APPENDIX K

Design Speed Memo

US 550 South Connection to US 160 SEIS Alternatives Analysis
FSA 5501-021 (19378)

Design Speed Technical Memorandum
November 19, 2013

PROJECT DESCRIPTION

The proposed US 160 to US 550 South Connection project will upgrade approximately 1.2 miles of US 550 to a four-lane facility from the area of La Plata County Road 220 (CR 220) to the junction with US 160 south of Durango. The May 2006 Final Environmental Impact Statement (EIS) for US 160 from Durango to Bayfield[23] identified a preferred alternative and the 2012 Supplemental EIS (SEIS) / Section 4(f) Evaluation[26] confirmed that preferred alternative with a slight modification. During the public comment period for the SEIS, additional alternatives were proposed to CDOT by representatives of the Webb Ranch.

The SEIS preferred alternative, known as the "Revised G Modified" alternative, would connect to the Grandview interchange (0.6 miles east of the existing US 160 / 550 intersection) and travel near the western edge of the Florida Mesa before rejoining the existing US 550 alignment south of CR 220. The alternative option submitted to CDOT during the SEIS comment period (known as alternative "R5") would generally follow the existing US 550 alignment, but improves deficiencies in the current horizontal and vertical alignments. This alternative also includes a possible interchange at the existing US 160 intersection location.

The US 550 South Connection to US 160 SEIS Alternatives Analysis study will analyze the two alignments described above, and possibly other alignments that lie geographically between "Revised G Modified" and "R5".

PROJECT SITE DESCRIPTION

As it enters Colorado from New Mexico at milepost (MP) zero, US 550 is a four lane divided highway that follows the Animas River. The highway transitions to a two lane highway by MP 3. The US 550 EA[25] and US 160 EIS[23] propose upgrading the existing two lane facility to four lanes from the state line north approximately 16 miles to the junction with US 160. Approximately 4.5 miles north of the border, US 550 leaves the river valley and climbs 300 feet up Bondad Hill to the top of the Florida Mesa. For the next 10 miles, US 550 remains on the top of the mesa in level to rolling terrain with flat curves and long sight distances. Just north of CR 220, US 550 begins the 200 vertical-foot descent down Farmington Hill to the junction with US 160. The current posted speed limit on US 550 is 60 mph south of CR 220, 45 mph through

the CR 220 intersection, and 35 mph on Farmington Hill. Design speed for the preferred alternative from the US 550 EA[25] and FONSI[24] is 70 mph south of CR 220, resulting in an expected posted speed limit of 65 mph.

PROBLEM STATEMENT

Determining the appropriate design speed to use for a project is arguably one of the most important tasks since many of the geometric features and design criteria will be chosen based on that parameter. *Design speed is different from the other controlling criteria in that it is a design control, rather than a specific design element.*[14, PG 24] Choosing the appropriate design speed for a facility is based on many factors including: functional classification, anticipated operating speed, desired speed limit, terrain, and corridor consistency. This memo will discuss the main factors used in determining a design speed before recommending the appropriate design speed for US 550 from MP 15.4 just south of CR 220 to the junction with US 160 at MP 16.6.

FUNCTIONAL CLASSIFICATION

The main function of US 550 in the Four Corners region is mobility. Most travelers are traveling significant distances between urban centers. The roadway also serves as the only north-south truck route in the region.

According to the AASHTO Policy on Geometric Design of Highways and Streets[16] (Green Book), US 550 should be classified as a Rural Principal Arterial which has the following characteristics: suitable for interstate travel, movement between urban centers, and integrated movement. The CDOT Straight Line Diagram lists the functional classification for US 550 as a Principal Arterial. Based on this functional classification and on other characteristics of the highway, the Colorado State Highway Access Code access category for US 550 is R-A (Rural Regional Highway). *This category is appropriate for use on highways that have the capacity for medium to high speeds and relatively medium to high traffic volumes over medium and long distances in an efficient and safe manner. They provide for interregional, intra-regional, and intercity travel needs. Direct access service to abutting land is subordinate to providing service to through traffic movements. This category is normally assigned to National Highway System routes, significant regional routes in rural areas, and other routes of regional or state significance*.[22, PG 37]

Traditionally, roadways with a higher functional classification should have a higher design speed. The AASHTO Green Book defines the lower limit for a high speed facility to be 50 mph.[16, PG 72] The Green Book also provides guidance that describes a range of values for each functional classification in relation to the project terrain. Higher design speed values are listed for facilities in level or rolling terrain and lower values are listed for mountainous terrain.

ANTICIPATED OPERATING SPEED

When determining the design speed for this segment of US 550, it will be important to consider that many drivers will be travelling long distances from the south on a facility designed for 70 mph and not yet near capacity.[25] *Numerous studies have indicated that reasonable and prudent drivers, as measured by the 85th*

percentile speed, will not significantly alter what they consider to be a safe operating speed, regardless of the posted speed limit unless there is constant heavy enforcement. In general, an appropriate design speed should be within approximately 5 mph of travel speeds.[6, PG 18] Table 4 in NCHRP Report 504 Design Speed, Operating Speed, and Posted Speed Practices summarizes the results of a survey distributed to agencies to determine their experience regarding the relationship between posted speeds and operating speeds. It denotes that for a design speed of 70 mph agencies would expect the operating speed of motorists to be close to the posted speed limit of 65 mph as they approach the CR 220 intersection.[2, PG 17] A Kentucky Transportation Center Report confirmed this. In their study of 4-lane rural highways, they found that *there was an agreement between operating and design speeds indicating the absence of any differences.*[18, PG 32]

DESIRED SPEED LIMIT / SPEED REDUCTION ZONES

Rather than crossing US 160 on a continuous dedicated route, US 550 traffic must transition onto US 160 at the north end of the project area. Alternatives studied for this transition range from the existing signalized "tee" intersection to low-speed right turns or left turns onto loop ramps or diamond interchange ramps. The turns from US 550 onto ramps occur either at traffic signals, roundabouts, or low-speed free-flow turns. Thus, for any alternative, the speed of northbound US 550 vehicles must be transitioned from a free-flow roadway designed for 70 mph between MP 0 and 15 (with an expected posted speed limit of 65 mph) to either a stop condition or low-speed transition at the junction with US 160. Two key considerations for this speed transition area include:

(1) Manual on Uniform Traffic Control Devices (MUTCD) requirements and AASHTO Green Book guidance.
(2) Standard Colorado statewide practice for speed reduction zones.

The MUTCD, 2009 edition, states that *A Reduced Speed Limit Ahead sign should be used to inform road users of a reduced speed zone where the speed limit is being reduced by more than 10 mph, or where engineering judgment indicates the need for advance notice to comply with the posted speed limit ahead.*[10 PG 124] This statement recognizes that large changes in speed limit need to have additional attention brought to them in order to gain driver compliance.

The AASHTO Green Book also addresses the issue of speed transition increments. *Given an overall range in design speeds of 15 to 75 mph used in geometric design, it is desirable to select design speeds in increments of 5 mph. Smaller increments would result in little distinction in the dimensions of design elements between one design speed and the next higher design speed; larger increments of 15 to 20 mph would result in too large a difference in the dimensions of design features between any two design speeds. In some instances, however, there may be an advantage in using intermediate increments to effect changes in the design speed.*[16, PG 69] Combined, the MUTCD and AASHTO guidance suggests that design speed changes should be done using increments in the range of 10 to 15 mph.

CDOT Staff Traffic at CDOT Headquarters in Denver was contacted to determine if any formal statewide policy or typical practice exists for speed reduction zones on state highways. Staff Traffic does not have a formal policy, but stated that their typical practice is to step speeds down in 10 to 15 mph increments. The length of the speed reduction zone is based on engineering judgment considering factors such as

comfortable deceleration distance, sign spreading relative to other signs, sign visibility versus roadway alignment or other topographic features, and MUTCD requirements for advance placement of "Reduced Speed Limit Ahead" sign.[28]

A review of current speed reduction practice on several similar state highways in the Durango area showed that local practice is consistent with the typical statewide practice. Speed reductions occur in 10 mph and 15 mph increments, with 10 mph increments being the most typical. Logic suggests that Durango-area drivers will expect US 550 speed reductions to be executed in similar increments.

Based on consistent guidance from MUTCD, AASHTO, CDOT Staff Traffic, and existing conditions on local Durango-area state highways, the speed reductions for northbound US 550 traffic approaching US 160 should be performed in increments of 10 mph to 15 mph.

TERRAIN

The Green Book states that *the topography of the land traversed has an influence on the alignment of roads and streets. Topography affects horizontal alignment, but has an even more pronounced effect on vertical alignment.*[16, PG 231] Three classifications are used to characterize terrain: level, rolling, and mountainous. Roadways can usually be constructed to high standards in curvature and sight distance in level terrain without difficulty. *In rolling terrain, natural slopes consistently rise above and fall below the road or street grade, and occasional steep slopes offer some restriction to normal horizontal and vertical roadway alignment.*[16, PG 231] *In mountainous terrain, longitudinal and transverse changes in the elevation of the ground with respect to the road or street are abrupt.*[16, PG 231]

The CDOT Straight Line Diagram classifies US 550 as mountainous terrain. Though US 550 travels through the mountainous region of southwestern Colorado, a majority of the 16 mile corridor from the New Mexico State Line to the junction with US 160 is different. US 550 follows the Animas River Valley for 4.5 miles before climbing up to the top of the Florida Mesa along a feature known as Bondad Hill. US 550 then travels along the top of the mesa for approximately 10.5 miles to just north of CR 220. The final half mile descends Farmington Hill to join with US 160. Grades in the corridor vary from 0.5% to as much as 6% with the majority of the grades being less than 1.5%. Of the 16 miles, 14.5 are best characterized as rolling or level terrain, including the 10 miles approaching the project area from the south. The steep terrain is limited to Bondad Hill and Farmington Hill.

Two areas on the US 550 corridor that could be considered for the designation of either rolling or mountainous terrain are Bondad Hill and Farmington Hill. There are many similarities between Bondad Hill and Farmington Hill and both present a challenge to designers. The most difficult challenge to designers is designing a reasonable facility that transitions several hundred feet in vertical elevation over a short distance (less than 1 mile). Lowering the design speed significantly through these two features would allow more geometric flexibility to create alignments that closely match the terrain. However, <u>AASHTO's A Guide for Achieving Flexibility in Highway Design</u> states that: *Designers should not "solve" a sensitive design problem by arbitrarily lowering the nominal design speed without also undertaking proactive measures such as traffic calming to reduce speeds.*[6, PG 92] The US 550 EA[25, PG 2-22] defined the design speed for the corridor as 70 mph except through Bondad Hill where the design speed was dropped to 60 mph. Subsequent design

though this area was able to improve the planned geometry at Bondad Hill to achieve a 65 mph design speed.

NCHRP Report 504 Design Speed, Operating Speed, and Posted Speed Practices studied which factors influence operating speed the most. A study of operating speed for 146 rural two-lane highways split between the three terrain classifications found that *generally, only a 1-mph difference exists between the different terrain types.*[2, PG 42] The AASHTO Guide for Achieving Flexibility in Highway Design[6, PG 18] Table 1-3 summarizes the Green Book[16] design speed criteria for level, rolling and mountainous terrain for Rural Arterials. The relevant portion from that table is shown below.

Functional Classification	Design Speed in Level Terrain (mph)	Design Speed in Rolling Terrain (mph)	Design Speed in Mountainous Terrain (mph)
Principal Arterial	60 - 75	50 - 60	40 - 50

This table indicates a wide range of design speeds depending on the type of terrain. It is important to note, however, that the evidence reported by NCHRP Report 504 does not support that driver's operating speeds are as influenced by terrain as they are by other factors such as functional classification, roadway alignment, and traffic volumes.[2, PG 40]

Bondad Hill and Farmington Hill represent the two discreet mountainous features along a 16 mile stretch of rolling roadway. Driver's speed is not so heavily influenced by terrain that the design speed of a facility should be arbitrarily lowered due to a change in terrain designation. In addition, the Green Book states that: *Terrain classifications pertain to the general character of a specific route corridor. Routes in valleys, passes, or mountainous areas that have all of the characteristics of roads or streets traversing level or rolling terrain should be classified as level or rolling.*[16, PG 231] Therefore US 550 should have a design speed of 50-60 mph consistent with a Rural Principal Arterial in rolling terrain.

CORRIDOR CONSISTENCY

Driver expectancy plays a key role in the operational effectiveness and safety of how a facility operates. While a lower design speed may seem appropriate for an individual segment of highway, such as US 550 descending Farmington Hill, consideration should be given to the approaching segments of highway in order to anticipate what driver's expectations may be.

Southbound US 550 travelers approaching the project area are leaving the urbanized US 550 / 160 corridor of southern Durango. They turn onto US 550 at an intersection or possible future interchange, then are presented with visual cues such as steep grades and sharp curves. These characteristics would support the idea of a design speed in the lower end of the range for rural arterials (40-50 mph).

Northbound traffic, however, has been travelling though mostly level to rolling terrain at high speeds on long tangents and sweeping curves for many miles as it approaches CR 220 and Farmington Hill. Research described in NCHRP 737 Design Guidance for High-Speed to Low-Speed Transition Zones for Rural Highways demonstrates that even with additional visual cues such as an approaching town, compliance with speed

reduction is difficult. It states: *When entering a lower speed zone, in particular after a period of driving at a high speed…drivers will generally underestimate their speed and consequently not reduce their speed enough to comply with the lower speed limit.*[20, PG 19] Although some might argue that the CR 220 intersection could be considered a cue to drivers that they should reduce their speed, several similar intersections between the New Mexico state line and CR 220 do not require drivers to reduce speed from a regulatory standpoint. In addition, there are no visual cues near CR 220 that alert drivers that they are entering a more congested urbanized area. These factors combine to suggest that northbound drivers will not comply with a dramatically lower speed limit. These characteristics support the idea of a design speed in the higher end of the range for rural arterials (50-75 mph).

Another corridor consistency concept is that introducing curves designed for lower speeds into an alignment where travelers have been traveling at a higher speed for long distances compromises safety. NCHRP and FHWA research demonstrates that gaining speed limit compliance is difficult without physical traffic calming measures[6] and that drivers will be unlikely to reduce their speed prior to passing the beginning of the lower-speed curve.[5, PG 236] *Underdesigned highway curves (i.e., curves with apparent safe operating speeds well below that of the open highway) should be viewed as important elements of any highway safety improvement program. Drivers do not totally decrease their open highway speeds to match a safe operating speed in advance of such sharp curves, and often apply their brakes within the curve.*[5, PG 231] *It is desirable that the running speed of a large proportion of drivers be lower than the design speed. Experience indicates that deviations from this desired goal are most evident and problematic on sharper horizontal curves. In particular, curves with low design speeds (relative to driver expectation) are frequently overdriven and tend to have poor safety records. Therefore, it is important that the design speed used for horizontal curve design be a conservative reflection of the expected speed on the constructed facility.*[16, PG 68] This supports the idea of curves down Farmington Hill designed for speeds not much below those of US 550 south of CR 220. In order to meet the project's purpose and need to improve safety, it is important to maintain consistency of design features related to speed throughout the corridor.

In summary, there are more potential safety issues for northbound drivers missing speed reduction cues than with southbound drivers accelerating from the intersection / interchange. Thus, corridor consistency considerations indicate that the higher end of the design speed range is more appropriate (50-75 mph).

CONCLUSION

This memo describes the key factors relevant in determining the appropriate design speed for the US 550 South Connection to US 160. The implications on design speed due to functional classification, anticipated operating speed, desired speed limit, speed reduction zones approaching US 160, terrain, and corridor consistency have all been examined.

Given the US 550 functional classification of Rural Principal Arterial, AASHTO guidance is that the design speed for the facility should be no lower than 50 mph. Anticipated operating speeds on the northbound project approach are anticipated to be near the 65 mph speed limit expected after the improvements outlined in the US 550 Environmental Assessment are constructed. That 65 mph speed limit and anticipated operating speed, combined with typical CDOT practices for speed reduction zones approaching

towns / interchanges, suggest speed limit reduction targets approaching US 160 from 65 mph to 55 mph, then later to 45 mph near the intersection or interchange. Corresponding desirable design speeds in the speed reduction zone would be from 70 mph to 60 mph, then later to 50 mph. If more aggressive 15 mph reductions were used, the minimum design speeds in the speed reduction zone would be from 70 mph to 55 mph, then later to 40 mph. The rolling terrain in the project area, combined with design guidance suggesting that design speeds should not be arbitrarily lowered based on the terrain designation, suggest a design speed in the range of 50 to 60 mph. Corridor consistency issues also point toward a design speed in the 50 to 60 mph range.

The overall ideas presented in this memo are summarized well by this section from the AASHTO A Guide for Achieving Flexibility in Highway Design: *Higher design speeds impose greater challenges and constraints on designers. Designers faced with difficult or constrained conditions may consider selecting a lower design speed for an element or portion of the highway. This practice can cause problems in that a large number of drivers may not "behave" as the designer desires or intends them to. Designs based on artificially low operating speeds, instead of the anticipated operating speeds of the reasonable and prudent driver, can result in inappropriate geometric features that violate driver expectations and degrade the safety of the highway. The emphasis should be on the consistency of design so as not to surprise the motorist with unexpected features. Therefore, the design speed should not be based on the speed limit unless the speed limit is based on the anticipated 85th percentile operating speed or is otherwise considered reasonable given expected operating speeds or physical constraints of the build environment.*[6, PG 18-19]

RECOMMENDATION

Based on all of the considerations described above, the following design speeds are recommended for US 550 between MP 15.4 and US 160:

Location	Desirable Minimum Design Speed	Absolute Minimum Design Speed[A]
US 550 from New Mexico State Line to CR 220 (Adjacent to SEIS Alternatives Analysis Study Area)	70 mph[B]	70 mph[B]
Southern curves (near CR 220 / MP 15.4)	60 mph	55 mph
Northern curves (near US 160)	50 mph	40 mph

A. Minimum design speeds should only be considered if it is not possible to obtain the desirable design speed.
B. Actual per US 550 EA, except 65 mph at Bondad Hill per US 550 FIR Design

NCHRP Report 737, Design Guidance for High-Speed to Low-Speed Transition Zones for Rural Highways, describes several techniques to visually cue drivers that speed reductions are required. These techniques include: raised medians, roundabouts, road diets, speed-activated feedback signs, gateway treatments, and transverse rumble strips. [20,PG 9-13] As project development progresses, consideration will be given to introducing such techniques, as appropriate, to aid drivers in the transition from a high speed facility south of CR 220 to a lower speed facility near the US 550 / US 160 intersection.

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