Wyoming Demonstration Project:

Diverging Diamond Interchange Project at College Drive

Final Report
March 2015

HIGHWAYS FOR LIFE
Accelerating Innovation for the American Driving Experience.

U.S. Department of Transportation
Federal Highway Administration

FOREWORD

The purpose of the **Highways for LIFE (HfL)** pilot program is to accelerate the use of innovations that improve highway safety and quality while reducing congestion caused by construction. **LIFE** is an acronym for **L**onger-lasting highway infrastructure using **I**nnovations to accomplish the **F**ast construction of **E**fficient and safe highways and bridges.

Specifically, HfL focuses on speeding up the widespread adoption of proven innovations in the highway community. Such “innovations” encompass technologies, materials, tools, equipment, procedures, specifications, methodologies, processes, and practices used to finance, design, or construct highways. HfL is based on the recognition that innovations are available that, if widely and rapidly implemented, would result in significant benefits to road users and highway agencies.

Although innovations themselves are important, HfL is as much about changing the highway community’s culture from one that considers innovation something that only adds to the workload, delays projects, raises costs, or increases risk to one that sees it as an opportunity to provide better highway transportation service. HfL is also an effort to change the way highway community decision makers and participants perceive their jobs and the service they provide.

The HfL pilot program, described in Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) Section 1502, includes funding for demonstration construction projects. By providing incentives for projects, HfL promotes improvements in safety, construction-related congestion, and quality that can be achieved through the use of performance goals and innovations. This report documents one such HfL demonstration project.

Additional information on the HfL program is at www.fhwa.dot.gov/hfl.

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16. Abstract

The Wyoming diverging diamond interchange project, which was 90 percent Federally funded and 10 percent State funded, was located at the College Drive Interchange on Interstate 25, approximately 3 miles south of Cheyenne at reference marker 7.85. The project received a Highways for LIFE grant of $400,000 and was the first of its kind in the State. The total length of the project was 1,080 feet, and the total length of the bridge was 220 feet. The project sought to reduce the congestion caused by slow-moving trucks and to increase pedestrian and vehicular safety throughout the interchange. The project converted the conventional diamond interchange into a diverging diamond interchange by incorporating minor structure alterations, ramp realignments, signal installations, and lighting.

The construction was carried out in four phases. During these phases, one lane was left open for traffic in each direction, and the traffic was controlled with flaggers and traffic control. Reduced speed limit signs, advanced warning signs, traffic drums, and arrows were also installed. Highways for LIFE safety goals for worker and motorist safety were met on this project.

Per Wyoming Department of Transportation's (WYDOT) estimates, a typical interchange reconstruction or rehabilitation would have taken, on average, two construction seasons, with a shutdown for the winter season and temporary traffic control for 18 months or longer. In contrast, the diverging diamond interchange was completed within 9 months. Thus, the as-built scenario resulted in 50 percent reduction in the time highway users are impacted, compared to traditional methods, thereby meeting the Highways for LIFE goal for faster construction.

During the construction period, WYDOT did not find any significant travel time delays or queuing along the College Drive interchange and ramps of I-25. The use of DDI, which cost $3,056,898.43, is expected to result in an estimated present worth savings of $8,782,000, which accounts for the reduction in user delays over 20 years and the cost of signalizing the interchange. Overall, the traveling public expressed satisfaction with the new facility and the construction approach.

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SI* (MODERN METRIC) CONVERSION FACTORS				
APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
(none)	mil	25.4	micrometers	µm
in	inches	25.4	millimeters	mm
ft	`	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	millimeters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela per square meter	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	Newtons	N
lbf/in^2 (psi)	poundforce per square inch	6.89	kiloPascals	kPa
k/in^2 (ksi)	kips per square inch	6.89	megaPascals	MPa
		DENSITY		
lb/ft^3 (pcf)	pounds per cubic foot	16.02	kilograms per cubic meter	kg/m^3
APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
µm	micrometers	0.039	mil	(none)
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela per square meter	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	Newtons	0.225	poundforce	lbf
kPA	kiloPascals	0.145	poundforce per square inch	lbf/in^2 (psi)
MPa	megaPascals	0.145	kips per square inch	k/in^2 (ksi)

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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ABBREVIATIONS AND SYMBOLS

DDI	Diverging Diamond Interchange
DOT	Department of Transportation
FHWA	Federal Highway Administration
HfL	Highways for LIFE
IRI	International Roughness Index
OBSI	On-Board Sound Intensity
OSHA	Occupational Safety and Health Administration
PDO	Property Damage Only
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users
WYDOT	Wyoming Department of Transportation

INTRODUCTION

HIGHWAYS FOR LIFE DEMONSTRATION PROJECTS

The Highways for LIFE (HfL) pilot program, the Federal Highway Administration (FHWA) initiative to accelerate innovation in the highway community, provides incentive funding for demonstration construction projects. Through these projects, the HfL program promotes and documents improvements in safety, construction-related congestion, and quality that can be achieved by setting performance goals and adopting innovations.

The HfL program - described in the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) - has provide incentives to a maximum of 15 demonstration projects a year. The funding amount may total up to 20 percent of the project cost, but not more than $5 million. Also, the Federal share for an HfL project may be up to 100 percent, thus waiving the typical State-match portion. At the State's request, a combination of funding and waived match may be applied to a project.

To be considered for HfL funding, a project must involve constructing, reconstructing, or rehabilitating a route or connection on an eligible Federal-aid highway. It must use innovative technologies, manufacturing processes, financing, or contracting methods that improve safety, reduce construction congestion, and enhance quality and user satisfaction. To provide a target for each of these areas, HfL has established demonstration project performance goals.

The performance goals emphasize the needs of highway users and reinforce the importance of addressing safety, congestion, user satisfaction, and quality in every project. The goals define the desired result while encouraging innovative solutions, raising the bar in highway transportation service and safety. User-based performance goals also serve as a new business model for how highway agencies can manage the highway project delivery process.

HfL project promotion involves showing the highway community and the public how demonstration projects are designed and built and how they perform. Broadly promoting successes encourages more widespread application of performance goals and innovations in the future.

PROJECT SOLICITATION, EVALUATION, AND SELECTION

FHWA issued open solicitations for HfL project applications in fiscal years 2006, 2007, 2008, and 2009. State highway agencies submitted applications through FHWA Divisions. The HfL team reviewed each application for completeness and clarity, and contacted applicants to discuss technical issues and obtain commitments on project issues. Documentation of these questions and comments was sent to applicants, who responded in writing.

The project selection panel consisted of representatives of the FHWA's Offices of Infrastructure, Safety, and Operations; the Resource Center Construction and Project Management Team; the Division offices; and the HfL team. After evaluating and rating the applications and supplemental information, panel members convened to reach a consensus on the projects to recommend for approval. The panel gave priority to projects that accomplish the following:

- Address the HfL performance goals for safety, construction congestion, quality, and user satisfaction.

- Use innovative technologies, manufacturing processes, financing, contracting practices, and performance measures that demonstrate substantial improvements in safety, congestion, quality, and cost-effectiveness. An innovation must be one that the applicant State has never or rarely used, even if it is standard practice in other States.

- Include innovations that will change administration of the State's highway program to more quickly build long-lasting, high-quality, cost-effective projects that improve safety and reduce congestion.

- Will be ready for construction within 1 year of approval of the project application. For the HfL program, FHWA considers a project ready for construction when the FHWA Division authorizes it.

- Demonstrate the willingness of the applicant department of transportation (DOT) to participate in technology transfer and information dissemination activities associated with the project.

HfL Project Performance Goals

The HfL performance goals focus on the expressed needs and wants of highway users. They are set at a level that represents the best of what the highway community can do, not just the average of what has been done. States are encouraged to use all applicable goals on a project:

- **Safety**
    - Work zone safety during construction—Work zone crash rate equal to or less than the preconstruction rate at the project location.
    - Worker safety during construction—Incident rate for worker injuries of less than 4.0, based on incidents reported via Occupational Safety and Health Administration (OSHA) Form 300.
    - Facility safety after construction—At least twenty percent reduction in fatalities and injuries in 3-year average crash rates, using preconstruction rates as the baseline.

- **Construction Congestion**
    - Faster construction—At least 50 percent reduction in the time highway users are impacted, compared to traditional methods.
    - Trip time during construction—Less than 10 percent increase in trip time compared to the average preconstruction speed, using 100 percent sampling.

  - Queue length during construction—A moving queue length of less than 0.5 miles in a rural area or less than 1.5 miles in an urban area (in both cases at a travel speed 20 percent less than the posted speed).

- **Quality**
  - Smoothness—International Roughness Index (IRI) measurement of less than 48 inches per mile.
  - Noise—Tire-pavement noise measurement of less than 96.0 A-weighted decibels (dB (A)), using the onboard sound intensity (OBSI) test method.

- **User Satisfaction**—An assessment of how satisfied users are with the new facility compared to its previous condition and with the approach used to minimize disruption during construction. The goal is a measurement of 4-plus on a 7-point Likert scale.

REPORT SCOPE AND ORGANIZATION

This report documents the Wyoming Department of Transportation (WYDOT) HfL demonstration project on College Drive over Interstate 25 in Cheyenne. The project featured a diverging diamond interchange (DDI). Relevant details to the HfL program are presented in this report, including the alternative analyses performed to determine the design, construction highlights, the use of the DDI, the HfL performance metrics, and an economic analysis.

PROJECT OVERVIEW AND LESSONS LEARNED

PROJECT OVERVIEW

Heavy truck traffic and the presence of multiple truck stops near the interchange were causing traffic backups, primarily due to the left-turn movements of the heavy truck traffic. This project utilized the DDI to relieve congestion at an interchange near a couple of truck stops located just off I-25. WYDOT was able to improve the interchange without impacting the existing structure over I-25. Figure 1 shows a map of the project location.

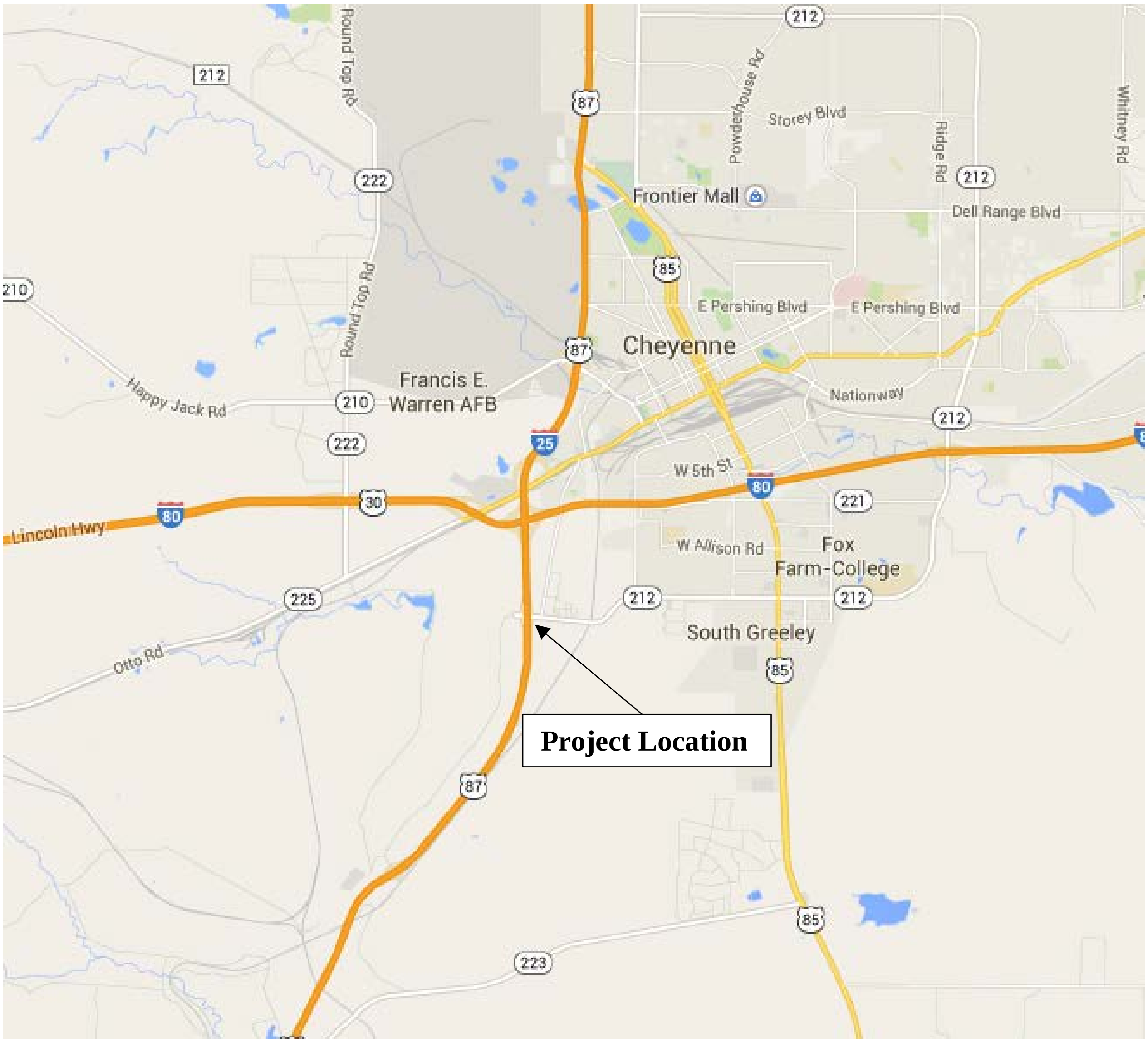

Figure 1. Map. Project location.

HfL Performance Goals

- The preconstruction accident data were evaluated in three separate categories: property damage only (PDO), personal injury, and fatal accidents. There were approximately 14 accidents per year at this location prior to construction. During construction, there were zero reported accidents in the work zone. Therefore, this HfL safety goal was met.
- There were no reported worker injuries on this project. Therefore, the safety goal on worker injuries was met.
- The 3-year postconstruction safety data on this facility have not yet been collected. Because this interchange is designed to significantly reduce the number of backups from heavy truck traffic, this goal is expected to be met.
- Per WYDOT's estimates, a typical interchange reconstruction or rehabilitation would have taken two construction seasons, with a shutdown for the winter season and temporary traffic control for 18 months or longer. In contrast, the DDI was completed within 9 months. Thus, the as-built project resulted in 50 percent reduction in the time highway users were impacted, thereby meeting the HfL goal for faster construction.
- During the construction period, WYDOT did not find any significant travel time delays or queuing along the College Drive interchange and ramps of I-25.
- No noise or IRI data were collected on this project.
- A user satisfaction survey indicated that, overall, the traveling public was satisfied with the new facility and WYDOT's approach.

Economic Analysis

The DDI option cost WYDOT around $3,056,898.43. However, it is expected to result in an estimated present worth savings of $8,782,000, which accounts for the reduction in user delays over 20 years and the cost of signalizing the interchange.

Lessons Learned

Following are some of the lessons learned after the completion of the DDI project:

- Paint the curbs yellow on the islands on the DDI to make them stand out more. Another solution for a future project is to design an island with a taller profile or have a domed middle.
- Nearby truck stop approaches can still create short duration operational problems. The solution to this was beyond the scope of this project. Although more distance to the nearest approaches on the crossroad would have been ideal, the DDI functions well despite the limited space.
- Pavement markings and lane assignment arrows were critical. WYDOT also added temporary arrows during construction to assist drivers with the transition of driving on the left side of the road. After construction, permanent arrows were placed.
- A DDI can be used in several situations and should not be reserved for purely congestion-related solutions where another type of interchange is not the solution.
- WYDOT felt that a forward compatibility analysis would help reduce the costs of any future expansion of the facility. In particular, DDIs are likely to have higher expenses for

expansion projects. This analysis was important on this project because WYDOT was able to use the two-lane DDI for current use but design it so that two additional lanes can easily be added in the future at a relatively low cost.[1]

- DDIs are still relatively new in the industry, but agencies should not be afraid of public backlash on a DDI project. A proactive public outreach program can help the public understand the benefits of the interchange.

CONCLUSIONS

WYDOT was able to construct a successful DDI that has eliminated the stacking issue on the interstate off-ramps. Although there was some concern from the public about the project, WYDOT used a robust outreach program to inform the public how the interchange would operate and when to expect changes to the interchange. WYDOT gained valuable insight into the use of a DDI and can now add this type of interchange into their program for future use. WYDOT proved that a DDI can be used successfully to help alleviate heavy truck traffic congestion.

PROJECT DETAILS

BACKGROUND

WYDOT describes the College Drive interchange as the "southerly gateway to the city of Cheyenne" because it provides access to the south side of the city in addition to Laramie County Community College. Because of its proximity to the interchange between I-25 and I-80, and the fact that it has truck stops in three of the four quadrants, heavy truck traffic is drawn to the area. Additionally, a large industrial park to the southwest that will also have rail access has recently been developed, increasing the truck traffic at this interchange. There are plans to further develop the surrounding area in the future as well. Current average daily traffic on College Drive is approximately 10,500 vehicles per day, with about 18 percent of that being truck traffic. The ramp termini are not signal-controlled. The truck traffic through the interchange has caused congestion, and the speed differential between the trucks and passenger vehicles poses a safety concern.

Recognizing the need for an improvement on the interchange, WYDOT began looking at options to improve safety and reduce congestion. Typically a DDI is used in densely populated areas to relieve traffic congestion. There are many benefits to using a DDI, including safety benefits (e.g., fewer conflict points, better sight distance at turns), operational benefits (e.g., simple left and right turns from all directions, better signal network synchronization), and cost benefits (e.g., existing bridge can be used as in this case, no additional right-of-way needed).[2] WYDOT had never before used a DDI but considered it a viable option to reduce the congestion in the interchange caused by heavy truck traffic. Figure 2 presents a closer view of the project location.

Figure 2. Photo. Closer view of the project location.

PROJECT DESCRIPTION

The Wyoming DDI project, which was 90 percent Federally funded and 10 percent State funded, was located at the College Drive interchange on I-25, approximately 3 miles south of Cheyenne at reference marker 7.85. The project received an HfL grant of $400,000 and was the first of its kind in the State. The total length of the project was 1,080 feet, and the total length of the bridge was 220 feet.

The project was intended to reduce the congestion caused by slow-moving trucks and to increase pedestrian and vehicular safety throughout the interchange. The project converted the conventional diamond interchange into a DDI by incorporating minor structure alterations, ramp realignments, signal installations, and lighting.

EXISTING CONDITIONS

The existing facility was a truck stop service diamond interchange containing truck and passenger fueling stations in three of the four interchange quadrants. Since the interchange was located approximately 2 miles south of a major system-to-system interchange between I-25 and I-80, it acted as a significant location for trucks refueling and parking during inclement weather when the interstates were closed. The interchange had dual lane, stop-controlled off-ramps to West College Drive and single lane on-ramps to I-25.

West College Drive also included a four-lane cross section that bridges over I-25 with a sidewalk on the north side of the roadway and guardrail barrier on the south side. The bridge had approximately 20 years of remaining service life. The interchange is surrounded by small intersections that attract significant traffic to nearby fast food restaurants, gas stations, truck service stations, and hotels.

Although this interchange has a relatively low traffic volume, there is a large amount of heavy truck traffic, which caused peak-hour operational problems. Left turn conflicts were observed when trucks turned left from West College Drive onto I-25 or from I-25 onto West College Drive. Although minimal, the opposing traffic caused the left-turning traffic on West College Drive to stop. A large percentage of truck traffic resulted in significant time loss due to intermittent heavy vehicle stoppages. Traffic operation concerns also resulted from the larger gaps that were required for the trucks in traffic to make a permitted left turn movements. This resulted in significant backups on the off-ramps that often queued onto mainline I-25, thus causing a major safety concern. Figure 3 presents the peak hour traffic counts along the intersections of the West College Drive. [(3)]

The overall volume of traffic was not cause of the issue, but rather the high percentage of truck traffic was causing operational problems. However, because of recent development in the area and plans for future development, WYDOT knew that the traffic congestion would only continue to worsen. HDR Inc, the design consultant on this project, used projected peak hour traffic volumes that represented the design year 2035. An assumed 1.25 percent growth rate was applied to 2011 existing traffic counts.

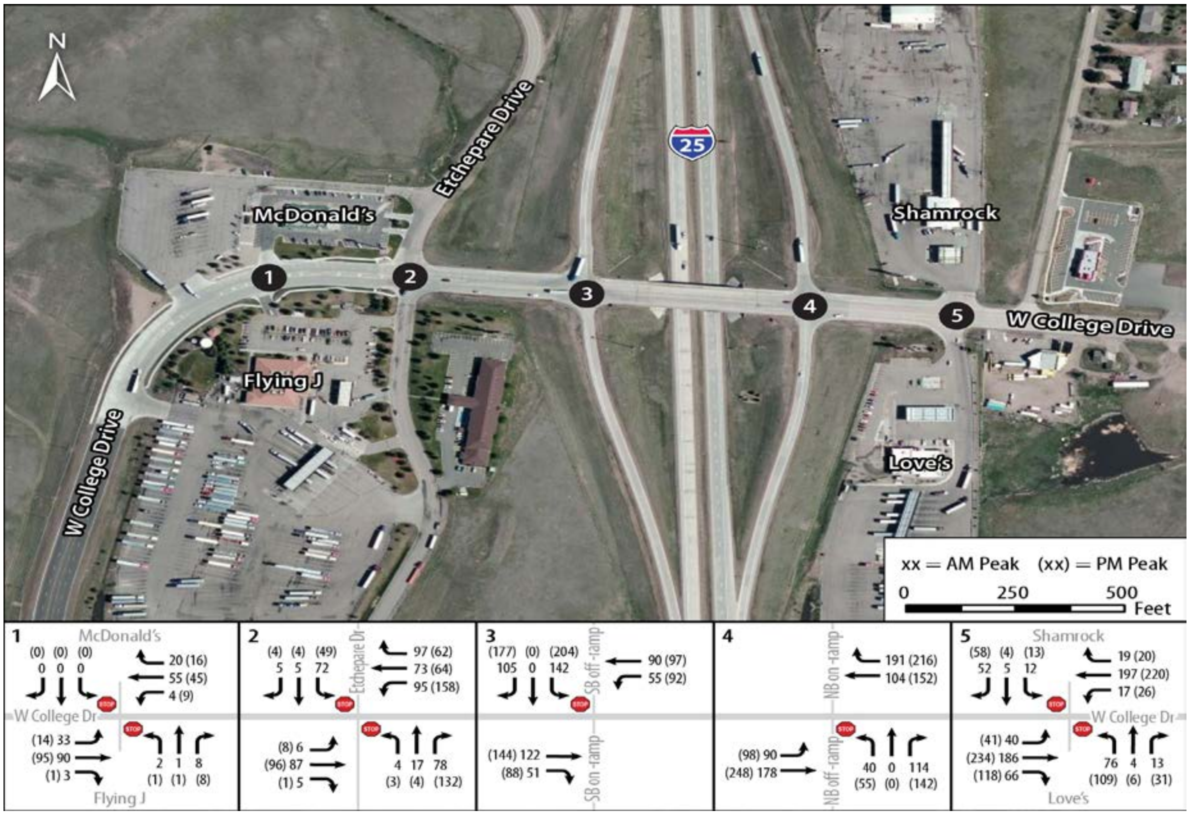

Figure 3. Photo. Traffic movements through the interchange.

WHY DDI?

A DDI can be used in several situations and should not be reserved for purely congestion-related solutions where another type of interchange is not the solution. Because of the lack of DDIs currently in operation, all the benefits may not be realized yet. The benefit for this project was "the operational advantages for the traffic, including trucks, and the lowering of greenhouse gas emissions." [(3)]

For this project, the DDI was chosen to improve the safety of the interchange by reducing traffic queue lengths on the ramps. The budget on this project was tight. The DDI configuration would improve the traffic backup situation and fit into the existing structure, so less work needed to be done during construction. Additionally, a two-lane DDI would suffice for the current traffic demands. Therefore, the project was able to stay under budget.

PROJECT GOALS

The main goal of the project was to decrease the queue time of the traffic during peak-hour congestion, which will improve the overall functionality of the interchange and increase safety. WYDOT project goals also aligned with the goals of the HfL program.

ALTERNATIVE ANALYSIS

WYDOT considered three options for the interchange to help alleviate the traffic, as described below.

Single Point Urban Interchange

Several years before this interchange became an official project, WYDOT researched using a single point urban interchange at this location. They ran some preliminary estimates on the cost of this option; the price was in the range of $6 million. Furthermore, WYDOT would have had to widen the bridge in addition to rebuilding almost 3,000 feet of I-25 because there would have been clearance issues with the new bridge. Because the budget was tight on this project, and the bridge was still in structurally good condition, WYDOT dismissed this option.

No-Build

As with every project, there is an option to do nothing. The structure itself did not need to be repaired and still had an estimated 20 years of service life left. The primary reason for this project was not to replace the structure, but to increase the traffic flow. With the current interchange, peak-hour traffic conditions were getting to the point of sometimes having traffic backed up on the off-ramps onto I-25. This was a great safety concern for WYDOT. Therefore, the no-build option included leaving the geometric configuration of the existing interchange but adding traffic signals to both the I-25 northbound and southbound ramp terminals. This option represented potential improvements without additional roadway work. (1)

2035 traffic estimations were used to create traffic simulation models for College Drive using VISSIM version 5.30-08. The same projected traffic volumes and model parameters were used for both the no-build option and the DDI option. The existing number of lanes and the future traffic volumes were used to optimize the signal phasing and timing plans. (1) However, the lane configurations were changed to include a dedicated left turn lane in both directions. Delays were between 1 and 2 minutes with this option. It was concluded that this option would not satisfy the future traffic demands of the interchange.

DDI

The design of the DDI was primarily done by WYDOT in-house with 30 percent of the plans done by a design consultant (HDR Inc.) that had experience with other DDI projects. The design consultant assisted in running some volume scenarios for traffic analysis and provided design reviews of what WYDOT prepared (to take advantage of the consultant's experience and lessons learned from previous work). The design consultant also provided a fatal flaw analysis (to make sure the designed DDI would work in addressing the challenges and fit in the location) as well as a sensitivity analysis.

Once the analysis was done, it was clear to WYDOT that this was an excellent choice for the interchange. Once WYDOT determined that they would proceed with the DDI configuration, WYDOT project staff met with representatives from Access Utah and the Utah DOT, since Utah had some experience with DDIs.

The DDI was evaluated with a two-lane configuration to compare to the no-build option. This option showed improvement with the traffic delays. Each ramp had an increase in the level of service by at least one grade when the DDI was used, compared to the no-build option. Another important aspect of the DDI is that the configuration will fit on the existing bridge and will improve capacity.

The DDI was chosen to help relieve the peak-hour traffic congestion. A four-lane DDI was considered because there has been new business and housing development proposed in nearby areas. Furthermore, the existing bridge could accommodate a four-lane DDI. However, nothing has been actually developed, and it may be years before any plans are finalized. Therefore, WYDOT decided to use the two-lane DDI instead. Only minor modifications will be needed to upgrade the two-lane DDI to a four-lane DDI, if WYDOT wishes to do so in the future.

The design consultant performed a sensitivity analysis to compare the two-lane DDI with the four-lane DDI. The two-lane DDI will be sufficient until there are an additional 300 vehicles per hour during the afternoon peak hour. The four-lane DDI would have a capacity of an additional 800 vehicles per hour.

Figure 4 shows the four-lane DDI configuration that was proposed. Figure 5 shows the chosen two-lane DDI configuration, with blue lines indicating what the four-lane configuration looks like on top of it.

Figure 4. Photo. Four-lane DDI configuration.

Figure 5. Photo. Two-lane DDI configuration with four-lane configuration shown with blue highlights.

BID INFORMATION

The project was a low-bid, design-bid-build project. Four bids were received. Table 1 summarizes all the bids and the engineer's estimate.

Table 1. Bid summary.

Company	Bid	% of Low Bid	% of Engineer's Estimate
Engineer's Estimate	$2,754,278.10		
S&S Builders, LLC Gillette, WY	$3,126,613.12	100%	113.52%
Simon Contractors and Subsidiaries Cheyenne, WY	$3,165,707.67	101.25%	114.94%
Reiman Corp. and Subsidiary Cheyenne, WY	$3,200,463.65	102.36%	116.20%
Concrete Works of Colorado, Inc. Lafayette, CO	$3,474,220.42	111.12%	126.14%

CONSTRUCTION DETAILS

Construction Phasing/Traffic Control

The construction was carried out in four phases. During these phases, one lane was left open for traffic in each direction, and the traffic was controlled with flaggers, temporary signals and other traffic control. Reduced speed limit signs, advanced warning signs, traffic drums, and arrows were also installed. Figure 6 through Figure 9 show the traffic drums and arrows used during the construction period.

Figure 6. Photo. During construction, showing traffic still using the bridge.

Figure 7. Photo. Arrows in the stoplights help guide drivers.

Figure 8. Photo. Arrows were painted on the roadway to help guide drivers.

Figure 9. Photo. Close-up of the center island.

Figure 10 through figure 17 present the temporary traffic control plans in the various construction.

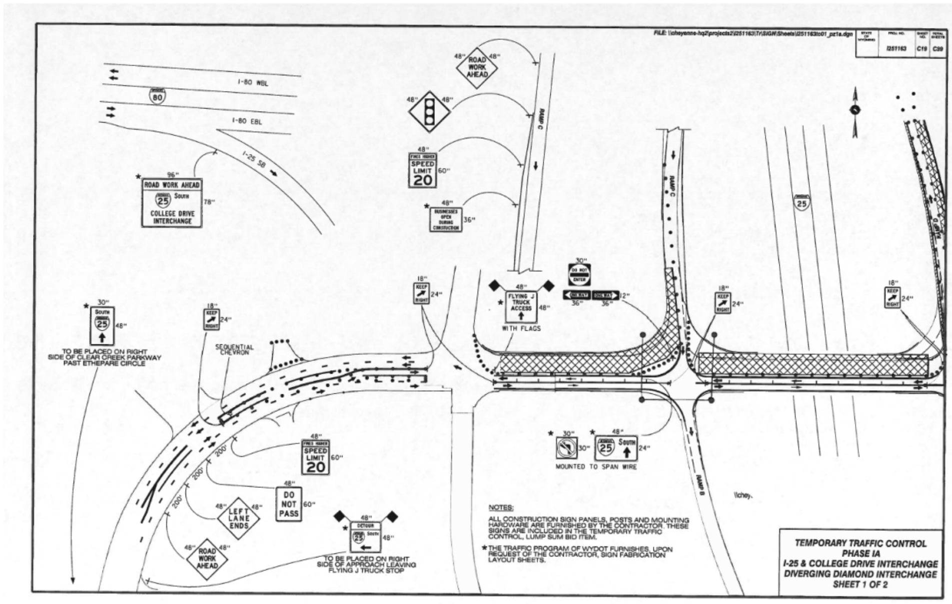

Figure 10. Diagram. Temporary traffic control for phase IA.

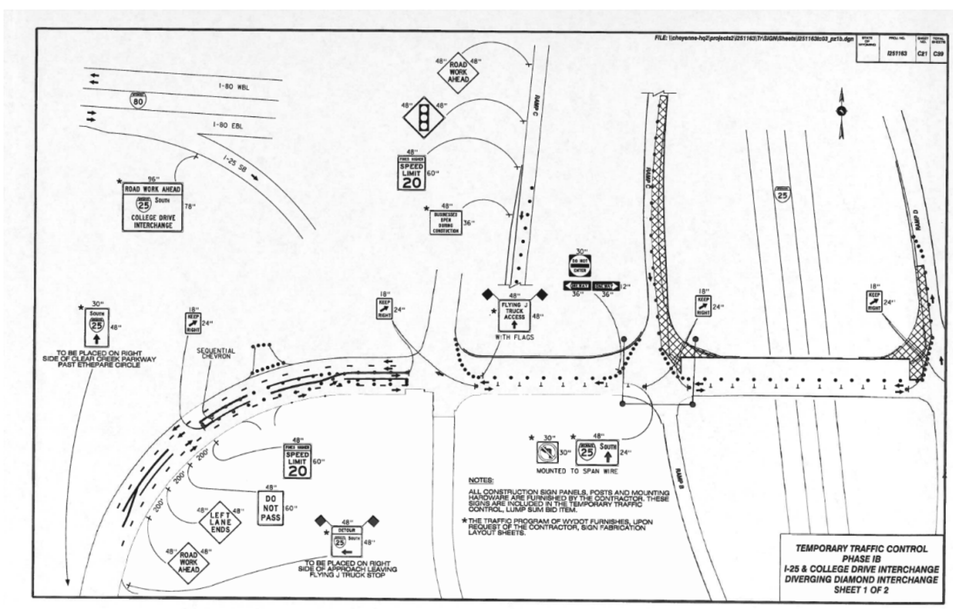

Figure 11. Diagram. Temporary traffic control for phase IB.

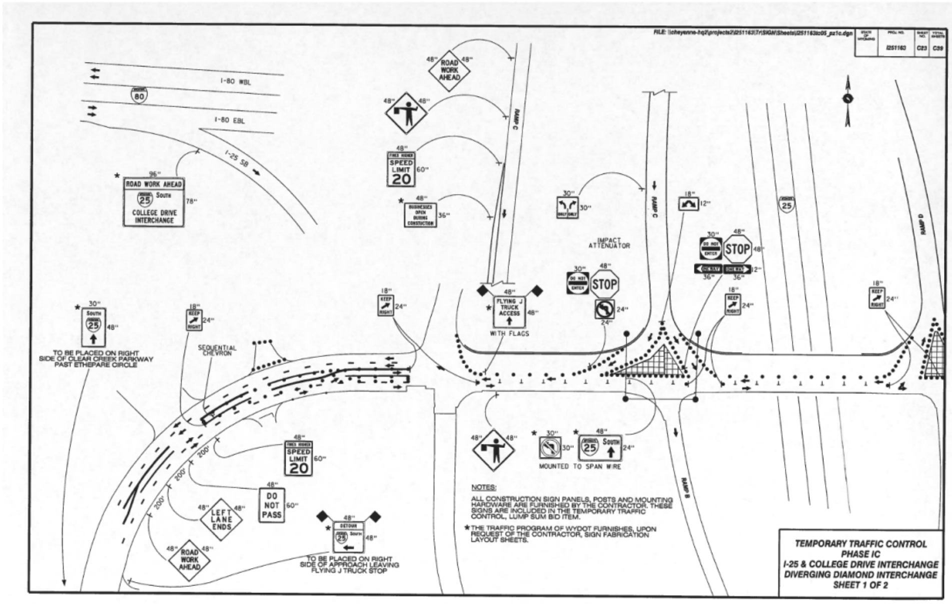

Figure 12. Diagram. Temporary traffic control for phase IC.

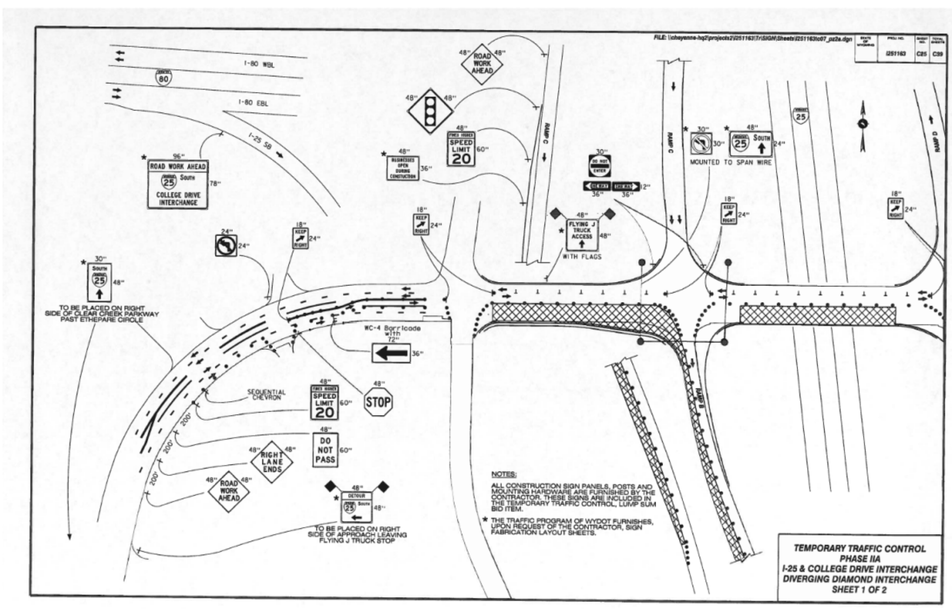

Figure 13. Diagram. Temporary traffic control for phase IIA.

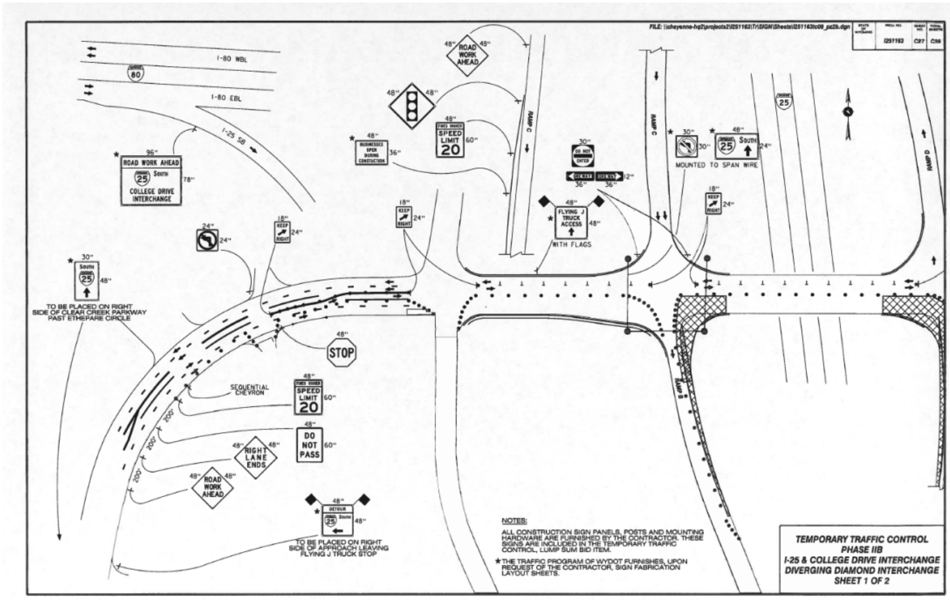

Figure 14. Diagram. Temporary traffic control for phase IIB.

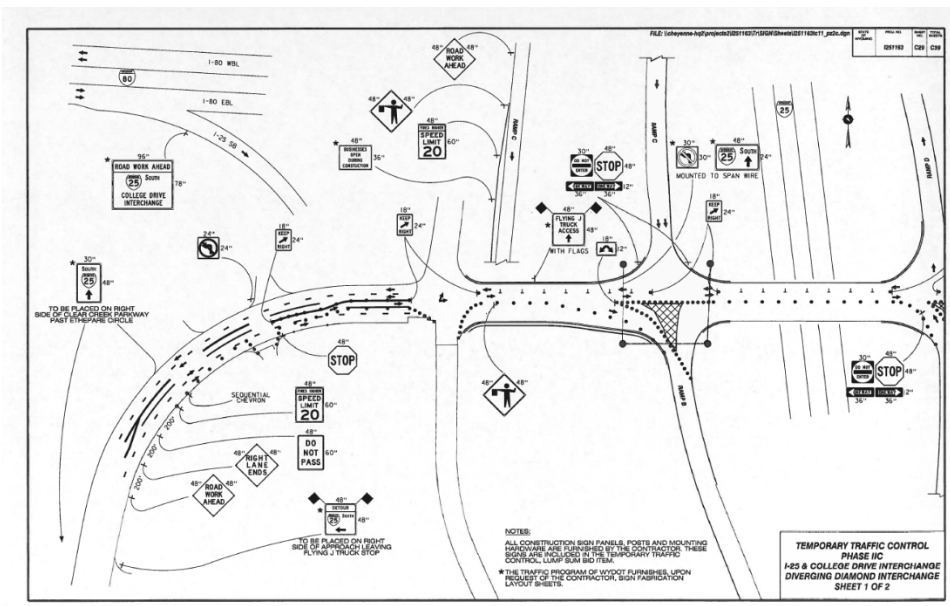

Figure 15. Diagram. Temporary traffic control for phase IIC.

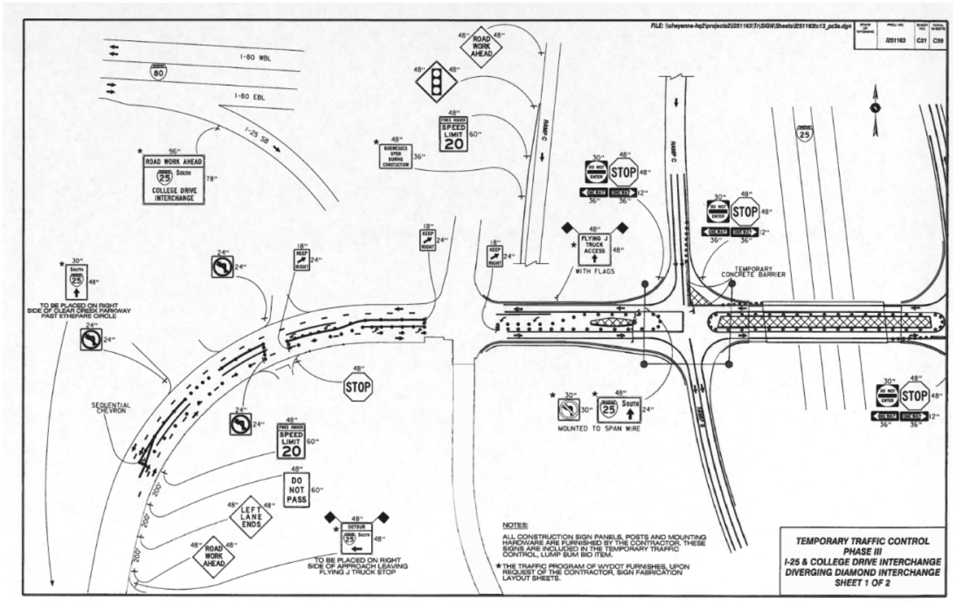

Figure 16. Diagram. Temporary traffic control for phase III.

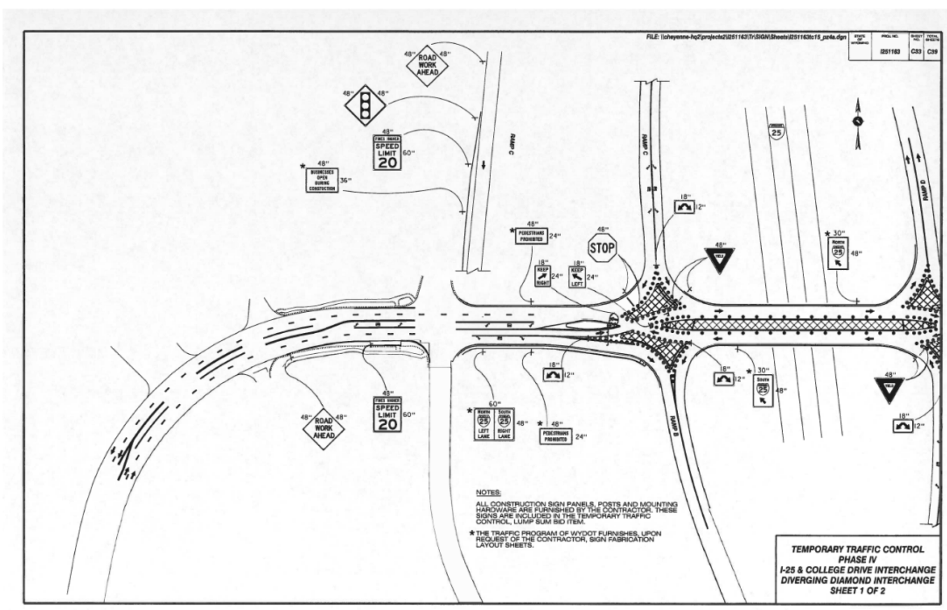

Figure 17. Diagram. Temporary traffic control for phase IV.

Construction

Construction on this project started in January 2013. Because WYDOT was using a two-lane DDI configuration, they were able to leave plenty of room on the shoulders for wider vehicles, stalled vehicles, or emergency vehicles. In a DDI configuration, a minimum cross-over angle of 30° is recommended. If the angle is too shallow, there is a risk of people making wrong turns. To obtain the minimum angle, WYDOT needed a 9-foot shoulder on the inside with 12-foot lanes.

They ended with angles of 32° (west) and 36° (east), so they were able to achieve good angles for the DDI. Figure 18 presents the construction activities for the DDI project.

Figure 18. Photo. Concrete paving and dowel alignment during construction.

To keep the traffic moving, WYDOT decided to pour a 10-inch concrete pavement up to the bridge and a thin epoxy overlay was put on the bridge structure. It should be noted that the through traffic on I-25 was not affected during the project construction. Figure 19 shows the typical section on the bridge. As can be seen, the 10-inch base extends even under the sidewalk.

The sidewalk in the middle of the interchange is raised with two barriers for protection. Previously, the sidewalk was on one side of the bridge, but with the DDI configuration it was moved to the center island. Although this configuration works, there is one issue with the DDI configuration in that the islands on the DDI do not stand out enough when users are exiting the interstate on the ramp intersections. Because of the raised interchange situation and that the crossroad is going over the interstate, the islands are not noticeable until the user is at the interchange. Although the islands are raised and stained, the curb portion is still gray. There have been a couple of island hits since the installations, so WYDOT is adding some flexible delineators at the noses of the islands for snowplowing operations. WYDOT is also planning to add yellow curb paint on the off-ramp side of the islands at the ramp intersections. Islands with a taller profile or that are domed in the middle would have helped mitigate this problem.

Good pavement markings helped operations, and lane assignment arrows were critical. During the final phases of construction, when the traffic was running in the DDI configuration while the contractor was working in the middle of the bridge, a few drivers complained and did not want to drive on the "wrong" side of the road. WYDOT added temporary arrows during construction to help guide drivers. When construction was more or less complete, the permanent lane arrows helped assure drivers they were going in the correct direction, which helped them over the mental hurdle of driving on the opposite side of the road. On this project, the signing is a little crowded because of the tight project limits. This may have to be adjusted over time.

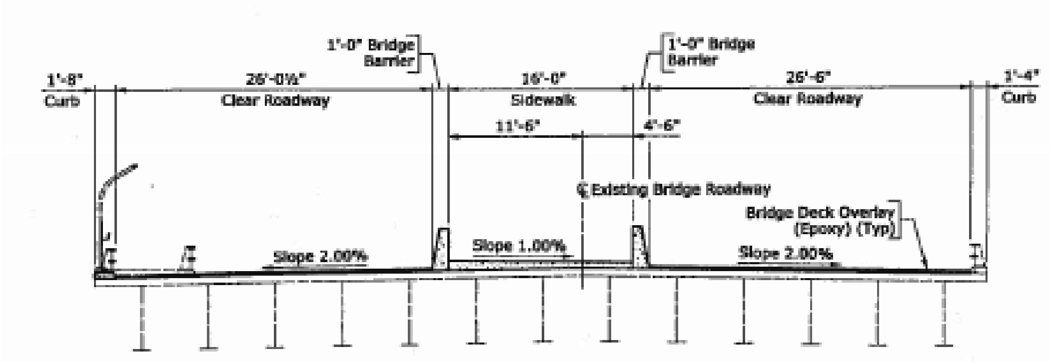

Figure 19. Diagram. Typical section at the structure.

New Traffic Signals and Lighting Systems

Prior to construction, WYDOT wanted to visualize where all the lighting poles, signs, and other appurtenances would be located. They created 3D visualizations and simulated the interchange in a moving video clip. WYDOT wanted to make sure that the public knew to drive on the left side of the interchange. They placed many signs, and the arrows are pointing at a 45° angle so that drivers know to stay to the left. Figure 20 shows a snapshot of the 3D visualization used by WYDOT. The lights use a simple two-phase operation: actuated, 60-second maximum cycle lengths, and running free with no coordination initially.

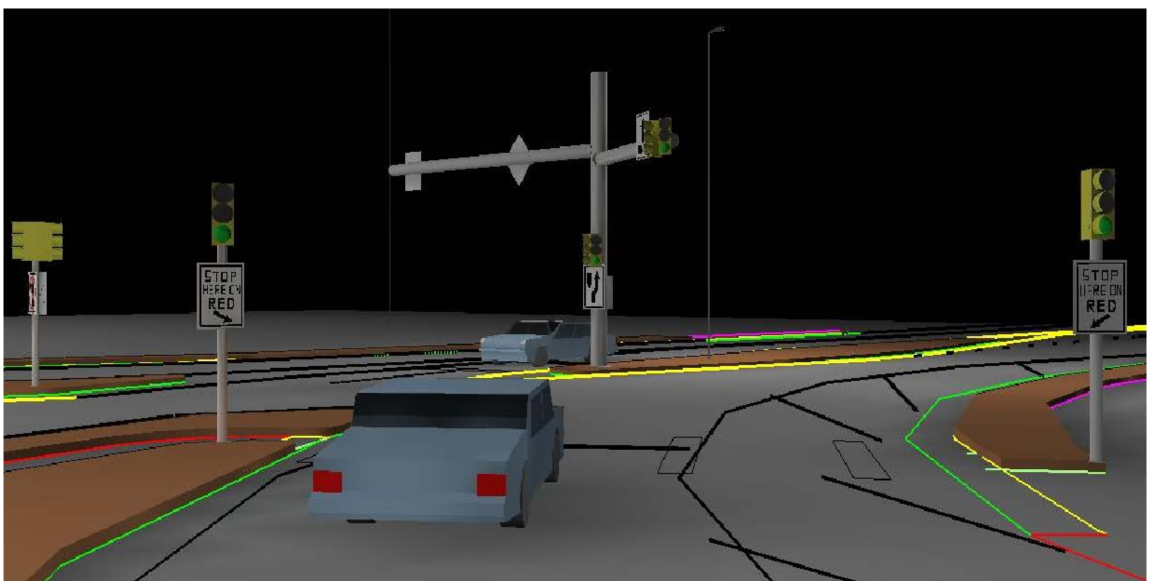

Figure 20. Illustration. 3D visualization of the light poles and signage.

Figure 21 and Figure 22 present panoramic and aerial views of the final DDI.

Figure 21. Photo. Panoramic view of the DDI (Note: distortion in image is due to composite of three views – left, straight, and right).

Figure 22. Photo. Aerial view of the completed DDI.

PUBLIC OUTREACH

In an effort to reach out to the public, WYDOT conducted two open house events. They advertised in newspapers, on websites, and on the radio. They also sent emails and had an extensive mailing list to spread the word about the project and public events. Figure 23 shows one of the newspaper advertisements used. Figure 24 shows the handout that was given to people who attended the open houses. The handout provided a color-coded diagram, along with a narrative on how to navigate the new interchange. WYDOT also hung banners (see Figure 25) at the open houses which explained the project purpose, benefits, and schedule.

Approximately 130 people attended the open houses. Furthermore, several announcements were made when the "switch over" was going to happen, to remind drivers. Members of WYDOT were also interviewed by local news stations about the project.

Because this project was using an interchange configuration not known to many area drivers, the project was big news.

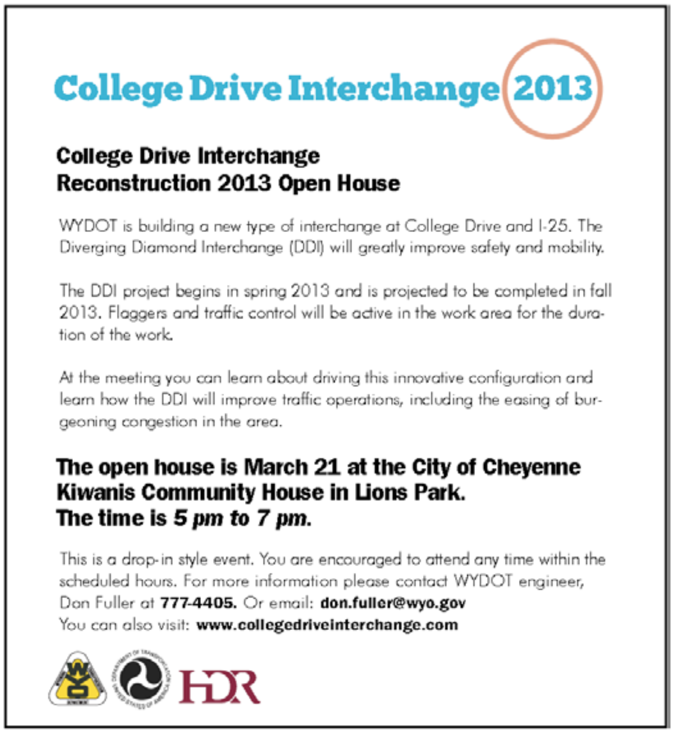

Figure 23. Illustration. Advertisement in newspapers for open house event.

College Drive

Diverging Diamond Interchange (DDI)

Traveling on College Drive:

1 ***Accessing Southbound I-25:*** If driving east toward the interchange, get into the far right lane and merge onto I-25. If driving west, get into the far left lane. Continue over the bridge and merge directly onto I-25.

2 ***Accessing Northbound I-25:*** If driving east, move onto the left lane. Continue over the bridge and move into the left turn lane, which will merge directly onto I-25. If driving west, move into the right lane and merge onto I-25.

3 ***Going Straight:*** Using any of the two regular traffic lanes, continue through the next crossing intersection where you will switch back to the right side of the roadway.

Traveling on I-25:

4 ***Northbound Etchepare Dr/Cir:*** Stay to the left when the off-ramp divides. Turn left and merge directly into westbound traffic lanes.

5 ***Northbound to Southwest Drive:*** Stay to the right when the off-ramp divides. Turn right and merge directly into the westbound traffic lanes.

6 ***Southbound to Etchepare Dr/Cir:*** Stay to the right when the off-ramp divides. Turn right and merge directly into the westbound traffic lanes.

7 ***Southbound to Southwest Drive:*** Stay to the left when the off-ramp divides. Turn left and merge into the eastbound traffic lanes.

Visit **www.collegedriveinterchange.com** to see the DDI in action!

For more information *please contact Don Fuller with Wyoming Department of Transportation at (307) 777-4405 or email Don.Fuller@wyo.gov*

HDR College Drive Interchange 2013

Figure 24. Illustration. Handout at open house events.

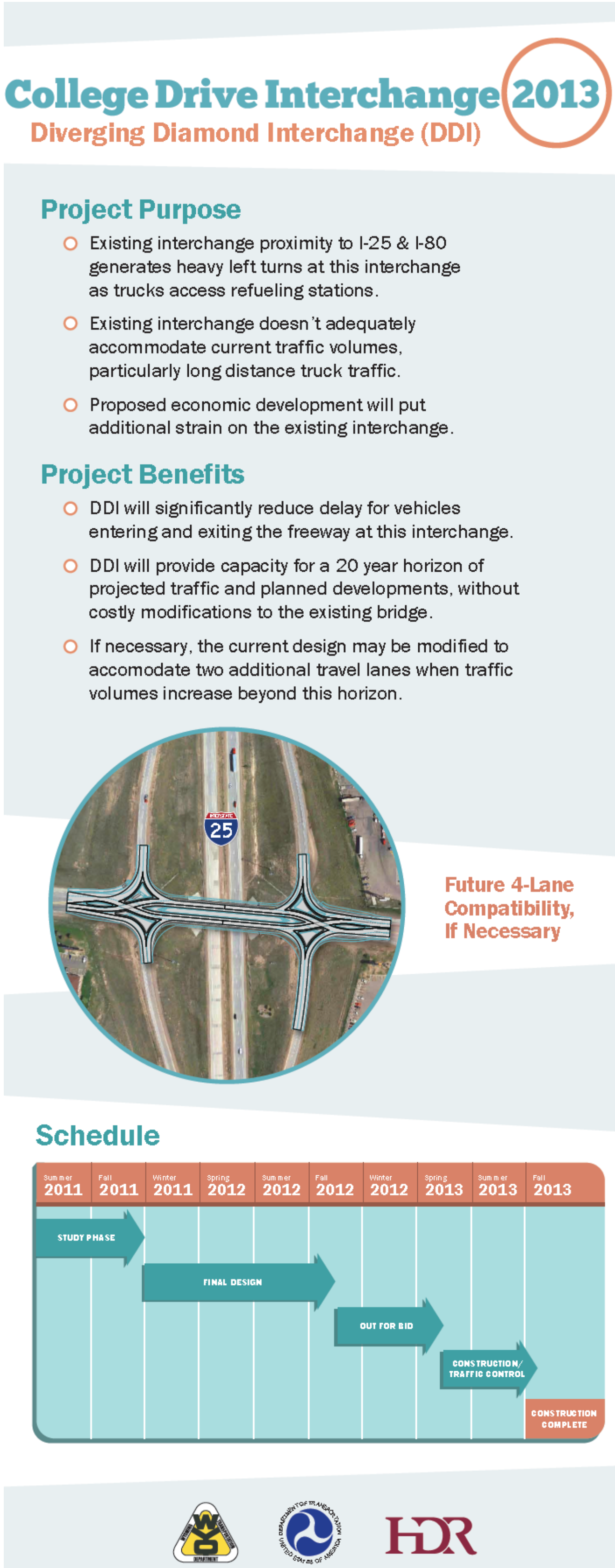

Figure 25. Illustration. Banner hanging at open house events.

DATA ACQUISITION AND ANALYSIS

SAFETY

The HfL program has three safety goals:

- Work zone safety during construction—Work zone crash rate equal to or less than the preconstruction rate at the project location.
- Worker safety during construction—Incident rate for worker injuries of less than 4.0, based on incidents reported via OSHA Form 300.
- Facility safety after construction—At least 20 percent reduction in fatalities and injuries in 3-year average crash rates, using preconstruction rates as the baseline.

Prior to construction, WYDOT's consultant for this project compiled the accident statistics for both College Drive and I-25 from 2006 through 2010. Table 2 summarizes the results. There were an average of 14 accidents per year, none fatal. Figure 26, Figure 27, and Figure 28 graphically show the results of the accident summary. The severity of an accident is categorized as follows:

- Fatality – Accident which caused a fatality.
- Personal Injury – Accident which caused one or more injuries of any type, but no fatalities.
- Property Damage Only – Accident that resulted in damages exceeding a threshold value, but no injuries or fatalities.

Table 2. College Drive/I-25 accident summary. (1)

<table>
<tr><th></th><th colspan="2">PDO</th><th colspan="2">Personal Injury</th><th colspan="2">Fatal Accident</th><th></th></tr>
<tr><th>Calendar Year</th><th>College Drive</th><th>I-25</th><th>College Drive</th><th>I-25</th><th>College Drive</th><th>I-25</th><th>Total</th></tr>
<tr><td>2006</td><td>3</td><td>9</td><td>2</td><td>0</td><td>0</td><td>0</td><td>14</td></tr>
<tr><td>2007</td><td>7</td><td>4</td><td>2</td><td>2</td><td>0</td><td>0</td><td>15</td></tr>
<tr><td>2008</td><td>9</td><td>4</td><td>2</td><td>1</td><td>0</td><td>0</td><td>16</td></tr>
<tr><td>2009</td><td>4</td><td>6</td><td>0</td><td>2</td><td>0</td><td>0</td><td>12</td></tr>
<tr><td>2010</td><td>4</td><td>6</td><td>5</td><td>0</td><td>0</td><td>0</td><td>15</td></tr>
<tr><td>Subtotals</td><td>27</td><td>29</td><td>11</td><td>5</td><td>0</td><td>0</td><td>72</td></tr>
<tr><td>Accident Totals</td><td colspan="2">56</td><td colspan="2">16</td><td colspan="2">0</td><td></td></tr>
<tr><td>Average per year</td><td colspan="2">11</td><td colspan="2">3</td><td colspan="2">0</td><td></td></tr>
<tr><td colspan="3">Average Number of Accidents per Year (total) =</td><td colspan="5">14</td></tr>
</table>

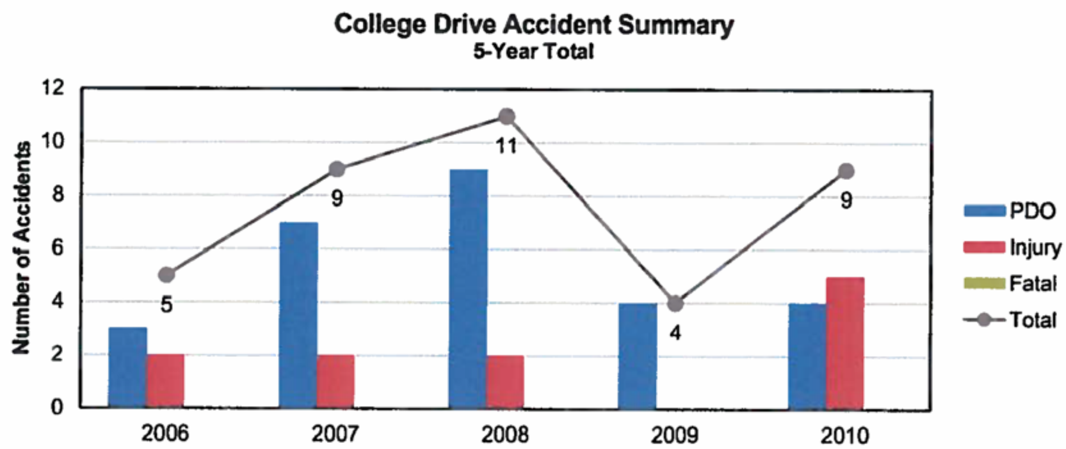

Figure 26. Graph. College Drive accident summary. (1)

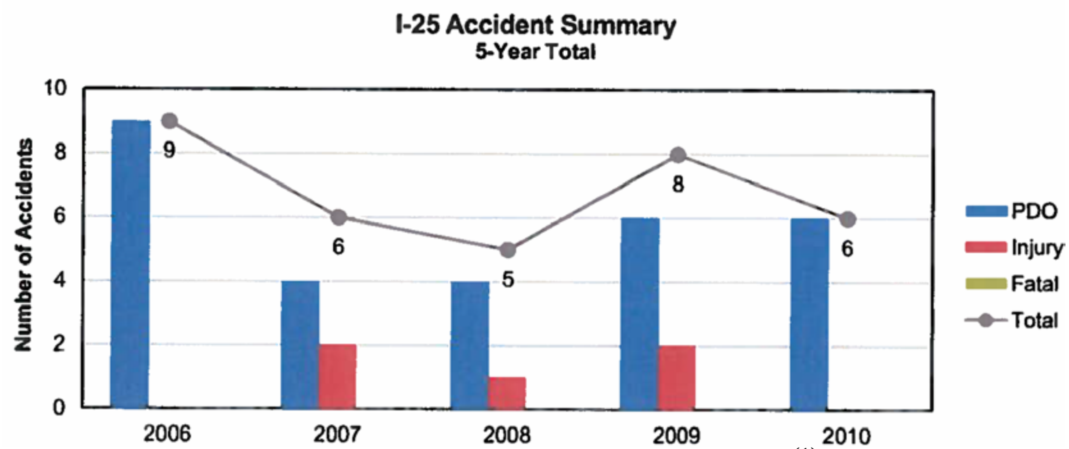

Figure 27. Graph. I-25 accident summary. (1)

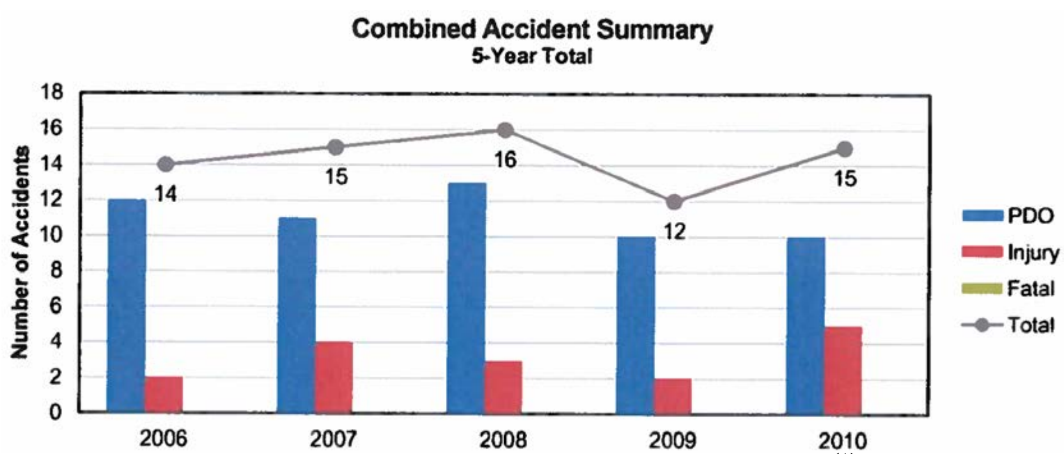

Figure 28. Graph. Combined accident summary. (1)

During construction, there were no reported accidents in the work zone. Therefore, the HfL safety goal for the work zone crash rate to be equal to or less than the preconstruction rate at the project location was met.

Likewise, there were no reported worker injuries on this project. Therefore, the HfL goal of an incident rate for worker injuries less than 4.0, based on the incidents reported via OSHA Form 300, was met. On the project site, there was plenty of room to barrier off the work. It proved to be a good setup for both the workers and the traveling public.

Longer term crash rate data cannot be collected yet, so it is not known whether this project meets the HfL goal that there should be at least a 20 percent reduction in fatalities and injuries in 3-year average crash rates. However, because this interchange is designed to significantly reduce the number of backups from heavy truck traffic, this goal is expected to be met.

CONSTRUCTION CONGESTION AND TRAVEL TIME STUDY

Faster Construction

The traditional alternative on this project would have been the no-build option that included leaving the geometric configuration of the existing interchange but adding traffic signals to the I-25 northbound and southbound ramp terminals. However, WYDOT felt that the use of traffic signals would have helped ease the traffic congestion problems for a relatively shorter period of time. In the long run, to enhance the facility capacity, WYDOT would have to reconstruct or rehabilitate the structure.

In contrast, the innovative design features of the DDI allowed WYDOT to retain the existing structure. The minor rehabilitation work carried out during the DDI construction included moving the pedestrian walkway to the center of the structure, aligning approximately ½ mile of each of the four ramps, and conducting approximately ¼ mile of work on College Drive on each end of the bridge.

Per WYDOT's estimates, a typical interchange reconstruction or rehabilitation would have taken two construction seasons, with a shutdown for the winter season and temporary traffic control for 18 months or longer. The DDI was completed within 9 months, resulting in a 50 percent reduction in the time highway users were impacted, thereby meeting the HfL goal for faster construction.

Travel Time and Queuing

WYDOT did not find any significant travel time delays or queuing along the College Drive interchange and ramps of I-25. The possible reason could be that WYDOT's traffic control plan required that a lane be kept open in each direction throughout the construction period. Additionally, traffic was controlled with flaggers and traffic control, which ensured that vehicles at the stops were allowed adequate time to move through the interchange.

QUALITY

Noise and Smoothness

WYDOT does not incorporate an IRI ride and standard noise measurement specifications for concrete paving and bridge work. Additionally, on this project, WYDOT retained the existing bridge conditions, and no removal or replacement of the bridge deck was carried out. Thus, no noise or IRI data were collected on this project.

User Satisfaction

To gauge user satisfaction with this project, WYDOT conducted a survey. Responses were requested in the 21-day period from Monday, September 15, 2014, to Monday, October 6, 2014. Two hundred eleven completed responses were received. The appendix presents the results of the user satisfaction survey.

ECONOMIC ANALYSIS

CONSTRUCTION TIME

The DDI project was awarded in November 2012, and the notice to proceed was issued in December 2012. The construction activities were conducted between January and April 2013. Table 3 presents an overview of the project construction schedule.

Table 3. Construction schedule.

Date	Item
11/15/2012	Project awarded
12/11/2012	Notice to proceed issued
01/04/2013	Pre-construction conference held
01/22/2013	Began installing temporary traffic control signals
01/24/2013	Finished installing temporary traffic control signals
01/28/2013	Started phase 2A
03/14/2013	Began pouring concrete
04/24/2013	Started phase 2B
05/24/2013	Started phases 1A and 1B
07/12/2013	Epoxy coated sidewalk area of bridge
07/14/2013-07/29/2013	Project shut down (Frontier Days)
08/30/2013	Finished pouring mainline concrete
09/17/2013	Poured north side barrier wall
09/19/2013	Placed epoxy north side of bridge deck
09/24/2013	Switched traffic to phase III configuration
09/30/2013	Poured south side barrier wall
10/02/2013	Placed epoxy on south side of bridge and traffic poles started to be placed
10/08/2013	Switched to phase IV traffic configuration
10/10/2013	Islands started
10/29/2013	Seeding begins
11/04/2013	Traffic signals fully operational and all traffic control removed
11/08/2013	Thermoplastics installation begins
11/20/2013	Project substantially completed
04/08/2014	Pavement marking installation begins

CONSTRUCTION COSTS

AGENCY COSTS

The DDI option cost WYDOT around $3,056,898.43, slightly lower than the original bid amount. The alternative to the DDI interchange is the no-build option based on the interchange study performed in September 2011.[1] Improvements to the interchange under the no-build scenario included signalizing the I-25 northbound and southbound ramp terminals. Typical costs for signalizing intersections range from $50,000 to $200,000, depending on the complexity of the intersection and the characteristics of the traffic using the intersection. For this analysis a cost of $100,000 for each of the two intersections at the interchange is assumed. In addition the annual operating cost of each signal ranges from $1,000 to $5,000. However, this is assumed to be balanced by the annual operation cost of the signals installed for the DDI.

USER COSTS

The DDI innovation was primarily related to the roadway design and did not have any significant impact on the traffic patterns during the construction. The project location had a higher percentage of trucks that took detour routes during the construction period to avoid delays. It can thus be assumed that DDI may not result in significant delays or cost benefits during construction, and that the user cost savings accrued over the future years of DDI operations are expected to increase as the traffic volume grows.

Table 4 presents a network performance comparison between the no-build and DDI scenarios. Table 5 presents the level of service corresponding to the vehicle delays on signalized intersections. Comparing tables 4 and 5, it can be concluded that the facility would provide level of service D with increased traffic congestion and delays.

Table 4 shows that in 2035, the use of DDI potentially results in decrease in total delay by 11 veh-h per AM peak hour per day, and by 32 veh-h per PM peak hour per day. Thus the total decrease in delay combining the AM and PM peak hours is 43 veh-h per day in year 2035.

In addition to improvements during the AM and PM peaks, the DDI is expected to reduce delays during off-peak hours as well. However, since traffic analysis was only performed for the AM and PM peaks, this value can only be estimated. Assuming the total delay is 50% of the peak hour delay during the hour prior to and following the AM and PM peaks, the total decrease in delay combining the AM and PM peak hours and the hours prior to and following the AM and PM peaks is 86 veh-h (5.5+11+5.5+16+32+16). For this analysis, the improvement in delay time during the remaining 18 hours of the day is assumed to be negligent. Assuming no difference in delay time in 2015 between the no build and DDI scenarios and linear increase in difference in delay time between 2015 and 2035, the total difference in delay over 20 years is:

20 years × 365 days/year × (0+86)/2 veh-h/day = 313,900 veh-h.

The estimated labor-related monetary present value of hourly delay costs for automobiles and trucks are $23.29 and $30.90/veh-h, respectively. The hourly delay cost for automobiles was estimated based on the median household income for Laramie County, Wyoming, which was $54,596 for the years 2008-2012, and the procedures presented in Mallela and Sadasivam. [(4) (5).] The hourly delay cost for trucks was estimated as a sum of 2013 wages of truck drivers in Laramie County ($18.50 for trucks) and the Bureau of Labor Statistics' Employer Cost of Employee Compensation ($9.09 in June 2014)[(6) (7)]. Adding present value of time-related depreciation costs ($1.23/veh-h for automobiles and $9.29/veh-h for trucks), the net monetary value of hourly delay costs for automobiles and trucks are $24.52 and $40.19, respectively.

Using these assumptions and cost figures, the present value of delay costs associated with 18 percent trucks and 82 percent automobiles are estimated as follows:

313,900 veh-h × 0.82 × \$24.52 /veh-h + 313,900 veh-h × 0.18 × \$40.19 /veh-h = \$8,582,000.

Table 4. 2035 network performance comparison [(1)]

Scenario	**Average Delay (seconds/vehicle)**	**Latent Delay[1] (vehicle-hours)**	**Latent Demand[2] (vehicles)**	**Total Delay[3] (vehicle-hours)**
2035 Morning Peak				
2035 No-Build	40	0	0	25
2035 DDI	23	0	0	14
Improvement	43%	0%	0%	44%
2035 Afternoon Peak				
2035 No-Build	98	7	64	66
2035 DDI	49	1	6	34
Improvement	50%	85%	91%	48%

[1]Total waiting time of vehicles that could not immediately enter the network at their original start time.
[2]Number of vehicles that could not enter the network before the end of the simulation period.
[3]Total delay time of all active and arrived vehicles within the model; includes stopped delay (time when vehicle speed is zero).

Table 5. Level of service criteria for signalized intersections. [(1)]

Level of Service	**Control Delay Per Vehicle (seconds per vehicle)**	**Description**
A	≤ 10	Best, very low delay at signalized intersections.
B	>10 and ≤ 20	More vehicles stop than with level of service A, causing more delays.
C	>20 and ≤ 35	The number of vehicles stopping is significant, yet many still pass through the intersection without stopping.
D	>35 and ≤ 55	Influence of congestion more noticeable. Many vehicles stop, and the proportion of vehicles not stopping declines. Cycle failure, where a vehicle has to wait through one or more cycles to pass through the intersection, occurs more frequently.
E	>55 and ≤ 80	Individual cycle failures are frequent.
F	>80	Unacceptable to most drivers; arrival flow rates exceed capacity.

COST SUMMARY

The use of DDI, which cost $3,056,898.43, is expected to result in an estimated present worth savings of $8,782,000 ($8,582,000 accounts for the present value of reduction in user delays over 20 years and $200,000 accounts for the cost of signalizing the intersections at the interchange).

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APPENDIX

User Satisfaction Survey Results

Figure 29. Chart. Responses on minimized disruptions.

Table 6. Responses on minimized disruptions.

Answer Choices	Responses	
	Number	Percent
Agree	115	54.50%
Neutral	50	23.70%
Disagree	36	17.06%
Don't Know	10	4.74%
Total	211	100%

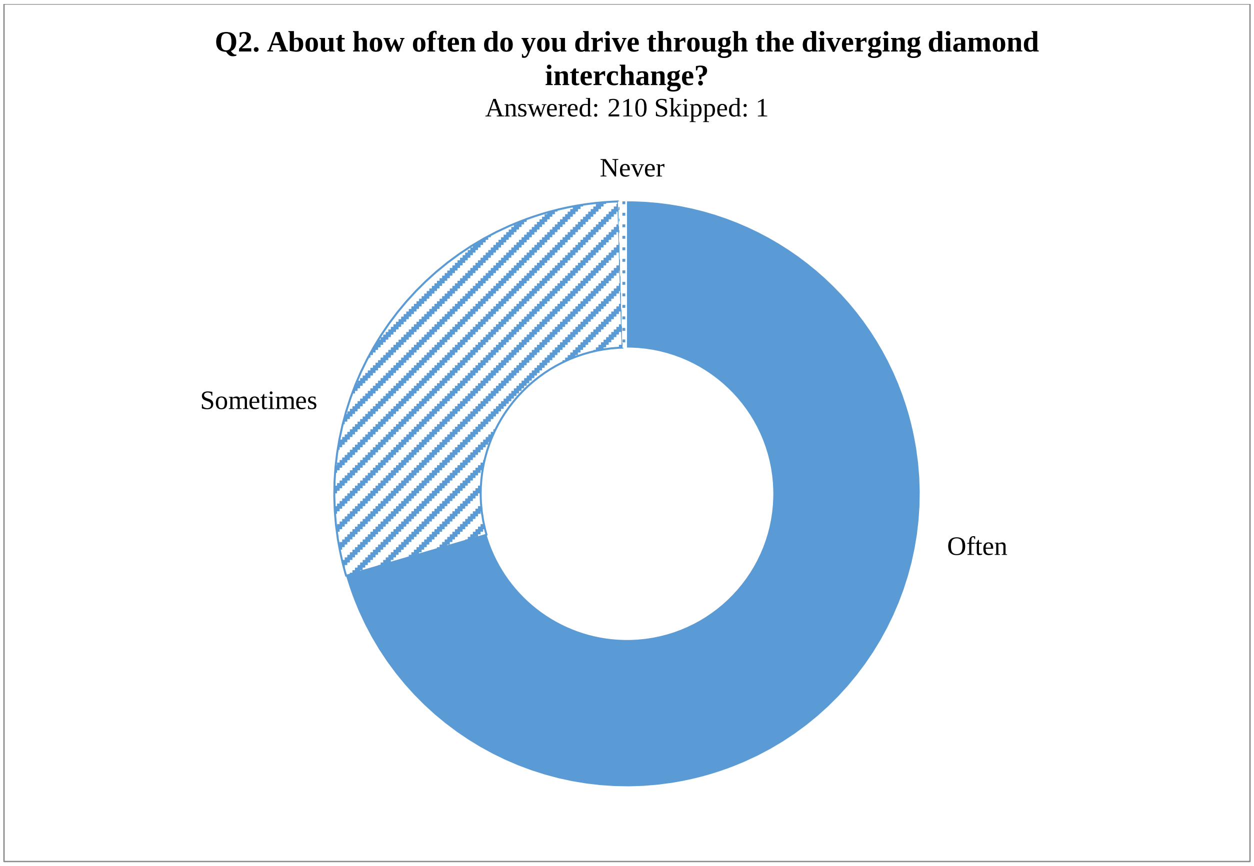

Figure 30. Chart. Responses on travel frequency.

Table 7. Responses on travel frequency.

Answer Choices	Responses	
	Number	Percent
Often	148	70.14%
Sometimes	61	28.91%
Never	1	0.47%
Total	210	100%

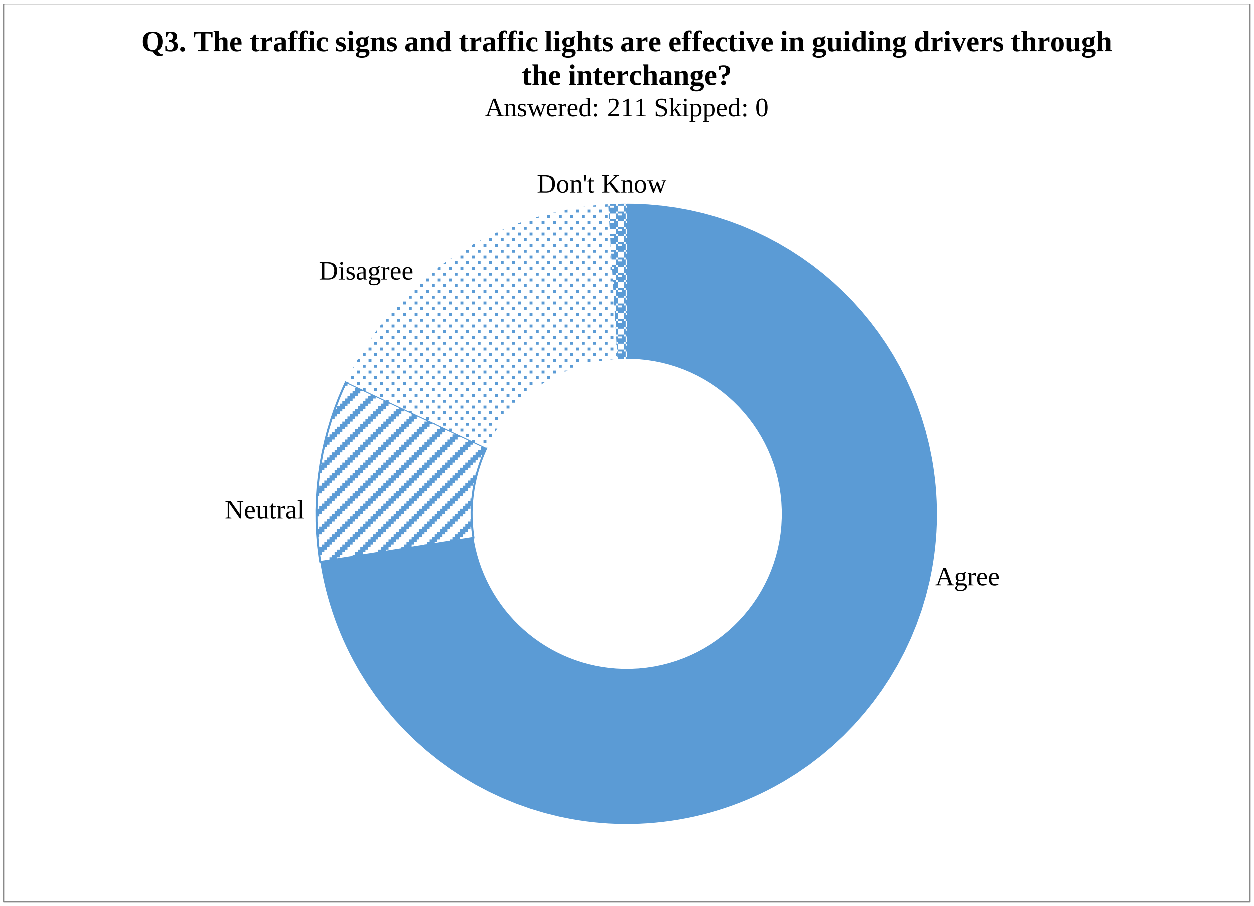

Figure 31. Chart. Responses on effectiveness of traffic lights.

Table 8. Responses on effectiveness of traffic lights.

Answer Choices	Responses	
	Number	Percent
Agree	153	72.51%
Neutral	20	9.48%
Disagree	36	17.06%
Don't Know	2	0.95%
Total	211	100%

Figure 32. Chart. Responses on effectiveness of striping.

Table 9. Responses on effectiveness of striping.

Answer Choices	Responses	
	Number	Percent
Agree	153	72.51%
Neutral	29	13.74%
Disagree	28	13.27%
Don't Know	1	0.47%
Total	211	100%

Figure 33. Chart. Responses on improved traffic flow.

Table 10. Responses on improved traffic flow.

Answer Choices	**Responses**	
	Number	**Percent**
Agree	152	72.04%
Neutral	28	13.27%
Disagree	28	13.27%
Don't Know	2	0.95%
Total	210	100%