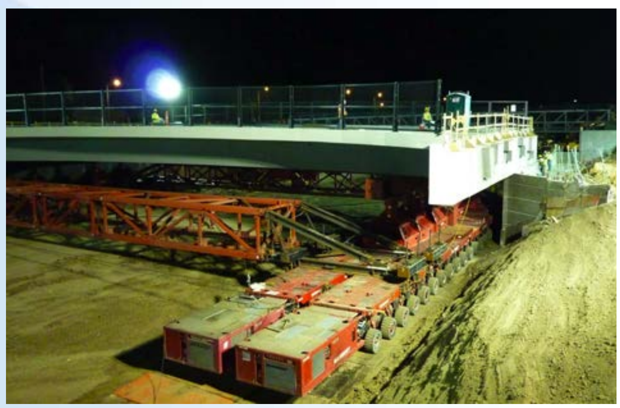
COLORADO DEMONSTRATION PROJECT:

Pecos Street over I-70 Bridge Replacement Using SPMT Technology

Final Report
October 2014

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. "Innovations" is an inclusive term used by HfL to 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 decisionmakers 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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1. Report	2. Government Accession No	3. Recipient's Catalog No
4. Title and Subtitle: Pecos Street over I-70 Bridge Replacement Using SPMT Technology		5. Report Date October 2014 6. Performing Organization Code
7. Authors Amar Bhajandas, P.E., and Suri Sadasivam		8. Performing Organization Report
9. Performing Organization Name and Address Applied Research Associates, Inc. 100 Trade Centre Drive, Suite 200 Champaign, IL 61820		10. Work Unit (TRAIS) C6B 11. Contract or Grant
12. Sponsoring Agency Name and Address Office of Infrastructure Federal Highway Administration 1200 New Jersey Avenue, SE Washington, DC 20590		13. Type of Report and Period Covered Final Report 14. Sponsoring Agency Code

15. Supplementary Notes
Contracting Officer's Representative: Julie Zirlin
Contracting Officer's Task Manager: Ewa Flom

16. Abstract
As part of a national initiative sponsored by the Federal Highway Administration under the Highways for LIFE program, the Colorado Department of Transportation was awarded a $3.76 million grant to replace the Pecos Street Bridge over I-70 to demonstrate the use of an alternative contract delivery method called construction management/general contractor (CM/GC) and the use of proven, innovative technologies for accelerated bridge removal and replacement. This report documents accelerated bridge construction technique using a self-propelled modular transporter (SPMT), which allowed substructure and superstructure work to proceed concurrently.

Under conventional construction methods, the project would have taken 15 months to build, causing significant delays to traffic on Pecos Street and I-70 due to limited closures and shutdowns. However, using the CM/GC approach and SPMT methodology, the bridge was replaced in only 7 months. The impact to travelers on I-70 was reduced to 50 hours over a weekend. Travelers on Pecos Street were impacted for 10 weeks, which were required to build roundabouts at both ends of the bridge to improve safety and capacity. By compressing the construction time, it is projected that 15 crashes were avoided at the site.

The construction costs for the innovative option were $0.65 million more than traditional methods would have been. However, user delay costs were reduced by an estimated $2.24 million. When bundled together, there was a net saving of $1.59 million. This represents about 9 percent of the $18.6 million spent for the construction and construction engineering for this project.

A public online survey indicated that, overall, more than 85 percent of the respondents were satisfied or very satisfied with the approach to minimizing traffic disruption during project construction.

Because of the success of this project, Colorado plans to accelerate bridge construction using SPMT on future projects, where this innovative technology is feasible and appropriate for conditions.

17. Key Words	18. Distribution Statement
Highways for LIFE, CM/GC, construction management general contractor, accelerated bridge construction, self-propelled modular transporter, SPMT, innovative construction, economic analysis, full lane closure.	No restriction. This document is available to the public through www.fhwa.dot.gov/hfl.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. # of Pages	22. Price
Unclassified	Unclassified	58	

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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	feet	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)

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ABBREVIATIONS AND SYMBOLS

ABC	Accelerated Bridge Construction
ADT	Average Daily Traffic
CM/GC	Construction Management/General Contractor
DOT	Department of Transportation
FHWA	Federal Highway Administration
HfL	Highways for LIFE
OSHA	Occupational Safety and Health Administration
QC/QA	Quality Control/Quality Assurance
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users
SPMT	Self-Propelled Modular Transporter

INTRODUCTION

HIGHWAYS FOR LIFE DEMONSTRATION PROJECTS

The Highways for LIFE (HfL) pilot program, the Federal Highway Administration's (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)—may 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 has issued open solicitations for HfL project applications since fiscal year 2006. 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 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 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 State 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—Twenty percent reduction in fatalities and injuries in 3-year average crash rates, using preconstruction rates as the baseline.
- **Construction Congestion**
    - Faster construction—Fifty 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 mile 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 measurement of less than 48 inches per mile.
    - Noise—Tire-pavement noise measurement of less than 96.0 A-weighted decibels, using the onboard sound intensity tests 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 accelerated bridge construction (ABC) techniques used to replace the Pecos Street Bridge over Interstate 70 in Denver, Colorado, over a 50-hour period during a weekend. The report describes the use of the innovative method of project delivery called construction manager/general contractor (CM/GC) that Colorado Department of Transportation (DOT) used to maximize design and construction efficiency. In this method, the owner engages a construction manager during the design process to provide constructability input.

The report presents project details relevant to the HfL program, including innovative construction highlights, rapid superstructure demolition and replacement using self-propelled modular transporter (SPMT) roll-in technology, HfL performance metrics measurement, economic analysis, and lessons learned.

Under conventional construction methods, the project would have taken 15 months to build and would have had considerable impacts to traffic. Instead, the Colorado DOT decided to construct substructure behind existing piers and concurrently build a superstructure at a nearby bridge staging area. The completed superstructure was rolled in place after demolition of the existing bridge during a 50-hour closure period. I-70 was immediately opened to traffic, and Pecos Street was opened to traffic following construction of roundabouts at each end of the bridge. A user satisfaction survey conducted following completion of the interchange showed that that over 85 percent of the respondents were satisfied with how closures were handled and with the projects results.

PROJECT OVERVIEW AND LESSONS LEARNED

PROJECT OVERVIEW

As shown in figure 1, the project site is approximately 1 mile west of the I-70/I-25 interchange, the largest and the most complex interchange in the entire State, carrying a combined average daily traffic (ADT) of 340,000. I-70 has an ADT of 123,000 west of Pecos Street and 118,000 east of Pecos Street. Pecos Street itself carries an ADT of 19,150 south of the bridge and 10,320 north of the bridge. Street layout and traffic information is shown in figure 2.

The concrete slab and girder bridge, built in 1965, was structurally deficient, with a sufficiency rating of 43.9. (See figure 3). The substructure was rated as "poor" due to deterioration, cracking, and spalling of the columns and abutments. (See figure 4).

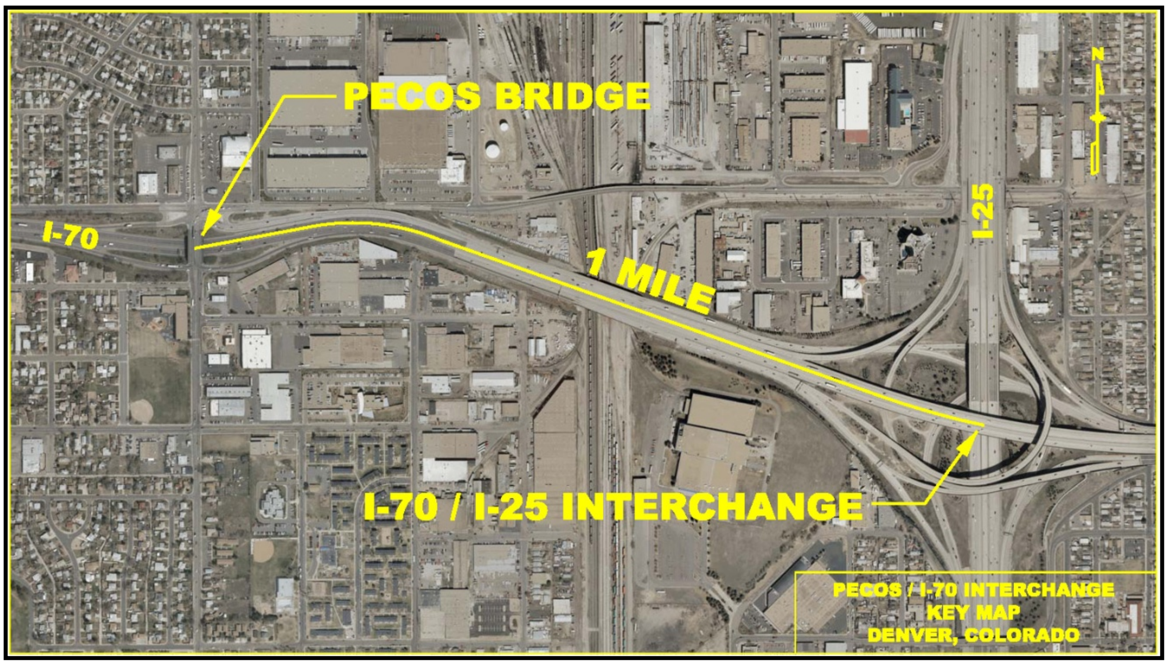

Figure 1. Map. Pecos Street project in relation to I-70 and I-25 interchange (courtesy: Colorado DOT).

Figure 2. Map. Pecos Street interchange with street layout and traffic information (courtesy: Colorado DOT).


Figure 3. Photo. Looking west under Pecos Street (courtesy: Colorado DOT).

Figure 4. Photo. Spalling of columns (courtesy: Colorado DOT).

The most significant challenge of this project was how to limit disruptions to traffic on I-70 and Pecos Street during bridge removal and replacement. Traditional construction would have required about 20 to 30 lane closures on this primary east-west interstate, undoubtedly snarling traffic in every direction in the vicinity. The Colorado DOT also estimates that the project would have taken about 15 months to complete. Additionally, traditional construction would have required construction alongside active traffic, which would have created safety concerns for road users and for the contractor and other personnel working within the work zones. The traffic impacts and safety vulnerabilities were unacceptable to the DOT, and they explored innovative methods to reduce construction time and exposure to safety-related risks.

The project initially was slated to be a bridge replacement project. However, after site visits, the project team identified traffic and geometric deficiencies that needed to be improved. The team considered 15 alternatives and concluded that replacing the traffic signals at each ramp intersection with modern roundabouts would provide the best solution.

To maximize design and construction efficiency, the Colorado DOT used the CM/GC contracting method. In this method, as described on the FHWA website [(1)]:

> The owner engages a construction manager during the design process to provide constructibility input. The construction manager is generally selected on the basis of qualifications, past experience or a best-value basis. During the design phase, the construction manager provides input on scheduling, pricing, phasing and other input that helps the owner design a more constructible project. At approximately an average of 60% to 90% design completion, the owner and the construction manager negotiate a "guaranteed maximum price" for the construction of the project based on the defined scope and schedule. If this price is acceptable to both parties, they execute a contract for construction services, and the construction manager becomes the general contractor. The CM/GC delivery method is also called the Construction Manager at-Risk (CMR) method by state law in some states.

The Colorado DOT used ABC to compress construction time, minimize traffic impacts, improve worker/road user safety, and advance ABC knowledge in the State. The agency considered using the bridge slide-in concept, which would have required constructing the replacement bridge using temporary abutments adjacent to the existing bridge, demolishing the old structure, and sliding the new superstructure onto new permanent abutments. This process would have reduced construction time through simultaneous construction of the substructure and superstructure, but it also would have required numerous lane closures on I-70. Instead, Colorado DOT used SPMT technology to transport the superstructure that would be built in a nearby bridge staging area.

The Colorado DOT applied for and successfully obtained $3.76 million in HfL funding. The agency was also successful in obtaining hazard elimination safety funds for the use of roundabouts at this location.

Pecos Street serves as a dividing line between the Sunnyside and Chaffee Park neighborhoods on the west and an industrial area on the east. Additionally, businesses on the fringes of the interchange serve the communities and the travelers contributing to the traffic flow. The project is located in an area of environmental justice, which effectively meant that any right-of-way takes would have substantial impacts to the community and were to be minimized to the extent possible. The minimization effort allowed footprints of both roundabouts to encroach upon the new bridge's envisioned footprint. To make the required turning radii within the highly constrained right-of-way, the bridge itself had to be widened at each end, giving it an hourglass shape in plan view.

The project team considered several different structure types and selected the cast-in-place, single-span post-tensioned concrete box-girder bridge, 156 feet long and with a depth that varied from 76 to 84 inches.

The project designer worked closely with the specialty contractor for the roll in of the superstructure, estimated to weigh 2,400 tons. Two transverse lifting diaphragms 15 feet from each abutment were designed into the bridge for lifting during transportation. The design team used 3D finite element software to design the bridge for all load conditions, including temporary loads generated into the structure during the move.

The substructure units were built behind the two existing piers and in front of the existing abutments, and the superstructure was built in a staging area in the southeast quadrant of the interchange, about 700 to 800 feet away from its final position on the bridge. The bridge staging area was over an abandoned roadway, away from traffic. The substructure and the superstructure were built concurrently, which reduced construction time from 15 months to 7 months.

First, a "rat slab" was constructed with trenches on either side for climbing jacks that would support the superstructure at the bridge staging area. Once the superstructure was completed, cured, and ready to be moved, it was lifted 17 feet above the ground level to enable the SPMT to be positioned under the lifting diaphragms. The project team collaborated extensively on the SPMT travel path design to ensure that the 3 percent maximum grade for equipment stability was not exceeded and that twisting was not induced. Furthermore, to protect the roadway from damage due to the massive weight, steel street cover plates were placed end to end along the travel path.

I-70 was closed to traffic on July 19, 2013, at 10:30 p.m. and reopened at 12:30 a.m. on July 22. During the weekend closure, the existing bridge was demolished, the site cleared of debris, the SPMT-supported structure rolled along the carefully chosen travel path, and the structure placed in its final position with the deck flush with the existing roadway surface. The travel path plates and fill material were removed once the bridge was in its final resting position, the area was cleared, and the road was opened to traffic.

During the entire move, the middle of the lifting diaphragm did not exceed the allowable deflection of 0.25 inches and the bridge did not develop any new cracks.

Colorado DOT set up a viewing area during the move for the public to witness this innovative method of bridge replacement. Over 1,000 observers participated.

The roundabout construction was completed once the superstructure was in place.

Pecos Street was opened to traffic on September 1, 2013.

The SPMT roll-in technology on this project is a first for the Colorado DOT. This project is also one of eight projects being evaluated for the CM/GC method of project delivery under a Colorado DOT/FHWA programmatic agreement. Throughout this project, the Colorado DOT gained important knowledge and experience using these innovative techniques. This experience will aid in identifying when these techniques can be leveraged to provide schedule, quality, and cost benefits. From users' perspective, by successfully removing and replacing a structure during a 50-hour window, Colorado DOT has shown it is among the leaders in implementing innovative technology and has undoubtedly raised expectations on project delivery in the future.

DATA COLLECTION

Safety, construction congestion, quality, and user satisfaction data were collected to demonstrate how the use of innovative features at this interchange helped achieve the HfL performance goals in these areas.

No worker injuries or motorist incidents were reported during construction, which means the Colorado DOT exceeded the HfL requirements for worker and motorist safety. This success can be attributed to preventive actions taken by Colorado DOT, which included:

- Inclusion of contractor safety performance and practices in the criteria for CM/GC best value selection.
- Use of input from local jurisdictions in detailed development of traffic control plans.
- Use of traveler information concerning traffic management changes and alternative travel strategies to reduce overall volumes at the site. The Colorado DOT made information available through media, the agency's website and 511 system, and changeable message signs along the corridor.

- A requirement that the contractor develop a project safety management plan. The minimum elements of this plan included designation of a safety officer to conduct regular safety meetings and job site safety reviews and reporting of violations.

Had conventional construction been used on this project, Pecos Street Bridge would have been built in phases extending over 15 months. With the use of innovative technology and concurrent construction of the substructure and superstructure, Colorado DOT was able to minimize road user impacts by completing the bridge faster—in about 47 percent of the time that conventional construction would have taken, exceeding the HfL goal of 50 percent.

Based on crash experience at the site, it is projected that by reducing the construction time, about 15 crashes were avoided, 2 of which could have been injury-related. Also, with construction of roundabouts, it is projected that during the 5-year post-construction period, the number of crashes should be decreased by 136 and those with injuries/fatalities should be decreased by 21. These projections are based on reduction in crash rate from a national study of 37 percent for all crashes and 51 percent for injury-related crashes, easily exceeding the HfL goal of 20 percent. [(2)]

With the superstructure being built at a nearby abandoned roadway site, trip time traveling through the project site was virtually unaffected by the construction, and there were no significant queues formed due to construction, easily meeting the HFL goals on trip time and queue lengths. In contrast, conventional construction would have caused considerable backups on I-70 due to lane closures and extensive queue lengths on Pecos Street due to phased construction.

In addition to the safety-related benefits, building the bridge superstructure away from traffic enabled easy construction access and improved quality. Longitudinal joints due to phased construction under the conventional construction were also avoided, as the deck was cast in one piece off site.

The project team performed an online post-construction survey, which was completed by 104 people who provided favorable (very satisfied or satisfied) ratings to virtually every aspect of the project. Overall, 85.5 percent of the respondents gave a favorable rating on how the project was built. Specifically, 69.9 percent felt that traffic flow at the interchange had improved, and 90.4 percent were satisfied or very satisfied with the use of ABC technology. Also, 77.8 percent of the respondents were satisfied or very satisfied with how traffic disruptions were minimized on I-70, 61.2 percent were satisfied or very satisfied with how they were minimized on Pecos Street, and 63.7 percent were satisfied or very satisfied with how disruptions of access to neighborhood and businesses were minimized.

ECONOMIC ANALYSIS

The benefits and costs of this innovative project approach were compared with the costs expected using the traditional approach. During project planning, Colorado DOT estimated that the construction cost of the bridge portion using traditional phased construction would be $4.0 million and the cost of building the bridge using SPMT would be $4.6 million, about 15 percent higher. Colorado DOT also computed user delay costs. These costs were $3.5 million for the conventional option and $1.3 million for the innovative option, which more than compensated for the increased construction cost. Although the use of SPMT increased the construction cost by $0.6 million, it lowered the delay costs by $2.2 million dollars. Overall, the innovative option provided a 3.66 benefit-to-cost ratio.

LESSONS LEARNED

Through this project, Colorado DOT gained valuable insights on the innovative processes deployed, both those that were successful and those that need improvement in future project delivery. Observations and lessons learned include:

- Assign adequate time for CM/GC negotiations. On this project, it took more time than originally anticipated.
- The CM/GC method of project delivery enabled the owner, designer, and contractor to work as a team on this complex project. Nonetheless, there are unknowns that arise during construction.
- The CM/GC approach appears to promote a good working relationship between the designer and the contractor due to working as a team in design.
- The final structure selection process with the owner, designer, and contractor working as a team was beneficial in arriving at the final design. The team considered seven different structure types before selecting the final design.
- The collaboration of the designer, contractor, and specialty subcontractor on designing the temporary and permanent construction elements was effective.
- Engage heavy lifter subcontractor in the design process to better understand loads induced on lifting diaphragms.
- Consider barrier rebar conflicts with post-tensioning anchorages in design.
- A lighter weight bridge reduces the number of axles needed and the cost of the SPMT, which was about $10,000 per axle for this project.
- Using plans not in final design allows for changes that can lead to change orders.
- The closure period for the demolition of the old structure and rolling in of the new superstructure was adequate.
- Public outreach efforts and pre-event and during event communications with stakeholders were effective.
- The SPMT equipment is sophisticated, yet it is dependent on the skill set of the operator, just like a crane is.
- It is important to be thoroughly familiar with the staging area and be thoroughly aware of all the grade changes and obstructions along each path of SPMT travel.
- Contract documents need to be complete and accurate to minimize extra costs and schedule impacts. These impacts are amplified when the schedule is compressed.

PUBLIC INVOLVEMENT

Colorado DOT’s comprehensive public outreach to local businesses and neighborhoods and the agency’s efforts to minimize disruption to their business and travel due to construction resulted in a 64 percent positive response from respondents to a survey. Over 61 percent were also satisfied with the way Pecos Street traffic was managed throughout construction, including closure of the street for 10 weeks. The availability of I-25 and I-76 very close to the project and diversion of I-70 traffic to these interstates minimized impediments to I-70 travelers during the 50-hour full closure period. Overall, almost 79 percent of survey respondents were satisfied or very satisfied with the agency's efforts to minimize travel disruption.

CONCLUSIONS

From the standpoint of construction speed, motorist and user safety, cost, and quality, this project was a success and embodied the ideals of the HfL program. Colorado DOT learned that careful planning, use of the CM/GC method of project delivery, use of ABC technologies during bridge construction, and construction of roundabouts at the interchange can result in projects that serve as watershed events in the way they are delivered to the public. A post-construction stakeholder survey clearly indicated that local residents, businesses, and commuters did not experience major delays as a result of the bridgework and were satisfied with the project.

Because of the success of this project, Colorado DOT plans to consider CM/GC and SPMT technology as viable tools in its accelerated bridge replacement toolkit on all future projects.

PROJECT DETAILS

BACKGROUND

As noted in the previous chapter, this project is located in the heart of the Denver metropolitan area, on a heavily traveled section of Pecos Street between the Federal Boulevard interchange and the I-70/I-25 interchange. It is about 1 mile west of the heavily traveled I-70/I-25 interchange. Figure 5 shows the site map. Eastbound I-70 has three lanes and serves as one of the primary routes to the Denver downtown business district and Denver International Airport. Westbound I-70, also with three lanes, serves as the primary route to local communities, cities, and mountains.

The scope of the project was to replace the Pecos Street three-span slab and girder bridge built in 1965 that had deteriorated to a sufficiency rating of 43.9.

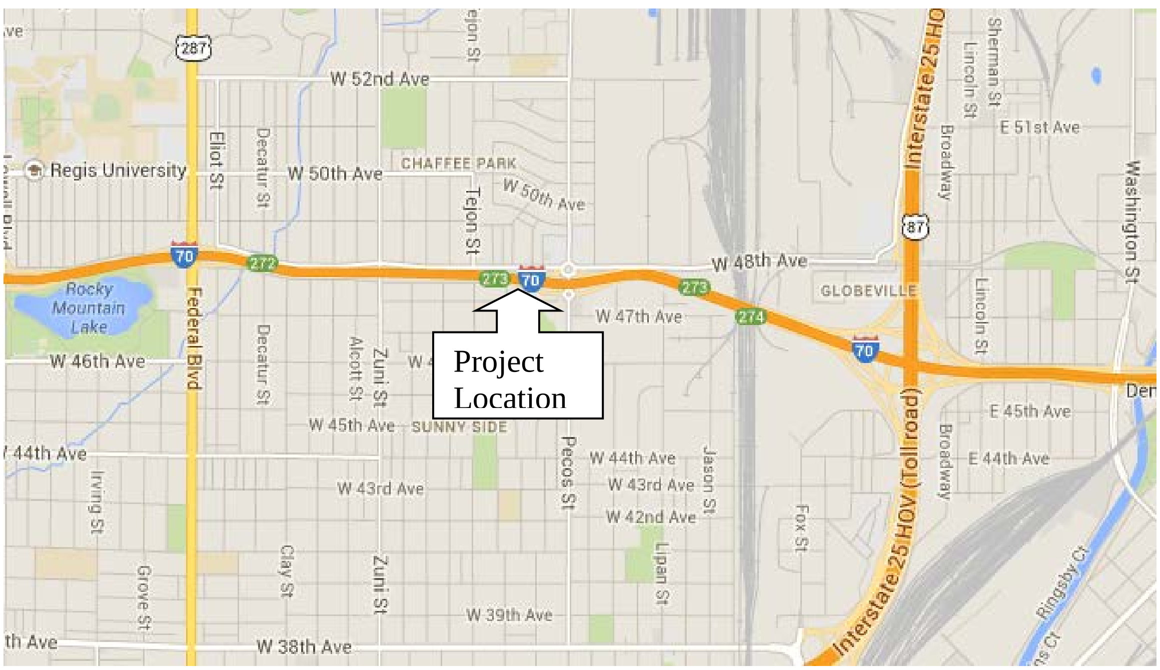

Figure 5. Map. Project location (courtesy: Colorado DOT).

Colorado DOT decided that this project would use ABC to minimize construction impacts to the traveling public. The agency also decided to use the CM/GC delivery process to maximize design and construction efficiency.

The project goals were as follows:

- Advance knowledge, experience, and cost efficiency of the Colorado DOT construction program and the construction industry in ABC and CM/GC project delivery.
- Provide a well-publicized, highly successful ABC project.
- Replace the poor structure and improve traffic operations and safety within the project

budget.

- Accelerate delivery of construction schedule and complete by October 1, 2013.
- Minimize inconvenience to the traveling public.
- Maximize the safety of workers and the traveling public.
- Facilitate a collaborative partnership with all of the members of the project team and stakeholders.
- Provide a high-quality design and construction.

CM/GC Project Delivery Method

Colorado DOT developed a project delivery selection matrix to guide the selection of the preferred method of project delivery. The matrix considers the following factors:

- Project complexity.
- Opportunities for innovation.
- Delivery schedule.
- Level of design.
- Project unknowns.
- Staff experience/availability.
- Level of oversight.
- Risk allocation.
- Competition, availability, and experience.
- Other factors.

The agency considered design-bid-build, design-build, and CM/GC project delivery methods and concluded that the CM/GC method was the most appropriate for this project.

Colorado DOT used the best value method to select the CM/GC contractor in December 2011. Having the contractor on board during design allowed valuable input for several project decisions, including structure type, foundation for abutments, selection of the ABC method, temporary supports at the bridge staging area, and the construction schedule. It enabled the contractor to pick the best staging area early in the design process and the designer to incorporate permanent diaphragms in the structure at the lift points. With contractor input on pricing, the costs of ABC were also more accurate, as were the overall costs for the project. The contractor’s bid was within 2 percent of the engineer’s estimate of $13.6 million.

PROJECT ENGINEERING

Site visits confirmed inadequate capacity and geometry for current and future traffic demands. The project team considered 15 alternatives, including:

- Restriping bridge to provide two southbound lefts.
- Adding lanes to bridge (two alternatives were considered).
- Relocating movements in north intersection (seven alternatives were considered).

- Full interchange (three alternatives—single point urban interchange, diverging diamond interchange, and offset intersection with flyovers).
- Modern roundabouts.

The project team opted to construct roundabouts because they accommodated north intersection movements, improved safety, and minimized the footprint of the bridge. The two-lane roundabouts required only four lanes across the structure. This resulted in an hourglass-shaped deck that was 63 feet wide in the middle, 130 feet wide at the northern end, and 80 feet wide at the southern end.

There is a significant amount of foot traffic and bicycles at this location, and the design team decided early in the design process that the best solution to accommodate these needs was to build a separate pedestrian bridge, in lieu of adding sidewalks to the vehicular structure. The team determined that the cost of a pedestrian bridge was comparable to a bridge with sidewalks.

The project team considered seven different structure types, including steel girders precast and cast-in-place concrete. The cast-in-place, post-tensioned concrete box-girder bridge was selected because it best satisfied the evaluation factors of construction costs, bridge move costs, procurement schedule, structure depth and aesthetics.[1] Figure 6 shows a plan view of the structure.

> The superstructure has a span length of 156 ft and consists of three cells with four webs. The two internal webs are straight with a thickness of 12 in. whereas the two external webs are curved in plan with a thickness of 15 in. Web spacing varies from 16 to 23.5ft. The superstructure is longitudinally post-tensioned internally in the webs and externally in the boxes. The overall depth of the superstructure varies from 76 to 84 in. The transversely post-tensioned deck has a thickness of 9 to15 in. The bottom slab has a thickness of 6 to 8.5 in. The non-prestressed reinforcement is epoxy coated.[1]

[1] ASPIRE, Winter 2014

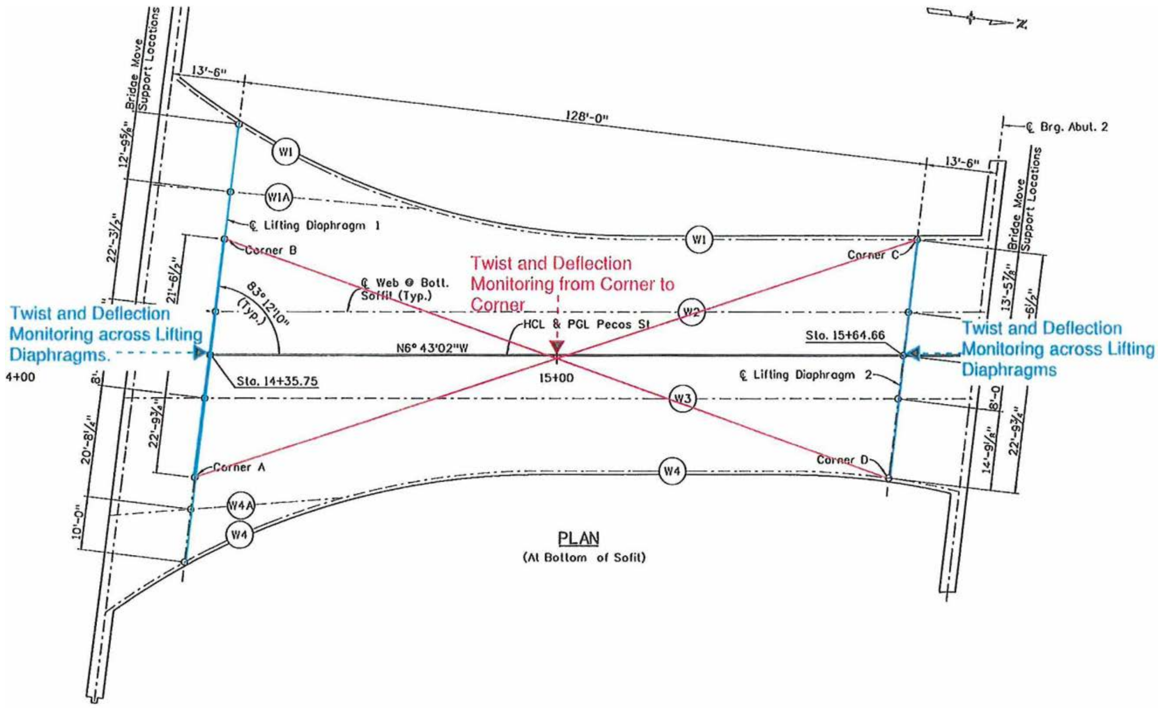

Figure 6. Diagram. Plan view of superstructure showing lifting diaphragms (courtesy: Colorado DOT).

Accelerated Bridge Construction Method Selection

The project team explored ABC for a number of reasons, including the high traffic volumes at the project location, preference for reduced construction schedule, safety concerns, and the ability to expand ABC construction knowledge in the State. The team went through a formal process using Utah DOT's ABC rating procedure and FHWA's decision-matrix framework for PBES as guides to determine the ABC rating for this project. See figure 7 for scoring and costs.

The cost information clearly indicates that ABC with the SPMT option had the lowest user delay costs. Additionally, conditions at the site affirmed the viability of the innovative option. The CM/GC approach provided an opportunity for the contractor to affirm conditions that included acceptable grades, room for substructure construction that could occur concurrently with superstructure construction, room for maintaining traffic, acceptable area for bridge staging, and suitability of the travel path between the staging area and the abutments. The proximity of the staging area in the southeast corner of the interchange is shown in red in figure 8.

	Project:	Pecos over I-70		
DOT DEPARTMENT OF TRANSPORTATION	By:	TWM	Checked:	
	Date:	9/15/2011		0/0/00
	Sheet No.	2	of	3

ABC Rating Procedure **August 2011**

Note: Do not adjust weight factors without prior consultation with CDOT Project Development Manager

ABC RATING SCORE FACTORS AND WEIGHTS					
	Score	Weight Factor	Adjusted Score	Maximum Score	Adjusted Score
Average Daily Traffic	5	10	50	5	50
Delay/Detour Time	2	10	20	5	50
Bridge Importance	1	5	5	5	25
User Costs	5	10	50	5	50
Economy of Scale	0	3	0	3	9
Safety	1	3	3	5	15
Railroad Impacts	3	10	30	5	50
Site Conditions	0	5	0	5	25
		Total Score	158	Max. Score	274

ABC Rating Score: 58 % of Maximum Score

The ABC Rating Score is driven by the four most heavily weighted factors: Average Daily Traffic, Delay/Detour Time, User Costs and Safety. For a detailed explanation, review the narrative on page 4 of the ABC Decision Making Process.

Cost Considerations:
Calculate the following costs for use in determining the lowest total project cost

TOTAL PROJECT COST EVALUATION			
	Alt #1: 3-phase Conv.	Alt #2: ABC with SPMT	Alt #3: ABC with slide-in
Bridge Const Costs	$3,552,000	$3,552,000	$3,552,000
ABC costs or overbuild	$450,000	$800,000	$250,000
User Delay Costs	$3,543,000	$1,305,000	$1,452,500
Bridge Project Cost	$7,545,000	$5,657,000	$5,254,500

User costs/bridge costs	**1.00**	**0.37**	**0.41**

Figure 7. Image. ABC rating procedure (courtesy: Colorado DOT).

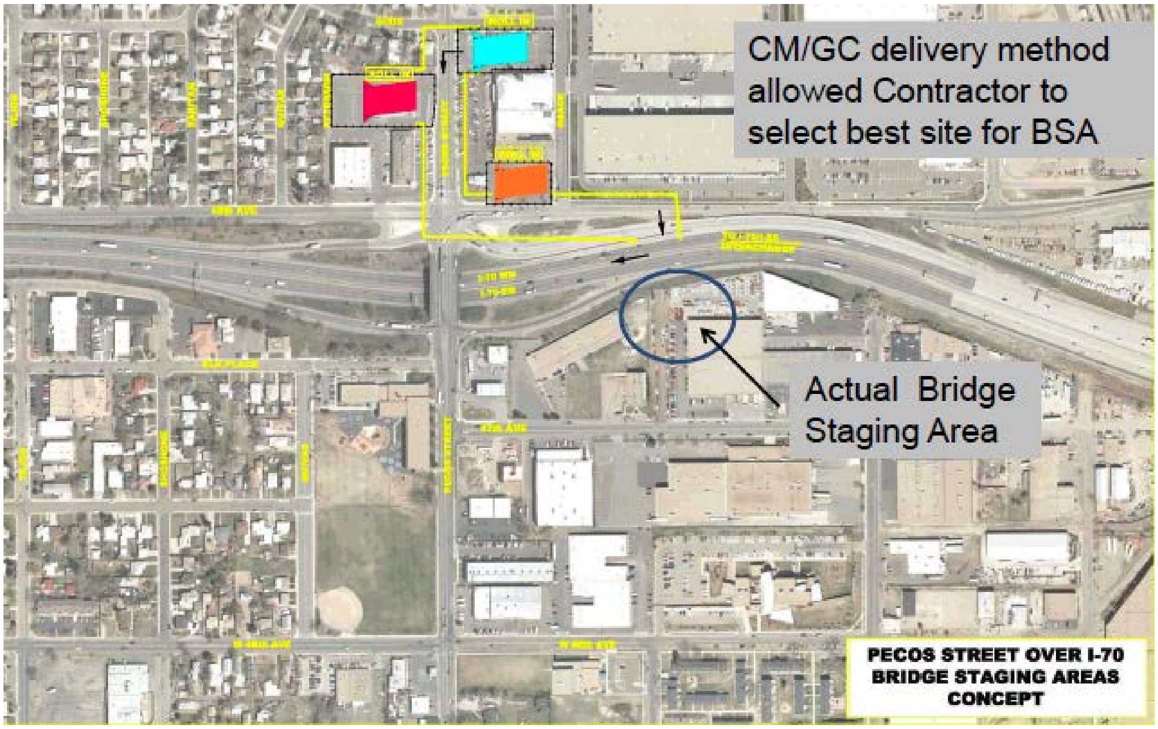

Figure 8. Map. Bridge staging area (courtesy: Colorado DOT).

PROJECT CONSTRUCTION

The construction timeline was as follows:

- January 2013: Begin construction.
- June 2013: Final concrete pour for superstructure.
- June 24, 2013: Close Pecos Street.
- July 19-21, 2013: 50-hour closure of I-70.
    - July 19, 10:30 p.m.: Close I-70 and begin bridge demolition.
    - July 20, noon: Begin moving bridge.
    - July 21, 1 a.m.: Place bridge in final position.
    - July 22, 12:30 a.m.: Open I-70.
- September 2013: Complete construction.

Concurrent construction of the superstructure and substructure required that the bridge abutments be constructed underneath the existing bridge. The abutments therefore required the use of low overhead caisson rig. Figure 9 shows construction of the foundation for the abutment under the old bridge, which also shows the traffic signals that were replaced by the roundabouts. Figure 10 shows substructure work being performed on both vehicular and pedestrian bridges.

Figure 9. Photos. Abutment construction under existing bridge (courtesy: Colorado DOT).

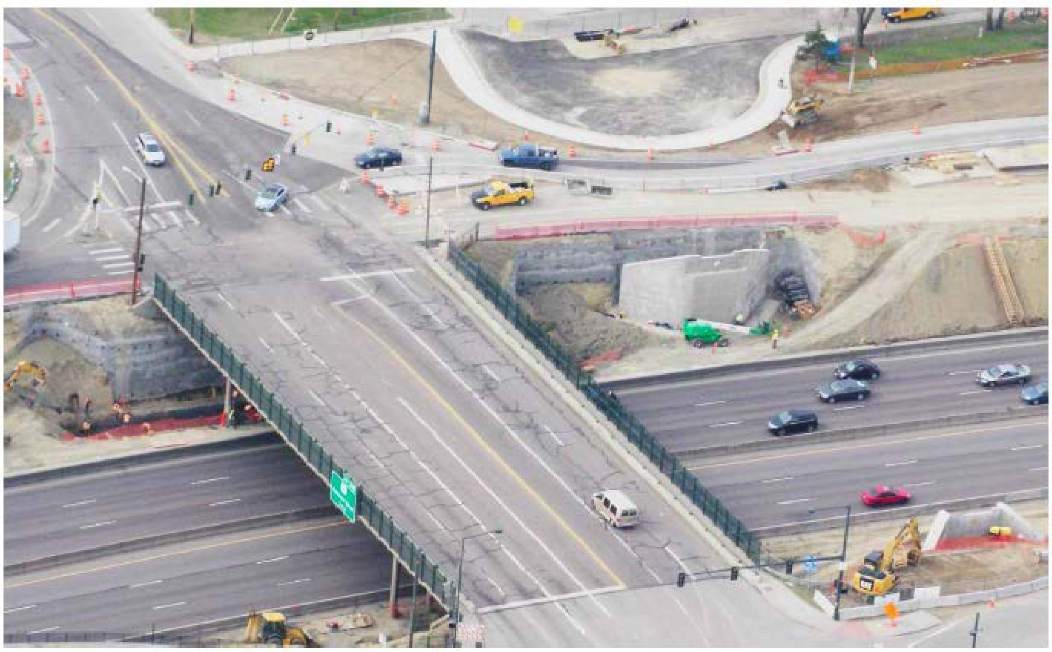

Figure 10. Photo. Substructure work being performed on vehicular and pedestrian bridges (courtesy: Colorado DOT).

Concurrent with the substructure construction, the bridge staging area construction got started in the southeast corner of the interchange with the casting of the “rat slab” or base slab and trenches for the lifting jacks (figure 11). A close-up view of the slab, which served as the level ground for the SPMT to lift the superstructure at the diaphragms, is shown in figure 12.

Figure 11. Photos. "Trench and "rat slab" construction in bridge staging area (courtesy: Colorado DOT).

Figure 12. Photo. Close-up of completed "rat slab" or base slab construction (courtesy: Colorado DOT).

The reinforcement for one of the two diaphragms at 15 feet from each end of the superstructure is shown in figure 13, and the overview of the bridge staging area showing reinforcement work in progress is shown in figure 14.

Figure 13. Photo. Epoxy-coated reinforcement for diaphragm (courtesy: Colorado DOT).

Figure 14. Photo. Overhead view of bridge staging area (courtesy: Colorado DOT).

The concrete finishing of deck for the superstructure poured in late May is shown in figure 15. Casting the deck at ground level avoided the challenges of concrete placement encountered in elevated decks.

Figure 16 shows the pedestrian bridge being positioned in place just to the west of the Pecos Street Bridge.

Figure 15. Photo. Deck finishing operation (courtesy: Colorado DOT).

Figure 16. Photo. Placement of pedestrian bridge (courtesy: Colorado DOT).

The superstructure is longitudinally post-tensioned internally in the webs and externally in the boxes. The four types of post-tensioning in the superstructure are shown in figures 17 through 20.

The transversely post-tensioned deck has a thickness of 9 to 15 inches. The bottom slab has a thickness of 6 to 8.5 inches.

Figure 17. Photo. Longitudinal internal tendons (courtesy: Colorado DOT).

Figure 18. Photos. Longitudinal external tendons (courtesy: Colorado DOT).

Figure 19. Photo. Vertical tendons in end diaphragms (courtesy: Colorado DOT).

Figure 20. Photo. Transverse deck tendons (courtesy: Colorado DOT).

Bridge Move

SPMTs are computer-controlled platform vehicles capable of moving very heavy objects weighing up to several thousand tons. (See FHWA's *Manual on Use of Self-Propelled Modular Transporters to Remove and Replace Bridges* for details. [(3)]) Using an SPMT requires considerable coordination and collaboration among the subcontractor specializing in SPMT, the prime contractor for the project, and the designer. In this instance, the project team conducted over a dozen meetings refining the design of the moving equipment and the design of the lifting diaphragms. The vertical stroke of the SPMT had to be such that it was adequate to lift the superstructure off the climbing jacks at the bridge staging area and set it on the abutments of the new bridge.

The completed superstructure shown in figure 21 also needed to be monitored for deflections and twist during lifting, transfer of support to lifting diaphragms, transport from the bridge staging area to the bridge abutments, and transfer to its final position. Both twist and deflection were monitored at points shown in figure 6 to ensure that they did not exceed the maximum specified (0.75 inches for twist and 0.25 inches for deflection). A total of 96 SPMT axles, each axle capable of carrying approximately 30 tons, were deployed to lift the superstructure, estimated to weigh 2,400 tons.

Figure 21. Photo. Completed superstructure on temporary supports (courtesy: Colorado DOT).

Figure 22 shows the temporary support in its lowered position, and figure 23 shows the support in raised position to accommodate rolling in of the SPMTs under the lifting diaphragms. Figure 24 shows the operator guiding a SPMT under one of the two lifting diaphragms, and figure 25 shows the frames connecting the SPMT units. Figure 26 shows workers connecting one of the two frames to a unit under one of the two lifting diaphragms.

Figure 22. Photo. End diaphragms on temporary support (courtesy: Colorado DOT).

Figure 23. Photo. Superstructure lifted at end diaphragm supports (courtesy: Colorado DOT).

Figure 24. Photo. Operator rolling SPMT into position under the lifting diaphragms (courtesy: Colorado DOT).

Figure 25. Photo. Frame used to connect equipment under lifting diaphragms (courtesy: Colorado DOT).

Figure 26. Photo. Workers connecting frame (courtesy: Colorado DOT).

The travel path design required significant coordination to ensure that the 3 percent maximum grade for the stability of equipment was not exceeded. Figure 27 shows a plan view of the travel path. Steel plates at least 1 inch thick were used along the travel path to avoid damage to the roadway due to the high stresses. They were laid end to end along the travel path and, as the SPMT moved past a point, the plates were lifted by the forklift and moved to the front.

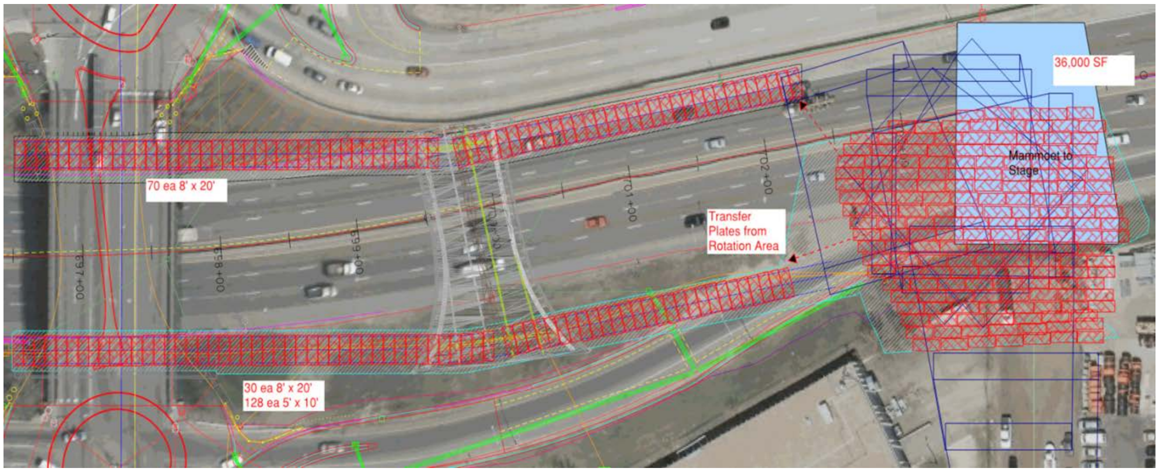

Figure 27. Photo. Plan view of travel path (courtesy: Colorado DOT).

Colorado DOT conducted a media blitz encouraging motorists to plan ahead for full closure of I-70 between I-25 and Federal Boulevard and provided tools such as Colorado DOT Mobile, 511, and www.cotrip.org to aid the planning effort. Motorists were encouraged to use Federal Boulevard to cross I-70 during the closure or use I-76 as an alternate route.

The closure of I-70 started at 10:30 p.m. on July 19. At approximately midnight, the demolition of the structure began (see figure 28). The demolition continued into daylight the next day. Figure 29 shows a view of the partially demolished bridge. The superstructure supported by SPMTs, shown in figure 30, was turned 180 degrees once it got on I-70 and then moved west on

I-70 traveling at approximately 100 to 120 feet per hour. Figure 31 shows the SPMT moving westward over steel plates along the travel path, and figure 32 shows the structure being aligned and positioned over the abutments.

Figure 28. Photo. Demolition of old structure underway (courtesy: Colorado DOT).

Figure 29. Photo. Daylight view of partially demolished structure (courtesy: Colorado DOT).

Figure 30. Photo. Superstructure on SPMT preparing to get on to I-70 (courtesy: Colorado DOT).

Figure 31. Photo. SPMT traveling over steel plates westward on I-70 (courtesy: Colorado DOT).

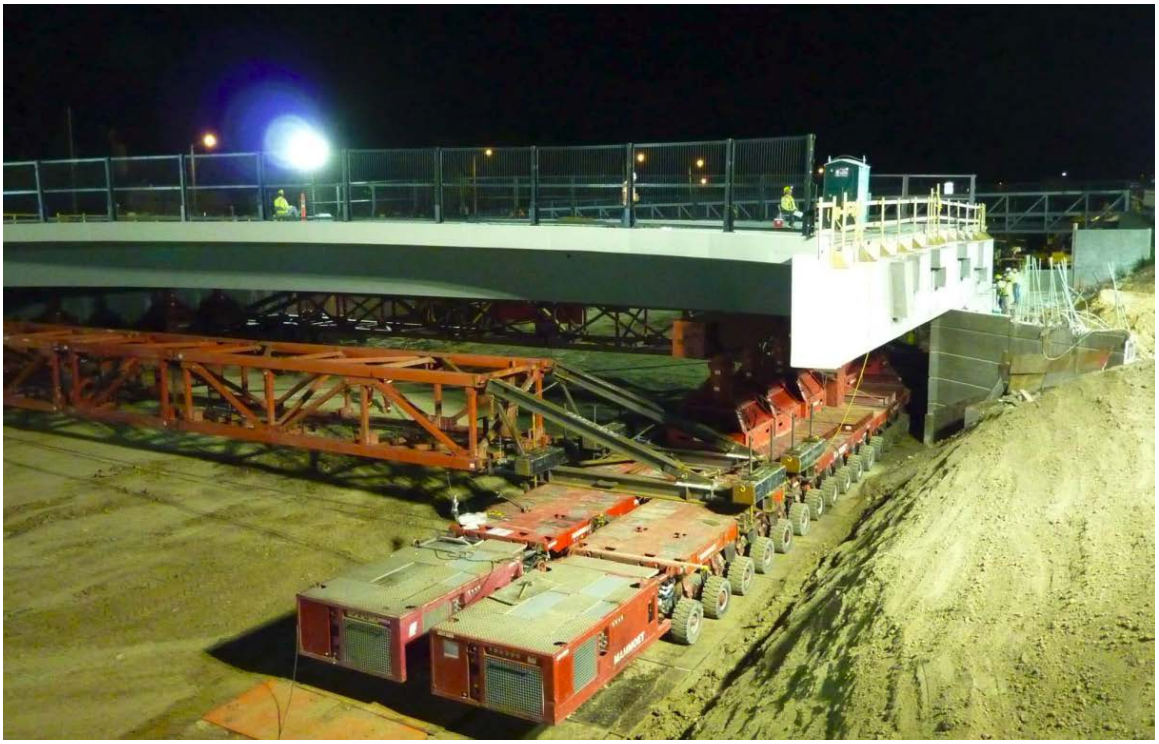
Figure 32. Photo. Superstructure being placed over abutments (courtesy: Colorado DOT).

Colorado DOT set up a viewing area on Saturday, July 20, for the public on the north side of I-70 near the westbound I-70 off-ramp to Pecos Street. Over 1,000 spectators observed the demolition, roll-in, and cleanup of the site. Live streaming of the bridge rollout was made available at www.coloradodot.info/projects/pecosoveri70, and a time-lapse video was also made available online following the bridge move.

I-70 was opened to traffic on Monday, July 22, 2013, at 12:30 a.m. Pecos Street remained closed through August for construction of roundabouts and median, installation of water lines, building of retaining walls, and installation of pedestrian signals and fence.

Colorado DOT installed a high-intensity activated crosswalk (HAWK) pedestrian signal to provide improved safety for pedestrians south and north of I-70 on Pecos Street. To the pedestrian, the HAWK signal is very similar to typical pedestrian signals. However, to motorists, there is a difference. The HAWK signal flashes yellow when activated by a pedestrian, indicating to the driver that pedestrians will be using the crosswalk. It then goes solid yellow before turning solid red like a typical signal requiring the driver to stop in advance of the crosswalk. Pedestrian signal heads at either end of the crosswalk display the “don’t walk” signal until the HAWK beacon displays the steady red signal.

As at conventional signal crossings, the pedestrian signals display flashing “don’t walk” indications when typical pedestrians no longer have enough time to cross. The HAWK beacon displays flashing red indicating that the driver must stop and yield to pedestrians in the crosswalk before proceeding. The HAWK beacon goes dark and the pedestrian signal remains in “don’t walk" mode until the signal is activated by another pedestrian. Figure 33 shows the pedestrian signal, and figure 34 shows the pedestrian bridge crossing over I-70.

Figure 33. Photo. Pedestrian crossing with HAWK signal (courtesy: Colorado DOT).

Figure 34. Photo. Completed pedestrian bridge on west side of Pecos Street Bridge (courtesy: Colorado DOT).

Thanks to the innovative approach on this project, the construction period for this project was considerably reduced, and Pecos Street was reopened on September 1, 2013. A plan view of the completed structure is shown in figure 35, and a profile view of Pecos Street Bridge is shown in figure 36.

Figure 35. Photo. Plan view of completed project (courtesy: Colorado DOT).

Figure 36. Photo. Profile view of Pecos Street Bridge over I-70 (courtesy: Colorado DOT).

DATA ACQUISITION AND ANALYSIS

Data collection on the Colorado DOT HfL project consisted of acquiring and comparing data on safety, construction congestion, quality, and user satisfaction before, during, and after construction. The primary objective of acquiring these types of data was to provide HfL with sufficient performance information to support the feasibility of the proposed innovations and to demonstrate that ABC technologies can be used to do the following:

- Achieve a safer work environment for the traveling public and workers.
- Reduce construction time and minimize traffic interruptions.
- Produce greater user satisfaction.

This section discusses how well the Colorado DOT project met the HfL performance goals related to these areas.

SAFETY

The use of SPMT technology for this project provided several safety benefits. The technology enabled the superstructure to be fabricated off site and assembled in the staging area adjacent to the existing bridge, yet away from the high volumes of traffic on the interstate. This improved the safety of the workers in the work zone as well as that of motorists, who were not exposed to typical work zone hazards. Also, work could be performed during the day and night without interruptions throughout the construction process.

The HfL performance goals for safety include worker and motorist safety during construction. During the construction of the Pecos Street project, no worker injuries were reported, which means Colorado DOT exceeded the HfL goal for worker safety (incident rate of less than 4.0 based on the rate reported on OSHA Form 300).

Colorado DOT's safety study for the project area found that there were 367 crashes during the 5-year period between 2005 and 2009, averaging 6.11 crashes per month. Of these, 42 were injury-related and there were 2 fatalities. It is estimated based on national studies that average crash rate increases by 30 percent due to construction.[2] Assuming that the same would have occurred at this location, the average crash rate during construction is estimated to have increased by:

6.11 * 0.30 = 1.83 crashes per month.

Therefore, with a reduction in construction time of 8 months due to faster construction, it is estimated that innovative faster construction reduced the number of crashes by:

1.83 * 8 = 14.64, or approximately 15 crashes.

---

[2] Bhajandas, A and Mallela, J., *I-84 Bridge over Dingle Ridge Road Replacement using Superstructure Slide-In Technology,* Draft Report, December 2013

Furthermore, based on Colorado DOT's crash rate experience at the site, approximately 11 percent (42 out of 367) of these crashes would have resulted in injuries/fatalities. Therefore, it can be projected that about 2 injuries were avoided by reducing the construction period by 8 months.

Colorado DOT anticipates that the addition of roundabouts at the interchange will reduce the crash rate even further. If this site reflects a typical experience in United States after roundabout construction, Colorado should see a reduction of 37 percent for all crashes and 51 percent for injury-related crashes, per *Roundabouts: An Informational Guide*, published by the FHWA.[(2)] If Colorado DOT's experience with roundabouts is consistent with national experience, it is projected that, during the 5-year post-construction period, the number of crashes should decrease by 136 to 231, and those with injuries/fatalities should decrease by 21 to 21. These projections will be compared with actual experience by tracking crash rate in the long term.

CONSTRUCTION CONGESTION

The HfL performance goal on construction congestion is a 50 percent reduction in the time highway users are impacted, compared to traditional construction.

If a traditional approach had been used to remove and replace Pecos Street Bridge, Colorado DOT estimated that it would have taken 15 months to complete the project. The project would have been constructed in phases, causing significant backups on Pecos Street over this period. In contrast, under the innovative roll-in option, the project was completed in one season over a period of 7 months. Pecos Street was closed to vehicular traffic from June 24, 2013, to September 1, 2013, a period of approximately 10 weeks. During this closure, motorists were advised to use Federal Boulevard that is about 1 mile away to cross I-70. Therefore, users of Pecos Street were inconvenienced only a small fraction of the time—15 percent of the time anticipated with traditional construction. Therefore, both the reduction in total construction time and impacts on motorists for this project exceeded HfL performance goals.

QUALITY

This project involved bridge replacement that matched the existing roadway grades. The only roadway work was to tie the new construction to the existing approach roadways. The new riding surfaces of the approaches and the new bridge deck, however, are a great improvement over the surfaces of the old bridge.

Building the bridge superstructure away from traffic enabled easy construction access and improved quality, avoiding any damage by traffic induced vibrations. The controlled environment allowed longer concrete cure times, better material staging areas, and smoother assembly. The casting of the deck in one piece also avoided longitudinal joints due to phased construction under the conventional approach.

USER SATISFACTION

The project designer conducted an online survey in November 2013 to measure satisfaction with the project and gather opinions about the construction techniques used, including ABC. The link to the survey was sent to an email list compiled throughout the project and also to Denver City and County Councilmember Judy Montero's email list. The designer also used Twitter and the designer's website to promote the survey. The following questions, results, and comments were compiled by the design firm:

> The survey was completed by 104 people. Results indicate that respondents were overwhelmingly satisfied or very satisfied with the project regarding the use of accelerated bridge construction techniques and its ability to minimize disruptions to I-70 and reduce the schedule. Respondents were slightly less satisfied with traffic disruptions on Pecos and the project's impact on local businesses and neighborhoods; however, more than 60% were still satisfied or very satisfied. This feedback is likely a result of the 10-week closure to construct the roundabouts. Below are the questions and highlights of the results.
>
> 1. How satisfied are you with the traffic flow of the new I-70 and Pecos Interchange compared to its previous condition?
>
> a. 69.9% Very Satisfied or Satisfied (36.9% Very Satisfied)
>
> 2. How satisfied were you with the accelerated bridge construction technique that was used to replace the existing Pecos Street Bridge? The bridge was built off-site and moved into place over a weekend in July.
>
> a. 90.4% Very Satisfied or Satisfied (62.5% Very Satisfied)
>
> 3. For traffic on I-70, how satisfied were you with the way traffic disruptions were minimized during the 7 months of construction?
>
> a. 77.8% Very Satisfied or Satisfied (41.3% Very Satisfied)
>
> 4. For traffic on Pecos Street, how satisfied were you with the way traffic disruptions were minimized? Pecos Street was closed over I-70 for 10 weeks.
>
> a. 61.2% Very Satisfied or Satisfied (13.6% Very Satisfied)
>
> 5. For access to local businesses and neighborhoods, how satisfied were you with the way traffic disruptions were minimized during the 8 months of construction?
>
> a. 63.7% Very Satisfied or Satisfied (17.6% Very Satisfied)
>
> 6. Colorado DOT is looking for ways to minimize disruption to traffic during construction. During public meetings, we learned that residents preferred short

durations of full road closures to several lane closures and restrictions over a longer construction schedule. Having experienced the short duration full closure option, how satisfied are you with the results of the I-70 and Pecos Interchange Replacement project?

a. 85.5% Very Satisfied or Satisfied (44.2% Very Satisfied)

The survey also allowed respondents to provide written comments and 59 were received. Of those, 24 were generally positive, while 30 were generally or slightly critical. Five were generally neutral. Nineteen of the comments were about the roundabouts, with 14 of these being critical of roundabouts. According to a recent Federal Highway Administration (FHWA) survey conducted of jurisdictions across the United States, there is significant negative public attitude toward roundabouts prior to construction, but a positive attitude after construction. It is neither surprising nor disappointing that 13% of all survey respondents had critical comments about roundabouts this soon after the completion of the I-70 and Pecos Interchange project.

Appendix A includes the tables and charts from the full survey.

ECONOMIC ANALYSIS

A key aspect of HfL demonstration projects is quantifying, as much as possible, the value of the innovations deployed. This entails comparing the benefits and costs associated with the innovative project delivery approach adopted on an HfL project with those from a more traditional delivery approach. The latter type of project is referred to as a baseline case and is an important component of the economic analysis.

For this economic analysis, Colorado DOT supplied the cost figures for both the as-built project and the baseline case.

CONSTRUCTION TIME

Through the use of innovative construction technology, Colorado DOT was able to dramatically reduce the impact of this project's construction on roadway users. A two-construction season project that would have taken an estimated 15 months to build was built in only 7 months with virtually no impact to the 123,000 vehicles that travel on I-70 every day. The only impact was during a 50-hour period when road users needed to travel on alternate routes.

The impact to the 19,150 users of Pecos Street lasted approximately 10 weeks compared to the 65 weeks that it would have been under conventional construction. Colorado DOT was able to reduce impact/inconvenience by 85 percent.

CONSTRUCTION COSTS

The traditional approach would have required construction in three stages and would have resulted in a wider bridge. Colorado DOT estimated that the overbuild would have cost $450,000. The innovative option using SPMT, while saving construction time, did incur $1,100,000 in additional costs resulting in increase in project construction cost for the bridge portion by $650,000.

USER COSTS

User costs are defined as added vehicle operating costs and delay costs to highway users due to construction activity. These costs are incurred because of extra travel distance using detours and when motorists are delayed by congestion in the work zone, slowdown due to reduced lane width, and channeling of traffic. Colorado DOT calculated user delay cost to be $3,543,000 for the baseline case and $1,305,000 for the innovative case, resulting in user cost savings of $2,238,000.

COST SUMMARY

The innovative option increased construction cost by $650,000. However, it reduced user delay costs by $2,238,000. When bundled together, there was a net saving of $1,588,000. This represents about 9 percent of the $18.6 million spent for the construction and construction engineering for this project.

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3. “Manual on Use of Self-Propelled Modular Transporters to Remove and Replace Bridges,” Federal Highway Administration, Washington, DC, (accessed October 7, 2014), http://www.fhwa.dot.gov/bridge/pubs/07022/chap00.cfm

ACKNOWLEDGMENTS

The authors acknowledge the invaluable insights and guidance of Highways for LIFE Team Leader Byron Lord, Program Coordinators Mary Huie and Kathleen Bergeron, and Ewa Flom, Program Manager for FHWA's Center for Accelerating Innovation. Their vast knowledge and experience with the various aspects of construction, technology deployment, and technology transfer helped immensely in developing both the approach and the technical matter for this document. The team also is indebted to Colorado DOT engineers Mickey Ferrell and Tamara Maurer and FHWA engineers Matt Greer, Benjamin Beerman, and Tim Cupples for their advice, assistance, and coordination during this project.

ARA would like to also acknowledge the project team for successfully delivering this project and providing photographs and documentation:

- Owner: Colorado DOT.
- Design Engineer: Wilson & Company.
- Contractor: Kiewit Infrastructure Co.
- Construction Management: Colorado DOT/Atkins/Rocksol.

APPENDIX A

I-70 AND PECOS INTERCHANGE REPLACEMENT PROJECT

EXECUTIVE SUMMARY

In November 2013, after the I-70 and Pecos Interchange Replacement project was completed, Wilson & Company performed a public online survey to measure public satisfaction with the project and to gather opinions about the construction techniques used, including accelerated bridge construction. The link to the survey was emailed to a project email list compiled throughout the project, as well as City and County of Denver Councilmember Judy Montero's email list. Wilson & Company also used Twitter and its website to promote the survey.

QUESTIONS AND RESULTS

The survey was completed by 104 people. Results indicate that respondents were overwhelmingly satisfied or very satisfied with the project regarding the use of accelerated bridge construction techniques and its ability to minimize disruptions to I-70 and reduce the schedule. Respondents were slightly less satisfied with traffic disruptions on Pecos and the project's impact on local businesses and neighborhoods; however, more than 60% were still satisfied or very satisfied. This feedback is likely a result of the 10-week closure to construct the roundabouts. Below are the questions and highlights of the results.

1. How satisfied are you with the traffic flow of the new I-70 and Pecos Interchange compared to its previous condition?
    a. 69.9% Very Satisfied or Satisfied (36.9% Very Satisfied)
2. How satisfied were you with the accelerated bridge construction technique that was used to replace the existing Pecos Street Bridge? The bridge was built off-site and moved into place over a weekend in July.
    a. 90.4% Very Satisfied or Satisfied (62.5% Very Satisfied)
3. For traffic on I-70, how satisfied were you with the way traffic disruptions were minimized during the 7 months of construction?
    a. 77.8% Very Satisfied or Satisfied (41.3% Very Satisfied)
4. For traffic on Pecos Street, how satisfied were you with the way traffic disruptions were minimized? Pecos Street was closed over I-70 for 10 weeks.
    a. 61.2% Very Satisfied or Satisfied (13.6% Very Satisfied)

5. For access to local businesses and neighborhoods, how satisfied were you with the way traffic disruptions were minimized during the 8 months of construction?

    a. 63.7% Very Satisfied or Satisfied (17.6% Very Satisfied)

6. Colorado DOT is looking for ways to minimize disruption to traffic during construction. During public meetings, we learned that residents preferred short durations of full road closures to several lane closures and restrictions over a longer construction schedule. Having experienced the short duration full closure option, how satisfied are you with the results of the I-70 and Pecos Interchange Replacement project?

    a. 85.5% Very Satisfied or Satisfied (44.2% Very Satisfied)

ADDITIONAL COMMENTS

The survey also allowed respondents to provide written comments and 59 were received. Of those, 24 were generally positive, while 30 were generally or slightly critical. Five were generally neutral. Nineteen of the comments were about the roundabouts, with 14 of these being critical of roundabouts. According to a recent Federal Highway Administration (FHWA) survey conducted of jurisdictions across the United States, there is significant negative public attitude toward roundabouts prior to construction, but a positive attitude after construction. It is neither surprising nor disappointing that 13% of all survey respondents had critical comments about roundabouts this soon after the completion of the I-70 and Pecos Interchange project.

The full survey is attached.

WILSON & COMPANY

USER SATISFACTION SURVEY RESULTS

Table 1. Satisfaction related to traffic flow.

1. How satisfied are you with the traffic flow of the new I-70 and Pecos Interchange compared to its previous condition?						
Very Satisfied	**Satisfied**	**Neutral**	**Dissatisfied**	**Very dissatisfied**	**Rating Average**	**Rating Count**
36.9%	33.0%	11.7%	11.7%	6.8%		
38	34	12	12	7	2.18	103
					answered question	**103**
					skipped question	**2**

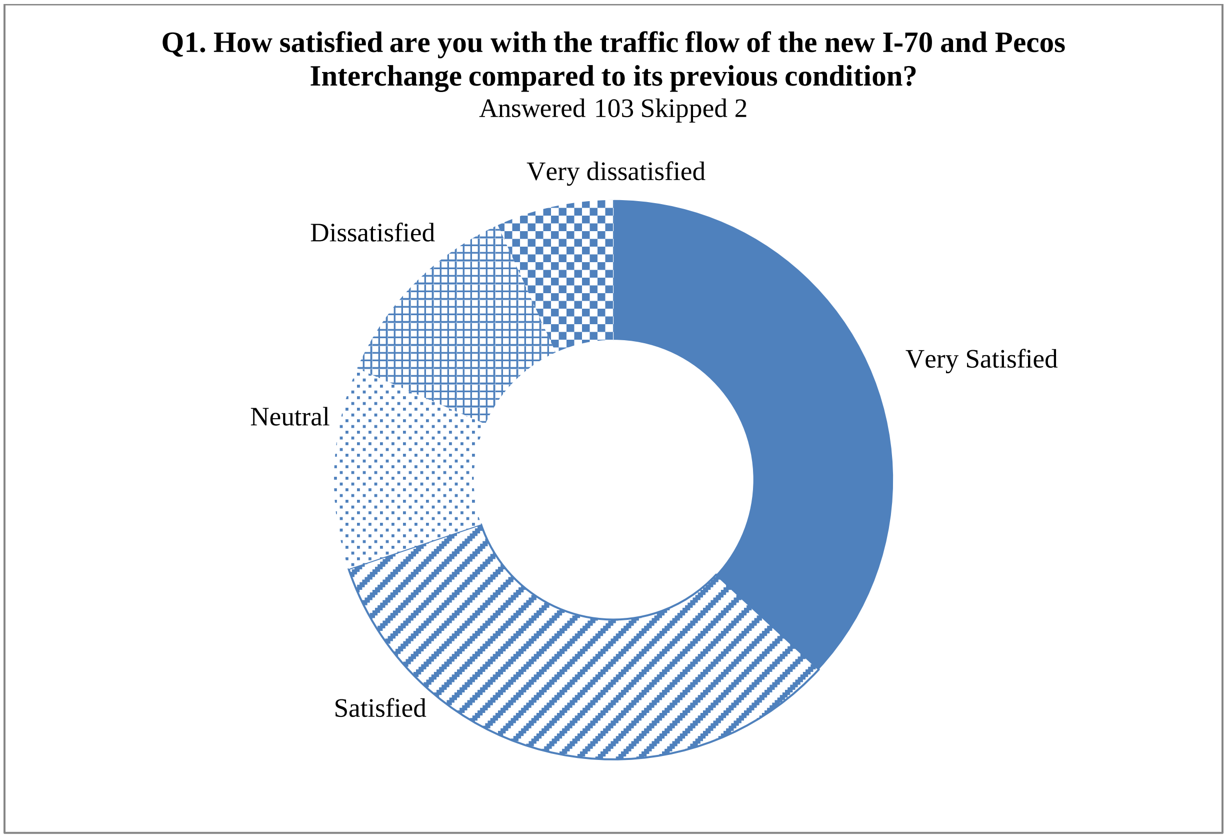

Figure 37. Chart. Satisfaction related to traffic flow.

Table 2. Satisfaction related to ABC techniques used.

2. How satisfied were you with the accelerated bridge construction technique that was used to replace the existing Pecos Street Bridge? The bridge was built off-site and moved into place over a weekend in July.						
Very Satisfied	**Satisfied**	**Neutral**	**Dissatisfied**	**Very dissatisfied**	**Rating Average**	**Rating Count**
62.5%	27.9%	5.8%	1.0%	2.9%		
65	29	6	1	3	1.54	104
					answered question	**104**
					skipped question	**1**

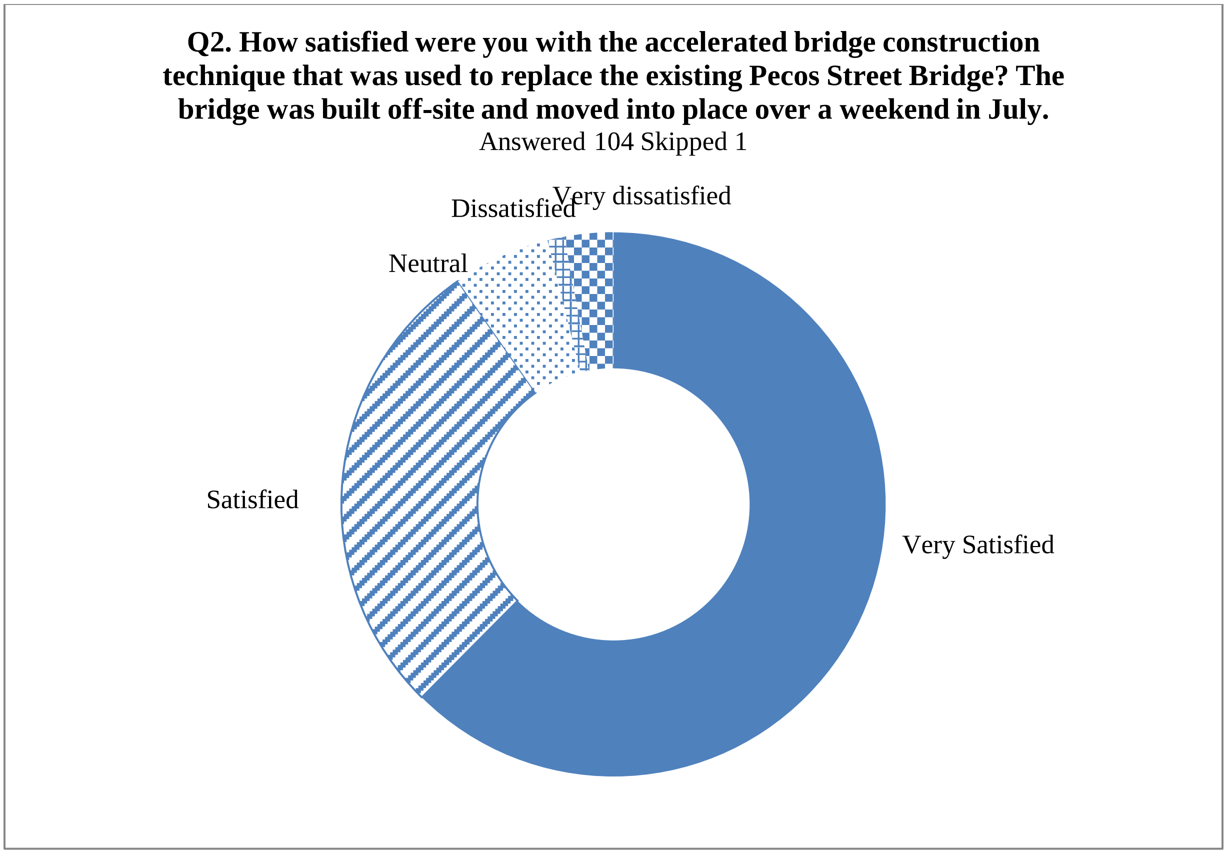

Figure 38. Chart. Satisfaction related to ABC techniques used.

Table 3. Satisfaction related to minimized traffic disruptions on I-70.

3. For traffic on I-70, how satisfied were you with the way traffic disruptions were minimized during the 7 months of construction?						
Very Satisfied	**Satisfied**	**Neutral**	**Dissatisfied**	**Very dissatisfied**	**Rating Average**	**Rating Count**
41.3%	36.5%	12.5%	5.8%	3.8%		
43	38	13	6	4	1.94	104
					answered question	**104**
					skipped question	**1**

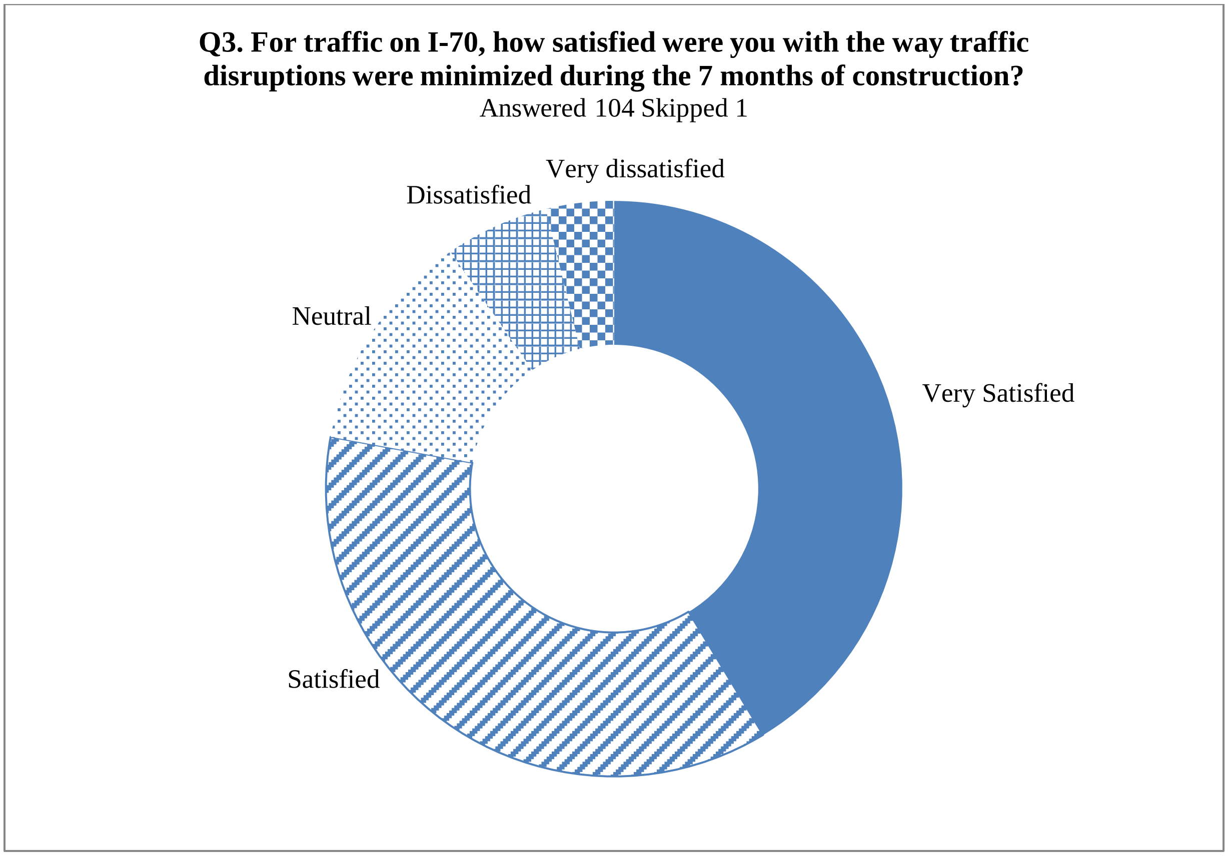

Figure 39. Chart. Satisfaction related to minimized traffic disruptions on I-70.

Table 4. Satisfaction related to minimized traffic disruptions on Pecos Street.

4. For traffic on Pecos Street, how satisfied were you with the way traffic disruptions were minimized? Pecos Street was closed over I-70 for 10 weeks.						
Very Satisfied	**Satisfied**	**Neutral**	**Dissatisfied**	**Very dissatisfied**	**Rating Average**	**Rating Count**
13.6%	47.6%	20.4%	9.7%	8.7%		
14	49	21	10	9	2.52	103
					answered question	**103**
					skipped question	**2**

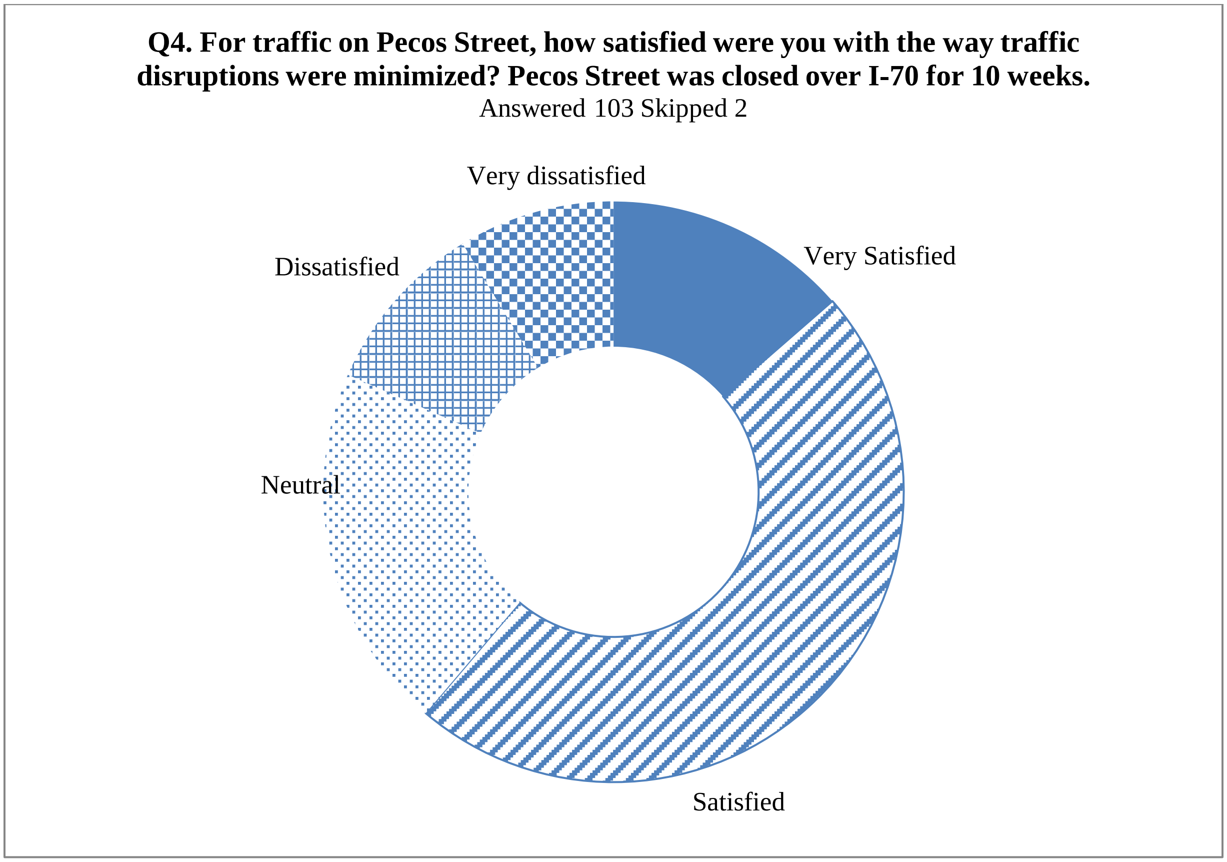

Figure 40. Chart. Satisfaction related to minimized traffic disruptions on Pecos Street.

Table 5. Satisfaction related to traffic access.

5. For access to local businesses and neighborhoods, how satisfied were you with the way traffic disruptions were minimized during the 8 months of construction?						
Very Satisfied	**Satisfied**	**Neutral**	**Dissatisfied**	**Very dissatisfied**	**Rating Average**	**Rating Count**
17.5%	45.6%	23.3%	9.7%	2.9%		
18	47	24	10	3	2.34	102
					answered question	**102**
					skipped question	**3**

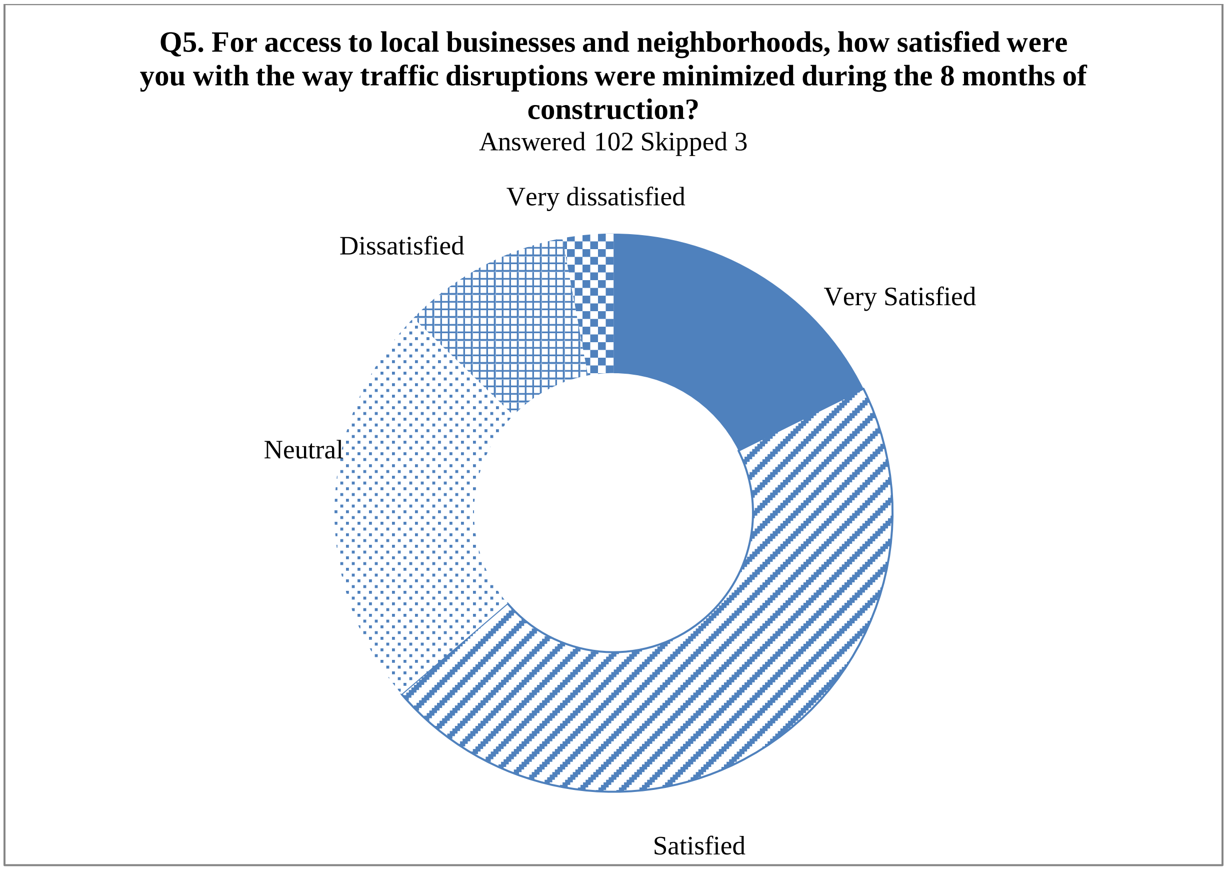

Figure 41. Chart. Satisfaction related to traffic access.

Table 6. Satisfaction related to results of the I-70 and Pecos Interchange Replacement project.

6. CDOT is looking for ways to minimize disruption to traffic during construction. During public meetings, we learned that residents preferred short durations of full road closures to several lane closures and restrictions over a longer construction schedule. Having experienced the short duration full closure option, how satisfied are you with the results of the I-70 and Pecos Interchange Replacement project?						
Very Satisfied	**Satisfied**	**Neutral**	**Dissatisfied**	**Very dissatisfied**	**Rating Average**	**Rating Count**
44.2%	41.3%	7.7%	4.8%	1.9%		
46	43	8	5	2	1.79	104
					answered question	**104**
					skipped question	**1**

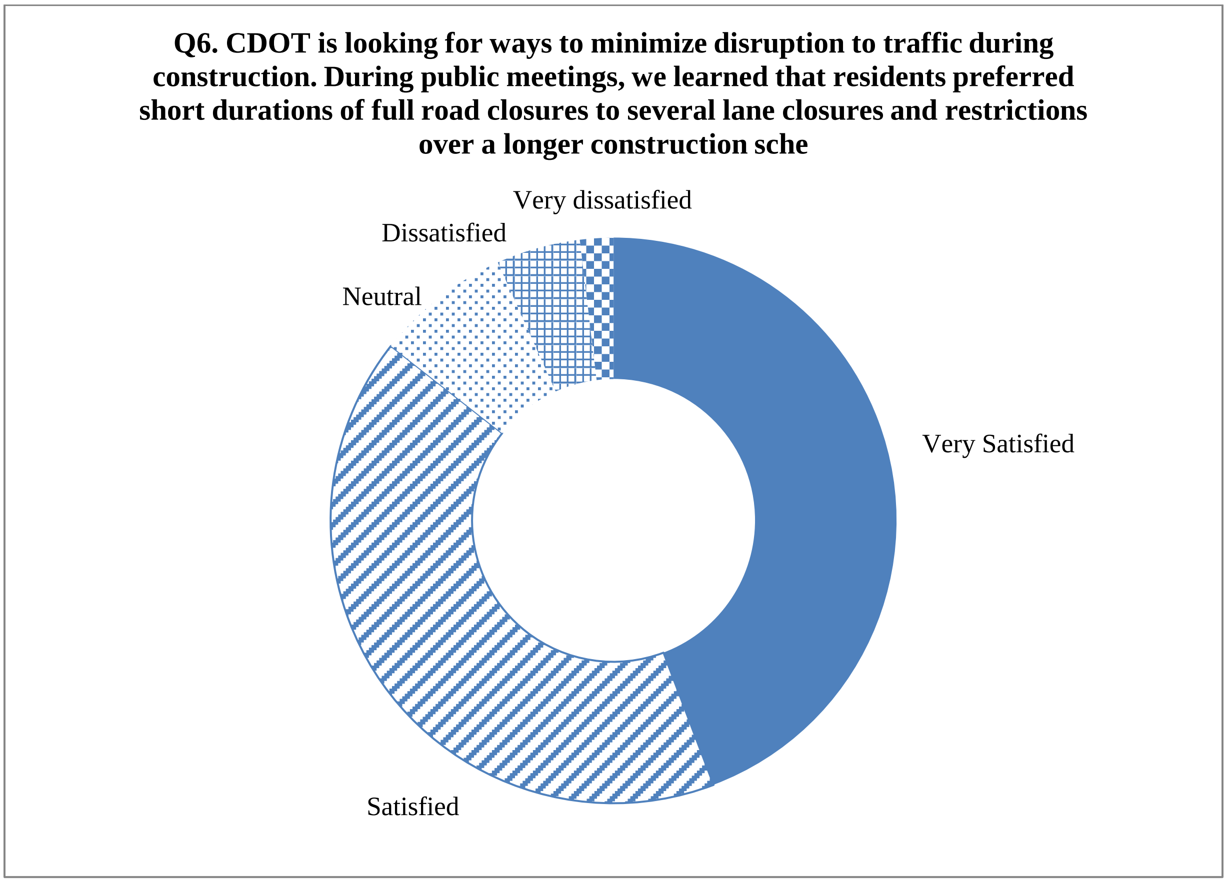

Figure 42. Chart. Satisfaction related to results of the I-70 and Pecos Interchange Replacement project.

Table 7. Additional user comments.

7. Additional comments		
		answered question 59
		skipped question 46
1	I was in the circle when a driver entered driving clockwise. I don't think Coloradoans understand traffic circles. Former NY resident w/ much traffic circle experience.	11/6/2013 13:27
2	i hate roundabouts, but this one with lanes that actually lead to exits (not just around and around in a circle) is great	11/6/2013 11:25
3	love the new system. no more bottle necks.	11/5/2013 20:55
4	The double rotaries can be a bit confusing at first or for some drivers, but overall love it.	11/5/2013 20:47
5	Love the new intersections! Hated the old traffic lights where people ran the red lights and created gridlock!	11/5/2013 20:00
6	Wasn’t expecting the European round abouts. It's a challenge to navigate, especially since most don't understand how they work	11/5/2013 18:15
7	public viewing of bridge replacement was great.	11/5/2013 17:54
8	More notification of the i-70 closure would have been helpful.	11/5/2013 17:40
9	the new road over i-70 on pecos is a cluster... i have never seen such confusion.. i guarantee the 2 roundabouts will cause a lot of accidents and angry drivers.	11/5/2013 16:43
10	A very bad idea	11/5/2013 16:41
11	Roundabouts are terrible.	11/5/2013 16:36
12	Every time I drive across the bridge, I notice a near accident. It's hard to see the traffic.	11/5/2013 16:20
13	CO drivers cannot easily navigate roundabouts. Stoplights are more recognizable.	11/5/2013 16:20
14	10 weeks felt like forever.	11/5/2013 16:11
15	That round about that was put in makes no sense. Whoever designed that really wasn't thinking. It is a mess.	11/5/2013 16:00
16	The Pecos entrance to the highway being my daily route to work, I felt the impact was minimized and closers were planned and detours posted well enough to feel a minimal impact over the shutdown. I am highly pleased with the result and with Colorado DOT's efforts in the project.	11/5/2013 15:49
17	It was fun watching the bridge being moved.	11/5/2013 15:43
18	The roundabout is okay. It does not work well for buses and trucks. The lanes and routing is confusing at times and you end up trying to avoid accidents. Specifically when you get off of Ii70 west and want to go pecos south.	11/5/2013 15:40
19	I am a civil engineer and I thought that the project went extremely well given the constraints. Well done.	11/5/2013 15:38
20	I think the interchanges look great, but worry that people don't know how to use traffic circles properly. I'm slightly annoyed that you can no longer turn left out of 7-11 onto Pecos. But overall, great job and the construction looks really great. (I especially like the neighborhood signs on each side!)	11/5/2013 15:38
21	I was told the closure was going to be 8 weeks and it took longer but at times it looked like no work was getting done on Pecos.	11/5/2013 15:35
22	The traffic circle design is awful, it looks awful, and seems somewhat unsafe driving through it. I'm disappointed that Colorado DOT basically dropped this pedestrian UNfriendly design on the neighborhood without even asking for input. You only sought input AFTER the design was done, and even that was merely lip service.	11/5/2013 15:35

7. Additional comments		
		answered question 59
		skipped question 46
23	The flow of traffic from I-70 West Bound to Pecos South bound is very confusing. I've had several "close call" accidents already. It is unclear who has the right of way.	11/5/2013 15:32
24	Traffic Circles are very confusing for drivers who rarely use the intersection	11/5/2013 15:31
25	Thanks, love the new bridge and flow!	11/5/2013 15:29
26	The only comment I have is that I wished Colorado DOT had reached out to the neighborhood organization (Sunnyside United Neighbors, Inc. - the Registered Neighborhood Organization) prior to starting construction. It would have been good to be more of a partner in disseminating information to the community.	11/5/2013 15:24
27	Area shops suffered financially during construction. Also, the Pecos St./I-70 intersection is unsafe. Pedestrians are not safe at this point.	11/4/2013 10:04
28	Very Cool Project - Good Job	11/4/2013 5:07
29	Still not sure the double-round-about was the way to go there. The southern round-about has a lane that curves from north bound to west/south bound but there is not reason for it.	11/3/2013 18:38
30	thanks for the updates..you did a good job.	11/3/2013 16:28
31	During the construction period, I had several incidents of near hits from traffic, both on I-70 and getting to Pecos. I was attempting to get to Pecos South from I-70. Traffic-both those getting on to Pecos and I-70, would not let me off. I was forced to go to Federal and learned the neighborhood to get to my destination. Even the detour signs did not efficient from my destination to get home. I even learned that there are areas of non-paved roads in the neighborhood!!!!!	11/2/2013 8:15
32	Now that the highway is more opened space wise the highway noise is extremely loud.. Need concrete. walls.	11/2/2013 6:00
33	The new interchange killed all business and traffic in this area!	11/1/2013 15:55
34	1. signs at roundabouts are clear, but more advance notice would be better when the approach is 4-lane; 2. open the viewing gallery area for the duration!	11/1/2013 15:18
35	thanks for the rapid project	11/1/2013 15:09
36	I worried about people getting in a hurry, not yielding to the left	11/1/2013 14:55
37	As a representative of RTD p, I feel Colorado DOT was extremely sensitive to the needs of public transportation, the disabled patrons that utilized our services, and the impact on the residents of the neighborhood . Colorado DOT did an excellent job.	11/1/2013 14:51
38	Great Job, would like to see more of this type of Bridge construction.	11/1/2013 13:48
39	I felt for the amount of traffic and the area the project went much better than anticipated. I had several people who were impacted by this project and their complaints were minimal. Maybe a surprise when something changed but they didn't subscribe to the updates like I did. This made it much better to make adjustments to my schedule. Thank you!	11/1/2013 13:37
40	Please do a similar project at Federal Blvd. and I-70.	11/1/2013 13:35
41	I drive Pecos and I-70 every day of the week. Colorado DOT did a great job on the IRP. I do would like to mention that I have noticed a visibility issue. When driving (in my case a compact car) into the Interchange point, coming from I-70 west, and at the stopping point, before getting into the round about,	11/1/2013 13:18

7. Additional comments		
		answered question 59
		skipped question 46
	it is difficult to see the cars coming from the round about located north of I-70 that are going south on	
42	Traffic circles are dangerous and should be avoided in future projects	11/1/2013 13:17
43	due to the location of 7-11 , children still cross directly from school to 7-11 in lieu of utilizing the designated crossing for peds; would have preferred ped crossing on the east side due to the projects and 7-11 being on the east side	11/1/2013 13:15
44	How can you call this an accelerated bridge project when Pecos street was closed for 2 months? Next time require Pecos to open over a weekend like real ABC projects.	11/1/2013 13:13
45	Been watching this for application to the Glenwood Springs bridge replacement, where alternatives are not readily available	11/1/2013 13:11
46	You all did a professional job, considerate of others, the project wasn't filled with trash, picked up after a section was completed. Congrats nice job	11/1/2013 13:10
47	I work at Toshiba which could have been greatly impacted by the construction, the reality was not bad at all! We also enjoyed the email updates as I posted them in our lunch room. Great Job, thank you!!!	11/1/2013 13:08
48	I never understood why the round a bouts we're talking American drivers sheesh!	11/1/2013 13:05
49	Pretty dangerous if you don't make people stop yielding isn't in the cards. Great job by construction just a lousy idea. Jeff	11/1/2013 13:03
50	Seams dangerous for pedestrians crossing the on ramp to I70	11/1/2013 13:02
51	Good job	11/1/2013 13:01
52	Wish the landscaping was better around the intersection.	11/1/2013 12:59
53	The final part of the project (landscaping, medians) took far to long and not having the full intersection open during this time caused too many traffic issues.	11/1/2013 12:58
54	Wish this could have been used on the Sheridan Bridge in Arvada	11/1/2013 12:57
55	I just wish more people knew how to drive in a traffic circle. I drive through this twice daily and have seen one accident and almost been in a few others.	11/1/2013 12:55
56	Study traffic signal timing at Pecos & 46th Ave	11/1/2013 11:35
57	That was the best bridge replacement that I've ever seen.	11/1/2013 8:33
58	Thank you for keeping construction limited to a short time. The roundabouts are a little challenging to get into during busy times - also difficult when trucks go through there - but I am glad the long lights are gone!	10/31/2013 16:36
59	When you cut our fibre optic line, and shut our business down for the better part of a day....that was really, really bad. "Call before you dig"??	10/31/2013 10:13