTER PRE-SIGNAL INSTALLATION	13
4.1 Physical Conditions (After Pre-Signal)	13
4.2 Operation of the Prince Road/UPRR Crossing (After Pre-Signal)	15
4.3 Pre-signal Operational Considerations	16
5.0 COMPARISON OF BEFORE VS. AFTER CONDITIONS	17
5.1 Traffic Volume Data Collection	17
5.2 Train Speed and Frequency	19
5.3 Approach Delay and Residual Queuing	20
5.3.1 <i>Stopped Time Approach Delay</i>	20
5.3.2 <i>Residual Queuing</i>	22
5.3.3 <i>Analysis of Delay and Queuing</i>	23
5.4 Residual Queuing and Approach Delay	23
5.5 Behavior, Violation and Conflict Data	25
5.6 Other Observations of the Prince Road/UPRR Crossing	29
6.0 IMPROVEMENTS IMPLEMENTED AS A PART OF THIS STUDY	31
7.0 FUTURE SAFTY AND OPERATION OF THE PRINCE ROAD/UPRR CROSSING	33
7.1 Future Traffic and Train Projections	33
7.2 Future Safety and Operational Predictions of the Prince Road/UPRR Crossing	34
8.0 BENEFIT-COST ANALYSIS OF THE PRE-SIGNAL	35
9.0 CONCLUTIONS AND RECOMMENDATIONS	35
9.1 Conclusions	35
9.2 General Assessment of the Pre-signal	36
9.3 Recommendations	38

<u>FIGURES</u>		<u>Page</u>
Figure 1	Vicinity Map	2
Figure 2	Condition Diagram (Before Pre-Signal)	3
Figure 3	Prince Rd/UPRR Crossing Before Pre-Signal (Looking West)	5
Figure 4	Prince Rd/UPRR Crossing Before Pre-Signal (Looking East)	5
Figure 5	Collision Diagram	8
Figure 6	Condition Diagram (After Pre-Signal)	14
Figure 7	Pre-Signal Installation at Prince Road/UPRR Crossing	15
Figure 8	Condition Diagram of Prince Road/UPRR with Remedial Crossing Improvements	32

<u>TABLES</u>		<u>Page</u>
Table 1	RR Crossing Controls - Sequence of Events Before Pre-Signal	6
Table 2	Summary of RR-Crossing Related Accidents	9
Table 3	Pre-Signal Activation – Sequence of Events for WB Traffic	16
Table 4	Summary of Data Collection from Machine Recorders	17
Table 5	Turning Movement Counts Before Pre-Signal Installation	18
Table 6	Turning Movement Counts After Pre-Signal Installation	18
Table 7	Traffic Count Correction	19
Table 8	Calculation of Average Annual Daily Traffic Volumes	19
Table 9	Train Speed and Frequency	20
Table 10	Train Volume and Elapsed Time Gates are Down	20
Table 11	Prince Road Delay Summary	21
Table 12	Prince Road Delay Comparison	22
Table 13	Summary of Behavior, Violation and Conflict Data	25
Table 14	Comparison of Violation Rates	26
Table 15	Comparison of Behavior Rates	27
Table 16	Comparison of Conflict Rates	28
Table 17	Benefits of the Pre-Signal Application	29
Table 18	Potential Concerns of the Pre-Signal Application	29
Table 19	Summary of Other Observations with Potential Solutions	30
Table 20	Future Traffic Projections	33
Table 21	Future Train Projections	34
Table 22	Future Train Crossing Time (Time Gates are Down)	34

APPENDICES

Appendix A	As-built Drawing
Appendix B	Accident Data
Appendix C	MUTCD Flashing Lights and Gates Pictorial
Appendix D	Traffic Data collected by Consultant
Appendix E	Traffic Data collected by ITE U of A Student Chapter
Appendix F	Train Data Collection
Appendix G	Behavior, Violation and Conflict Data Sheets
Appendix H	Benefit-Cost Analysis

1.0 INTRODUCTION

At the request of member agencies of the Pima Association of Governments (PAG) that reside in Pima County, Arizona, the Pima Association of Governments (PAG) has initiated a project to explore and evaluate various types of controls and applications for Rail-Highway Crossings that can be used within the PAG Region. The purpose of this project is two-fold:

- To provide an evaluation of the “pre-signal” traffic signal control application at the Union Pacific Railroad crossing on Prince Road at the Interstate-10 Traffic Interchange in the City of Tucson, Arizona.
- To identify local, national, and international state-of-the-practice highway-rail at-grade crossing strategies.

The purpose of this Technical Memorandum # 1 is to provide a comprehensive “Before and After” evaluation of the pre-signal control that has been installed by the City of Tucson at the Union Pacific Railroad (UPRR) Crossing on Prince Road just east of the I-10 Traffic Interchange.

The City of Tucson installed the “pre-signal” control at this highway-railroad crossing in an effort to reduce the frequency of motorists stopping on the railroad tracks during red light indications and to improve the overall safety of the crossing. The location of this crossing is shown in the vicinity map in Figure 1. Since this application is the first of its type in the Tucson area, the conditions and operation of traffic at this railroad crossing are evaluated in this report based on data that was collected before and after the “pre-signal” was installed. As a result, this report will attempt to answer the following questions:

- Ø Did the pre-signal improve the safety of the Prince Road/UPRR Crossing?
- Ø Did the pre-signal improve the operation of traffic at the Prince Road/UPRR Crossing?
- Ø Should the pre-signal control be considered for other crossings in the region? If so, for what types of conditions would it be applicable?

2.0 CONDITIONS BEFORE PRE-SIGNAL INSTALLATION

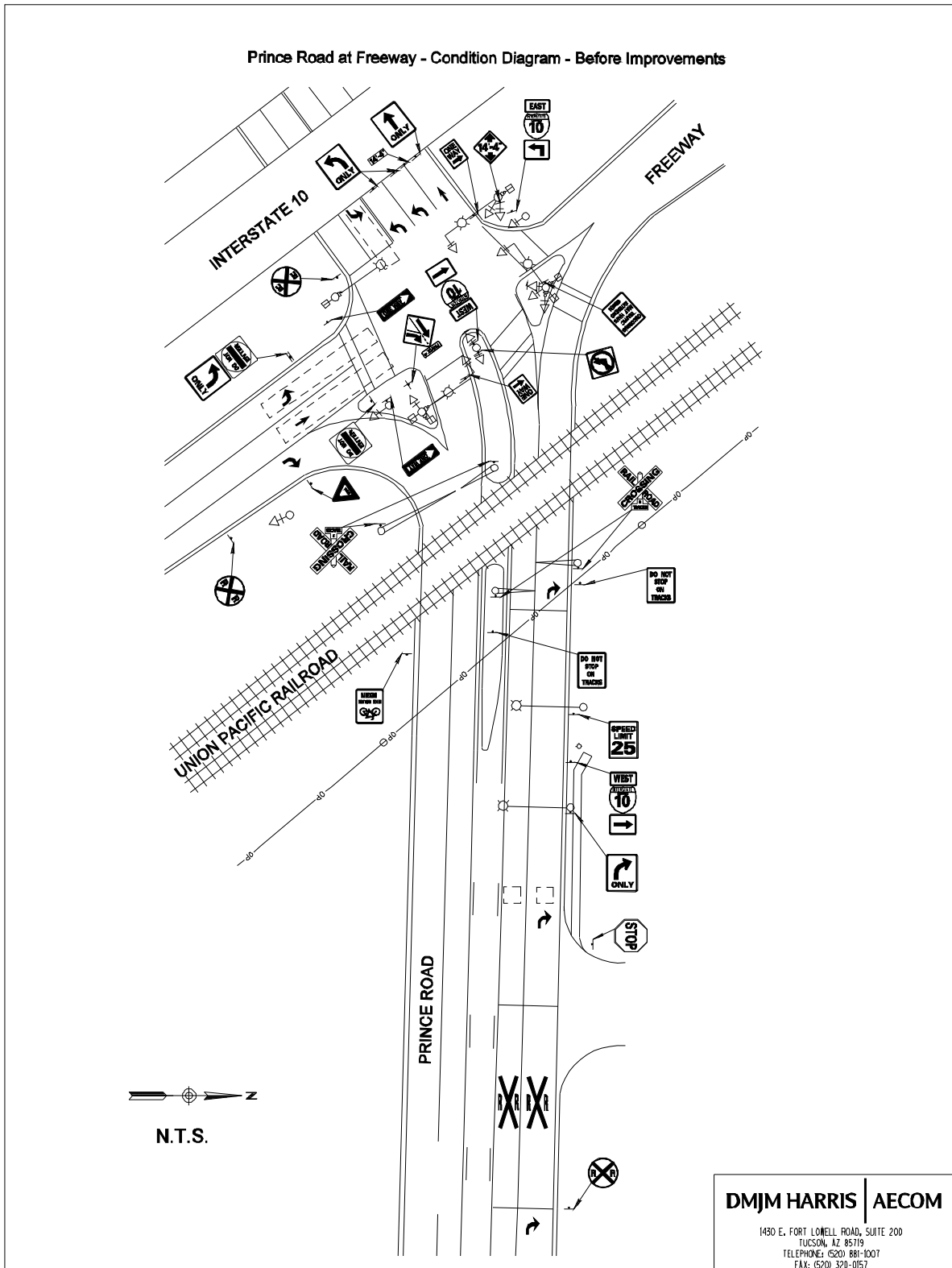
The conditions and operation of the Prince Road/UPRR highway-rail crossing before the “pre-signal” was installed are described in this section of the report. This serves two purposes. First to document the issues related to the crossing prior to the pre-signal being installed, and second to establish a “baseline” set of data that can be compared to the conditions and operation of the crossing after the Pre-Signal was installed. The “pre-signal” was constructed during March and April of 2004 and was turned on in the first week of May 2004.

2.1 Physical Conditions (Before Pre-Signal)

Interstate 10 was constructed in the 1950s and 1960s, parallel to the Southern Pacific Railroad tracks that were constructed between Phoenix and Tucson in the 1800’s. The Southern Pacific Railroad was acquired by the Union Pacific Railroad in 1998. From the northwest side of Tucson, through Pima County and the Town of Marana, the Offset between the tracks is relatively close ranging between 100 and 300 feet. The result of this parallel design is that each cross-road that forms an interchange with I-10 has a rail-highway crossing on the east side of the interchange. The only exceptions to this are the Miracle Mile and Orange Grove Road interchanges, where a grade separation was constructed between the roads and the UPRR tracks.

Figure 1: Vicinity Map of Prince Road/UPRR Crossing

Figure 2: Condition Diagram of Prince Road/UPRR Crossing (Before Pre-Signal)



Prince Road is a major east-west arterial street on the north side of Tucson. Within the City of Tucson City Limits, Prince Road spans approximately 5 miles from Business Center Drive just west of I-10 to the Rillito River just east of Country Club Road. In general, Prince Road has a 5-lane cross-section consisting of two through lanes in each direction separated by a two-way left-turn lane. I-10 is elevated and grade separated from Prince Road forming a typical tight urban diamond interchange with ramps and one-way frontage roads on both sides. Prince Road and the Union Pacific Railroad tracks are at grade. A drawing of the crossing is provided in Figure 2. This drawing is approximately to scale as it was based on hand drawn as-built drawings that were modified in 1990 and contained in Appendix A.

I-10 and the UPRR are essentially parallel in the vicinity of Prince Road with an approximate angle of North 40 degrees West. This results in a 50 degree skew angle between the UPRR tracks and Prince Road. West of the UPRR tracks, Prince Road curves to the south to intersect I-10 at right angles. The westbound approach of Prince Road to the I-10 interchange consists of a short, small radius curve. The traffic signals for the westbound approach to the I-10 interchange are adequately aimed at Prince Road to ensure they are visible for on-coming traffic.

2.2 Operation of the Prince Road/UPRR Crossing (Before Pre-Signal)

Prior to the installation of the Pre-Signal in May 2004, the Prince Road/UPRR crossing was controlled with standard flashing-light signals and gates on the approach to the tracks. A photograph looking west at the Prince Road crossing is provided in Figure 3.

The flashing light signals consist of two, standard, side-by-side, red signals that flash intermittently. Three sets of flashing light signals were provided for westbound traffic, one set on the right side of the road and two sets in the median of Prince Road. Similarly, three sets of flashing light signals are provided in the eastbound direction, with one set on the right side of the road and two in the median. The flashing light signals are mounted on vertical poles, referred to as “A-poles” in Arizona. Cross-buck railroad signs are mounted above each of the flashing light signals on the A-poles. A photograph looking east at the Prince Road/UPRR crossing is provided in Figure 4.

Gates on each side of the roadway are provided on the upstream side of the tracks in each direction. The median sufficiently deters vehicles from driving around the gates. White stop bars were provided in advance of the tracks, as well as the standard railroad crossing pavement markings. The pavement markings and signing at the Prince Road/UPRR crossing are shown in Figure 2. Due to the heavy traffic volumes on Prince Road and the breaking of vehicles on the approach to the tracks, the railroad crossing pavement markings wear out rapidly. This is evident in the photograph in Figure 3.

Figure 3: Prince Road/UPRR Crossing Before Pre-Signal (4-13-04 Looking West)



Figure 4: Prince Road/UPRR Crossing Before Pre-Signal (4-13-04 Looking East)



The operation of the signals and gates when a train approaches this crossing is a standard operation. Sensors are located on the tracks upstream of the crossing. When the sensor detects a train, the electrical pulse sends a message to the railroad active warning system controller. The controller sends electrical current to the flashing-light signals, which start flashing. After the railroad signals have been flashing for a period of approximately 5 seconds, the gates are lowered across the roadway to stop traffic.

The detection of a train approaching on the tracks also sends a message to the traffic signal controller that runs the traffic signal phasing at the Prince Road/I-10 interchange. This is referred to as the “railroad pre-emption” of the traffic signal. Upon receiving this message, the controller turns the westbound traffic signals green to ensure that all cars on the approach clear the tracks, then turns the traffic signal to yellow, and then to flashing red. The complete sequence of events for the railroad and traffic signal controls on the westbound approach are summarized in Table 1.

**Table 1: RR Crossing Controls - Sequence of Events for Westbound Traffic
 (Before Pre-signal was installed)**

Event Sequence	System Action (When Interchange Signal is green when activated)	System Action (When Interchange Signal is red when activated)
1	Approaching Train Activates Sensors Flashing-light signals are activated Interchange Signal is green	Approaching Train Activates Sensors Flashing-light signals are activated Interchange Signal is red
2	Gates begin to lower	Interchange signal turns green for westbound traffic
3	Gates are lowered all the way WB Interchange Signal remains green	Gates begin to lower
4	Interchange Signal turns yellow	Gates are lowered all the way WB Interchange Signal remains green
5	Interchange Signal turns red	Interchange Signal turns yellow
6	Interchange Signal changes to flashing red	Interchange Signal turns red
7	Train Passes	Interchange Signal changes to flashing red
8	Gates are raised	Train Passes
9	Interchange signal turns green	Gates are raised
10		Interchange signal turns green

2.3 Accident Experience

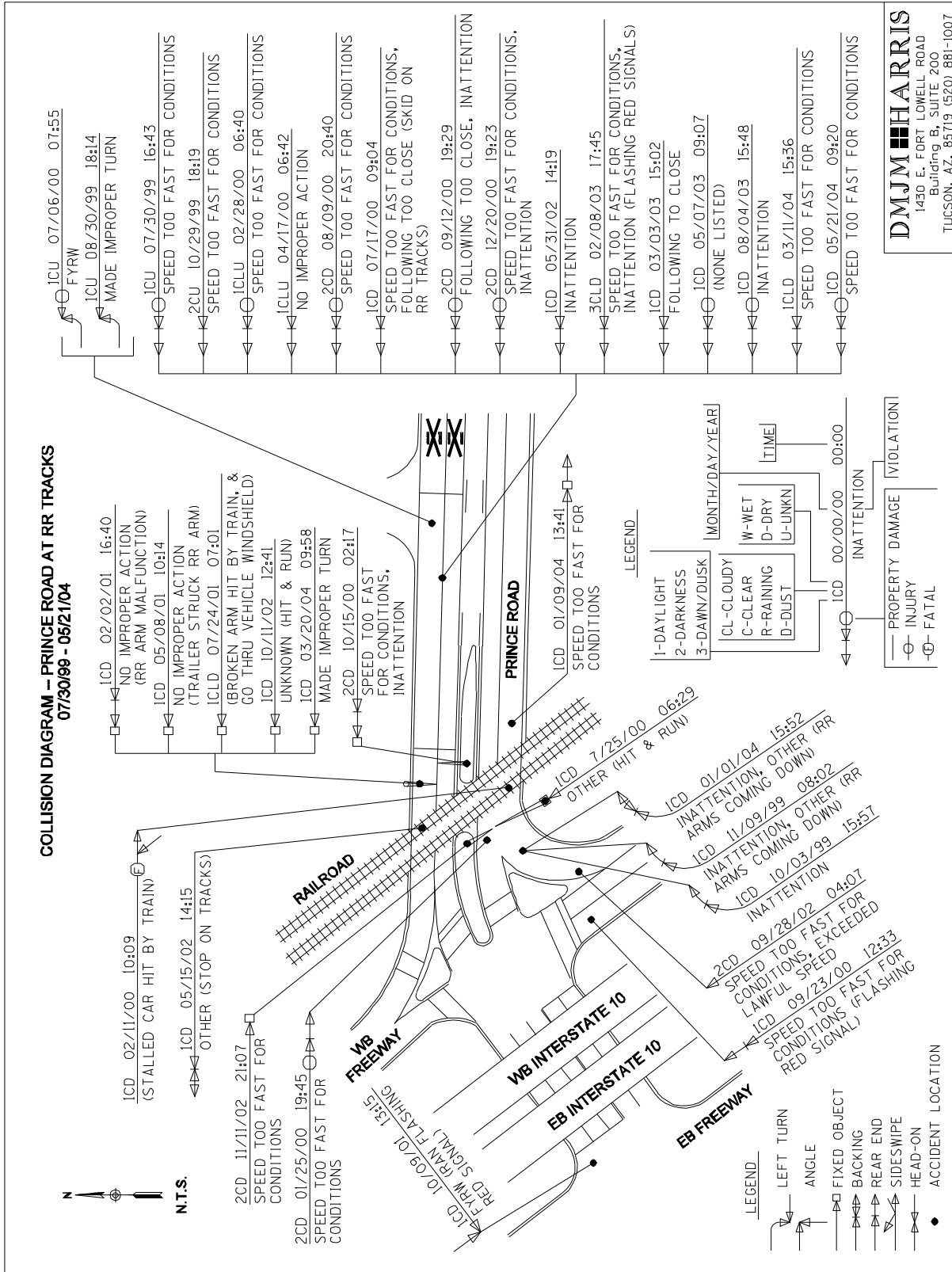
To evaluate the historical accident experience of the Prince Road/UPRR Crossing, accident records were requested from the Arizona Department of Transportation for the five-year period of June 1, 1999 through May 31, 2004. Accident records were provided for all recorded accidents on Prince Road and intersecting cross-streets from I-10 on the west to Runway Drive on the east, including the I-10 interchange intersections and the Runway Drive intersection. A total of 254 accidents were recorded. The data are summarized in Appendix B.

ADOT provided listings of the accidents and the actual police reports. To decipher which of the 254 accidents were related to the operation of the UPRR Crossing, each police report was reviewed. The police reports that clearly described accidents being related to the operation of the railroad crossing were noted, and these accidents were coded with a “Yes” designation under the “RR Track Related” column heading in the “Accident Listing Summary – All Accidents” in Appendix B. The “RR Track Related” accidents were sorted from the other accidents to provide the “Accident Listing Summary – RR Related Only Accidents”, also contained in Appendix B. The actual police reports are not contained in this report, but will remain on file and are available to PAG member agencies upon request.

It is possible that some of the accidents that were not designated as “RR Related” may have been related to the railroad crossing, too. However, there is no way to decipher the relation of collisions to the railroad crossing unless it was clearly noted in the police report. As a result, this accident analysis is predicated on the accuracy of the police reports of each accident.

Of the 254 total accidents, 35 were noted as being related to the railroad crossing in the police reports. These accidents include vehicles hitting the railroad traffic control equipment, vehicles running into the gates, vehicles taking evasive action due to the gates, rear-end collisions that occurred when the gates were down, and one vehicle that was hit by a train. The railroad related accidents are summarized in Table 2 and illustrated in the collision diagram in Figure 5. A more detailed Accident Summary Table is provided in Appendix B.

Figure 5: Collision Diagram



DMJM HARRIS
 1430 E. FORT LOWELL ROAD
 Building B, Suite 200
 TUCSON, AZ 85719 (520) 881-1007

Table 2: Summary of RR-Crossing Related Accidents

Accident Characteristic	Number of Accidents by Year						
	7-1-99 to 12-31-99	2000	2001	2002	2003	1-1-04 to 6-30-04	Total
TYPE							
Rear-end (WB)	2	6		1	4	2	15
Rear-end (NB)		1					1
Rear-end (NB-EB)	2						2
Left-turn (EB to NB)	1	1					2
Angle			1				1
Hit Fixed Object (RR Gates)		2	3	2		1	8
Hit Fixed Object (RR Signal Pole)						1	1
Backing (EB)		1				1	2
Backing (WB)				1			1
Veh. Hit by Train		1					1
Non-Collision				1			1
Total Accidents	5	12	4	5	4	5	35
Fatal		1					1
Injury	1	6			2	1	10
Property Damage	4	5	4	5	2	4	24

Of the 35 railroad related accidents, 10 accidents resulted in injuries and one accident resulted in a fatality. The fatal accident occurred on February 11, 2000 and was a very sad occurrence in which a mother and her infant child were hit by a train. The driver, the mother, was eastbound in the curb lane and stopped on the tracks. A train approached the crossing and the vehicle stalled when the mother tried to clear the tracks. Unable to start her car, the mother got out of the car and attempted to remove the child from the car seat. She unbuckled her child from the car seat prior to the arrival of the train but was unable to remove the child. Simultaneously, other people at the scene tried to push the vehicle off the tracks; and asked the mother to take the vehicle out of “park”. The train hit the vehicle with the child unbuckled in the car seat. The child was ejected

and sustained fatal injuries. When the train struck the car, the mother, who was outside the car, was hit by the car as the train struck the car and received minor injuries.

Analysis of the events of the fatal accident reveals some key safety issues related to rail-highway crossings. Stalling of vehicles on the tracks is a serious safety concern related to railroad crossings where queuing over the tracks occurs with regularity. Stalling a vehicle or getting stranded on railroad tracks may occur due the following:

- A vehicle is not idling properly, and the engine stops running when the car stops on the tracks.
- The vehicle just stalls as the driver tries to move it.
- A panicked driver who tries to move their vehicle in a hurry to avoid the train, erratically steps on the gas pedal, clutch and/or brake and stalls the vehicle.
- If the gates come down near the vehicle and the driver takes the wrong action such as backing up the driver may not successfully get his/her vehicle off the tracks.
- Once stalled, many vehicles are difficult to get restarted

Therefore, it may be prudent to design railroad crossings to minimize the possibility of vehicles stalling or getting stranded on the railroad tracks.

Nine of the 10 accidents that resulted in injury, were westbound vehicles either approaching the tracks or the end of the queue when the crossing traffic controls were in operation. It is speculated that the injury accidents are more common in the westbound direction approaching the tracks due to the higher speeds of westbound traffic than eastbound and northbound right-turning traffic at the I-10/Prince Road T.I.

As indicated in Table 2, the predominant type of railroad related accident was the rear-end collision, of which there were 18. Of the 18 rear-end collisions, 15 occurred on the westbound approach to the railroad tracks when either the flasher was activated, the gates were coming down or a train was passing through. As illustrated in Figure 5, most of the injury accidents (8 of 10) were westbound rear-end collisions approaching the tracks. Of the other three rear-end collisions, one was in the eastbound direction involving a vehicle that was proceeding too fast for conditions and resulted in an injury. The other two rear-end accidents involved northbound vehicles from the frontage road hitting vehicles waiting to turn east that were stopped due to an on-coming train.

The second most common type of accident that was reported was vehicles hitting the railroad gates, of which there were 8 occurrences. Some of these accidents occurred while the gates were coming down. In one case, the gates malfunctioned and a vehicle hit them. When the officer arrived on the scene, the gates were still malfunctioning, as was noted in the police report.

A number of other types of accidents related to the railroad crossing occurred; however, the frequency of these accidents ranged from 1 to 2 over the five year evaluation period. These include left-turn, backing, angle, no-collision, and hitting a railroad signal pole. One fatal accident involved a vehicle that stalled on the tracks and was hit by an on-coming train, as previously described.

The detailed accident summary table in Appendix B provides insights into other accident characteristics. The 35 accidents involved 60 vehicles, of which 14 people were injured and one person was killed. There were 10 single vehicle accidents, 24 accidents that involved two

vehicles and one accident that involved three or more vehicles. Most of the accidents occurred on dry pavement and most occurred during daylight. The most common contributing factors that were cited by police were “Speed too fast for Conditions” of which there were 14 and “Inattention” of which there were 7. “Followed too closely” and “Failed to Yield Right-of-Way” were also cited more than once.

The detailed accident summary also summarizes the accidents by time of day, day of week, month and year. The time that accidents occurred were distributed somewhat evenly throughout the day from 6:00 AM to 8:00 AM. The hour with the most accidents was 3:00 to 4:00 PM with 5 occurrences, and the second was 9:00 to 10:00 AM with four occurrences. More accidents occurred on Tuesdays with 10 occurrences, and Fridays with 7 occurrences. Most of the accidents, 21 of 35, occurred during the warmer months from May through October. More accidents occurred in 2000, 12, than any other year. Based on the detailed accident summary, no strong significant trends were evident.

3.0 INSTALLATION OF THE PRE-SIGNAL

The City of Tucson Traffic Engineering staff identified safety and operational issues at the Prince Road/UPRR crossing and the need to address these issues prior to this evaluation. These safety and operational issues included the consistent behavior of vehicles stopping on the railroad tracks during red light indications and the trends of accidents at railroad crossings along I-10. To address safety and operational issues at the Prince Road/UPRR Crossing, the City of Tucson proposed to install a “Pre-Signal” in advance of this roadway/railroad crossing as part of the PAG Rail/Highway Study. The “Pre-signal” was constructed in March and April of 2004 and was turned on in the first week of May 2004.

3.1 What is a “Pre-Signal”

A simple definition of a “Pre-Signal” is a typical traffic signal that displays red, yellow and green lights and is installed on the approach to a railroad crossing that is located near a signalized intersection for the purpose of stopping traffic in advance of the railroad tracks. The photograph in Figure 7 on page 15 shows the “Pre-Signal” that was installed at the Prince Road/Union Pacific Railroad crossing in the City of Tucson, Arizona.

To provide more detailed information regarding “Pre-Signal” Traffic Control Signals, the different types of traffic controls identified in the Manual of Uniform Traffic Control Devices, (MUTCD) 2003 Edition, published by the Federal Highway Administration, are described in the following paragraphs.

The other traffic controls for at-grade railroad crossings identified in the 2003 MUTCD have been implemented for several decades for the purpose of stopping traffic at railroad crossings when a train is approaching. Two types of traffic control are defined in the MUTCD, passive controls and active controls. Passive controls typically refer to controls that remain in effect whether or not a train is present, such as signing and markings. Active controls refer to controls that are activated when a train approaches the crossing.

Traffic controls that apply to locations where safety issues and/or traffic and train volumes are substantial include stop signs placed at the railroad crossing, flashing-light signals, and gates. The use and application of these types of railroad crossing traffic controls are defined in detail in

Section 8 of the 2003 MUTCD. Stop signs are typically used at railroad crossings that have low volumes of trains (an average of two or more per day) and on roadways with low to moderate traffic volumes, or where there has been a history of accidents which can be corrected with a stop sign. The flashing-light signals, sometimes referred to as railroad crossing signals, consist of two side by side red signal indications that flash intermittently when a train is approaching. The flashing-light signals are typically installed on a pole on the side of the road at the tracks and supplemental flashing –light signals may be mounted on a mast arm that spans over travel lanes. The MUTCD does not define specific traffic or train volume thresholds for considering the installation of flashing-light signals, but does suggest that the conditions of the crossing be evaluated to determine if they are needed. Railroad crossing gates consist of a red and white striped beam that is lowered across the travel lanes when a train is approaching. Similar to flashing-light signals, the MUTCD suggests that each crossing be evaluated to determine if gates are needed. The flashing-light signals and gates are considered “Active Railroad Traffic Controls” as they inform motorists of approaching trains. They are typically used at crossings, which have more vehicular and/or train traffic. The illustration of flashing lights and gates contained in the 2003 MUTCD is provided in Appendix C.

The 2003 MUTCD also allows the use of Traffic Control Signals at or near a highway-grade crossing in Section 8D.07 as follows:

Option:

Traffic control signals may be used instead of flashing-light signals to control road users at industrial highway-rail grade crossings and other places where train movements are very slow, such as in switching operations.

Standard:

The appropriate provisions of Part 4 relating to traffic control signal design, installation, and operation shall be applicable where traffic signal control signals are used to control road users instead of flashing-light signals at highway-rail grade crossings.

Traffic control signals shall not be used instead of flashing-light signals to control road users at a mainline highway-rail grade crossing.

Based on these criteria, a traffic control signal is not applicable at the Prince Road/UPRR crossing. However, the 2003 MUTCD defines a “pre-signal” and its use in the following terms:

Guidance:

If a highway-rail grade crossing is located within 15 m (50 ft) (or within 23 m (75ft) for a highway that is regularly used by multi-unit vehicles) of an intersection controlled by a traffic signal, the use of pre-signals to control traffic approaching the grade crossing should be considered.

Standard:

If used, the pre-signals shall display a red signal indication during the track clearance portion of the signal preemption sequence to prohibit additional vehicles from crossing the railroad track.

Guidance:

Consideration should be given to using visibility-limited signal faces (see section 4A.02) at the intersection for the downstream signal faces that control the approach that is equipped with pre-signal.

Option:

The pre-signal phase sequencing may be timed with an offset from the signalized intersection such that the railroad track area and the area between the railroad and the downstream signalized intersection is generally kept clear of stopped vehicles.

Standard:

If a pre-signal is installed at an interconnected highway-rail grade crossing near a signalized intersection, a STOP HERE ON RED (R10-6) sign shall be installed near the pre-signal or at the stop line if used. If there is a nearby signalized intersection with

insufficient clear storage distance for a design vehicle, or the highway-rail grade crossing does not have gates, a NO TURN ON RED (R10-11) sign shall be installed for the approach that crosses the railroad tracks.

Option:

At locations where a highway-rail grade crossing is located more than 15 m (50ft)(or more than 23 m (75ft) for a highway regularly used by multi-unit vehicles) from an intersection controlled by a traffic control signal, a pre-signal may be used if an engineering study determines a need.

If highway traffic signals must be located within close proximity to the flashing light signal system the highway traffic signals may be mounted on the same overhead structure as the flashing light signals.

The distance between the Prince Road/UPRR crossing and the westbound stop bar of the I-10/Prince Road T.I. is approximately 50 feet if measured along the lane line between the right-turn and through lanes. In addition, several trucks, buses and other vehicles pulling trailers traverse this crossing. As indicated in this report, vehicles stopping at a red light at the interchange often stop with the back end of there vehicle on or near the tracks. For these reasons, the Prince Road/UPRR crossing meets the criteria for the installation of a “pre-signal”.

3.2 Coordination with the Union Pacific Railroad

Coordination between Union Pacific Railroad Company and City of Tucson was a key element in the installation of the Pre-signal. Since the Pre-signal is located on the other side of the tracks from the interchange traffic signal, the wiring for the pre-signal was routed from the traffic signal controller, under the railroad tracks through an existing conduit that was in place and to the Pre-signal pole. This required the UPRR’s cooperation and approval. The Union Pacific provided a timely response and granted the City of Tucson permission to pull the wire through the conduit.

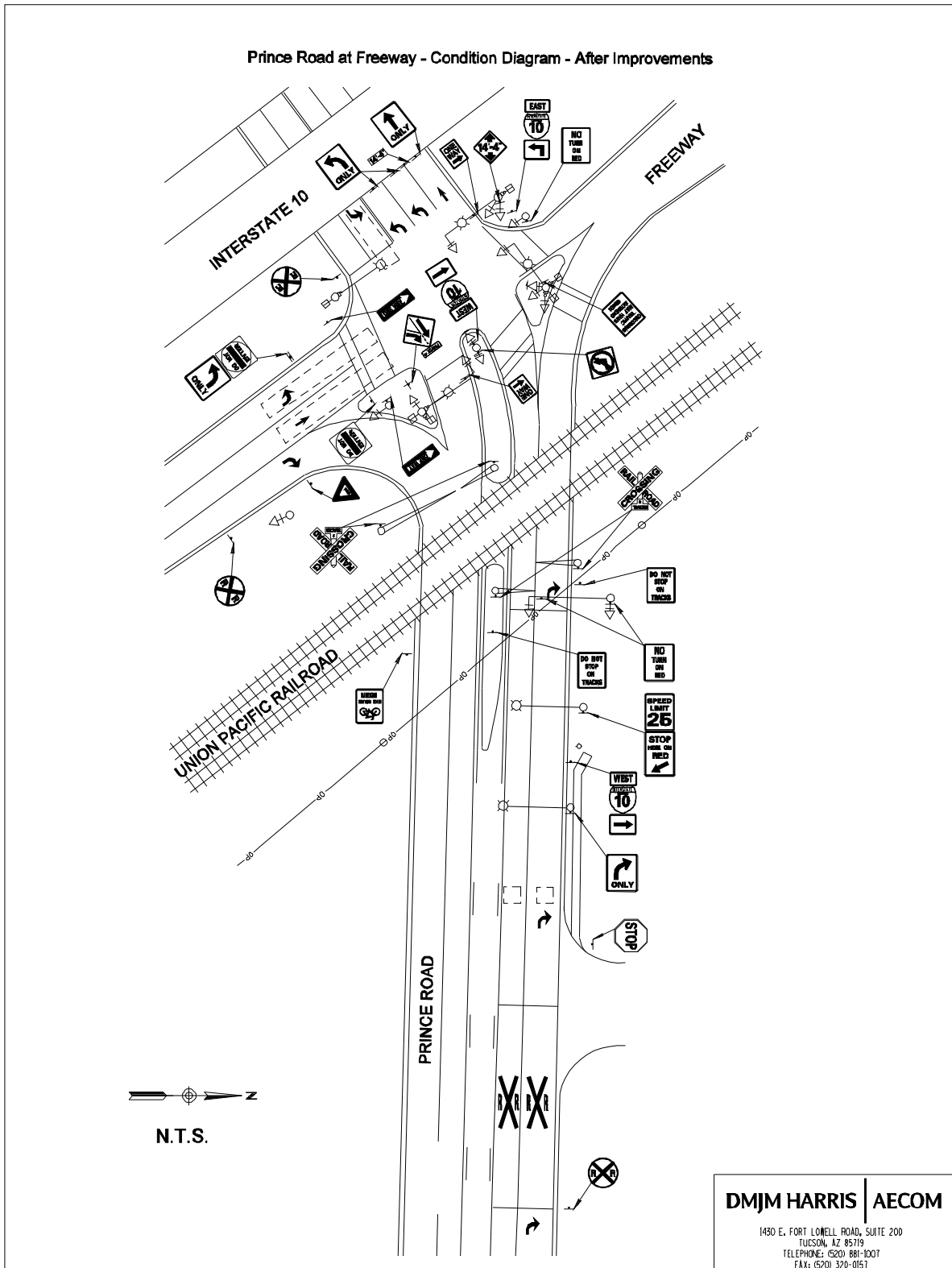
4.0 CONDITIONS AFTER PRE-SIGNAL INSTALLATION

The conditions and operation of the Prince Road/UPRR highway-rail crossing after the “Pre-Signal” was installed are described in this section of the report.

4.1 Physical Conditions (After Pre-Signal)

The physical aspects of the Prince Road/UPRR crossing remained essentially the same before and after the pre-signal was installed. No geometric changes to the roadway, railroad tracks, or interchange were made. The traffic control changes made to the crossing include the installation of the pre-signal for westbound traffic on the east side of the crossing. In addition to the installation of the “pre-signal”, a few signs were also installed. These include a “STOP HERE ON RED” sign mounted under the 25 mph speed limit sign and two “NO TURN ON RED” signs mounted on the “pre-signal”, one on the pole and one on the mast arm. No changes were made to the existing flashing-light signals and the automatic gate system. A Condition Diagram of the crossing after the Pre-signal was installed is provided in Figure 6 and a photograph of the Pre-signal is provided in Figure 7.

Figure 6: Condition Diagram of Prince Road/UPRR Crossing (After Pre-Signal)



**Figure 7: Pre-Signal Installation at Prince Road/UPRR Crossing
(12-24-04 Looking West)**



4.2 Operation of the Prince Road/UPRR Crossing (After Pre-Signal)

The installation of the pre-signal changes the operation of westbound traffic in a number of different ways. First, the Pre-signal is wired to the I-10/Prince Road T.I. traffic signal and was programmed to turn red 7 seconds prior to the interchange turning red, allowing westbound vehicles that clear the pre-signal to also clear the interchange signal.

When a train approaches the crossing, the sensor pre-empts the traffic signal at the interchange. When this happens the pre signal is pre-empted to change yellow at the same time. The Pre-signal then turns red. The sequence of operation is defined in Table 3.

A general assessment of the operation of the Pre-signal reveals a number of advantages. One apparent advantage of the operation of the Pre-signal is that it reduces the occurrence of traffic queuing back from the interchange over the railroad tracks, which often results in vehicles stopped on the tracks by inattentive drivers. A second advantage is that it reinforces the flashing-signal light indications at the railroad tracks with typical yellow and red light displays which motorists seem to understand. A third advantage is that it provides a yellow clearance interval for traffic approaching the tracks, compared to the flashing-light signal indication that is

instantaneously enacted when a train approaches. This may reduce the occurrence of people slamming on their brakes when the railroad flashers are activated or other possible erratic maneuvers that occur. However, the yellow clearance interval of the pre-signal is activated at the same time as the flashing lights.

Table 3: Pre-Signal Activation - Sequence of Events for Westbound Traffic

Event Sequence	System Action (If Pre-Signal is green when activated)	System Action (If Pre-Signal is red when activated)
1	Approaching Train Activates Sensors Flashing-light signals are activated Interchange Signal is green Pre-Signal changes to yellow	Approaching Train Activates Sensors Flashing-light signals are activated Interchange Signal is red Pre-Signal is red
2	Pre-Signal turns red	Interchange Signal turns Green Pre-Signal remains red
3	Gates begin to lower	Gates begin to lower
4	Gates are lowered all the way Interchange Signal is still green for westbound	Gates are lowered all the way Interchange Signal remains green for westbound
5	Interchange Signal turns yellow	Interchange Signal turns yellow
6	Interchange Signal turns red	Interchange Signal turns red
7	Interchange Signal changes to flashing red Pre-signal remains solid red	Interchange Signal changes to flashing red Pre-signal remains solid red
8	Train Passes	Train Passes
9	Gates are raised Flashing lights turn off	Gates are raised Flashing lights turn off
10	Pre-signal turns green Interchange signal turns green	Pre-signal turns green Interchange signal turns green

4.3 Pre-signal Operational Considerations

The following observations were made after the pre-signal was installed that relate to the operation of the pre-signal and sequence of events noted in Table 3.

- When a train activates the crossing controls when the pre-signal is green, the pre-signal changes yellow at the same time the flashing-light signals are activated, resulting in simultaneous signal indications that have different meanings.
- The pre-signal remains red for several seconds after the gates are raised all the way. Many motorists run the red signal during this time. This all red period is to notify drivers that the stop and go operation during the flashing red period is ending prior the resumption of normal signal operation.
- When a train activates the crossing controls shortly after the time the pre-signal turns green, the pre-signal changes back to red, in conformance with MUTCD, resulting in a very short pre-signal green phase. This can be confusing to drivers but is a common occurrence with signal pre-emption particularly with priority pre-emption.

5.0 COMPARISONS OF BEFORE VS. AFTER CONDITIONS

Several different sets of data were collected before and after the pre-signal was installed. These data sets will be compared to determine what advantages and/or disadvantages are realized with the operation of the Pre-signal. The comparisons of the before and after data sets are summarized in the following subsections of this report.

5.1 Traffic Volume Data Collection

A variety of traffic volume data were collected for this project. This includes traffic data collected with machine recorders and manual turning movement counts collected by the Institute of Transportation Engineers, University of Arizona Student Chapter.

Machine recorders were set for 24-hour periods on typical weekdays before and after the pre-signal was installed. The machine recorders registered traffic volumes, vehicle classification by number of axles, and vehicle speed. The machine recorder data are provided in Appendix D and is summarized in Table 4.

Table 4: Summary of Data Collection from Machine Recorders on Prince Road East of UPRR Crossing

Date of Count	Direction	24-Hour Count	Classification		Speed	
			% ≥ 4 Axles	# Buses	50 th %	85 th %
May 5&6, 2004 (Before)	EB	9038	4.1%	32	39.8	44.4
	WB	9781	3.5%	61	39.8	46.8
	Both	18,819	3.8%	92	39.8	45.6
Dec. 9, 2004 (After)	EB	6333	3.8	26	38.7	44.2
	WB	9959	5.5	100	37.7	43.9
	Both	16,292	4.8%	126	38.2	44.1

Table 4 indicates that the percentage of heavy vehicles increased from 3.8% in the before period to 4.8% in the after period and the number of buses observed increased from 92 in the before period to 126 in the after period. The speed data in Table 4 indicates that the 50th percentile and 85th percentile speeds of traffic were approximately 1.5 mph lower in the after period when the pre-signal was in place and in normal operations.

Turning Movement Counts were performed for the intersection by the University of Arizona ITE Student Chapter. To perform these turning movement counts, the City of Tucson supplied video tapes of the intersection operation that was recorded from Auto scope cameras mounted on luminary poles at the intersection. Turning Movement Counts were performed for 4 separate 1-hour periods on a typical weekday and for one hour on a Saturday afternoon. The data are included in Appendix E and summarized in Table 5 and 6.

The turning movement count data in Tables 5 and 6 indicate an increase in traffic of approximately 5% from the before period to the after period. Tables 5 and 6 indicate an increase in westbound Prince Road traffic of approximately 8% from the before period to the after period.

Table 5: Turning Movement Counts Before Pre-Signal Installation
 (Percentages of Total Traffic are shown in Parentheses)

Time Interval	Day of Week	WB Approach			EB Egress		
		Through	Right	Total	From Through	From Ramp	Total
7:00-8:00 AM	Wed. 4/7/05	411 (76%)	133 (24%)	544	352	387	739
12:00-1:00 PM	Wed. 4/7/05	526 (70%)	229 (30%)	755	299	389	688
2:30-3:30 PM	Wed. 4/7/05	596 (66%)	303 (34%)	899	305	524	829
5:00-6:00 PM	Wed. 4/7/05	504 (58%)	367 (42%)	871	328	422	750
1:00-2:00 PM	Sat. 4/3/05	505 (64%)	282 (36%)	787	273	433	706
5Hr Totals		2542 (66%)	1314 (34%)	3856	1557 (42%)	2155 (58%)	3712

Table 6: Turning Movement Counts After Pre-Signal Installation
 (Percentages of Total Traffic are shown in Parentheses)

Time Interval	Day of Week	WB Approach			EB Egress		
		Through	Right	Total	From Through	From Ramp	Total
7:00-8:00 AM	Wed. 9/29/04	553 (74%)	199 (26%)	752	415	452	867
12:00-1:00 PM	Wed. 9/29/04	572 (70%)	246 (30%)	818	325	330	655
2:30-3:30 PM	Wed. 9/29/04	632 (63%)	376 (27%)	1008	409	496	905
5:00-6:00 PM	Wed. 9/29/04	535 (56%)	416 (44%)	951	318	384	702
1:00-2:00 PM	Sat. 10/09/04	430 (67%)	214 (33%)	644	317	329	646
5hr Totals		2722 (65%)	1451 (35%)	4173	1784 (47%)	1991 (53%)	3775

To compare the 24-hour traffic volumes before and after the pre-signal was installed, a number of adjustments need to be made. The before and after traffic volume data in Tables 4, 5 and 6 were collected during different months of the year; therefore, the seasonal variation of traffic at I-10 and Prince Road needs to be accounted for. Seasonal variation and weekday factors compiled on I-10 at Grant were provided by the Arizona Department of Transportation. These factors are included in Appendix D.

In addition to the seasonal variation, the 24-hour machine traffic count performed on December 9, 2004 in the eastbound direction appears to be low. Due to this lower volume, the data would indicate that the traffic volumes decreased in the after period. The fact that eastbound traffic of 6333 vehicles per day constitutes only 39% of the total traffic on Prince Road may be an

indication that this traffic count is low. Other data sets suggest that the eastbound traffic ranges from 46 to 47% of the total traffic on Prince Road. To account for this apparent error in traffic and the seasonal variation, the traffic volume data are adjusted in Table 7 to provide a before and after comparison of daily traffic.

Table 7: Traffic Count Correction

Date of Count	Direction	24-Hour Count	5-Hr Counts	Error Adjustment	Corrected Volumes
May 5&6, 2004 (Before)	EB	9038(48%)	3712(49%)		9038(48%)
	WB	9781(52%)	3856(51%)		9781(52%)
	Both	18,819	7568		18,819
Dec. 9, 2004 (After)	EB	6333(39%)	3775(47.5%)	Assume 47.5%	9010(47.5%)
	WB	9959(61%)	4173(52.5%)	Assume 9959(52.5%)	9959(52.5%)
	Both	16,292	7948	9959/0.525 = 18,969	18,969
Increase (After/Before)		0.866	1.050		1.008

Table 8: Calculation of Average Annual Daily Traffic Volumes (Seasonally Adjusted)

Date of Count	Direction	Corrected Volumes	Seasonal Adjustment Factors	Average Annual Daily Traffic (AADT) Volumes
May 5&6, 2004 (Before)	EB	9038(48%)	0.92	
	WB	9781(52%)		
	Both	18,819		17,313
Dec. 9, 2004 (After)	EB	9010(47.5%)	0.90	
	WB	9959(52.5%)		
	Both	18969		17,072
Increase (After/Before)		1.008		0.986

In conclusion, the corrected traffic volumes shown in Table 8 indicate that there was a slight increase of 0.8% in traffic from the before period to the after period. However, this translates to a slight decrease in the Average Annual Daily Traffic. Since the Average Annual Daily Traffic statistic includes weekend volumes, which are typically lower, the estimated Weekday Annual Average Daily Traffic for 2004 on Prince Road is approximately 19,000 vehicles per day.

5.2 Train Speed and Frequency

The frequency of trains at the Prince Road/UPRR Crossing varies somewhat from day to day and throughout the year due to railroad operations and market demands. Contrary to popular belief, there is not a consistent train schedule as the rail schedule is affected by several factors. To quantify the number and speed of trains at the Prince Road/UPRR, trains were recorded by the traffic data collection vendor and by the ITE, University of Arizona Student Chapter.

The data collection subcontractor recorded the time and speed of each train that traversed the crossing during the 12-hour period from 7:00 AM to 7:00 PM. These data are included in Appendix F and summarized in Table 9:

Table 9: Train Speed and Frequency

Period	Date	Duration	# of Trains	% Direction	Highest 1 Hour Period		Speed Data (mph)	
					Freq.	Time Period	Range	Average
Before	5-6-04	12 hrs	19	53% NB	5	2:30-3:30 PM	15-45	24.2
After	12-8-04	12 hrs	20	55% SB	4	10:45-11:45 AM	15-46	32.2

The data collected by the subcontractor indicates that the number of trains counted in the before period is essentially the same as those counted during the after period. The speed of trains measured during the before period is significantly lower than the average speed of trains in the after period.

The train data collected by the ITE, University of Arizona Student Chapter was recorded from video tapes of the intersection provided by the City of Tucson. These tapes consisted of images recorded from detection cameras mounted on light poles near the crossing. These data are also included in Appendix F and are summarized in Table 10.

Table 10: Train Volume and Elapsed Time Gates are Down

Period	Date	Duration	# of Trains	% Direction	Highest 1 Hour Period		Time Gate Down (min:sec)	
					Freq.	Time Period	Range	Average
Before	4-7-04	24 hrs	50	53% SB	4	Several Periods	0:55-9:39	2:44
After	9-29-04	24 hrs	43	53% NB	4	1:00-3:00 AM 9:00-10:00 PM	0:45-4:47	2:52

The data in Table 10 indicates that the number of trains was higher on 9-29-04 than on 4-7-04. The other important statistic in Table 10, indicate that the average time the gates were down was essentially the same in the before and the after periods. Moreover, this average time that the gates were down is just under 3 minutes.

It is evident from the data in Appendix F that the frequency of trains is relatively consistent around the clock, i.e. the frequency of trains at night is approximately equal to the frequency during day time hours. From both data sets, it is concluded that approximately 40 to 50 trains per day traversed this railroad crossing in 2004. The data sheets in Appendix F indicate that the gates are down for approximately 2 hours to 2 hours and 20 minutes per day. This means that approximately 9% of the time, on average, the gates are down across the road.

5.3 Approach Delay and Residual Queuing

5.3.1 Stopped Time Approach Delay

Delay measurements were taken on the westbound Prince Road approach to the I-10 interchange to provide a measure of effectiveness of the operation of the Pre-Signal at the

railroad tracks. The stopped time delay of the westbound approach provides an interesting statistic, as it is a measure of both the operation of the interchange and the UPRR crossing.

The stopped time delay measurements were performed by the ITE, University of Arizona Student Chapter. Observations of queued traffic were recorded every 15 second for selected hours of a day and the stopped time delay was calculated, accordingly. The data sheets are provided in Appendix E. The delay data are summarized in Table 11 below:

Table 11: Prince Road Delay Summary

	Day	Weekday								Saturday		Summary		
	Time	7:00-8:00 AM*		12:00-1:00PM*		2:30-3:30 PM		5:00-6:00 PM		1:00-2:00PM*		Average Delays		
	Movement	TH	RT	TH	RT	TH	RT	TH	RT	TH	RT	TH	RT	Both
Delay	Before	19	19	4	1	4	2	8	5	13	14	9.6	8.2	8.9
	After	11	11	30	20	17	16	18	18	5	3	16.2	13.6	14.9
Volume												Total Volumes		
	Before	411	133	526	229	596	303	504	367	505	282	2542	1314	3856
	After	553	199	572	246	623	376	535	416	430	214	2713	1451	4164
#Trains	Before	3*		2		1		2		3*		8		
	After	1		2*		1		1		0		5		

*Indicates periods when trains occupied tracks for a significantly longer period of time in either the before or after period, as illustrated in the “Train Movement” and “Queue Length” charts in Appendix E.

Table 11 indicates that the stopped time delay was higher in the “After” period with the pre-signal in place and operational. However, conclusions cannot be drawn from Table 11 since the conditions in the before and after periods were different for some of the hours noted with an *. As noted, the time that trains occupied the tracks and the number of trains were significantly different in some of the before and after periods. This is evident in “Train Movement” charts shown in Appendix E that are discussed in the following section.

To evaluate the delay further, Table 11 was modified by eliminating the three one-hour periods where trains occupied the tracks for longer periods of time in either the “Before” or “After” period. Therefore, the 7:00 to 8:00 AM, the 12:00 to 1:00 PM, and the 1:00 to 2:00 PM (Saturday) time periods were excluded in Table 12.

Table 12 compares only those time periods that had an approximately equal amount of time when trains occupied the tracks (gates were down) in the “Before” and “After” periods. This only includes the data from the weekday periods of 2:30 to 3:30 PM and 5:00 to 6:00 PM.

Table 12: Prince Road Delay Comparison

	Day	Weekday				Summary		
	Time	2:30-3:30 PM		5:00-6:00 PM		Average Delay		
	Movement	TH	RT	TH	RT	TH	RT	Both
Delay	Before	4	2	8	5	6	3.5	4.8
	After	17	16	18	18	17.5	17	17.3
Volume						Total Volume		
	Before	596	303	504	367	1100	670	1770
	After	623	376	535	416	1158	792	1950
Time Trains Occupied Tracks						Total Time		
	Before	0:01:44		0:03:28		0:05:12		
	After	0:02:04		0:03:08		0:05:12		
Number of Trains						Total Number of Trains		
	Before	1		2		3		
	After	1		1		2		

Table 12 reveals the total average delay during the After period was 12.5 seconds higher than that of the Before period. However, there are still some inequalities with the before and after conditions. One obvious inequality is the increase in traffic volume from the before period to the after period, which is approximately 10%. This increase in traffic volume may be a significant contributing factor to the increase in delay reflected in Table 12. The increase in traffic and other factors that contributed to the increase in delay from the before to the after period are discussed in detail in Section 5.3.3.

5.3.2 Residual Queuing

As part of the data collection effort, the University of Arizona ITE Student Chapter graphed the number of vehicles that queued on the westbound approach of the I-10/Prince Road interchange before and after the pre-signal was installed. These graphical data are presented in the “Queue Length” charts in Appendix E.

Three graphs are provided for five selected hours of the day. The top graph plots the right lane queue length in numbers of vehicles on the vertical axis (ordinate) versus time on the horizontal axis (abscissa). The middle graph plots the through lane queue length in numbers of vehicles on the vertical axis (ordinate) versus time on the horizontal axis (abscissa). And the bottom graph plots the number of trains that occupied the crossing on the vertical axis (ordinate) versus time on the horizontal axis (abscissa). To illustrate the queue length and number of trains on each

set of graphs, the “Before” data points are shown in black, and the “After” data points are shown in gray.

These graphs show that the vehicular queues were longer after the pre-signal was installed. Overall, the queue lengths illustrated in the graphs for the “Before” period were generally 5 vehicles or less when a train was not present. The queue lengths for the “After” period were generally 15 vehicles or less. However, the traffic conditions in the after period were different than the traffic conditions in the before period. In addition, the queue lengths in the after period were estimated and not observed, as the camera was adjusted downward when the pre-signal was installed to improve detection. Consequently, the field of view no longer contained the end of the queue. These issues are further analyzed and discussed in Section 5.3.3.

Another interesting phenomenon that is illustrated in these graphs is the increase in queue length during the presence of a train crossing Prince Road. In general, the graphs illustrate significantly longer queues when a train was present in the “After” period. However, it is important to note that the traffic conditions during the before period were somewhat different than the after period as the cycle length was increased and a “NO RIGHT TURN ON RED” sign was installed. These and other issues are discussed in detail in Section 5.3.3.

5.3.3 Analysis of Delay and Queuing

To effectively compare the “Before” and “After” delay and queuing data, it is important to note the differences between these two data sets. As noted previously, the traffic conditions and data collection techniques were somewhat different in the “Before” period than in the “After” period. To draw meaningful conclusions from the delay and queuing data, these differences are evaluated in detail in the following paragraphs.

First, the traffic volumes recorded in the “After” period were 8 to 10 percent higher than those recorded in the “Before” period. Table 11 indicates a 8 percent increase for all five one hour periods and Table 12 indicates a 10 percent increase for the two one hour periods. This increase in traffic volume may be a significant contributing factor to the increase in delay reported in Table 12 and the queuing illustrated in Appendix E. Based on engineering judgment, it is concluded that at least a portion of the reported increase of 12.5 seconds delay per vehicle is the result of this increase in traffic.

A second possible reason for the increase in delay and queuing may be associated with the prohibition of right-turns on red when the Pre-signal was installed. During the before period prior to the installation of the Pre-signal, right-turn on red (RTOR) movements were permitted. As part of the Pre-signal installation, a “NO RIGHT TURN ON RED” sign was erected. The prohibition of right-turn-on-red movements in the after period may have been a contributing factor to the increase in delay in the after period. As a result of this study, the City of Tucson later removed the “NO RIGHT TURN ON RED” sign to improve the operation of traffic at the crossing.

A third possible reason that the delay was higher in the “After” period, is a possible overestimation of the delay during the collection of the delay data. When the pre-signal was installed, the video detection cameras were adjusted downward to provide detection on the westbound approach. This downward aiming of the camera restricted the cameras view of the entire approach; therefore, the field of view in the video tapes collected during the “After” period only included the front portion of the queue. To account for this, the University of Arizona ITE Student Chapter estimated the end of the queue using an average arrival rate of traffic. While this assumption seems to be logical, it was an estimation of the queue length rather than an

actual measurement of it. If this estimation of queue length was higher than the actual queue length, both the delay and queue lengths reported in this evaluation would be overestimated. It is unknown whether this was the case, and as a result, it may be possible that an underestimation of the actual delay was made for some or all of the hours measured.

Several other technical reasons why the delay and queuing were higher in the “After” period are speculated. The installation of the Pre Signal at a point on Prince Road upstream from the I-10 interchange introduces a second restriction point on Prince Road where vehicles are subject to traffic signal control. This will naturally have the affect of increasing delay for a few reasons. First, there is a second location where start-up loss applies. Second, the pre-signal catches some cars at the end of the green ball indication that would have otherwise traversed the railroad tracks and interchange, resulting in more cars waiting at the light. Third, when the Pre-signal was installed the cycle length of the interchange traffic signal was increased. The cycle length was changed from 60 seconds for the off-peak hours to 90 seconds after the Pre-signal was installed. The AM peak cycle length was modified from 90 seconds to 120 seconds, and the mid-day and PM peak cycle length were changed from 90 seconds to 100 seconds.

In summary, there are several apparent reasons that the delay and traffic queues were higher in the “After” period. Some of these factors may have biased the results of this analysis to some extent, while others are technical explanations for the increase in delay. These factors (or reasons) that the delay increased in the “After” period are listed below as either potential biases or technical factors:

Factors that may have biased the results of this study:

- The traffic volumes were higher (10%) during the “After” period.
- Right-turn on Red Movements were permitted in the Before period and prohibited in the After period.
- Queue length calculations that were used to estimate queue length in the “After” period in lieu of actual measurements, which may have resulted in an overestimation of queue length and delay.

Technical Factors that explain why the Pre-signal increased delay and queuing:

- The pre-signal results in another restriction point to traffic, where stopping and start-up losses apply.
- The pre-signal catches some cars at the end of the green ball indication that would have otherwise traversed the railroad tracks and the interchange.
- The cycle length of the Interchange was significantly increased by 10 to 30 seconds to accommodate the clearances and coordination offsets needed for the Pre-signal operation.
- A steady red clearance interval of 6 seconds was introduced with the installation of the Pre-signal to provide appropriate clearance time through the interchange.
- The Pre-signal resulted in less traffic proceeding through the flashing lights and more people that stop on the approach to the tracks.
- The Pre-signal operation reduces the ability of westbound vehicles to make right-turns on red by stopping prior to the I-10 interchange.
- The Pre-signal stays red for a period of 6 seconds after the gates are raised and the flashing lights turn off once a train passes.

All of these factors may contribute to the increase in delay on the westbound approach of the “After” period data as presented in Table 12. In short, the delay of the westbound approach was

higher in the After period with the Pre-signal in operation. It appears that this delay is the result of both technical issues related to the operation of the Pre-signal and to potential biases in the data collected for this study. Therefore, it is concluded that the installation of the Pre-signal at this location had the effect of increasing the delay on the westbound approach of Prince Road by an amount less than 12.5 seconds per vehicle.

5.5 Behavior, Violation and Conflict Data

To gain a better understanding of the operation and safety characteristics of the Pre-Signal, driver behaviors and violations were observed and recorded for several hours before and after the Pre-signal was installed. Driver behaviors are defined as any actions that the drivers made when approaching or traversing the railroad tracks and the interchange. Violations refer to those actions that violate specific traffic laws.

At the same time, traffic conflicts were recorded to assess the safety characteristics of the crossing both before and after the Pre-signal was installed. A traffic conflict is defined as an evasive movement by a driver to avoid a collision. Typical traffic conflicts are slamming on the breaks to avoid hitting the vehicle in front and swerving to avoid a vehicle making a turn.

To collect behavior, violation and conflict data, an observer was parked in the vicinity of the railroad tracks to collect all three types of data. Eight 1-hour periods throughout a typical weekday were selected to record these data. In addition, the behavior, violation and conflict data was collected for two 1-hour periods on Saturday afternoon. The “Traffic Conflict Techniques for Safety and Operations”, published by the Federal Highway Administration, March 1990 were used as a guideline to collect these data. The behavior, violation and conflict data are provided in Appendix G.

The behavior, violation and conflict data were collected during one weekday and one Saturday both before and after the Pre-signal was installed. The dates of the before and after data are summarized in Table 13. The data collected on Saturday, 10-2-04, are included in Appendix G, but were not used in this evaluation because the UPRR had closed the railroad tracks for repair that day, and therefore, no trains were present.

Table 13: Summary of Behavior, Violation and Conflict Data in Appendix G

DATE	DAY	Before or After Pre-Signal	Number of Hours
4-13-04	Tuesday	Before	8
5-8-04	Saturday	Before	2
10-2-04	Saturday	After	2 Tracks Closed
10-5-04	Tuesday	After	8
11-6-04	Saturday	After	2

To evaluate the Behavior, Violation and Conflict data, the weekday data collected on 4-13-04 and 10-5-04 were entered into a summary sheet for comparison purposes. The Weekday Comparison Summary Sheet is contained in Appendix G. In addition, the 8-hour traffic volume totals were entered into this sheet to calculate the rates of behaviors, violations and conflicts both before and after the Pre-Signal was installed. A column was provided to indicate those rates where a significant change in the data were realized. If a difference of only 1 observation was made in the before period versus the after period, or vice versa, the difference was

assumed to be insignificant. Similar to Weekday Comparison Summary Sheet, a Saturday Comparison Summary Sheet was also assembled and included in Appendix G. The Saturday Comparison Summary Sheet contains 2 hours of data that were collected on Saturday afternoons before and after the Pre-signal was installed. To simplify the results in the Weekday and Saturday Comparison Summary Sheets, the data from these spreadsheets were further reduced in Tables 14, 15, and 16 for analysis purposes.

Table 14: Comparison of Violation Rates (Number of Occurrences/Thousand Vehicles)

Violation	Weekday			Saturday		
	Rate Before	Rate After	Change	Rate Before	Rate After	Change
Run traffic signal	4.54	1.78	Less	4.45	0.00	Less
Proceed through RR gates	0.00	0.00	No Change	0.00	0.00	No Change
Cross RR tracks when gate is coming down	1250*	542*	Less	375*	500*	No Change**
Stop on RR tracks	3.30	0.79	Less	1.91	0.00	Less
School bus & Haz-Mat trucks did not stop @ tracks	0.00	0.20	No Change	0.00	0.00	No Change
Run Pre-signal red light		9.08	Significant***		9.32	Significant***
WB right-turn on red (violated posted sign)		8.29	Significant***		11.65	Significant***

* Rate is reported in Number of Occurrences per One Thousand Trains.

** Before period had 3 occurrences/8 trains, After period had 1 occurrence/2 trains.

*** The rate of occurrences in the after period appears to be significant.

The comparison of the Violation Rates before and after the Pre-signal was installed is summarized in Table 14. The Weekday and Saturday data show the following benefits of having the pre-signal in place at the Prince Road/UPRR crossing:

- Less westbound drivers run the traffic signal at the interchange.
- Fewer drivers cross the tracks when the gate is coming down (weekday only).
- Less drivers stop on the railroad tracks.

The only violations related to the operation of the pre-signal include the following:

- The occurrence of drivers running the Pre-signal red light.
- The occurrence of westbound drivers turning right on red.

The rate of occurrence of drivers that turn right on red in violation of the “No Right-Turn On Red” sign has been significant in terms of the number of occurrences; however, it does not appear to be a significant operational problem. During the “After” period, there were several westbound signs in the vicinity of the Prince Road crossing. As a result, it is reasonable to assume that many motorists did not see the “No Right-Turn On Red” sign. Second, the operation of right-turn on red movements, even with the Pre-signal in place, appears to be an acceptable behavior in terms of both the safety and efficiency of traffic. For this reason, the City of Tucson decided to remove the “No Right-Turn On Red” sign. Since the Pre-signal is located approximately 50 feet in advance of the interchange, the act of a vehicle proceeding through the Pre-signal in the right lane can be interpreted as an illegal maneuver. However, if the Pre-signal is considered as part of the interchange signal system, it could be interpreted as a legal maneuver.

The comparison of the behavior rates in Table 15 also reveals many interesting issues regarding the operation of the Pre-signal. The Weekday and Saturday data show the following benefits that were realized by having the pre-signal in place at the Prince Road/UPRR crossing:

- Less drivers stopping at the tracks on a green light.
- Less drivers speeding to beat the railroad gates coming down.
- Fewer drivers stopping with front end too close to the tracks and in the way of the gates.
- Fewer drivers stopping with the back-end of their vehicle on or near the tracks.
- Less westbound drivers changing lanes after the crossing the tracks.

Table 15: Comparison of Behavior Rates (Number of Occurrences/Thousand Vehicles)

Behavior	Weekday			Saturday		
	Rate Before	Rate After	Change	Rate Before	Rate After	Change
Stop at tracks when gate is up, signal green	0.00	0.00		0.64	0.00	
Stop at traffic signal (WB TH), gate up, signal green	1.44	0.00	Less	0.64	0.78	
Speeding to beat gates coming down	1125*	333*	Less	500*	500*	
Speeding to beat traffic signal	0.21	2.96	More	1.27	3.11	More
Abrupt stopping/skidding	0.21	0.59	More	0.00	0.00	
+ School bus stopped at tracks	3.98	4.23	Both Good	0.00	0.39	No Change
Stop with front end near tracks, in way of gate	14.02	0.99	Less	12.07	0.00	Less
Stop with back end on tracks, interchange signal is red	5.57	0.00	Less	1.91	0.00	Less
Cramming beyond tracks	0.41	0.00	Less	0.00	0.00	
Move into thru lane from RT lane after crossing tracks	0.00	0.00		2.54	0.00	Less
Vehicle backing up when gates coming down	0.00	0.00		250	0.00	Less
Drive thru red pre-signal, stop at interchange signal	N/A	3.75	Significant* *	N/A	36.49	Significant**
Stop beyond “Stop here on red (arrow)” Sign	N/A	20.13	Significant* *	N/A	11.65	Significant**
Run red pre-signal when gates go up	N/A	0.00		N/A	3.88	Significant**

* Rate is reported in Number of Occurrences per One Thousand Trains.

** The rate of occurrences in the after period appears to be significant.

Based on the data in Table 15, Behaviors of concern related to the operation of the pre-signal include the following:

- More drivers speeding to beat the red light indication.
- The occurrence of drivers running the red light of the pre-signal.
- The occurrence of drivers stopping beyond the “Stop Here On Red (Arrow)”
- The occurrence of drivers running the red pre-signal when the gates are going up.

The comparison of the conflict data in Table 16 indicates that there were very few conflicts on the east leg of the I-10/Prince Road interchange and at the Prince Road/UPRR railroad

crossing. During the “Before” period, three conflicts were recorded through during different times of the day. All were different conflict types. Therefore, there was no trend of conflicts during the “Before” observation period.

Table 16: Comparison of Conflict Rates**

Conflict Type	Weekday			Saturday		
	Rate (Number)* Before	Rate (Number)* After	Change	Rate (Number)* Before	Rate (Number)* After	Change
Rear-end, NB RT approach	N/A (1)	N/A (0)		0 (0)	0 (0)	
Rear-end, WB approach	0 (0)	0.79 (4)	More	0 (0)	0 (0)	
Left-turn, WB TH with EB LT into driveway	0.21 (1)	0 (0)		0 (0)	0 (0)	
Sideswipe, WB approach lane change	0.21 (1)	0 (0)		0 (0)	0 (0)	

* The number of conflicts is shown in parenthesis.

** Conflict Rate = Number of Conflicts/thousand vehicles.

The only type of conflict of which there was more than one, was “Rear-end, Westbound Approach”, of which there were four during the “After” observation period. Interesting facts regarding these conflicts are that all four occurred during the same 1-hour period from 2:00 to 3:00 PM on Tuesday, October 5, 2004. Three of the four conflicts were trucks that were traveling at a high rate of speed and had to slam on their breaks to avoid vehicles stopped or stopping in front of them. During this time period several westbound trucks were observed approaching the railroad tracks at higher rates of speed than normal traffic. Whether these trucks were dispatched by a particular business or distribution site is unknown, but this occurrence of high speed trucks approaching the tracks was not observed in any other of the time periods when conflict data was collected.

For these reasons, it is concluded that the 4 “Rear-end, WB approach” conflicts are not representative of normal operations at this crossing. Instead, they appear to be the result of the behavior of a subset of drivers that occurred during one time period on a given day. Therefore, it is concluded that there was no demonstrated trend of traffic conflicts at the Prince Road/UPRR crossing either before or after the Pre-Signal was installed.

To summarize the benefits and issues of concern related to the safety and operation of the Pre-signal at the Prince Road/UPRR crossing, the results of the analysis of the Behavior, Violation and Conflict data are summarized in Tables 17 and 18. Table 17 lists the benefits and Table 18 lists the potential concerns.

Table 17: Benefits of the Pre-Signal Application in Terms of Behaviors, Violations and Conflicts

	List of Benefits of a Pre-Signal
Violation Improvements	<ul style="list-style-type: none"> • Less westbound drivers run the traffic signal at the interchange. • Fewer drivers cross the tracks when the gate is coming down (weekday only).
	<ul style="list-style-type: none"> • Less drivers stop on the railroad tracks.
	<ul style="list-style-type: none"> • Less drivers stopping at the tracks on a green light. • Less drivers speeding to beat the railroad gates coming down.
Behavior Improvements	<ul style="list-style-type: none"> • Fewer drivers stopping with their front ends too close to the tracks and in the way of the gates. • Fewer drivers stopping with the back-end of their vehicle on or near the tracks.
	<ul style="list-style-type: none"> • Less westbound drivers changing lanes after the crossing the tracks.
Conflicts	<ul style="list-style-type: none"> • No Typical Trend of Traffic Conflicts

Table 18: Potential Concerns of the Pre-Signal Application in Terms of Behaviors, Violations and Conflicts

	List of Potential Concerns	Possible Solutions
Violation Concerns	<ul style="list-style-type: none"> ○ The occurrence of drivers running the Pre-signal red light. 	Enforcement and/or Public Information
	<ul style="list-style-type: none"> ○ The occurrence of westbound drivers turning right on red. 	Remove the “No Right Turn On Red” Sign
Behavior Concerns	<ul style="list-style-type: none"> ○ More drivers speeding to beat the red light indication. 	Enforcement and/or Public Information
	<ul style="list-style-type: none"> ○ The occurrence of drivers running the red light of the pre-signal. 	Enforcement and/or Public Information
	<ul style="list-style-type: none"> ○ The occurrence of drivers stopping beyond the “Stop Here On Red (Arrow)”. 	This sign is ambiguous to an extent. Consider removing it or supplementing it with a bright stop bar.
	<ul style="list-style-type: none"> ○ The occurrence of drivers running the red pre-signal when the gates are going up. 	Enforcement and/or Public Information
	<ul style="list-style-type: none"> ○ Trucks that approach the UPRR tracks at a high rate of speed. 	Enforcement and/or Public Information

5.6 Other Observations of the Prince Road/UPRR Crossing

Simultaneous to the collection of the Behavior, Violation and Conflict data, other observations of traffic and the operation of the Prince Road/UPRR Crossing were recorded. These observations are included with the behavior, violation and conflict data sheets in Appendix G. To summarize these observations, they are listed in Table 19. Potential Solutions are offered for observations that may constitute an operational concern.

Table 19: Summary of Other Observations with Potential Solutions

Observation/Comment	Applicable Period	Potential Solutions	Action/ Recommended Solution
WB thru movement slows over tracks & at interchange	Before	Reconstruct Geometry of Interchange	Reconstruction of this interchange and bridge over RR tracks is planned in FY 2010
WB RT semi-trucks stopped at interchange extend over tracks.	Both	Install Pre-signal	The Pre-signal reduced the occurrence of trucks extending over tracks.
Stop bar on WB approach is worn out	Before	Re-stripe Stop Bar with durable material	Pavement Markings were reapplied.
Tracks have a slight dip from road surface.	Before	Not a significant issue	None
Pedestrians crossing RR tracks use street	Before	Construct sidewalks outside of gates	Reconstruction of this interchange and bridge over RR tracks is planned in FY 2010
NB RT to EB Prince swing out into median lane	Both	Reconstruct Geometry of Interchange	Reconstruction of this interchange and bridge over RR tracks is planned in FY 2010
Storage between interchange and tracks holds two cars.	Before	Not a significant issue	None
WB Queue at RR X-ing dissipates in one to four cycles	Before	Signal Timing was efficient. Function of conditions.	None
Some cars slow excessively to cross tracks	Before	Rubber Planking provides adequate surface at RR Xing	None
Most school buses arrive 2-3 PM and are WB	Before	Fact	None
Most traffic proceeds through red Pre-signal when gates go up	After	Consider Enforcement	None
Red Pre-signal, changes briefly to green, and changes back to red when train comes - Confuses Drivers	After	This is required to cycle through movements prior to arrival of train	
May need “Stop Here on Red (Arrow) Sign on left in median for WB	After	Consider Install this sign	Sign was installed
WB RT drivers stopped past stopped stop line and was unable to see green signal	After	Evaluate Signal Heads in field. Relocate Pre-signal pole closer to tracks.	Side mounted signal on Pre-signal pole is provided. Further research is needed to consider possibility of installing Pre-signal on far side of tracks.
Few WB vehicles store at Interchange red light, most store on approach to Pre-signal	After	Not Needed	No action needed
“No Right Turn On Red” sign is not visible at night and late afternoon.	After	Consider Removal of Sign	Sign was removed
Activation of yellow pre-signal	After	Consider advance detection to allow advance activation	Further research is needed ¹
Pre-signal stays red after gates go up and flashing light turns off	After	Revise timing and signal controller	Further research is needed ²
Short pre-signal green time	After	Consider advance detection to allow advance activation	Further research is needed ¹

1. Research needs to be conducted to determine the net benefits of these potential solutions.
2. Research needs to be conducted to evaluate the safety effects of reducing the 6 second clearance interval of the Pre-signal.

As noted in Table 19, many improvements have been made to this Railroad crossing. In addition, a project is scheduled to widen I-10, which includes the realignment of Prince Road with a bridge over the railroad tracks. This improvement is scheduled for construction in 2010. In addition, a number of issues related to the operation of the Pre-signal that may warrant further research to improve are listed below:

Potential Areas of Research to Improve Pre-Signal Operation

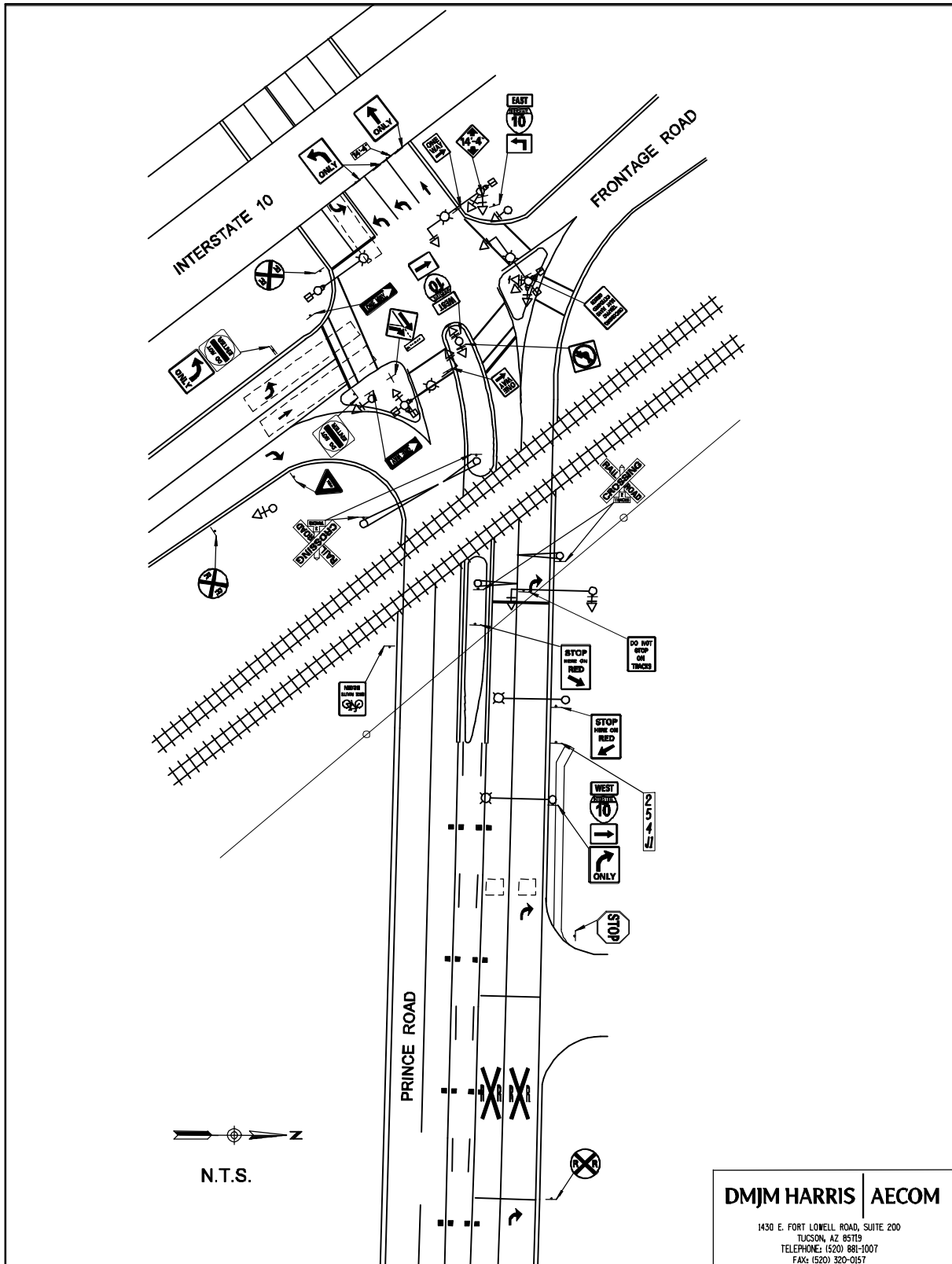
- Activation of the pre-signal yellow - When a train activates the crossing controls when the pre-signal is green, the pre-signal changes yellow at the same time the flashing-light signals are activated, resulting in simultaneous signal indications that have different meanings. A potential solution to this issue is to install advanced detection to activate the pre-signal yellow indication prior to the flashing red lights.
- Reduction of red clearance after gates are up - The pre-signal remains red for several seconds after the gates are raised all the way and the flashing light turns off after a train passes. Many motorists run the red signal during this time. A potential solution is to re-program the controller to have the pre-signal turn green when the flashing lights turn off.
- Short pre-signal green time - When a train arrives immediately after the time the pre-signal turns green for traffic, it results in a short green time that can be confusing to motorists. This short phase is occasionally needed to cycle through required phases prior to the train arriving. A potential solution to this issue is to install advanced detection to enable the traffic signal controller to activate the pre-signal. Northern Arizona University is researching this possibility.

6.0 IMPROVEMENTS IMPLEMENTED AS PART OF THIS STUDY

After the Pre-signal was installed, several modifications were made to the I-10/Prince Road/UPRR crossing to improve the clarity of the traffic controls at the UPRR crossing. These modifications may be useful for practitioners to know who are interested in installing a Pre-signal at a location. These modifications were discussed at the Technical Advisory Committee meetings for this project and implemented by the City of Tucson to improve the railroad crossing. The remedial improvements are illustrated in Figure 8 and are listed below:

- Refreshed Pavement Markings at Crossing
- Removed “NO TURN ON RED” signs
- Removed Ground Mounted “DO NOT STOP ON TRACKS” Signs
- Installed overhead “DO NOT STOP ON TRACKS” sign on Pre-signal Mast Arm
- Removed 25 MPH Speed Limit Sign
- Installed “STOP HERE ON LEFT (ARROW)” Sign on left side in median
- Relocated I-10 Route Shield sign to improve visibility of regulatory signs and Pre-signal

Figure 8: Condition Diagram of Prince Road/UPRR with Remedial Crossing Improvements



7.0 FUTURE SAFETY AND OPERATION OF THE PRINCE ROAD/UPRR CROSSING

This section of the report attempts to predict the future safety and operational characteristics of the Pre-signal at the Prince Road/UPRR crossing.

Realistically, it is very difficult to predict the future delay of the westbound traffic at the Prince Road/UPRR crossing in the future. This is due to the fact that there are so many factors that will change. Among them are anticipated changes to the transportation system. Currently the reconstruction of I-10 is scheduled to start this year. This widening of I-10 will impact traffic patterns in the area and will divert a significant amount of local mainline traffic onto Prince Road. It will also divert much of the local mainline traffic onto the frontage roads and will have a significant impact on the signal phasing of the interchange. Due to the reconstruction of the I-10 mainline, a valid “before” and “after” comparison of the accident experience in relation to the installation of the pre-signal will not be possible.

In addition, projects within the next 25 years will likely include the reconstruction of major interchanges, such as Prince Road, to provide more lanes and potentially a grade separation between the railroad and Prince Road. Other future projects will likely include the extension of Aviation Parkway to intersect with I-10 and possibly the construction of other new local freeways.

To predict the effects of all these possible changes is out of the scope of this project. For this reason, only general predictions of the future conditions at this crossing are made in this report.

7.1 Future Traffic and Train Projections

To estimate the future safety and operational characteristics, projections of future traffic volumes and train projections are required. It is reasonable to expect that both the traffic on Prince Road and the number of trains per day will increase in the future.

To estimate future traffic volumes, the Pima Association of Governments was contacted and future traffic forecasts from the PAG model were requested. PAG was unable to provide model results for this project due to other priorities. The existing 24-hour traffic volumes and the 2030 traffic volumes for Prince Road are provided in Table 20. The 2030 projection was calculated assuming a uniform growth rate of 3% over 25 years with a growth factor of 1.75.

Table 20: Future Traffic Projections

	2004 24-hour Traffic	2030 Forecast	Growth Factor	% Growth per year
Prince Road	20454	35,800	1.75	3%

To establish future train projections, the Union Pacific Railroad was contacted. A source at the UPRR indicated that the number of trains would not increase in future years but the length of trains would increase in future years by approximately 2% per year. The prediction of no increase in the number of trains in future years is questionable and may result in a gross underestimate of future train activity. With this information, reasonable train projections were made assuming a 50% increase in the number of trains in 2030 (a 2% per year increase) as shown in Table 21. It is estimated that 75 trains per day will cross the UPRR Crossing.

Table 21: Future Train Projections

	#Trains/Day in 2004	% Growth per year	Growth Factor	#Trains/Day in 2030
UPRR Tracks	50	2%	1.50	75

With the increase in Traffic and Trains at the Prince Road/UPRR crossing, significant changes in the operation and delays experienced at this crossing can be expected.

The future number of trains will increase the time that trains occupy the Prince Road/UPRR crossing. Assuming that the average crossing time of a train increases in the future, it is assumed that the average time the gates are down will increase from 2 minutes 44 seconds to 3 minutes in 2030. With this information, the increase in the time that the gates are down in 2030 is calculated in Table 22.

Table 22: Future Train Crossing Time (Time Gates are down)

	2004			2030			Increase Factor
	Avg. Crossing Time	#Trains/Day	Total Crossing Time/Day	Avg. Crossing Time	#Trains/Day	Total Crossing Time/Day	
UPRR Tracks	2.73 min.	50	136.5 min.	3.00 min.	75	225 min.	1.65

Converting the data in Table 22 to hourly data also reveals some useful statistics. In 2004, the average number of minutes per hour that the gates were down was 5.7 minutes, or approximately 9% of the time. In 2030, the estimated average number of minutes per hour that the gates will be down will be 9.4, which is approximately 16% of the time.

7.2 Future Safety and Operational Predictions of the Prince Road/UPRR Crossing

As noted above, it is very difficult to make predictions for this crossing in the future. If it is assumed that the Prince Road/UPRR crossing still exists 25 years from now, the predictions made herein would provide a reasonable guess at what the conditions at the crossing could be. In general, we predict that the traffic volumes will increase by a factor of about 75% and the occupation of the railroad tracks at the crossing will increase by about 65%. With the pre-signal in place the conflict, behavior and violation data support the conclusion that the accident experience will be reduced in 2005. However, with the increase in traffic and trains over the next 25 years, the number of accidents per year from this point forward are expected to increase, too, assuming no significant improvements to the interchange and railroad crossing are made. The future delay of the crossing may increase exponentially in relation to the increases in future traffic and trains. On the other hand, improvements made to the interchange and frontage road could significantly affect this crossing in a positive way. Therefore, a prediction of 2 times the existing delay would be a reasonable guess. To try and predict the delay and safety with any more accuracy than stated herein, would probably be fictitious, even using logic based methods to do so.

8.0 BENEFIT-COST ANALYSIS OF THE PRE-SIGNAL

A benefit-cost analysis is provided to determine how effective the pre-signal is in addressing safety at the crossing. This analysis is based on an estimated reduction of accidents only and does not account for costs associated with increases or decreases in travel time. The historical accident data summarized in this report are used as a basis to make the following assumptions:

- The fatal accident is not affected by the pre-signal; therefore, assume %0 reduction of fatal accidents
- No Incapacitating Injuries occurred, and therefore, assume %0 reduction of incapacitating Injury accidents.
- ½ of the injury accidents are Non-incapacitating injuries.
- Assume 30% reduction of Non-incapacitating injury accidents.
- ½ of the injury accidents are Possible/Minor injuries.
- Assume 30% reduction of Possible/Minor injury accidents.
- Assume 30% reduction of property damage only and unreported accidents.

In addition, the following data are also used:

- Cost of Pre-signal = \$60,000
- Annual Operating and Maintenance Costs = \$2,500
- Life of Improvement = 10 years
- Interest Rate = 6%

With these data, the benefit-cost spreadsheet used by the Arizona Department of Transportation to assess safety projects was filled out and is included in Appendix H. The accident costs are recent costs that ADOT uses. Based on the spreadsheet, the benefit-to-cost (B/C) ratio of the pre-signal is 2.73. Since this installation is significantly greater than 1.0, it is concluded that the pre-signal is very beneficial in addressing accidents and safety. The fact that the B/C ratio is significantly greater than 1.0 indicates that as long as the assumptions made herein are somewhat reasonable, this conclusion will not change.

9.0 CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions

Based on the findings of this report, the following conclusions are made:

1. Prior to the installation of the pre-signal at the Prince Road/UPRR crossing, vehicles regularly stopped on the railroad tracks during red light indications, which constituted a safety problem and a violation of the regulatory signs.
2. Based on Accident Experience, 35 accidents related to the Prince Road/UPRR crossing occurred over the past five years. The most significant trend of accidents was the occurrence of 15 westbound rear-end collisions, of which 8 resulted in one or more injuries. One eastbound accident occurred when a vehicle was hit by a train resulting in one fatality.
3. The number of trains that traverse the Prince Road/UPRR crossing ranges from 40 to 50 trains per day on average.
4. The average time that the gates are down at the crossing is 2 minutes and 48 seconds per train, and 2 hours and 6 minutes per day, which is about 9% of the time.

5. The frequency of trains at the Prince Road/UPRR crossing is consistent around the clock, with no one hour of the day having more trains on a consistent basis than any other.
6. The coordination and cooperation between the City of Tucson and the Union Pacific Railroad was an essential step in the installation of the Pre-signal, as wiring was routed through existing conduit under the railroad tracks.
7. The delay of the westbound approach increased once the Pre-signal was installed. Part of this increase was due to biasing factors such as an increase in traffic volume of 10% and the prohibition of right-turn on red movements after the Pre-signal was installed. Part of the increase is due to the Pre-signal itself, for several operational reasons listed in this report, such as a significant increase in the cycle length of the interchange traffic signal. Consequently, it is concluded that the Pre-signal increased the westbound approach delay by an amount somewhat less than 12.5 seconds per vehicle.
8. The queue length diagrams indicate that queues that develop at the railroad tracks when a train is present, dissipate quickly once the train leaves in both the “Before” and “After” periods of the pre-signal installation.
9. The operation of the pre-signal significantly decreased the occurrence of several violations and negative behaviors that occurred at the crossing prior to the pre-signal being installed. In particular, the pre-signal significantly reduced the number of vehicles that stop on or to close to the railroad tracks.
10. The operation of the pre-signal created a few violations and undesirable behaviors. These include running the red pre-signal and turning right on red against the posted signs. These violations do not have significant safety consequences. Therefore, it is concluded that these violations can be effectively decreased with signing improvements, enforcement, and public information.
11. The number of vehicular conflicts in both the “Before” and “After” periods is insignificant, and no significant trends were found in either period.
12. Remedial signing and striping improvements that were made after the Pre-signal was operational, improved the operation and traffic controls at the Prince Road/UPRR crossing.
13. The future conditions of the Prince Road/UPRR crossing are difficult to make due to several changes that will be made to the transportation system in the Tucson Metropolitan Area starting this year.
14. Further research may be beneficial in the following aspects of the Pre-signal operation:
 - Activating the yellow clearance interval of the pre-signal to start before the flashing lights when a train is approaching.
 - Reducing the time the pre-signal stays red after a train passes, the gates are up, and the flashing lights turn off.
 - Minimizing the occurrence of short green intervals before a train activates the crossing control system.
15. The Benefit-Cost analysis conducted in this study reveals a benefit-to-cost ratio of 2.73, which is very favorable. Note that this analysis excluded accident types that would not be affected by the pre-signal and excluded the fatal accident that occurred.

9.2 General Assessment of the Pre-Signal Control

A general assessment of the pre-signal is made herein to provide an overview of the experience at the Prince Road/UPRR crossing. The questions stated at the beginning of the report are answered as follows:

Ø **Did the Pre-Signal improve the safety of the Prince Road/UPRR Crossing?**

Yes, based on the Conflict, Violation, and Behavior data, the operation of the Pre-signal significantly reduced the occurrence of motorists stopping on the railroad tracks and other undesirable violations and behaviors. Historical accident data was only available for the “Before” period. In terms of projected accident reduction, the Pre-signal had a favorable benefit to cost ratio of 2.73 to 1 at this location. The Pre-signal also improved the visibility of the Railroad crossing to westbound approaching traffic.

Ø **Did the Pre-Signal improve the operation of traffic at the Prince Road/UPRR Crossing?**

Yes and No. Yes, the Presignal reduced several types of violations and undesirable behaviors at the Prince Road/UPRR Crossing, resulting in better operation of traffic. No, the Pre-signal appeared to have increased the average stopped time delay per vehicle by an amount less than 12 seconds per vehicle.

Ø **Should the Pre-Signal control be considered for other crossings in the region? If so, for what types of conditions would it be applicable for?**

Yes, but new installations should be monitored to optimize operations. The pre-signal application should be considered for high volume approaches to RR crossings where queuing over the tracks is common and where tracks are in close proximity to a signalized intersection. The criteria in the MUTCD should be followed, which is:

- The use of pre-signal control *should* be considered if a highway rail-crossing is within 50 feet of a signalized intersection (or 75 feet if the crossing is regularly used by multi-unit vehicles).
- The use of pre-signal control *may* be considered if a highway rail-crossing is greater than 50 feet from a signalized intersection (or 75 feet if the crossing is regularly used by multi-unit vehicles) if an engineering study determines there is a need.

Since the pre-signal is a relatively new type of control, a follow-up review to fine tune signing, striping and signal timing is recommended. If needed, follow-up enforcement and public information may be needed to improve compliance to the pre-signal control.

In addition to these three questions the following questions are summarized regarding the installation and operation of the pre-signal:

Ø **What Benefits were realized with the installation of a pre-signal at the Prince Road/UPRR crossing?**

- Keeps people/vehicles off of the tracks.
- Improved visibility of the traffic signals on the approach.
- Improved compliance (less running of the flashing light indications)
- Provides clear understandable indication to the motorists.
- Provides a yellow change interval for the railroad signal on a busy, high speed approach.
- Improves the safety of the crossing – reduces violations and undesirable behaviors.

Ø **What Disadvantages and Costs were realized with the installation of a pre-signal at the Prince Road/UPRR crossing?**

- Effort to install Pre-signal requires personnel with signal operation expertise.
- Cost of Pre-signal includes construction, maintenance and power.
- Some undesirable behaviors and violations such as drivers proceeding through the Pre-signal red light, and drivers speeding to beat the Pre-signal red light.

Ø **What issues can be improved or need to be addressed?**

- Compliance with the pre-signal indications by motorists.
- Reduction in number of signs. The number of signs was reduced based on this study.
- Possible improvements to the signal timing. This requires more research.
- The allowance of right-turn on red movements on the pre-signal approach. This was implemented successfully.

Ø **What can we expect in the future regarding the use of pre-signals at other locations?**

- More pre-signals will be installed.
- We will learn more about the operations of pre-signals.
- We will develop better applications of the pre-signal.

Ø **Other observations regarding the flashing-light signals and pre-signals include:**

- The flashing –light signals used at railroad crossings are not consistent in meaning with other flashing red lights used on the transportation system. The flashing-light railroad signal requires traffic to stop and not proceed. Other flashing red signals require traffic to stop and permit traffic to proceed when clear. This may contribute to confusion and violations by motorists.
- The pre-signal is wired to the signal controller, which provides more flexibility for signal timings and displays than the railroad flashing-light signal; therefore, more and better applications will be realized with the use of pre-signals in the future.
- The railroad flashing light indications result in an immediate change from a free flow condition (for most traffic) to a required stop condition with no intermediate change interval. This may contribute to the occurrence of rear-end accidents and the violation of the flashing red railroad signals.

9.3 Recommendations

Based on the findings of this report and the conclusions made herein, the following recommendations are made regarding the use of pre-signals at railroad crossings:

1. Pre-signals should be considered at other highway-rail crossings near signalized intersections in Pima County and Arizona at locations where the following types of safety and operational issues can be improved:
 - When Vehicular queues regularly extend across the railroad tracks.
 - When vehicles regularly stop on or too close to the railroad tracks.
 - Where the installation of a pre-signal will improve the visibility of the signals on the approach to the intersection.
 - Where there is a regular trend of rear-end accidents.
 - Where the following undesirable behaviors occur on a regular basis:
 - Vehicles traversing the tracks during the flashing light indication.
 - Vehicles speeding up to “beat the gates”.
 - Vehicles proceeding through the gates when down or coming down.
 - Where a yellow change interval prior to the flashing red light stop conditions would eliminate abrupt stopping and rear-end accidents.
 - Where supplemental traffic controls to the railroad flashing-light signals would be beneficial. Typical locations may include:
 - High-speed approaches
 - High-volume approaches

- Approaches with sight distance restrictions.
2. The Guidelines provided in the MUTCD should be followed when considering the installation of pre-signals. They are:
 - The use of pre-signal control *should* be considered if a highway rail-crossing is within 50 feet of a signalized intersection (or 75 feet if the crossing is regularly used by multi-unit vehicles).
 - The use of pre-signal control *may* be considered if a highway rail-crossing is greater than 50 feet from a signalized intersection (or 75 feet if the crossing is regularly used by multi-unit vehicles) if an engineering study determines there is a need.
 3. After a pre-signal is installed, a “follow-up” type review of the operation of the pre-signal and the highway-rail crossing should be made to address issues and to optimize the operation of the crossing.
 4. The specific improvements identified in Tables 18 and 19 should be considered for the Prince Road/UPRR crossing. They include the following:
 - Re-stripe the stop bar with durable material.
 - Construct sidewalks outside the gates.
 - Reduce the signing at the crossing by removing the speed limit sign and the “NO RIGHT TURN ON RED” signs.
 - Install a “STOP HERE ON RED SIGN (Arrow)” in the median.
 - Provide enforcement at the pre-signal at regular intervals and publicize it.
 - Provide public information about stopping on the railroad tracks.
 - Change the operation of the pre-signal to accomplish the following:
 - Activate the yellow clearance interval of the pre-signal to start before the flashing lights come on when a train is approaching.
 - Reduce the time the pre-signal stays red after a train passes, the gates are up, and the flashing lights turn off.
 - Minimize the occurrence of short green intervals before a train activates the crossing control system.