Design Exceptions: Evaluating Shoulder Width using the Highway Safety Manual

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Design Exception Success

Presentation Overview

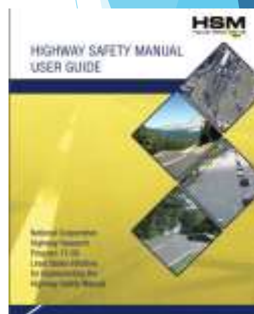
- Introduction
- Identify Design Exception
- Safety Analysis
  - Predictive Method
- Economic Appraisal
- Mitigation Strategies
- Justification, Documentation and Approval Requirements

Introduction-Tools You May Need

- Provide a demonstration of the Highway Safety Manual's application in a Shoulder Width Design Exception.

Introduction- New FDOT HSM User Guide

- Practical Guide to help navigate the predictive method.
- State Safety Office Website.
- Published in June 2015.
- NCHRP 17-50 HSM User Guide
  - Final Draft on-line



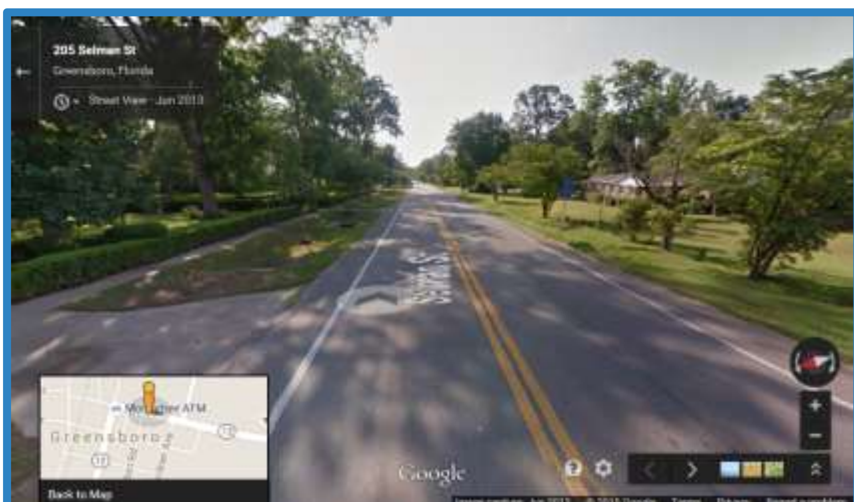
Identify Design Exception

- 13 Controlling Criteria
  - Design Speed
  - Lane Widths
  - Shoulder Widths
  - Bridge Widths
  - Structural Capacity
  - Vertical Clearance
  - Grades
  - Cross Slope
  - Superelevation
  - Horizontal Alignment
  - Vertical Alignment
  - Stopping Sight Distance
  - Horizontal Clearance

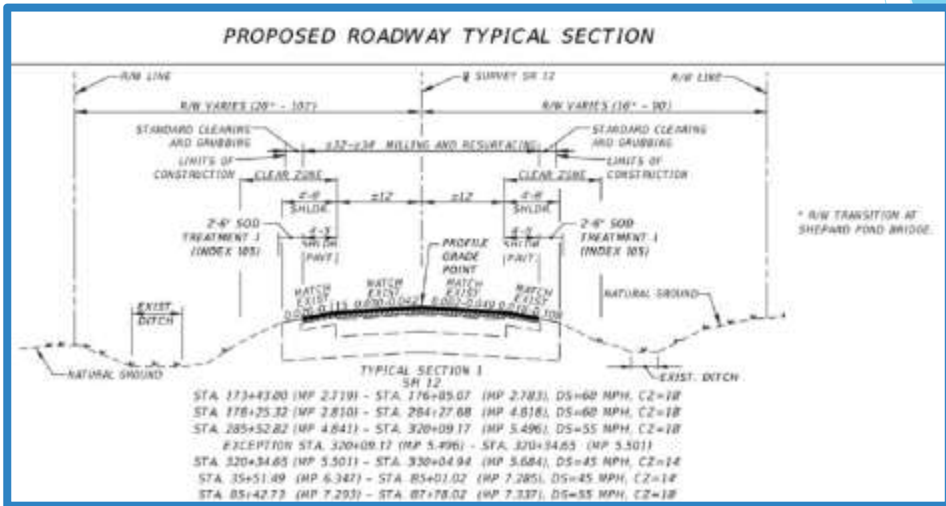
- ***Chapter 23 in Vol. 1 of PPM***
- ***FHWA Mitigation Strategies for Design Exceptions***

State Road 12 Gadsden County

Typical Section Looking North



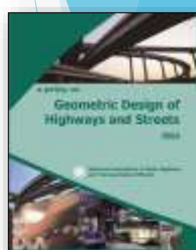
Approved Typical Section



Minimum Shoulder Width Criteria (effective or stabilized widths)

- FDOT PPM Criteria
  - New Construction (Ch. 2)
    - 8 feet (low volume)
    - 5 feet paved
  - RRR (Ch. 25)
    - 6 feet (all volumes)
    - 4 feet paved

- AASHTO Greenbook Criteria
  - New Construction
    - 8 feet (> 2000 ADT)
    - 0 foot paved



Evaluate Existing Shoulder Widths

- Effective Width: 4 to 5 Feet
  - 6 feet Required
- Paved Width: 4 to 5 Feet
  - Paved Widths less than 4 Feet Require a Design Variation

Identify Design Exception

- 13 Controlling Criteria
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  - Vertical Alignment
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Safety Analysis

- Historical Crash Method (HCM)
  - Uses Historical Crashes
  - 5 year Analysis
  - Uses Crash Reduction Factors (CRFs)
- Predictive Method
  - Statistically Predicts Crashes
  - Design Life Analysis
  - Uses Crash Modification Factors (CMFs)
  - Types
    - Roadside Safety Analysis Program (RSAP)
    - Highway Safety Manual (HSM)

Safety Analysis

- Predictive Method
  - The two Predictive Methods listed in our Plans Preparation Manual are:
    - Highway Safety Manual.
    - Roadside Safety Analysis Program (RSAP)
    - Both methods use specific roadway geometric features and traffic volumes to quantitatively estimate safety performance of proposed alternatives.

AASHTO Highway Safety Manual (HSM) 2010/2014

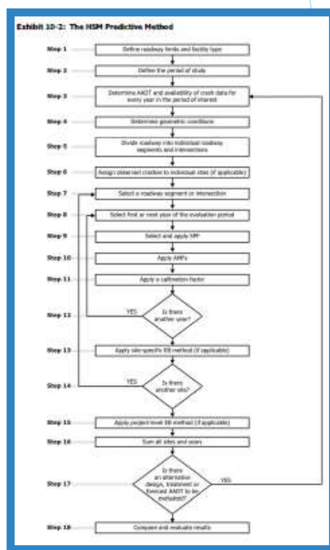
- Consist of 3 Volumes and a Supplement
  - Part A Fundamentals
  - Part B Process
  - Part C Predictive Method
  - Part D Countermeasures

HSM Part C: Predictive Method

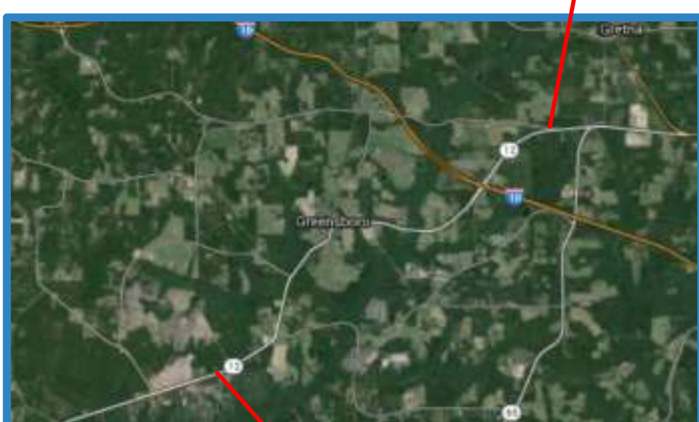
- Provides equations that statistically predict the number of crashes
  - Rural Two Lane Roads Ch. 10
  - Rural Multilane Roads Ch. 11
  - Urban/ Suburban Roads Ch. 12
  - Urban/ Rural Freeways Ch. 18 (2014 Supplement)
  - Ramps Ch. 19 (2014 Supplement)

HSM Predictive Method (18 Steps)

- Steps 1 – 4: Collect Existing Conditions
- Steps 5 – 8: Segment Roadway and Assign Crashes
- Steps 9 – 13: Apply SPFs, CMFs, Cf and EB Adjustment
- Steps 15 – 18: Design Life and Alternative Analysis



Step 1: Define roadway limits and facility type (Scope)



Step 1: Define roadway limits and facility type (Scope)

2 PROJECT DESCRIPTION

The CONSULTANT shall investigate the status of the projects and become familiar with concepts and commitments (typical sections, alignments, etc.) developed from prior studies. If a Preliminary Engineering Report is available from a prior or current Project Development and Environmental (PD&E) study, the CONSULTANT shall use the approved concepts as a basis for the design unless otherwise directed by the DEPARTMENT.

Financial Project ID: 428848-1-32-01

This 3R project primarily consists of resurfacing SR 12 from the Yon Creek Bridge to West of SR 10 (US 90). Existing travel lanes, parking lanes, auxiliary lanes, median crossovers, and paved shoulders will be resurfaced. The typical section consists of two (2) 12' travel lanes and variable width shoulders (5' paved). In the vicinity of the SR 8 (I-10) overpass, SR 12 widens to include a raised median and provides two (2) 12' travel lanes in each direction. The right-of-way varies throughout the project limits. No additional right-of-way will be required.

A flashing beacon exists within the limits of Greensboro at the intersection of SR 12 and CR 270 (Selman Street)(CMP 6.008). No work is anticipated for this signal.

Minor ADA improvements will be included in this project within the limits of Greensboro. These improvements may consist of repairing deficient sidewalk, replacing/retrofitting non compliant curb ramps, and meeting clear space requirements. An ADA Survey Report will be required. See Section 4.9.

The CSX railroad crossing at CMP 5.499 has been replaced in separate project.

Step 2: Define the study period (Project Design Life)

- 5 year study of observed crashes (CARS Data)
  - 2007 – 2011
  - CARS Data (Typically KABC only)
  - Total Crashes Sorted by KABCO
- 20 year study for Life Cycle cost analysis. (HSM/EB Model)
  - 2011 – 2031
  - 20 Year Expected Resurfacing Cycle

Step 2: Crash Types KABCO Factors (Default % Distribution for Rural 2-lane)

- **K = Fatal Crashes (1.3%)**
- **A = Incapaciting Injury Crashes (5.4%)**
- **B = Non-Incapacitating Injury Crashes (10.9%)**
- **C = Possible Injury Crashes (14.5%)**
- **O = Property Damage Only crashes. (67.9%)**
- All Crashes (100%)
- KABC Crashes (32.1%)

Step 3: AADT and Crash Data (Research)

- Obtain AADTs and Growth Rates for
  - AADTs
    - Opening Year: 2011 4500 veh/day
    - Design Year: 2031 5500 veh/day
  - Crash Data Needs
    - 2007 -2011 Minimum
    - Request from Project Manager.

Step 4: Geometric Conditions (Typical and Layout)

- Geometric Design Features, Traffic Control, Features, and Site Characteristics
  - Length of Segment (miles)
  - AADT (vehicles per day)
  - Lane Width (feet)
  - Shoulder Width (feet)
  - Shoulder Type (paved/ gravel/ composite/ turf)
  - Curve Data
  - Grade
  - Driveway Density (driveways/mile)

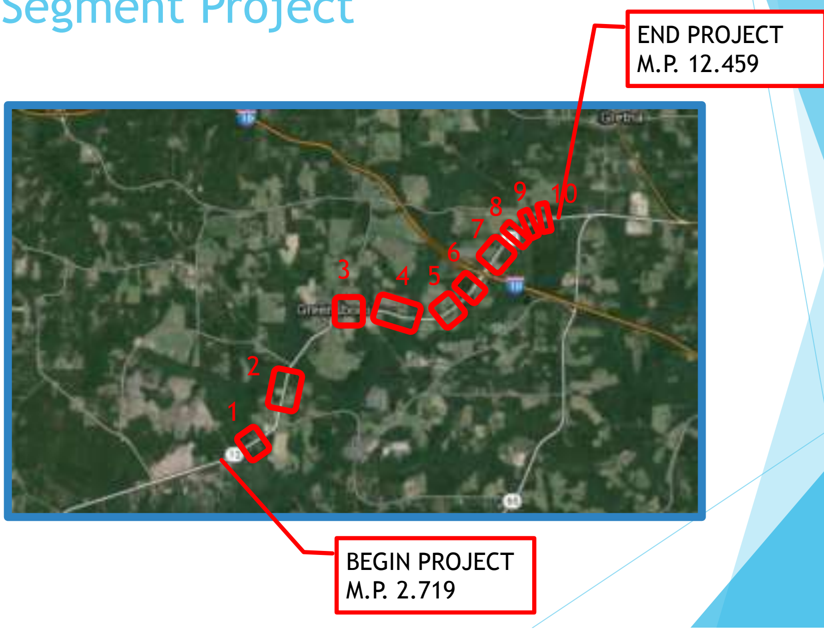
Step 4: Geometric Conditions (Spreadsheet)

Worksheet 1A -- General Information and Input Data for Rural Two-Lane Two-Way Roadway Segments

General Information		Location Information	
Analyst	Jeremy Fletcher	Roadway	SR 12 Greensboro
Agency or Company	FDOT	Roadway Section	MP 6.76 to MP 7.17
Date Performed	05/28/15	Jurisdiction	FDOT
		Analysis Year	2007

Input Data		Base Conditions	Site Conditions			
Length of segment, L (mi)		--	0.409			
AADT (veh/day)	$AADT_{MAX}$ = 17,800 (veh/day)	--	4,300			
Lane width (ft)		12	12			
Shoulder width (ft)		6	Right Shld:	4	Left Shld:	4
Shoulder type		Paved	Right Shld:	Paved	Left Shld:	Paved
Length of horizontal curve (mi)		0	0.0			
Radius of curvature (ft)		0	0			
Spiral transition curve (present/not present)		Not Present	Not Present			
Superelevation variance (ft/ft)		< 0.01	0			
Grade (%)		0	0			
Driveway density (driveways/mile)		5	12			
Centerline rumble strips (present/not present)		Not Present	Not Present			
Passing lanes [present (1 lane) /present (2 lane) / not present)]		Not Present	Not Present			
Two-way left-turn lane (present/not present)		Not Present	Not Present			
Roadside hazard rating (1-7 scale)		3	3			
Segment lighting (present/not present)		Not Present	Not Present			
Auto speed enforcement (present/not present)		Not Present	Not Present			
Calibration Factor, Cr		1	1.00			

Step 5: Segment Project



Step 6: Assign Observed Crashes

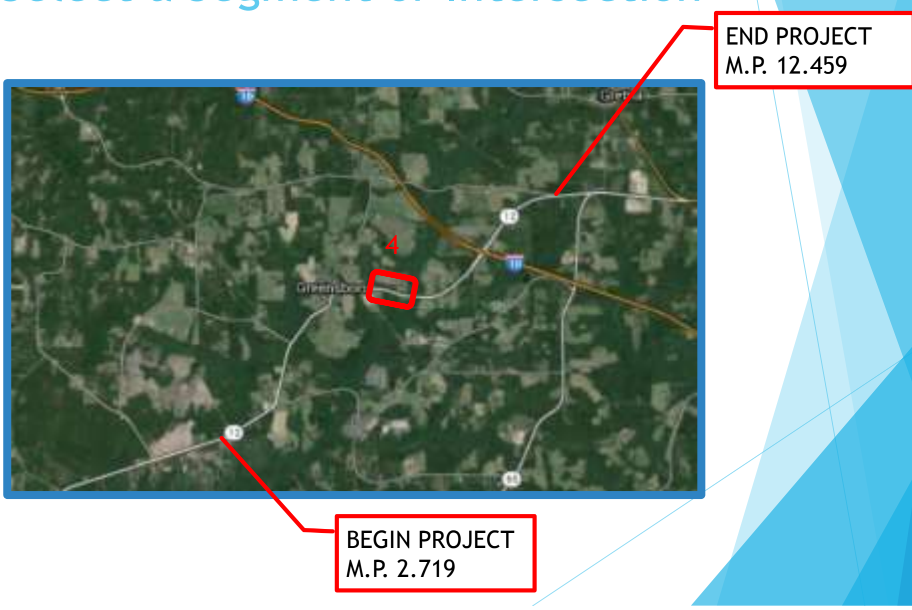
EXCEPTION AREAS	STA	MP	TO	STA	MP	LENGTH	Total Crashes Occurring in Areas	Event Codes Related to Shoulder Width															
								2	8	9	10	11	16	17	18	19	20	21	22	23	27	31	Total
1	184+65.00	2.932	TO	193+64.00	3.102	899	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
2	242+24.00	4.022	TO	270+66.00	4.560	2842	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	32+60.00	6.101	TO	41+60.00	6.272	900	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	57+13.00	6.757	TO	78+77.00	7.166	2164	4	[illegible]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	105+41.00	7.671	TO	119+61.00	7.940	1420	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	122+69.00	7.998	TO	144+95.00	8.420	2226	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
7	193+55.00	9.341	TO	248+92.00	10.389	5537	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	270+89.00	10.805	TO	287+74.00	11.124	1685	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	301+01.00	11.376	TO	317+82.00	11.694	1681	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
10	341+80.00	12.148	TO	356+61.00	12.429	1481	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
					Total	20835	34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3

Harmful event Code	Description	Harmful event Code	Description
2	Head-on	19	Hit fence
8	Coll. w/ parked car	20	Hit conc. barrier wall
9	Coll. w/ mv on roadway	21	Hit bridge/pier/abutment/rail
10	Coll. w/ pedestrian	22	Hit tree/shrubbery
11	Coll. w/ bicycle	23	Coll. w/ construction barricade
16	Utility/light pole	27	Hit fixed Object
17	Hit pole	31	Overturned
18	Hit guardrail		

Step 6: Observed Crash Adjustments (PDOs)

- Florida CARS Data typically only includes KABC Crashes. To account for PDO crashes, an increase should be applied to the observed crash data to determine the Total Observed Crash Rate for the site.
  - Section 4 Observed 5 year Crashes = 4
    - KABC Crashes = 32.1% of Total Crashes [Table 10-3]
    - PDO Crashes = 67.9% Crashes [Table 10-3]
  - Adjustments: Total Crashes = 4 ÷ 0.321
    - Total Observed Crashes = 12.46 Over 5 Years (2.5 Crashes/Year)

Step 7: Select a Segment or Intersection



Step 7: Selected Segment 4

Step 8: Determine 1st Year

- Opening Year
  - 2011
- Observed Crash Data (5 Years)
  - 2007 - 2011
- Design Year
  - 2031

Step 9: Select and apply SPF

- Rural Two-lane, Two-way Roads
  - $N_{spfrs} = AADT \times L \times 365 \times 10^{-6} \times e^{(-0.312)}$
    - N_{spfrs} = Total Number of Crashes for Base Conditions
      - Used in Before and After Calculations
    - AADT = Annual Average Daily Traffic (veh/day) = 4500 veh/day
    - L = length of segment (miles) = 0.409 miles
  - $N_{spfrs\text{-}2011} = 4500 \times 0.409 \times 365 \times 10^{-6} \times e^{(-0.312)}$
    - 0.49 Crashes/year (Predicted in 2011)

Step 10: Apply CMFs

Table 10-7. Summary of Crash Modification Factors (CMFs) in Chapter 10 and the Corresponding Safety Performance Functions (SPFs)

Facility Type	CMF	CMF Description	CMF Equations and Tables
Rural Two-Lane Two-Way Roadway Segments	CMF_{1r}	Lane Width	Table 10-8, Figure 10-7, Equation 10-11
	CMF_{2r}	Shoulder Width and Type	Table 10-9, Figure 10-8, Table 10-10, Equation 10-12
	CMF_{3r}	Horizontal Curves: Length, Radius, and Presence or Absence of Spiral Transitions	Table 10-7
	CMF_{4r}	Horizontal Curves: Superelevation	Equation 10-14, 10-15, 10-16,
	CMF_{5r}	Grades	Table 10-11
	CMF_{6r}	Driveway Density	Table 10-11
	CMF_{7r}	Centerline Rumble Strips	See text
	CMF_{8r}	Passing Lanes	See text
	CMF_{9r}	Two-Way Left-Turn Lanes	Equation 10-18, 10-19
	CMF_{10r}	Roadside Design	Equation 10-20
	CMF_{11r}	Lighting	Equation 10-21, Table 10-12
	CMF_{12r}	Automated Speed Enforcement	See text

Step 10: HSM: CMF Figure 10-8

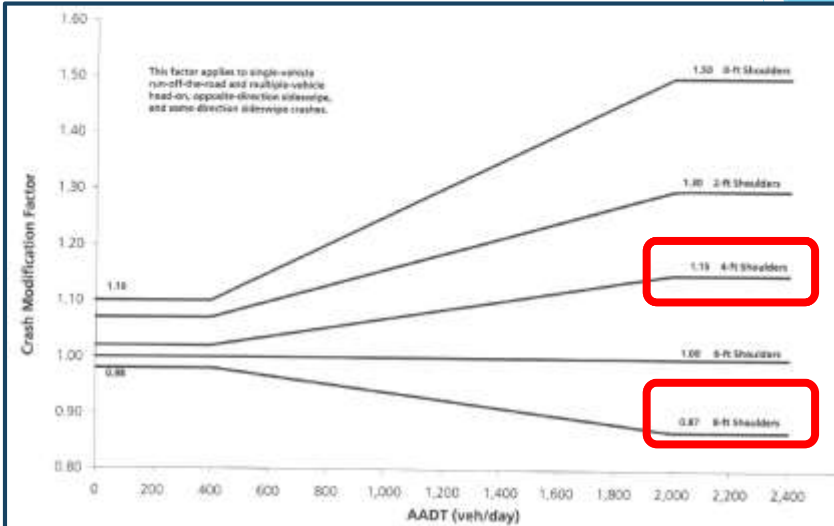


Figure 10-8. Crash Modification Factor for Shoulder Width on Roadway Segments

Step 10: Shoulder Width CMF Table 10-9

Table 10-9. CMF for Shoulder Width on Roadway Segments (CMF_{wra})

	AADT (vehicles per day)		
Shoulder Width	**< 400**	**400 to 2000**	**> 2000**
0 ft	1.10	$1.10 + 2.5 \times 10^{-4}$ (AADT − 400)	1.50
2 ft	1.07	$1.07 + 1.43 \times 10^{-4}$ (AADT − 400)	1.30
4 ft	1.02	$1.02 + 8.125 \times 10^{-5}$ (AADT − 400)	1.15
6 ft	1.00	1.00	1.00
8 ft or more	0.98	$0.98 + 6.875 \times 10^{-5}$ (AADT − 400)	0.87

Note: The collision types related to shoulder width to which this CMF applies include single-vehicle run-off the-road and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe crashes.

Step 10: Shoulder Type CMF Table 10-10

Table 10-10. Crash Modification Factors for Shoulder Types and Shoulder Widths on Roadway Segments (CMF_{tra})

Shoulder Type	Shoulder Width (ft)						
	0	1	2	3	4	6	8
Paved	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Gravel	1.00	1.00	1.01	1.01	1.01	1.02	1.02
Composite	1.00	1.01	1.02	1.02	1.03	1.04	1.06
Turf	1.00	1.01	1.03	1.04	1.05	1.08	1.11

Note: The values for composite shoulders in this table represent a shoulder for which 50 percent of the shoulder width is paved and 50 percent of the shoulder width is turf.

Step 10: Apply CMFs

- Shoulder Width CMF Adjustment Equation
  - CMF_{2r} = (CMF_{wra} x CMF_{tra} - 1.0) x p_{ra} + 1.0 [HSM Equation 10-12]
    - CMF_{2r} = Crash Modification Factor for Shoulder Width and Type
    - CMF_{wra} = Crash Modification Factor for Shoulder Width = 1.15
    - CMF_{tra} = Crash Modification Factor for Type = 1.0
    - P_{ra} = Proportion of total crashes represented by related crashes = 0.574
  - CMF_{2r} = (1.15 x 1.0 - 1.0) x 0.574 + 1.0
    - **1.09 CMF Adjustment to Total Crashes (4' Paved Shoulder)**

Step 10: CMF Combined Table

Crash Modification Factors for Shoulder Width and Type (Rural 2-Lane High Speed)							
Assumed AADT Greater than 2000	Shoulder Width (Feet)						
Shoulder Type	0	1	2	3	4	6	8
Paved							
CMF Width-Related	1.50	*1.40*	1.30	*1.23*	1.15	1.00	0.87
CMF Type **Paved**	1.00	1.00	1.00	1.00	1.00	1.00	1.00
CMF Adjusted to Total Crashes	**1.29**	**1.23**	**1.17**	**1.13**	**1.09**	**1.00**	**0.93**
Composite Shoulders							
CMF Width	1.50	*1.40*	1.30	*1.23*	1.15	1.00	0.87
CMF Type **Composite** (50/50 Paved)	1.00	1.01	1.02	1.02	1.03	1.04	1.06
CMF Adjusted to Total Crashes	**1.29**	**1.24**	**1.19**	**1.15**	**1.11**	**1.02**	**0.96**
Turf Shoulders							
CMF Width	1.50	*1.40*	1.30	*1.23*	1.15	1.00	0.87
CMF Type **Turf**	1.00	1.01	1.03	1.04	1.05	1.08	1.11
CMF Adjusted to Total Crashes	**1.29**	**1.24**	**1.19**	**1.16**	**1.12**	**1.05**	**0.98**
HSM Equation 10-12	*Values in italics have been pro-rated based on adjacent values*						
CMF (Total Crashes) = CMF (Related Crashes) * CMF (Total Crashes) * % Related Crashes (57.4%)							
References: HSM Table 10-9, 10-10							

Step 11: Apply Calibration Factors

- Florida Calibration Factor for a Rural 2-lane, 2-way Roadway Segment is 1.0
  - FDOT State Safety Office Web Site (Segments and Intersections)
- $N_{predicted} = N_{spfrs} \times C_x \times (CMF_{1r} \times CMF_{2r} \times \ldots \times CMF_{12r})$ [HSM: Eq. 10-2]
  - $N_{predicted}$ = Predicted Average Crashes for a Roadway Segment and Year
  - N_{spfrs} = Total Number of Crashes for Base Conditions = 0.49 crashes/year
  - C_x = Calibration Factor for Roadway Segment = 1.0
  - CMF = CMF_{2r} = Crash Modification Factor for Shoulder Width and Type = 1.09
  - $CMF_{Hzcurve}$ = 1.09 (Based on 2900' Radius for a 0.2 Mile Curve)
- $N_{predicted}$ = 0.49 x 1.0 x (1.09 x 1.09)
  - 0.582 Crashes/year (Predicted in 2011)

Step 11: Worksheet $N_{Predicted}$

Worksheet 1B – Crash Modification Factors for Rural Two-Lane Two-Way Roadway Segments												
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
CMF for Lane Width	CMF for Shoulder Width and Type	CMF for Horizontal Curves	CMF for Super-elevation	CMF for Grades	CMF for Driveway Density	CMF for Centerline Rumble Strips	CMF for Passing Lanes	CMF for Two-Way Left-Turn Lane	CMF for Roadside Design	CMF for Lighting	CMF for Automated Speed Enforcement	Combined CMF
CMF 1r	*CMF 2r*	*CMF 3r*	*CMF 4r*	*CMR 5r*	*CMF 6r*	*CMF 7r*	*CMF 8r*	*CMF 9r*	*CMF 10r*	*CMF 11r*	*CMF 12r*	*CMF comb*
from Equation 10-11	from Equation 10-12	from Equation 10-13	from Equations 10-14, 10-15, or 10-16	from Table 10-11	from Equation 10-17	from Section 10.7.1	from Section 10.7.1	from Equation 10-18 & 10-19	from Equation 10-20	from Equation 10-21	from Section 10.7.1	(1)x(2)x ... x(11)x(12)
1.00	1.09	1.09	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.183

Worksheet 1C – Roadway Segment Crashes for Rural Two-Lane Two-Way Roadway Segments							
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Crash Severity Level	**N spf rs**	**Overdispersion Parameter, k**	**Crash Severity Distribution**	**N spf rs by Severity Distribution**	**Combined CMFs**	**Calibration Factor, Cr**	**Predicted average crash frequency,**
	from Equation 10-6	from Equation 10-7	from Table 10-3 (proportion)	(2)TOTAL x (4)	(13) from Worksheet 1B		(5)x(6)x(7)
Total	0.492	0.58	1.000	0.492	1.18	1.00	0.582
Fatal and Injury (FI)	--	--	0.321	0.158	1.18	1.00	0.187
Property Damage Only (PDO)	--	--	0.679	0.334	1.18	1.00	0.395

Step 12: Predicted Crashes (4' Shoulder)

Service Life Year	AADT	$N_{SPFTotal}$	Calib. Factor	$CMF_{Total\ Before}$	$N_{predictedTotal}$ Before
2011	4500	0.49	1.00	1.183	0.582
2012	4545	0.50	1.00	1.183	0.588
2013	4590	0.50	1.00	1.183	0.593
2014	4636	0.51	1.00	1.183	0.599
2015	4683	0.51	1.00	1.183	0.605
2016	4730	0.52	1.00	1.183	0.611
2017	4777	0.52	1.00	1.183	0.618
2018	4825	0.53	1.00	1.183	0.624
2019	4873	0.53	1.00	1.183	0.630
2020	4922	0.54	1.00	1.183	0.636
2021	4971	0.54	1.00	1.183	0.643
2022	5021	0.55	1.00	1.183	0.649
2023	5071	0.55	1.00	1.183	0.655
2024	5121	0.56	1.00	1.183	0.662
2025	5173	0.57	1.00	1.183	0.669
2026	5224	0.57	1.00	1.183	0.675
2027	5277	0.58	1.00	1.183	0.682
2028	5329	0.58	1.00	1.183	0.689
2029	5383	0.59	1.00	1.183	0.696
2030	5436	0.59	1.00	1.183	0.703
2031	5491	0.60	1.00	1.183	0.710
				Total	13.519

Step 12: Predicted Crash Comparison (4’ vs 8’ Shoulder)

Service Life Year	AADT	$N_{SPF Total}$	Calib. Factor	$CMF_{Total-Before}$	$N_{predictedTotal}$ Before	CMF_{Total} After	NpredictedTotal After
2011	4500	0.49	1.00	1.183	0.582	1.041	0.512
2012	4545	0.50	1.00	1.183	0.588	1.041	0.517
2013	4590	0.50	1.00	1.183	0.593	1.041	0.522
2014	4636	0.51	1.00	1.183	0.599	1.041	0.527
2015	4683	0.51	1.00	1.183	0.605	1.041	0.533
2016	4730	0.52	1.00	1.183	0.611	1.041	0.538
2017	4777	0.52	1.00	1.183	0.618	1.041	0.543
2018	4825	0.53	1.00	1.183	0.624	1.041	0.549
2019	4873	0.53	1.00	1.183	0.630	1.041	0.554
2020	4922	0.54	1.00	1.183	0.636	1.041	0.560
2021	4971	0.54	1.00	1.183	0.643	1.041	0.565
2022	5021	0.55	1.00	1.183	0.649	1.041	0.571
2023	5071	0.55	1.00	1.183	0.655	1.041	0.577
2024	5121	0.56	1.00	1.183	0.662	1.041	0.583
2025	5173	0.57	1.00	1.183	0.669	1.041	0.588
2026	5224	0.57	1.00	1.183	0.675	1.041	0.594
2027	5277	0.58	1.00	1.183	0.682	1.041	0.600
2028	5329	0.58	1.00	1.183	0.689	1.041	0.606
2029	5383	0.59	1.00	1.183	0.696	1.041	0.612
2030	5436	0.59	1.00	1.183	0.703	1.041	0.618
2031	5491	0.60	1.00	1.183	0.710	1.041	0.625
				Total	13.519		11.896

Step 13: Weighting using the Empirical Beyes Method (EB)

- HSM Page 3-24

“…the statistical reliability is improved by combining the observed crash frequency and the estimate of the average crash frequency from a predictive model”

“The EB method is only applicable when both predicted and observed crash data are available for the specific roadway network conditions for which the estimate is being made.”

“It can be used to estimate expected average crash frequency for both past and future periods.”

Step 13: Empirical Beyes Method (EB)

- Weighting Factor Calculations [HSM EQ. 3-10]
  - w = Weighted Adjustment = 1/(1 + k x (Σ $N_{predicted\ (all\ study\ years)}$)
    - k = 0.236/L [HSM Equation 10-7]
    - k = 0.236/0.4miles = 0.577
    - Σ $N_{predicted}$ (2011) = 0.512 Crashes
    - w = 1/(1 + 0.577 x 0.512) = 0.77 (2011)
    - The longer the segment area with crash data, the higher the values are weighted to the predictive model.

Step 13: Empirical Beyes Method (EB)

- Observed Crash Frequencies and Predicted Crashes Needed
  - $N_{expected}$ = w x $N_{predicted}$ + (1 – w) x $N_{observed}$ [HSM Eq. 3-9]
    - $N_{expected}$ = Total Number of Expected Crashes
    - $N_{predicted}$ = Total Number of Predicted Crashes
    - $N_{observed}$ = Observed Crashes
    - w = Weighted Adjustment = 1/(1 + k x (Σ $N_{predicted\ (all\ study\ years)}$)
  - $N_{expected}$ = 0.77 x 0.512 + (1 – 0.77) x 2.5
    - 1.02 Total Crashes Expected [2011]

Step 14: Next Segment or Intersection

- Repeat the process for all sites/segments:
  - $N_{expected}$ for each segment and intersection
  - Weighting factor can be calculated individually by year or used on all years. (Example: w = 0.77)
  - Apply average observed crash rate (Example: 2.5/year) to all future years for life cycle analysis.

Step 14: Expected Crash Summary

$N_{Expected(FI)}$ Before (4')	$N_{Expected(FI)}$ After (8')	Delta N_{fi}	$N_{Expected(PDO)}$ Before	$N_{Expected(PDO)}$ After	Delta N_{PDO}	$N_{Expected(Total)}$ Before	$N_{Expected(Total)}$ After	Delta N_{total}
0.33	0.31	0.02	0.69	0.66	0.04	1.02	0.97	0.05
0.33	0.31	0.02	0.70	0.66	0.04	1.03	0.97	0.05
0.33	0.31	0.02	0.70	0.66	0.04	1.03	0.98	0.05
0.33	0.31	0.02	0.70	0.67	0.04	1.04	0.98	0.06
0.33	0.32	0.02	0.71	0.67	0.04	1.04	0.99	0.06
0.34	0.32	0.02	0.71	0.67	0.04	1.05	0.99	0.06
0.34	0.32	0.02	0.71	0.67	0.04	1.05	0.99	0.06
0.34	0.32	0.02	0.72	0.68	0.04	1.06	1.00	0.06
0.34	0.32	0.02	0.72	0.68	0.04	1.06	1.00	0.06
0.34	0.32	0.02	0.72	0.68	0.04	1.06	1.01	0.06
0.34	0.32	0.02	0.73	0.69	0.04	1.07	1.01	0.06
0.34	0.33	0.02	0.73	0.69	0.04	1.07	1.01	0.06
0.35	0.33	0.02	0.73	0.69	0.04	1.08	1.02	0.06
0.35	0.33	0.02	0.74	0.70	0.04	1.08	1.02	0.06
0.35	0.33	0.02	0.74	0.70	0.04	1.09	1.03	0.06
0.35	0.33	0.02	0.74	0.70	0.04	1.10	1.03	0.06
0.35	0.33	0.02	0.75	0.70	0.04	1.10	1.04	0.06
0.35	0.33	0.02	0.75	0.71	0.04	1.11	1.04	0.06
0.36	0.34	0.02	0.75	0.71	0.04	1.11	1.05	0.06
0.36	0.34	0.02	0.76	0.71	0.04	1.12	1.05	0.06
0.36	0.34	0.02	0.76	0.72	0.04	1.12	1.06	0.07

Step 15: Alternative-Apply project level EB Method

- This step is applicable to existing conditions when observed crash data are available, but cannot be accurately assigned to specific sites.
- Since our example has accurate locations of the observed crashes, this step is not applicable to the example shown.
- Can be used to perform Life Cycle Cost Analysis based on Crash Rate Deltas instead.

Step 16: Sum all Sites and Years

Step 16: Sum all Sites and Years

- Add up the $N_{expected}$ for all Sites to Include
  - Segments
    - Tangent Sections
    - Curved Sections
  - Intersections

Step 17 Mitigation Strategies

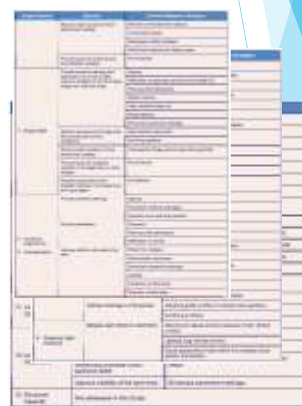
- Mitigation is a thorough process. Every Exception is unique.

- Mitigation Strategies for Design Exceptions (July 2007) is a resource for evaluating and implementing.

Step 17 Mitigation Strategies

TABLE 22
Potential Mitigation Strategies

Design Element	Objective	Potential Mitigation Strategies
1. Design Speed	Reduce operating speeds to the design speed.	Cross-sectional elements to manage speed.
2. Lane Width & 3. Shoulder Width	Optimize safety and operations by distributing available cross-sectional width.	Select optimal combination of lane and shoulder width based on site characteristics.
	Provide advance warning of lane width reduction.	Signing.
	Improve ability to stay within the lane.	Wide pavement markings.
		Recessed pavement markings.
		Raised pavement markings.
		Delineators.
		Lighting.
		Centerline rumble strips.
		Shoulder rumble strips.
		Painted edgeline rumble strips.
	Improve ability to recover if driver leaves the lane.	Paved or partially-paved shoulders.
		Safety edge.



Step 17: Alternative Designs and Countermeasures

- Optimize widths across section
- Edge Line Rumble Stripes
- Safety Edge
- Improved delineation
- Better Clear Zone
- Roadway Lighting

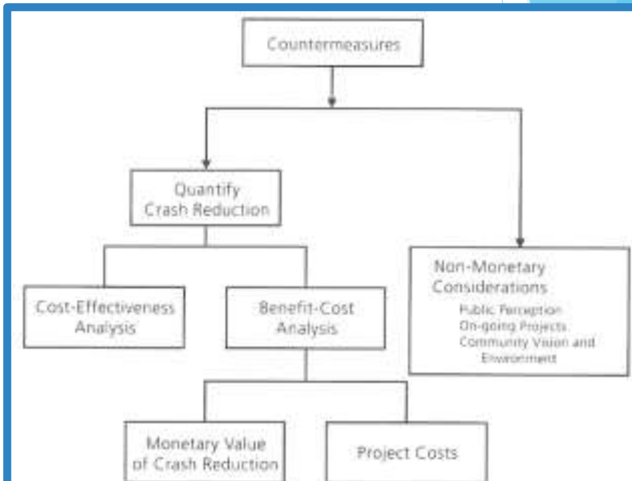


Figure 7-2. Economic Appraisal Process

Step 18: Compare and Evaluate Results

- Economic Appraisal of Crash reduction Benefits
- Construction costs for the improvements
- Net present value and Benefit Cost

Step 18: Annual Costs Fatal and Injuries

Year	Year in Service Life	Delta N_n	Crash $Cost_n$	AM_n
1	2011	0.02	$603,848	$12,077
2	2012	0.02	$603,848	$12,077
3	2013	0.02	$603,848	$12,077
4	2014	0.02	$603,848	$12,077
5	2015	0.02	$603,848	$12,077
6	2016	0.02	$603,848	$12,077
7	2017	0.02	$603,848	$12,077
8	2018	0.02	$603,848	$12,077
9	2019	0.02	$603,848	$12,077
10	2020	0.02	$603,848	$12,077
11	2021	0.02	$603,848	$12,077
12	2022	0.02	$603,848	$12,077
13	2023	0.02	$603,848	$12,077
14	2024	0.02	$603,848	$12,077
15	2025	0.02	$603,848	$12,077
16	2026	0.02	$603,848	$12,077
17	2027	0.02	$603,848	$12,077
18	2028	0.02	$603,848	$12,077
19	2029	0.02	$603,848	$12,077
20	2030	0.02	$603,848	$12,077
21	2031	0.02	$603,848	$12,077
				$253,616

Step 18: Annual Costs Property Damage

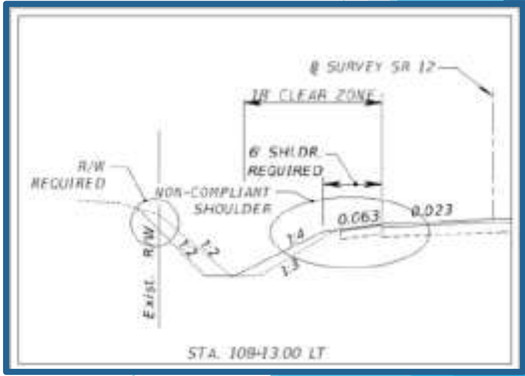
Delta N_{PDO}	Crash $Cost_{PDO}$	AM_{PDO}
0.040	$7,600	$304
0.040	$7,600	$304
0.040	$7,600	$304
0.040	$7,600	$304
0.040	$7,600	$304
0.040	$7,600	$304
0.040	$7,600	$304
0.040	$7,600	$304
0.040	$7,600	$304
0.040	$7,600	$304
0.040	$7,600	$304
0.040	$7,600	$304
0.040	$7,600	$304
0.040	$7,600	$304
0.040	$7,600	$304
0.040	$7,600	$304
0.040	$7,600	$304
0.040	$7,600	$304
0.040	$7,600	$304
0.040	$7,600	$304
0.040	$7,600	$304
		$6,384

Step 18: Total Present Value of Crashes

AM_{Total}	(P/A,I,y) Factor	PV_{Total}
$12,381	1.00	$12,381
$12,381	1.89	$23,352
$12,381	2.78	$34,358
$12,381	3.63	$44,942
$12,381	4.45	$55,118
$12,381	5.24	$64,903
$12,381	6.00	$74,311
$12,381	6.73	$83,358
$12,381	7.44	$92,057
$12,381	8.11	$100,421
$12,381	8.76	$108,463
$12,381	9.39	$116,196
$12,381	9.99	$123,632
$12,381	10.56	$130,782
$12,381	11.12	$137,656
$12,381	11.65	$144,267
$12,381	12.17	$150,623
$12,381	12.66	$156,734
$12,381	13.13	$162,611
$12,381	13.59	$168,261
$12,381	14.03	$173,694
	Total Present Value	**$2,158,118**

Step 18: Construction and R/W Costs

- Construction Costs (widen 4000’ of shoulder from 4’-8’)
  - Embankment, MOT, Mobilization, Drainage $100,000
- R/W Costs (6-8 Parcels)
  - $700,000
- Environmental Impacts = Unknown
- Total Projected Costs = $800,000



Step 18: Benefit Cost/Net Present Value

- Two Ways to analyze:
  - 1. Net Present Value = Benefits-Costs
    - $2,158,000 - $800,000 = $1,358,000 Net Present Value in Shoulder Widening (Used in Prioritization of Projects)
  - 2. Benefit/Cost: Benefits/Costs
    - $2,158,000/$800,000 = 2.70
- Benefits = Present Value of Crash Reduction ($2,158,000)
- Cost = Current Design, Construction, and R/W Costs ($800,000+)

Justification and Approval

Most Common Reasons for Denial

Justification/Documentation

- Criteria
- Evaluation / Analysis
  - Crash
  - Benefit/Cost
- Mitigation Strategies

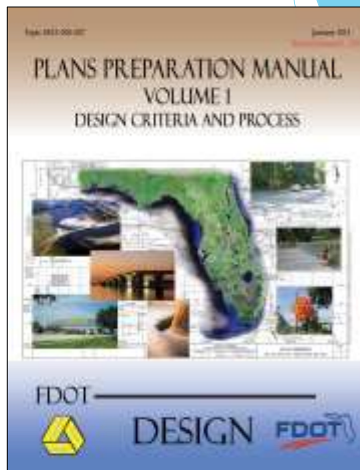
Justification

- A Strong Case for an Exception Can Be Made If:
  - The Required Criteria Are Not Applicable to the Site Conditions.
  - The Project Can be just as Safe by Not Following Nominal Criteria
  - The Environmental or Community Needs Prohibit Meeting Criteria.

Justification

- A Case Should Not Be Made Based Solely On the Following:
  - Money
    - Too Expensive to fix
  - Time
    - Schedule, Schedule, Schedule
  - Similar to other designs
    - This is the way we did it on another project

Documentation



- Plans Preparation Manual Chapter 23
  - Hope to soon streamline documentation required.
  - See Section 23.5 for other requirements or Call us.

Approvals

Submittal and Approval Process

- Submit early
- Adequate appendices
- Submit through project manager.
- Denial not necessarily imply a disagreement with the decision
- Reminder…Most Design Exceptions are ultimately approved.

Approval Process (PPM Exhibit 23-B)

Exhibit 23-B Central Office Approvals-
Design Exceptions and Design Variations

Design Element	State Roadway Design Engineer	State Structures Design Engineer	State Transportation Planner	Chief Engineer	FHWA Division Admin.*
	Approval	Approval	Review	Approval	
Design Speed Exception	X				
-FIHS/SIS	X		X	X	
Design Speed Variation -FIHS/SIS			X	X	
Lane Width Exception	X				
Shoulder Width Exception	X				
Bridge Width Exception	X	X			
Bridge Width Variation (Category 2 Structures)		X			
Structural Capacity of Bridge Exception		X			
Structural Capacity of Bridge Variation					
-Category 2 Structures		X			
-Deficient Load Ratings (Category 1 and 2 Structures)		X			
-Traffic Railing (Category 1 and 2 Structures)		X			
Vertical Clearance Exception	X				
-16' for rural interstate routes or single urban interstate route	X				X
-All Category 1 and 2 Structures	X	X			
Vertical Clearance Variation (Category 2 Structures)		X			
Grades Exception	X				
Cross Slope Exception	X				
Superelevation Exception	X				

Exhibit 23-B Central Office Approvals-
Design Exceptions and Design Variations (continued)

Design Element	State Roadway Design Engineer	State Structures Design Engineer	State Transportation Planner	Chief Engineer	FHWA Division Admin.*
	Approval	Approval	Review	Approval	
Horizontal Alignment Exception	X				
Vertical Alignment Exception	X				
Stopping Sight Distance Exception	X				
Horizontal Clearance Exception	X				
-RR-South Fla Rail Corridor	X				
-Category 1 and 2 Structures	X	X			
Horizontal Clearance Variation (Category 2 Structures)		X			
Design Variation: Rumble strip requirements	X				
Design Variation: Crossovers on Limited Access Facilities	X				X
Design Variation: Patterned Pavement Technical Special Provisions	X				
Roundabout Designs-All	X				
Colored Bike Lane Assessments (The first 3 years after installation)	X				
Design Variation: Community Structures Non-Interstate	X				
Design Variation: Community Structures Interstate	X				X
Lump Sum Contracts (Non-Typical)	X				

*Design Exceptions on full FHWA oversight projects

Conclusion

- A well documented justification and engineering analysis will typically result in an approval by the Department.
- More Examples to come…

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Jeremy Fletcher, P.E., P.S.M
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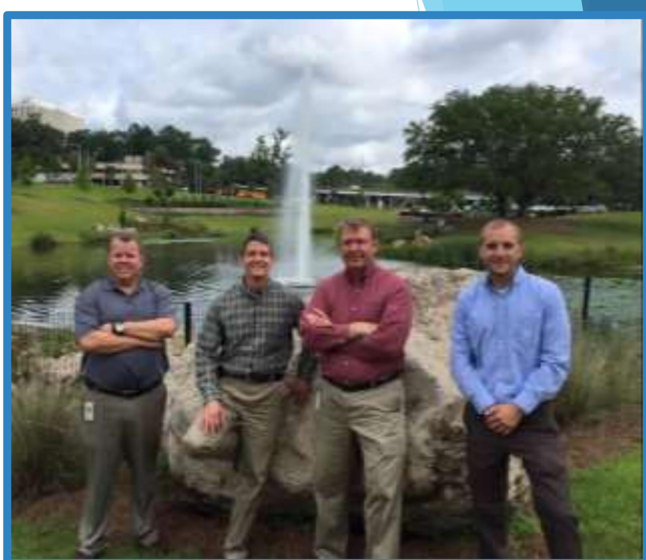

Who has the first question?