PART D— ACCIDENT MODIFICATION FACTORS

CHAPTER 16— SPECIAL FACILITIES AND GEOMETRIC SITUATIONS

EXHIBITS

APPENDIX A

CHAPTER 16 SPECIAL FACILITIES AND GEOMETRIC SITUATIONS

16.1. INTRODUCTION

This chapter presents AMFs for traffic control and operational element treatments at various facilities.

Chapter 16 presents Accident Modification Factors (AMFs) for design, traffic control, and operational elements at various special facilities and geometric situations. Special facilities include railroad-highway grade crossings, work zones, two-way left-turn lanes, and passing and climbing lanes. The information is used to identify effects on expected average crash frequency resulting from treatments applied at interchanges and interchange ramp terminals.

The *Part D Introduction and Applications Guidance* section provides more information about the processes used to determine the AMFs presented in this chapter.

Chapter 16 is organized into the following sections:

- Definition, Application and Organization of AMFs (Section 16.2)
- Crash Effects of Railroad-Highway Grade Crossings, Traffic Control, and Operational Elements (Section 16.3)
- Crash Effects of Work Zone Design Elements (Section 16.4)
- Crash Effects of Two-Way Left-Turn Lane Elements (Section 16.5)
- Crash Effects Of Passing And Climbing Lanes (Section 16.6)
- Conclusion (Section 16.7)

Appendix A presents the crash effects of treatments for which AMFs are not currently known.

16.2. DEFINITION, APPLICATION AND ORGANIZATION OF AMFS

Chapter 3 provides a thorough definition and explanation of AMFs.

AMFs quantify the change in expected average crash frequency (crash effect) at a site caused by implementing a particular treatment (also known as a countermeasure, intervention, action, or alternative), design modification, or change in operations. AMFs are used to estimate the potential change in expected crash frequency or crash severity plus or minus a standard error due to implementing a particular action. The application of AMFs involves evaluating the expected average crash frequency with or without a particular treatment, or estimating it with one treatment versus a different treatment.

Specifically, the AMFs presented in this chapter can be used in conjunction with activities in *Chapter 6 Select Countermeasures*, and *Chapter 7 Economic Appraisal*. Some *Part D* AMFs are included in *Part C* for use in the predictive method. Other *Part D* AMFs are not presented in *Part C* but can be used in the methods to estimate change in crash frequency described in Section C.7 of the *Part C Introduction and Applications Guidance*. *Chapter 3 Fundamentals*, Section 3.5.3 Accident Modification Factors provides a comprehensive discussion of AMFs including: an introduction to AMFs, how to interpret and apply AMFs, and applying the standard error associated with AMFs.

The treatments are organized into 3 categories: treatments with AMFs; treatments with trend information; and, no trend or AMF information.

In all *Part D* chapters, the treatments are organized into one of the following categories:

1. AMF is available;
2. Sufficient information is available to present a potential trend in crashes or user behavior, but not to provide an AMF; and
3. Quantitative information is not available.

Treatments with AMFs (Category 1 above) are typically estimated for three accident severities: fatal, injury, and non-injury. In *Part D*, fatal and injury are generally combined and noted as injury. Where distinct AMFs are available for fatal and injury severities, they are presented separately. Non-injury severity is also known as property-damage-only severity.

Unless otherwise specified, fatal and injury AMFs are generally combined and categorized as injury crashes.

Treatments for which AMFs are not presented (Categories 2 and 3 above) indicate that quantitative information currently available did not meet the criteria for inclusion in the HSM. The absence of an AMF indicates additional research is needed to reach a level of statistical reliability and stability to meet the criteria set forth within the HSM. Treatments for which AMFs are not presented are discussed in Appendix A.

16.3. CRASH EFFECTS OF RAILROAD-HIGHWAY GRADE CROSSINGS, TRAFFIC CONTROL, AND OPERATIONAL ELEMENTS

16.3.1. Background and Availability of AMFs

There are two main types of railroad-highway crossings: at grade and grade-separated. A grade-separated railroad-highway crossing eliminates the conflict points between rail and road and removes the potential for crossing accidents.[13] The HSM focuses on railroad-highway at-grade crossings. Grade-separated crossings are not discussed.

In general, the discussion focuses on crossings with heavy freight rail. Where distinct information on light passenger rail and heavy freight rail is available, these modes are noted separately. Private crossings are not addressed separately.

Signs and Markings

Advance traffic control and warning devices for railroad-highway grade crossings typically consist of signs and pavement markings. Other advance control and warning devices include flashing light signals, vehicle activated signals, and transverse rumble strips. The advance traffic control and warning devices used vary with the crossing design.[1]

Signals and Gates

Section 16.3 provides AMFs for common treatments related to railroad highway grade crossing, traffic control, and operational elements.

Traffic control at railroad-highway grade crossings includes traffic signal preemption, traffic signal interconnection, pre-signals in the vicinity of railroad-highway grade crossings, and gates. The type of traffic control at a railroad-highway grade crossing depends on a number of factors including daily train volumes, vehicle volumes, and sight distances.

Traffic control devices used to warn road users that a train is approaching a railroad-highway grade can be passive or active:[4]

- Passive traffic control systems typically consist of signs and pavement markings that identify and direct motorists' and pedestrians' attention to a grade crossing. Stand-alone passive devices provide no information to motorists on whether a train is approaching. [9] These devices provide static messages; the message conveyed by the advanced warning signs and markings remain constant regardless of the presence or absence of a train.[3,6,10,11,14]
- Active traffic control systems are inactive until a train approaches. An approaching train activates some combination of automatic gates, bells or flashing lights. Active devices provide crossing users with an auditory or visual clue that a train is approaching the crossing in question. In some cases, for example when gates are lowered, the traffic control device physically separates crossing users from the railroad right-of-way.

Illumination

Artificial illumination is occasionally provided at railroad-highway grade crossings. No quantitative information about the crash effects of illumination at railroad-highway grade crossings was found for this edition of the HSM. *Chapter 14*, presents reference material for potential crash effects of illumination.

Exhibit 16-1 summarizes the treatments related to railroad-highway grade crossing, traffic control, and operational elements and the corresponding AMFs available.

Exhibit 16-1: Treatments Related to Railroad-Highway Grade Crossing Traffic Control and Operational Elements

HSM Section	Treatment	Rural Two-Lane road	Rural Multi-Lane Highway	Freeway	Expressway	Urban Arterial	Suburban Arterial
16.3.2.1	Install flashing lights and sound signals	✓	✓	N/A	N/A	✓	✓
16.3.2.2	Install automatic gates	✓	✓	N/A	N/A	✓	✓
Appendix A	Install crossbucks	T	T	N/A	N/A	T	T
Appendix A	Install vehicle-activated strobe light and supplemental signs	T	T	N/A	N/A	T	T
Appendix A	Install four-quadrant automatic gates	T	T	N/A	N/A	T	T
Appendix A	Install four-quadrant flashing light signals	T	T	N/A	N/A	T	T
Appendix A	Install pre-signals	T	T	N/A	N/A	T	T
Appendix A	Provide constant warning time devices	T	T	N/A	N/A	T	T

NOTE: ✓= Indicates that an AMF is available for the treatment.

T = Indicates that an AMF is not available but a trend regarding the potential change in crashes or user behavior is known and presented in Appendix A.

N/A = Indicates that the treatment is not applicable to the corresponding setting.

16.3.2. Railroad-Highway Grade Crossing, Traffic Control and Operational Treatments with AMFs

16.3.2.1. Install Flashing Lights and Sound Signals

Active traffic control systems are inactive until a train approaches. An approaching train activates some combination of automatic gates, bells, or flashing lights. Active devices provide crossing users with an auditory or visual clue that a train is approaching the crossing in question.

Rural two-lane road, rural multi-lane highways, urban, and suburban arterials

The crash effects of installing flashing lights and sound signals at railroad-highway grade crossings that previously had only signs are shown in Exhibit 16-2.

The base condition for this AMF (i.e., the condition in which the AMF = 1.00) is the absence of flashing lights and sound signals at railroad-highway crossings (passive control).

Exhibit 16-2: Potential Crash Effects of Installing Flashing Lights and Sound Signals (2)

Treatment	Setting (Crossing Type)	Traffic Volume	Accident Type (Severity)	AMF	Std. Error
Install flashing lights and sound signals	Unspecified (Unspecified)	Unspecified	Grade crossing (all severities)	**0.50**	**0.05**
Base Condition: Passive control at railroad-highway crossing.					

NOTE: **Bold** text is used for the most reliable AMFs. These AMFs have a standard error of 0.1 or less.

16.3.2.2. Install Automatic Gates

Automatic gates are active control devices that physically separate crossing users (cars, pedestrians, bicycles) from the railroad right-of-way.

Rural two-lane road, rural multi-lane highways, urban, and suburban arterials

The crash effects of installing automatic gates at railroad-highway grade crossings that previously had passive traffic control are shown in Exhibit 16-3.*(Error! Reference source not found.)*

The crash effects of installing automatic gates at railroad-highway grade crossings that previously had flashing lights and sound signals are shown in Exhibit 16-3.*(Error! Reference source not found.)*

The base condition of the AMFs (i.e., the condition in which the AMF = 1.00) consists of crossings with passive traffic control or crossings with flashing lights and sound signals, in either case with an absence of automatic gates.

Exhibit 16-3: Potential Crash Effects of Installing Automatic Gates(2)

Treatment	Setting (Crossing type)	Traffic Volume	Accident type (Severity)	AMF	Std. Error
Install automatic gates at crossings that previously had passive traffic control	Unspecified (Unspecified)	Unspecified	Grade crossing (All severities)	**0.33**	**0.09**
Install automatic gates at crossings that previously had flashing lights and sound signals				**0.55**	**0.09**
Base Condition: Crossings with passive traffic control or crossings with flashing lights and sound signals, in either case with an absence of automatic gates.					

NOTE: **Bold** text is used for the most reliable AMFs. These AMFs have a standard error of 0.1 or less.

The gray box below presents an example of how to apply the preceding AMFs to assess the change in expected average crash frequency when installing automatic gates on a rural two-lane road grade rail crossing.

Effectiveness of Installing Automatic Gates

Question:

As part of a roadway improvement project, a rail crossing with flashing lights and sound signals is now being considered for the installation of automatic gates. What will be the likely reduction in the expected average crash frequency?

Given Information:

- Existing roadway = rural two-lane road
- Crossing type = at-grade crossing
- Existing traffic control = flashing lights and sound signals
- Expected average crash frequency with existing treatment = 0.25 crashes/year

Find:

- Expected average crash frequency with installation of automatic gates
- Change in expected average crash frequency

Answer:

1) Identify the applicable treatment AMF

   $AMF_{Treatment}$ = 0.55 (Exhibit 16-3)

2) Calculate the 95th Percentile Confidence Interval Estimation of Crashes with the Treatment

   Expected Crashes with Treatment: = (0.55 ± 2 x 0.09) x (0.25 crashes/year) = 0.09 or 0.18 crashes/year

   The multiplication of the standard error by 2 yields a 95% probability that the true value is between 0.09 and 0.18 crashes/year. See Section 3.5.3 in *Chapter 3 Fundamentals* for a detailed explanation.

3) Calculate the difference between the expected average crash frequency without the treatment and with the treatment.

   Change in Expected Average Crash Frequency:
   Low Estimate = 0.25 – 0.09 = 0.16 crashes/year reduction
   High Estimate = 0.25 – 0.18 = 0.07 crashes/year reduction

4) **Discussion: The implementation of automatic gates at the rail crossing may potentially produce a reduction of between 0.16 and 0.07 crashes/year.**

16.4. CRASH EFFECTS OF WORK ZONE DESIGN ELEMENTS

16.4.1. Background and Availability of AMFs

Work zones can result in disruptions in driving speed, trip routes, and driver expectancy. Accidents in work zones can cause additional delays and congestion.

Exhibit 16-4 summarizes treatments related to work zone design elements and the corresponding AMF availability.

Exhibit 16-4: Treatments Related to Work Zone Design Elements

HSM Section	Treatment	Rural Two-Lane road	Rural Multi-Lane Highway	Freeway	Expressway	Urban Arterial	Suburban Arterial
16.4.2.1	Modify work zone duration and length	-	-	✓	-	-	-
Appendix A	Use crossover closure or single lane closure	-	T	T	T	-	-
Appendix A	Use Indiana Lane Merge System (ILMS)	-	-	T	-	-	-

NOTE: ✓ = Indicates that an AMF is available for the treatment.

T = Indicates that an AMF is not available but a trend regarding the potential change in crashes or user behavior is known and presented in Appendix A.

- = Indicates that an AMF is not available and a crash trend is not known.

16.4.2. Work Zone Design Treatments with AMFs

16.4.2.1. Modify Work Zone Duration and Length

Section 16.4 provides crash effects information for work zone design elements.

Freeways

Work zone design elements include duration in number of days, and length in miles. Equation 16-1 and Exhibit 16-5 present an AMF for the potential crash effects of modifying work zone duration. Equation 16-2 and Exhibit 16-6 present an AMF for the potential crash effects of modifying work zone length. These AMFs are based on research that considered work zone durations from 16 to 714 days, work zone lengths from 0.5 to 12.2 mi, and freeway AADTs from 4,000 to 237,000 veh/day.[8]

The base condition of the AMFs (i.e., the condition in which the AMF = 1.00) is a work zone duration of 16 days and/or work zone length of 0.51 miles. The standard errors of the AMFs below are unknown.

Expected average crash frequency effects of increasing work zone duration [8]

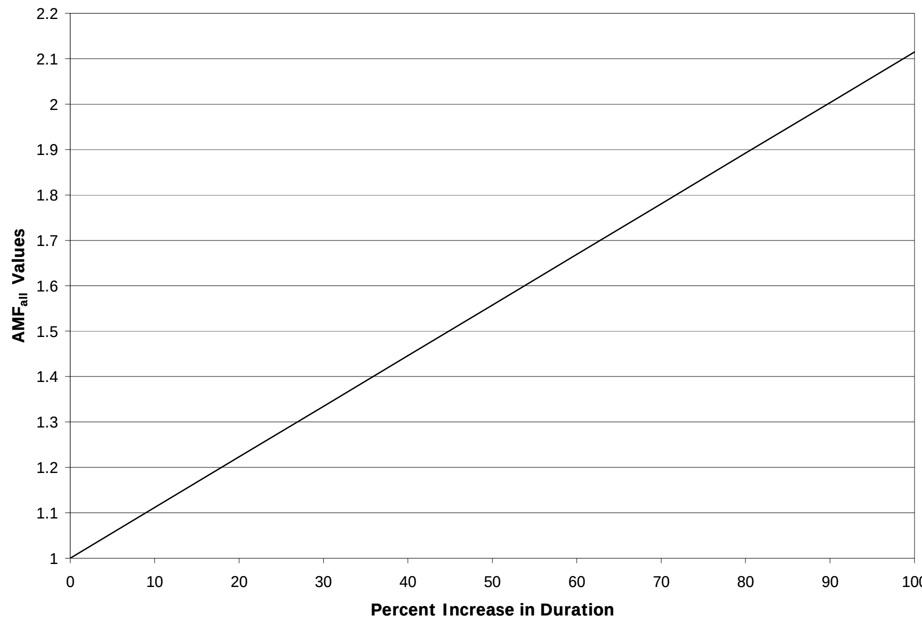
$$AMF_{all} = 1.0 + \frac{(\%\ increase\ in\ duration \times 1.11)}{100} \qquad (16\text{-}1)$$

Where,

AMF_{all} = accident modification factor for all crash types and all severities in the work zone

% increase in duration = the percentage change in duration (days) of the work zone

Exhibit 16-5: Expected Average Crash Frequency Effects of Increasing Work Zone Duration



Expected average crash frequency effects of increasing work zone length (miles)[8]

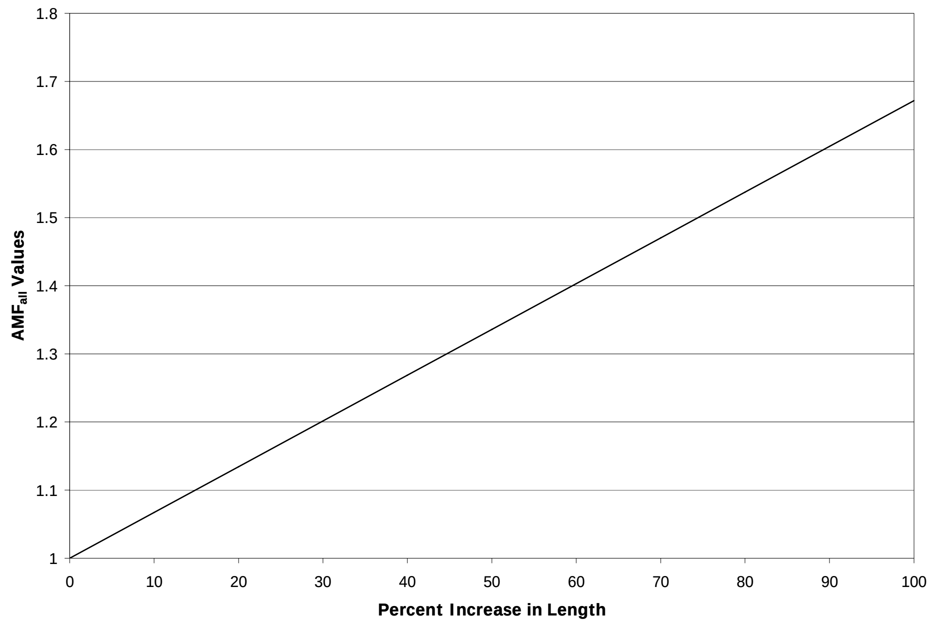
$$AMF_{all} = 1.0 + \frac{(\%\ increase\ in\ length \times 0.67)}{100} \qquad (16\text{-}2)$$

Where,

AMF_{all} = the accident modification factor for all crash types and all severities in the work zone

% increase in length = the percentage change in length (mi) of the work zone

Exhibit 16-6: Expected Average Crash Frequency Effects of Increasing Work Zone Length (miles)



The gray box below presents an example of how to apply Equation 16-2 and Exhibit 16-5; and Equation 16-3 and Exhibit 16-6 to assess the crash effects of modifying the work zone duration and length concurrently.

Effectiveness of Modifying the Work Zone Duration

Question:

A 5 mile stretch of highway is being rehabilitated. The design engineer has identified a construction period of 9 months with a full project length work zone. What will be the likely change in the expected average crash frequency?

Given Information:

- Base Condition for AMFs
  - Project Work Zone length = 0.51 miles
  - Project Work Zone duration = 16 days
- Proposed Work Zone Length = 1 miles
- Proposed Work Zone Duration = 32 days
- Expected Average Crash Frequency under the Base Scenario (See Part C Predictive Methods) = 6 crashes/year

Find:

- Expected Average Crash Frequency under Proposed Scenario
- Change in Expected Average Crash Frequency

Answer:

1) Calculate the Work Zone Length AMF_{length}

$$AMF_{length} = 1.0 + \frac{(\%\ increase\ in\ length \times 0.67)}{100} \quad \text{(Equation 16-2)}$$

$$AMF_{length} = 1.0 + \frac{(96 \times 0.67)}{100} =$$

$$AMF_{length} = 1.64$$

2) Calculate the Work Zone Duration $AMF_{duration}$

$$AMF_{duration} = 1.0 + \frac{(\%\ increase\ in\ duration \times 1.11)}{100} \quad \text{(Equation 16-1)}$$

$$AMF_{duration} = 1.0 + \frac{(100 \times 1.11)}{100} =$$

$$AMF_{duration} = 2.11$$

3) Calculate the Combined AMF_{total} Work Zone Condition

$AMF_{total} = AMF_{length} \times AMF_{duration} = 1.64 \times 2.11 = 3.46$

Both AMFs are multiplied to account for the combined effect of work zone length and duration.

4) Calculate the expected number of crashes under the proposed work zone scenario.

Expected Crashes under the Proposed Work Zone Scenario =
= 3.46 x (6 crashes/year) = 20.8 crashes/year

5) Calculate the difference between the expected average crash frequency under the base condition and with the treatment.

Change in Expected Average Crash Frequency

20.8 - 6.0 = 14.8 crashes/year increment

6) Discussion: The proposed work zone length and duration may potentially cause an increment of 14.8 crashes/year, when compared to a base scenario work zone length and duration.

16.5. CRASH EFFECTS OF TWO-WAY LEFT-TURN LANE ELEMENTS

Section 16.6 provides crash effects information for two-way left turn lane elements.

16.5.1. Background and Availability of AMFs

Two-way left turn-lanes (TWLTL) are intended to reduce potential conflicts with turning traffic and to provide a refuge from through vehicles for drivers waiting to turn left. Potential offsetting challenges may, however, arise:

- Where drivers increase their speed on the through lanes due to the left-turning traffic being removed;
- In urban areas where the TWLTL increases the width that pedestrians have to walk across the road;
- In urban areas where pedestrians may treat the TWLTL as a refuge area;
- Where traffic volumes back up into the TWLTL, blocking the TWLTL for the opposing direction;
- Where the driveway entrance is poorly designed and cannot readily accommodate the turning traffic which may then slow down or even stop as it crosses the through lanes;
- Where driveways and access points are not clearly marked and conspicuous, drivers may not be able to see where to turn resulting in slowing or quick stopping;
- Where drivers use the TWLTL for passing. A TWLTL that leads to the loss of a passing lane requires careful evaluation[5];
- Where seven-lane urban arterials (six through lanes/one TWLTL) are constructed, turning and crossing traffic have longer crossing times. Increased driver risk taking may occur; and,
- Where a curb lane is an HOV lane with low traffic volumes, encouraging drivers turning from a TWLTL to risk crossing the HOV lane even when their view is blocked, since they do not expect a vehicle to be in that lane.

Exhibit 16-7 summarizes treatments related to two-way left-turn lanes and the corresponding AMF and trend availability.

Exhibit 16-7: Treatments Related to Two-Way Left-Turn Lanes

HSM Section	Treatment	Rural Two-Lane road	Rural Multilane Highway	Freeway	Expressway	Urban Arterial	Suburban Arterial
16.5.2.1	Provide Two-Way Left-Turn Lane	✓	-	-	-	T	T

NOTE: ✓= Indicates that an AMF is available for the treatment.

T = Indicates that an AMF is not available but a trend regarding the potential change in crashes or user behavior is known and presented in Appendix A.

- = Indicates that an AMF is not available and a crash trend is not known.

16.5.2. Two-Way Left-Turn Lane Treatments with AMFs

16.5.2.1. Provide Two-Way Left-Turn Lane

A TWLTL, or continuous center left-turn lane, is a special lane in the center of the highway. The lane is reserved for vehicles making mid-block left-turns, i.e., turns into or out of access points between intersections. A TWLTL is a common treatment on urban and suburban arterials with many access points.

Rural two-lane roads

The potential crash effects of providing a TWLTL on rural two-lane roads where driveway density is known and consists of at least five driveways per mile is shown in Equation 16-3 and Exhibit 16-8, for driveway-related left-turn accidents.(7) The potential crash effect for non-driveway-related accidents or non-left-turn driveway accidents is not certain at this time.

The base condition for this AMF (i.e., condition in which AMF = 1.0) is the absence of TWLTL or a driveway density less than five driveways per mile. The standard error of this AMF is unknown.

$$AMF = 1.0 - \left(0.7 \times p_{dwy} \times p_{LT/D}\right) \qquad (16\text{-}3)$$

$$p_{dwy} = \frac{\left(0.0047 \times DD\right) + \left(0.0024 \times DD^{2}\right)}{1.199 + \left(0.0047 \times DD\right) + \left(0.0024 \times DD^{2}\right)} \qquad (16\text{-}3A)$$

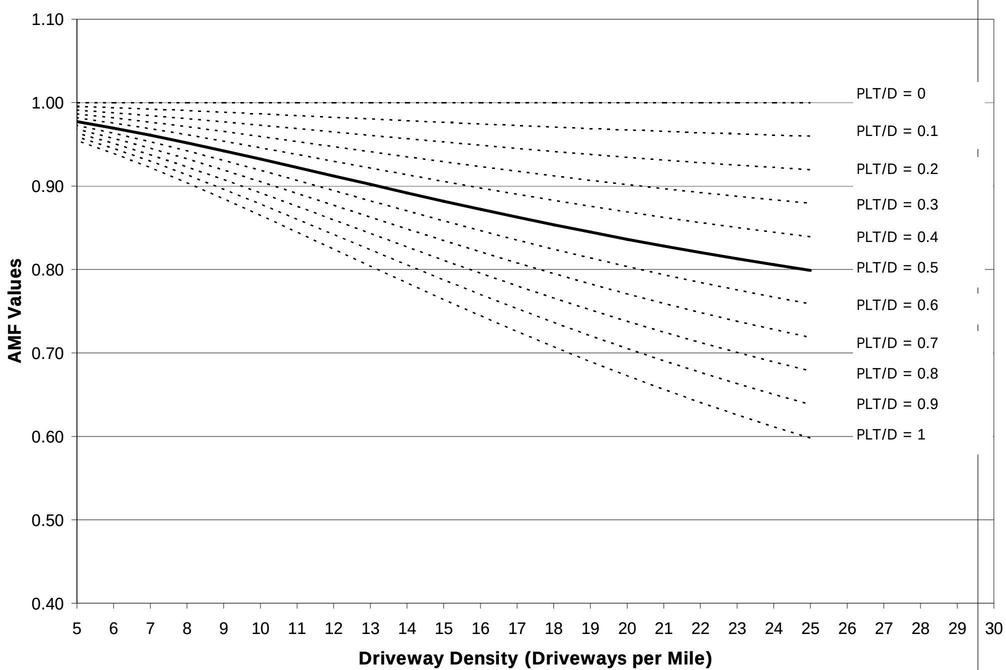
Where,

P_{dwy} = driveway-related accidents as a proportion of total accidents

DD = driveway density (driveways per mile)

$P_{LT/D}$ = left-turn accidents subject to correction by a TWLTL as a proportion of driveway-related accidents (can be estimated to be 0.5)

Exhibit 16-8: Potential Crash Effects of Providing a TWLTL on Rural Two-lane Roads with Driveways



16.6. CRASH EFFECTS OF PASSING AND CLIMBING LANES

16.6.1. Background and Availability of AMFs

A passing lane may be provided in one direction on two-lane two-way rural roads to increase overtaking opportunities and reduce delays. A climbing lane may be provided to overcome delays caused by slow-moving vehicles on steep upgrades. Other similar treatments include:

- Short four-lane sections. Short four-lane sections are created where passing lanes are provided in both travel directions.

- Turnouts. A turnout is a widened, unobstructed shoulder area that allows slow-moving vehicles to pull out of the through lane to give passing opportunities to following vehicles.(1)

- Shoulder use sections. Driving on shoulders is usually illegal; however, shoulders may be used by slow-moving vehicles in certain areas to allow other vehicles to pass. Some shoulders are signed where shoulder use is allowed.

Exhibit 16-9 summarizes treatments related to passing and climbing lanes and the level of information presented in the HSM.

Exhibit 16-9: Treatments Related to Passing and Climbing Lanes

HSM Section	Treatment	Rural Two-Lane road	Rural Multilane Highway	Freeway	Expressway	Urban Arterial	Suburban Arterial
16.6.2.1	Provide a Passing/Climbing Lane or a Short Four-Lane Section	✓	N/A	N/A	N/A	N/A	N/A

NOTE: ✓= Indicates that an AMF is available for the treatment.
N/A = Indicates that the treatment is not applicable to the corresponding setting.

16.6.2. Passing and Climbing Lane Treatments with AMFs

16.6.2.1. Provide a Passing Lane/Climbing Lane or a Short Four-Lane Section

Passing lanes allow vehicles to pass, and may have the potential to reduce crashes such as head-on, same-direction sideswipe, and opposite-direction sideswipe crashes at some locations. Passing-related head-on crashes are a relatively low percentage of all head-on crashes.[12] Passing lanes may affect traffic operations 3 to 8 mi downstream of the passing lane due to the segregation they permit between faster and slower vehicles.[7,12]

Climbing lanes allow vehicles to pass on grades, and may have the potential to reduce rear-end and same-direction sideswipe crashes at some locations that may result from speed differentials and conflicts between slow-moving and passing vehicles. Climbing lanes allow traffic platoons which have formed behind slower vehicles to dissipate without using an oncoming traffic lane to complete a passing maneuver.

Rural two-lane roads

The potential crash effects of providing a passing lane or climbing lane in one direction on a rural two-lane road is shown in Exhibit 16-10. [7] The potential crash effects of providing a short four-lane section on a rural two-lane road is also shown in Exhibit 16-10. [7]

The base condition of the AMFs (i.e., the condition in which the AMF = 1.00) is a two-lane rural road.

Exhibit 16-10: Potential Crash Effects of Providing a Passing Lane/Climbing Lane or Short Four-Lane Section on Rural Two-Lane Roads [7]

Treatment	Setting (Road type)	Traffic Volume	Accident type (Severity)	AMF	Std. Error
Provide passing lane or climbing lane	Rural (Two-lane)	Unspecified	All types (All severities)	0.75	N/A°
Provide short four-lane section				0.65	N/A°
Base Condition: Two-lane rural road.					

NOTE: ° Standard error of AMF is unknown.

16.7. CONCLUSION

The treatments discussed in this chapter focus on the potential crash effects of treatments that are applicable to roadway specific facilities and geometric situations. The material presented represents the AMFs known to a degree of statistical stability and reliability for inclusion in this edition of the HSM. Additional qualitative information regarding potential treatments is contained in Appendix A.

Appendix A presents the treatments which have an identified trend or no known information.

Other chapters in *Part D* present treatments related to specific site types such as roadway segments and intersections. The material in this chapter can be used in conjunction with activities in *Chapter 6 Select Countermeasures*, and *Chapter 7 Economic Appraisal*. Some *Part D* AMFs are included in *Part C* for use in the predictive method. Other *Part D* AMFs are not presented in *Part C* but can be used in the methods to estimate change in crash frequency described in Section C.7 of the *Part C Introduction and Applications Guidance*.

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APPENDIX A

A.1 INTRODUCTION

The appendix presents general information, trends in crashes and/or user-behavior as a result of the treatments, and a list of related treatments for which information is not currently available. Where AMFs are available, a more detailed discussion can be found within the chapter body. The absence of an AMF indicates that at the time this edition of the HSM was developed, completed research had not developed statistically reliable and/or stable AMFs that passed the screening test for inclusion in the HSM. Trends in crashes and user behavior that are either known or appear to be present are summarized in this appendix.

This appendix is organized into the following sections:

- Railroad-Highway Grade Crossings, Traffic Control, and Operational Elements (Section A.2)
- Work Zone Design Elements (Section A.3)
- Work Zone Traffic Control and Operational Elements (Section A.4)
- Two-Way Left-Turn Lane Elements (Section A.5)
- Treatments with Unknown Crash Effects (Section A.6)

A.2 RAILROAD-HIGHWAY GRADE CROSSINGS, TRAFFIC CONTROL, AND OPERATIONAL ELEMENTS

A.2.1 Trends in Crashes or User Behavior for Treatments with no AMFs

A.2.1.1 Install Crossbucks

Rural two-lane road, rural multi-lane highway, urban and suburban arterial

Installing crossbucks at railroad-highway grade crossings that previously had no signs appears to have the potential to reduce all grade crossing crashes.[2] However, the magnitude of the potential crash effects is not certain at this time.

A.2.1.2 Install Vehicle-Activated Strobe Light and Supplemental Signs

Rural two-lane road, rural multi-lane highway, urban and suburban arterial

Research has evaluated supplementary traffic control devices at passive railroad-highway grade crossings. The existing MUTCD W10-1 sign was supplemented with a "LOOK FOR TRAIN AT CROSSING" sign in conjunction with a strobe-light activated by approaching vehicles.[3]

Research results indicate that installing a vehicle-activated strobe light and supplemental sign, in addition to the MUTCD W10-1 sign at passive railroad-highway grade crossings, appears to have the potential to reduce average vehicle speeds near the crossing.[3]

A.2.1.3 Install Four-Quadrant Automatic Gates

Rural two-lane road, rural multi-lane highway, urban and suburban arterial

Installing four-quadrant automatic gates (one gate on each quadrant of the railroad/roadway intersection) appears to significantly reduce drivers violating crossing signals, and appears to have the potential to reduce the average number of vehicles crossing while the gate arms are being lowered.(13) No conclusive results about the potential crash effects of installing four-quadrant automatic gates were available for this edition of the HSM.

A.2.1.4 Install Four-Quadrant Flashing Light Signals

Rural two-lane road, rural multi-lane highway, urban and suburban arterial

Installing four-quadrant flashing light signals with overhead strobe lights appears to have no substantial affect on driver behavior compared to standard two-quadrant flashing light signals.(4) No conclusive results about the potential crash effects of installing four-quadrant flashing light signals were available for this HSM.

A.2.1.5 Install Pre-Signals

Rural two-lane road, rural multi-lane highway, urban and suburban arterial

Installing pre-signals to control traffic entering the railroad-highway grade crossing appears to have the potential to reduce risky driver behavior in the vicinity of the crossing. For instance, within 10 seconds of a train's arrival and while the flashing light signals are activated, both the number of crossings per signal activation and the number of vehicles crossing have been shown to decrease.(4) No conclusive results about the potential crash effects of installing pre-signals were available for this HSM.

A.2.1.6 Provide Constant Warning Time Devices

Rural two-lane road, rural multi-lane highway, urban and suburban arterial

Train predictors can be used to provide constant warning times to road users. Providing a constant warning time appears to have the potential to reduce the number of vehicles crossing the tracks between activation of the warning device and the train's arrival at the crossing.(18) Installing train predictors and the resulting constant warning times generally lead to fewer long warning times at crossings, and a potential reduction in incidences of risky driver behavior.(18) No conclusive results about the potential crash effects of providing constant warning time devices were available for this HSM.

A.3 WORK ZONE DESIGN ELEMENTS

A.3.1.1 Operate Work Zones in the Daytime or Nighttime

Rural two-lane roads; rural multilane highways; urban and suburban arterials; expressways

Time of day operations are considered a work zone design element. Compared to the no work zone condition, accidents appear to increase at work zones during nighttime more than during daytime.(10,21) Recent research has quantified the daytime and nighttime increases in accidents at work zones, in comparison to the pre-work-zone condition.(21) Work zone illumination appears to affect the safety of a work zone.(2) However, the magnitude of the crash effect is not certain at this time.

A.3.1.2 Use Roadway Closure with Two-Lane Two-Way Operation or Single-Lane Closure

Rural multilane highways, freeways, and expressways

There are two main types of lane closure design for work zones on freeways, rural multilane roadways, and urban and suburban arterials:

1. Roadway closure with a median crossover and two-lane two-way operations (TLTWO): All the lanes in one travel direction of a divided or undivided multilane highway are closed. Vehicles must cross over to use a lane that is normally dedicated to opposing traffic. The two main categories for median crossover design are flat diagonal designs and reverse curve designs.[9] Temporary centerlines, concrete median barriers, or other dividers may be used to separate the traffic. Concrete median barriers may be installed temporarily to separate traffic traveling in opposite directions in the TLTWO section. With this design, work crews may perform work on the closed roadway without having traffic near them. However, heavy traffic volumes, loaded trucks, nighttime, and bad weather can create safety concerns in the TLTWO.

2. Single (or partial) lane closure: One or more lanes in one travel direction are closed. The number of lanes closed depends on the total number of lanes on the roadway and the construction circumstances. A single lane closure does not directly affect traffic on the non-construction side of the roadway. Traffic on the construction side passes close to or adjacent to the work zone and work crew.

Work zones with crossover closures appear to have the potential to increase all accident types and severities compared to the non-work zone condition. [1,9,16] Roadway closures with a TLTWO section also appear to result in a potential increase in severe accidents and head-on crashes in the TLTWO section compared to the non-work zone condition.[9] Pavement surface and shoulder conditions may be important elements for crossover closures, particularly in the TLTWO section.[9]

Work zones with single lane closures appear to result in a potential increase in all accident types and severities compared to the non-work zone condition.[1,9,16] Single lane closures appear to have the potential to increase fixed object crashes compared to the non-work zone condition.[9]

There is some evidence that there may be a greater chance of a higher severity crash in a roadway closure with a TLTWO section than in a partial closure.[16] However, the magnitude of the potential crash effects is not certain at this time.

A.3.1.3 Use Indiana Lane Merge System (ILMS)

Freeways

The ILMS is an advanced dynamic traffic control system designed to encourage drivers to switch lanes well in advance of the work zone lane drop and entry taper.[20]

At many work zones, it is necessary to close one or more lanes. Vehicles must then merge into the lanes available. The transition area at the beginning of a work zone requires drivers to adapt their driving behavior to the new, and possibly unexpected, conditions ahead. Speed changes, lane positioning, and interacting with other drivers may be required.

The ILMS appears to have the potential to reduce the number of merging conflicts and to reduce vehicle delay on divided rural four-lane freeways with AADT of 42,000 veh/day or more.[20] No conclusive results about the potential crash effects of using the Indiana Lane Merge System (ILMS) were available for this HSM.

A.4 WORK ZONE TRAFFIC CONTROL AND OPERATIONAL ELEMENTS

A.4.1 General Information

Signs and Signals

The MUTCD classifies signs into three categories: regulatory, warning, and guide.[5] The MUTCD provides standards, guidance, and options for providing signs within the right-of-way for all highway types. Many agencies supplement the MUTCD information with their own guidelines and standards.

The type of signs and signals used in work zones generally depends on the road class and setting, the work zone layout, the work zone duration, the cost, whether the work zone is static or moving, and institutional constraints (e.g., whether trained flaggers are available). Combinations of signs and signals are commonly used, including speed signs and flashing arrows.

Delineation

Delineation includes all methods of defining the roadway operating area for drivers, and has long been considered a key element to guide drivers. Delineation is likely to have added impact in work zones where the conditions are unfamiliar or have changed substantially from the non-work zone condition. In work zones, temporary delineation methods may be used.

Methods of delineation include devices such as pavement markings (made from a variety of materials), raised pavement markers (RPMs), chevron signs, object markers, and post-mounted delineators (PMDs).[15] Delineation may be used alone to convey regulations, guidance, or warnings.[5] Delineation may also be used to supplement other traffic control devices such as signs and signals. The MUTCD provides guidelines for retroreflectivity, color, placement, material types, and other delineation issues.[5]

Pavement markings can be obscured by snow, debris, and water on the road surface. Visibility and retroreflectivity can be reduced over time by weather, vehicle tire wear, and location.[5]

Rumble Strips

Rumble strips warn drivers by creating vibration and noise when driven over. The objective of rumble strips is to reduce crashes caused by drowsy or inattentive drivers. In general, rumble strips are used in areas where the noise generated is unlikely to disturb adjacent residents; that is, in non-residential areas. Temporary rumble strips may be used in work zones as a traffic control device.

A.4.2 Trends in Crashes or User Behavior for Treatments with no AMFs

A.4.2.1 Install Changeable Speed Warning Signs

Changeable speed warning signs can provide individual or collective information to drivers. Individual changeable speed warning signs give individual drivers real-time feedback regarding each driver's speed. The signs can be an alternative to having law enforcement officers stationed at work zones. Collective changeable speed warning signs give information such as the percentage of road users exceeding the speed limit.[2]

Freeways

Installing individual changeable speed warning signs, that display the license plate and speed of a speeding vehicle in a freeway work zone, appears to have the potential to reduce injury and non-injury accidents.[22] However, the magnitude of the potential crash effects is not certain at this time.

Installing individual changeable speed warning signs that display personalized messages to high-speed drivers at work zones on Interstate highways appears to reduce vehicle speeds more than static MUTCD signs.[8] This treatment appears to be effective in work zone projects of long duration, from 7 days to 7 weeks. For work zones longer than 3,500 feet, a second changeable speed warning sign may reduce the tendency of drivers to speed up as they approach the end of a work zone.[8]

Installing individual changeable speed warning signs in advance of a single lane closure work zone on a freeway appears to have the potential to reduce the speed of traffic approaching the work zone.[14]

Rural two-lane roads

Installing individual changeable speed warning signs appears to have the potential to reduce average vehicle speed and the percentage of speeding vehicles at rural, short-term (typically a single day) work zones.[6]

A.4.2.2 Install Temporary Speed Limit Signs and Speed Zones

All road types

It is generally accepted that speed selection by drivers is a key factor in work zone crashes.[22]

Conventional practice for speed limits or speed zones in work zones follows the static signing procedures, using regulatory or advisory speed signs found in the MUTCD.[5] The procedure depends on the road type and setting, the work zone layout, the work zone duration, whether the work zone is static or moving, the cost of the speed control, and institutional constraints, such as the availability of a police presence or trained flaggers. Combinations of speed controls are commonly used.

Changing the posted speed limit generally has little effect on operating speeds.[17] Drivers select their speed using perceptual and "road message" cues. *Chapter 2* contains more information on driver speed choice.

It is generally accepted that installing temporary speed limit signs and speed zones in work zones, whether advisory or regulatory, has little to no effect on vehicle speeds.[22] It is also generally accepted that drivers adjust their vehicle speed and lane position according to the environment, the geometry of the roadway and work zone, the lateral clearance, and other factors, rather than on signing.[10] If speed limits are dramatically reduced, the limit may not match the perception of safe driving speed for the majority of drivers which may result in instability in the traffic flow through the speed zone.[23] Conclusive results about the potential crash effects of temporary speed limit signs and speed zones were not available for this HSM.

A.4.2.3 Use Innovative Flagging Procedures

All road types

Innovative flagging procedures include having a flagger with a speed sign paddle in one hand and motioning to traffic with the other hand, or a flagger motioning to traffic to slow down with one hand and pointing to a posted speed sign. Difficulties with flagging procedures include flagger fatigue and boredom, and ensuring that flaggers follow the procedures consistently.(14)

A flagger positioned in advance of a single lane closure on a freeway and holding a 45-mph sign paddle in one hand while motioning traffic to slow down with the other appears to have the potential to reduce average traffic speeds compared to having no flaggers present in advance of the work zone. (14) An alternative to this procedure is a flagger wearing bright coveralls and using a larger speed paddle sign.

On rural two-lane roads, rural freeways, urban freeways, and undivided urban arterials, a flagger motioning traffic to slow down with one hand and then pointing to the nearby posted speed sign appears to have the potential to reduce average traffic speeds more than standard MUTCD flagging procedures. (19) The average speed reduction appears to be greater on rural two-lane roads and urban arterials than on urban or rural freeways. Conclusive results about the potential crash effects of using innovative flagging procedures were not available for this HSM.

Using flaggers on both sides of the travel lanes of a freeway appears to result in greater speed reductions compared with using a flagger on one side only. (19)

The MUTCD provides guidance on the safety of workers in work zones.

A.4.2.4 Install Changeable Message Signs

All road types

Active speed control devices include changeable message signs, flaggers, and law enforcement. Passive measures (e.g., static signing) are generally thought to be less effective on traffic operations than active measures, but the difference in effectiveness is not certain at this time. (8)

Installing changeable message signs in advance of the work zone or within a work zone with the alternating messages "WORKERS AHEAD" and "SPEED LIMIT 45 MPH" appears to have the potential to reduce vehicle speeds, but only among vehicles close to the changeable message signs. (22) No quantitative information about the potential crash effects of installing changeable message signs with other speed limits in work zones is currently available.

A.4.2.5 Install Radar Drones

Radar drones emit a signal equivalent to that of a speed radar gun. These devices are used to communicate to drivers with radar detectors of possible hazards on the road ahead including dangerous curves, accidents, etc. The devices may be temporarily or permanently installed.

Rural two-lane roads

Installing radar drones at short-term (typically a single day) work zones on rural two-lane roads appears to have the potential to reduce vehicle speeds and the percentage of drivers who were speeding before the taper approaching the work zone and in the work zone.(6)

Rural multilane highways, urban and suburban arterials

Installing radar drones in short and long-term work zones on urban and rural interstate highways and on urban and rural roadways with AADTs ranging from 20,000 veh/day to 70,000 veh/day appears to have the potential to reduce mean speeds and the number of vehicles exceeding the speed limit by more than 10 mph.[7]

A.4.2.6 Police Enforcement of Speeds

All road types

Police enforcement methods include a police traffic controller, a stationary patrol car, a stationary patrol car with emergency lights or radar, and a circulating patrol car. [19]

Speed enforcement by police in work zones on rural two-lane roads, rural freeways, urban freeways, and undivided urban arterials appears to have the potential to reduce average vehicle speeds. [19] Police enforcement appears to be most effective over the length of highway receiving the treatment. [10]

A.5 TWO-WAY LEFT-TURN LANE ELEMENTS

A.5.1.1 Provide Two-Way Left-Turn Lane

Urban and suburban arterials

The potential crash effects of providing a TWLTL on urban and suburban arterials appears to be similar for rural two-lane roads.[11,12] However, the magnitude of the potential crash effects is not certain at this time. See Section 16.5.2.1 in the body of Chapter 16 Special Facilities for additional information.

A.6 TREATMENTS WITH UNKNOWN CRASH EFFECTS

A.6.1 Railroad-Highway Grade Crossing, Traffic Control, and Operational Elements

- Install stop or yield signs
- Install retroreflective advance warning signs
- Install transverse rumble strips on the approach to railroad-highway grade crossings
- Install advance warning flashers or beacons on the approach to railroad-highway grade crossings
- Place enhanced pavement markings on the approach to railroad-highway grade crossings
- Provide warning bells or flag persons on the approach to railroad-highway grade crossings
- Use train whistles
- Implement traffic signal preemption

A.6.2 Work Zone Design Elements

Lane Closure Design

- Modify crossover closure design
- Modify median crossover design for crossover closures
- Modify centerline treatment of TLTWO zone
- Modify single lane closure design

Lane Closure/Merge Design

- Use late merge control strategy;
- Use early merge control strategy;
- Position work zone on right-side or left-side of roadway;
- Modify merge design, including taper lengths and lane widths;
- Modify diverge design at the end of a work zone;
- Use the shoulder as a travel lane;
- Temporarily realign lanes; and,
- Modify location of the work zone relative to interchange ramps and roadway intersections.

A.6.3 Work Zone Traffic Control and Operational Elements

Signs and Signals

- Place signs in advance of work zone
- Use diverging lights or flashing arrows display
- Use temporary traffic signals, manual traffic direction, flaggers, or remote-control flags
- Improve visibility and clarity of signs
- Install active or passive warning signs or flashing arrows
- Use temporary diversions
- Install ITS applications

Delineation

- Install post-mounted delineators (PMDs)
- Place temporary centerline and/or edgeline markings
- Install raised pavement markers (RPMs)
- Install chevron signs on horizontal curves

- Install flashing beacons to supplement signage
- Mount reflectors on guardrails, curbs, and other barriers
- Place temporary transverse pavement markings

Rumble Strips

- Install continuous shoulder rumble strips
- Install continuous shoulder rumble strips and wider shoulders
- Install centerline rumble strips
- Install transverse rumble strips
- Install rumble strips with different dimensions and patterns
- Install edgeline rumble strips
- Install mid-lane rumble strips

Speed Limits and Speed Zones

- Use standard MUTCD flagging procedures
- Install real-time portable Variable Speed Limit systems
- Use radar activated horn system
- Reduce lane width
- Broadcast Citizens Band (CB) messages
- Provide automated speed enforcement

A.6.4 Two-Way Left-Turn Elements

- Number of through lanes on the road
- Width of the TWLTL
- How the TWLTL was incorporated (e.g., re-striping existing roadway width or widening the road)
- Volume of turning vehicles and opposing vehicles
- Capacity of storage for turning vehicles
- Driveway design
- Treatment at intersections
- Posted speed limit
- Markings
- Signage

- Land use (urban, rural, suburban)
- Presence of pedestrians
- Presence or prohibition of parallel street parking

A.6.5 Passing and Climbing Lane Elements

- Use three-lane alternate passing lane design
- Modify design elements, e.g., length, spacing, horizontal and vertical alignment, sight distance, tapers, merges, shoulders
- Modify posted speed limits and operating speed
- Install signage and pavement markings
- Modify density of intersections and/or access points along the auxiliary lane.
- Inclusion of passing and climbing lanes on the roadway as a whole (corridor approach)
- Provide a turnout
- Provide shoulder use sections

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