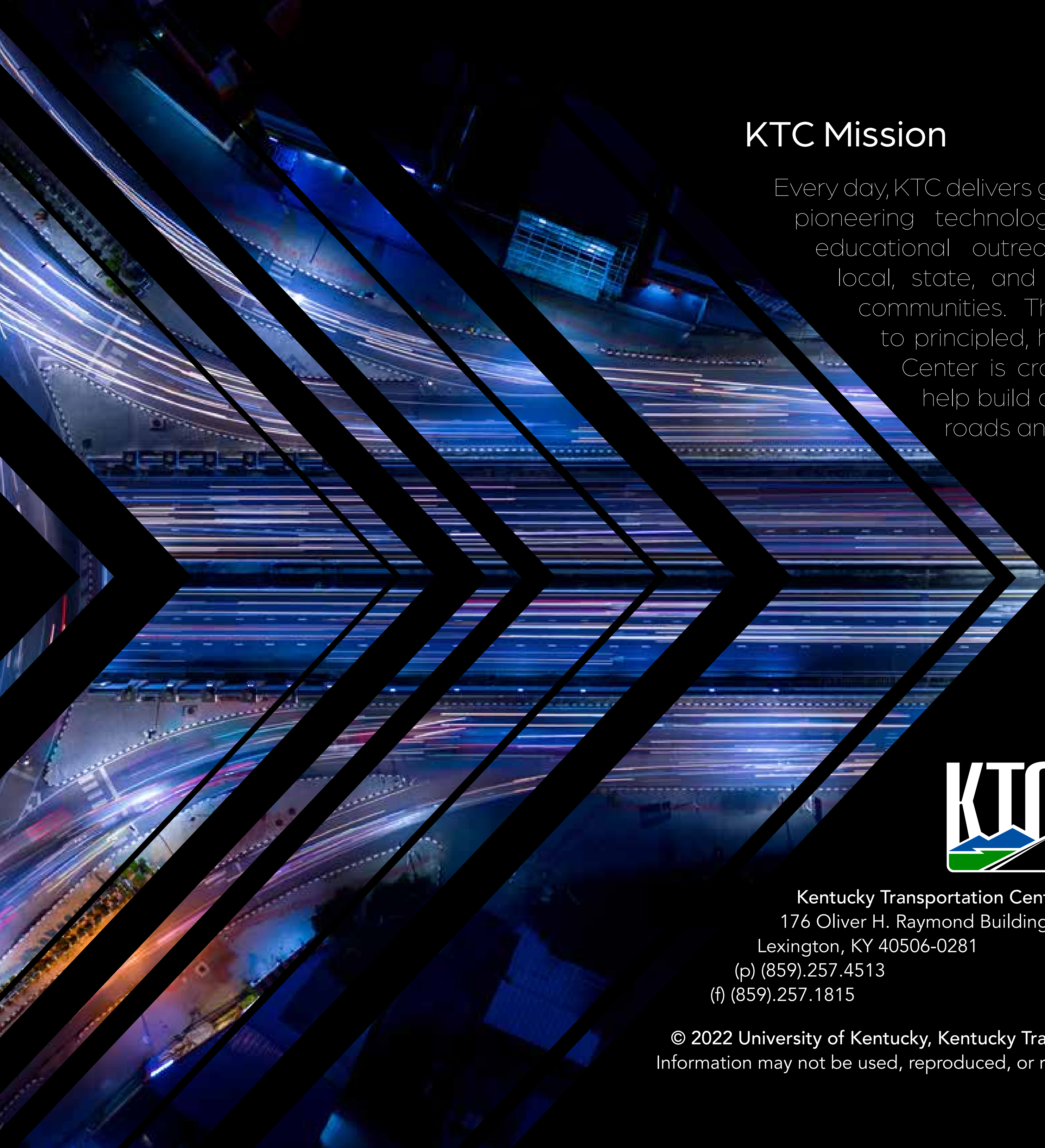
Design MythBusters



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Design MythBusters

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16. Abstract
When highway project designs depart from design values found in the Kentucky Transportation Cabinet (KYTC) *Highway Design Manual* and AASHTO's *A Policy on Geometric Design of Highways and Streets*, project managers at the agency must obtain either a design exception or design variance. While designers are more comfortable with exceptions and variances than they were 10 or 20 years ago, some hesitancy remains, especially among the Cabinet's consultants. Misperceptions about what exceptions or variances entail or about their performance may underlie this reluctance. Exceptions and variances are best conceptualized as formal justifications for design decisions. Project managers merely need to describe why a design does not adhere to published guidance and illustrate that safety and mobility performance are not significantly compromised — in every instance new designs offer improvement over existing conditions. The limited number of research studies on design exceptions have found no evidence to suggest facilities where exceptions have been used have worse safety performance than those which abide by typical design values. To encourage project managers and designers to embrace cost-effective, context-adapted designs — and the role of variances and exceptions play in delivering those solutions — this report presents design axioms and case studies that document projects on which exceptions and variances have been used with success. Most of the exceptions and variances used on these projects were minor (e.g., narrowing shoulders, reducing design speeds), were critical for addressing the stated purposes and needs, and resulted in a solution that blended the improved roadway with the surrounding contexts. Additional examples of mostly Highway Safety Improvement Program (HSIP) projects are catalogued that illustrate how creative fixes can be used to mitigate safety concerns.

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Executive Summary

The Kentucky Transportation Cabinet (KYTC) requires design exceptions and variances when a highway design incorporates features that depart from design values found in the *Highway Design Manual* and AASHTO's *A Policy on Geometric Design of Highways and Streets*. The judicious use of design exceptions and variances helps project managers and designers deliver context-adapted, cost-effective, and safe highway projects. Over the past 10 to 20 years designers have been more willing to deploy exceptions and variances. However, many designers — especially those in the beginning stages of their careers — feel inclined to stick with design values found in published guidance, even though that guidance is not statutorily or legally binding. This can be problematic because faithful adherence to published design values can drive up costs and result in projects that are mismatched with geometric conditions found on adjacent highway segments, without offering significant improvements in safety performance. The goal of this report is to demystify the design exception (and variance) process by demonstrating the benefits of exceptions and variances. Indeed, exceptions and variances should not be feared. They should be viewed as tools in the designer's toolkit that are used to deliver projects that meet identified purposes and needs.

Published research on design exceptions and variances is scarce, but no evidence suggests their use degrades safety or operational performance. Agent et al.'s 2002 study of design exceptions used in Kentucky between 1993 and 2000 found no evidence that facilities on which design exceptions had been applied suffered higher crash rates than (a) average rates at similar facility types or (b) at projects sites prior to improvements being carried out. More recent studies conducted in Utah, Indiana, and Georgia, which leverage sophisticated modeling techniques, have similarly found no basis for concluding that design exceptions produce negative safety outcomes. More simply put, designers should have no anxiety over using exceptions or variances. Of course, this is not to say these tools should be wielded haphazardly. Their use should always be thoughtful and considered (FHWA 2007).

Following our introduction to exceptions and variances we present eight axioms for highway design synthesized from interviews with KYTC staff with over 150 years of combined experience. These axioms are straightforward, but are helpful reminders for beginning and seasoned designers alike:

- Analyze Problems with a Diagnostic Mindset
- Design to the Context
- Do Not Fear Design Exceptions and Variances
- Understand When Design Exceptions and Variances Are Needed
- Embrace Creativity and Cost-Efficient Solutions
- Adopt a Multidisciplinary Perspective in Communication and Problem Solving
- Don't Fall in Love with a Single Solution
- Be Intellectually Curious and Pose Questions

To illustrate design exceptions and variances in action, we present eight case studies from around Kentucky. Each case study identifies the project and location, provides an overview of the purpose and need, describes existing site characteristics, reviews the design solution, and briefly summarizes the design exceptions and/or variances obtained by the project team. Project types covered in these case studies include bridge replacement, road widening, modification of bridge approaches, road reconstruction, and interchange construction. Some of the best learning designers and project managers can do is through case studies. By seeing how exceptions and variances are applied on real-world projects, designers and project managers can learn how to produce context-adapted, cost-effective solutions that meld with the templates and geometrics of existing facilities as well as the built and biophysical landscapes.

While design exceptions and variances are valuable tools, before jumping into a solution that involves reconstructing facilities, it is helpful to step back and determine whether anything needs to be built at all to solve safety-related problems. For example, a roadway with inadequate sight distance may not need a construction-based solution — the issue could be corrected simply by cutting down tree branches and trimming or removing other woody vegetation. The report wraps up with examples of Highway Safety Improvement Program (HSIP) projects that illustrate the adoption of low-cost or creative fixes to mitigate safety problems. These case studies, along with those on design exceptions and variances, will help designers and project managers approach projects with a critical eye and arrive at solutions that are the best fit for the project context.

CHAPTER 1 - Motivation and Background

This report attempts to demystify design exceptions and variances by presenting research and case studies which illustrate how they facilitate the use of context-adapted design solutions. What is a design exception? Mason and Mahoney (2011) offer a formal definition — the process and resulting documentation associated with a geometric feature created or perpetuated by a highway construction project that does not conform to the minimum criteria set forth in standards and policies (p. 5). Perhaps a little too formal for everyday conversation.

Table 1.1 Controlling Criteria By Project Type

High-Speed Roadways (≥ 50 mph)	
• Design speed	• Lane width
• Shoulder width	• Horizontal curve radius
• Superelevation rate	• Stopping sight distance
• Maximum grade	• Cross-slope
• Vertical clearance	• Design loading structural capacity
Other Roadways (< 50 mph)	
• Design speed	• Design loading structural capacity

Grounding our discussion in the Kentucky Transportation Cabinet's (KYTC) policies will make everything a little more concrete. The Federal Highway Administration (FHWA) has established controlling criteria for projects on the National Highway System (NHS) — 10 criteria for high-speed roadways (design speed > 50 mph) and two (2) criteria for all other roadways (Table 1.1). KYTC has adopted these same criteria for all projects, irrespective of what system a roadway is on. But what is meant by controlling criteria? If a project manager plans to use design values that deviate from those found in the *Highway Design Manual* and AASHTO's *A Policy on Geometric Design of Highways and Streets* (2018) on these routes, they must request a design exception. The request documents what criteria will not be met, existing roadway characteristics, alternatives that were studied, an evaluation of the roadway's safety and operational impacts, mitigation strategies, and compatibility with adjacent road segments. The Design Executive Summary (DES) records the exceptions used and provides justification for their adoption.

When are variances needed? In two situations — although this may seem a little confusing. First, if a project's design speed is less than 50 mph and the design values for any of the 10 controlling criteria applied to high-speed roadways deviate from typical ranges, the project manager must request a variance. For example, if the shoulder width for a roadway with a design speed < 50 mph departs from typical value ranges, a variance is needed. The second situation in which a variance is necessary is when the designs of other geometric elements depart from common practices (e.g., sidewalk width, median width, guardrail end treatments).

Think of the 50-mph design speed as a threshold. At or above 50 mph, exceptions are needed if a design veers beyond typical value ranges for any of the 10 controlling criteria. If the design speed is less than 50 mph, exceptions are needed only when the design values for (a) design speed or (b) design loading structural capacity depart from typical value ranges. The DES cover sheet (Figure 1.1) reinforces this distinction. The fourth and fifth sections include checklists where project managers indicate if an exception or variance is needed. Boxes are provided to specify existing conditions, AASHTO-prescribed guidance, and typical values.

To the beginning designer, exceptions and variances may have an ominous connotation — they should be avoided if at all possible. But this is the wrong way to conceptualize them. Exceptions and variances are better thought of as methods of justification. That is, the project manager and project team use their engineering judgment to choose a design value which departs slightly from typical values and then explain why they have made that selection and demonstrate it will not significantly impact roadway or bridge performance. As the research presented below indicates, how frequently design exceptions are used varies across state departments of transportation (DOTs), but there is no evidence to indicate they produce inferior safety outcomes. And the designs always improve upon the existing condition.

Figure 1.1 KYTC Design Executive Summary Form

Updated 11/25/20

DESIGN EXECUTIVE SUMMARY

County:		Item #:		
Route Number(s):		State Program #:		
BMP/EMP:		Federal Project #:		
Type of Work:		State Project #:		
Highway Plan Project Description:				

EXISTING CONDITIONS

ADT (current):	Truck Class:		Trucks:
Existing Functional Classification: ☐ Urban ☐ Rural	Terrain:	Route is on (check all that apply): ☐ NHS ☐ NN ☐ Ext Wt ☐ None	
Posted Speed Limit: mph "or" Statutory Speed Limit:		☐ 35 mph (urban) ☐ 55 mph (rural)	
Existing Bike Accommodations: None		Ped: ☐ Sidewalk ☐ Other:____N/A_____	

PROPOSED CONDITIONS

Design Functional Classification: ☐ Urban ☐ Rural	Design ADT ( ): DHV:	Access Control: Spacing:__________	By Permit

CONTROLLING CRITERIA:	EXISTING CONDITIONS (Estimated based upon existing geometrics.)	AASHTO Guidance (for design speed)	Recommendation	Design Exception (check if needed for Design Speed)	
Design Speed		Minimum: Selected:		☐	
Note: For any remaining controlling criteria that are less than AASHTO recommended guidance: If recommended design speed is ≥ 50 mph, exceptions are needed; If recommended design speed is < 50 mph, variances are needed.				Exception (≥ 50 mph)	Variance (< 50 mph)
Lane Width, No. of Lanes				☐	☐
Shoulder Width (Minimum Usable)				☐	☐
Horiz. Curve Radius (Minimum)				☐	☐
Max. Superelev. Rate (emax= %)				☐	☐
Stopping Sight Distance (Minimum)				☐	☐
Max. Grade (%)				☐	☐
Normal Cross Slope (%)				☐	☐
Vert. Clearance (ft.)				☐	☐

OTHER CRITERIA:				Design Variance
Border Area (urban)				☐
Sidewalk Width, slope				☐
Bike Lane Width, slope				☐
Shared Use Path Width				☐
Other:				☐

1.1 National Research

Mason and Mahoney (2011) arguably produced the most comprehensive study of design exception practices at state DOTs. Although slightly dated at this point, it offers insights into how often agencies use design exceptions, the most common types of exceptions, and justifications for obtaining exceptions. They surveyed 46 agencies on their approaches to design exceptions. Table 1.1 lists the number of design exceptions processed annually. Most agencies reported processing 50 or fewer exceptions per year; about one-quarter of agencies processed more than 75 per year (Table 1.1). These are raw data and do not account for the number of projects each year, so they do not provide information on the relative frequency of design exceptions — which is likely a better measure of how integrated design exceptions are into agency practices and cultures.

Table 1.2 Design Exception Usage at State DOTs

Number of Design Exceptions Processed Each Year	Number of DOTs
0 – 25	20
26 – 50	9
51 – 75	2
76 – 100	4
> 100	7
Unknown	4

Asked about common types of design exceptions used at their agencies, respondents cited horizontal alignment, shoulder width, vertical alignment, stopping sight distance, lane width, superelevation, and design speed. Harwood et al. (2013) spoke with personnel at 10 agencies to understand their design exception policies. Caltrans, which processed approximately 500 exceptions per year, most frequently issued exceptions for lane and shoulder widths on conventional highways, while in rural areas exceptions were typically used to maintain route consistency (i.e., implement a context-adapted design that does not clash with adjacent segments) and to address environmental impacts. In terms of justifications for requesting design exceptions, the most frequent are restrictive rights of way, high construction costs, environmental impacts, and community disruption (Mason and Mahoney 2011). Political pressure and needing to make up for budgetary shortfalls can also underlie requests for exceptions (Harwood et al. 2013). At the Georgia DOT, designers are taught to regard exceptions as a method for documenting departures from controlling criteria. They are not intended to discourage design flexibility. The Minnesota DOT has established standardized language to document design exceptions.

Mason and Mahoney (2011) found that most agencies view design exceptions as a process which adds value to design. Agencies must be deliberate in how they administer design exceptions, however. To mitigate potential liability issues, it is important for agencies to generate and preserve reports that provide engineering justifications for the exception and describe the physical and environmental factors that make an exception necessary. It is important to document the alternative actions considered, explain why the exception was used, provide evidence the facility on which the exception is used is safe, and catalogue the possible operational implications of using exceptions. Despite their utility, agencies encounter challenges with design exceptions. Their use can be both time- and cost-intensive, staff may lack clarity on how exceptions are submitted, and requests made late in the project development process can hamper delivery — most agencies want to tackle design exceptions early because they are on the critical path. Design exception processes can be streamlined and clarified by publishing unambiguous guidance, providing training, and establishing standardized practices for documenting exceptions (e.g., templates, checklists).

1.2 The Safety Implications of Design Exceptions

Only a few studies have looked at whether design exceptions degrade safety. We briefly summarize their key findings below.

• Agent et al. (2002) investigated the use of design exceptions in Kentucky between 1993 and 2000. Over half of design exceptions throughout this period were granted for projects on KY routes, with 28 percent on non-state maintained routes, 16 percent on US routes, and just 4 percent on interstates. The most common design exceptions were for using design speeds lower than posted speed limits, minimum sight distance, minimum curve radius, and shoulder width. Justifications for exceptions frequently referenced the goal of matching new construction to existing roadway conditions, crash history, and historic or environmental features. Based on an evaluation of 86 sites, Agent et al. concluded that roadways on which design exceptions had been used did not see higher crash rates than average rates recorded at similar facility types or at the site before the project was carried out. At the six sites with higher crash rates they determined the increases were not attributable to design elements covered by the design exception.

• Wood and Porter (2013) conducted a Utah-based study that examined whether crash frequency and severity for roadway segments where design exceptions were obtained differed from similar road segments where no exceptions were used. Based on 63 non-freeway projects built between 2001 and 2006, they concluded that roadway segments on which at least one design exception was used had the same expected crash frequencies as segments where no exceptions were used. They also found no difference in crash severity distributions.

• Malyshkina and Mannering (2010) compared the performance of roadway segments where design exceptions had been implemented to similar segments which did not use an exception. Examining the performance of over 100 roadways in Indiana, they found that design exceptions did not negatively impact safety. When considering exceptions, agencies should pay close attention to potential consequences at sites that have elevated crash frequencies — horizontal curves, interior shoulders on multilane highways, and urban roadways. For example, because wider interior shoulders on multilane highways can reduce crash frequencies, it is critical to take this under consideration when assessing an exception to use narrower shoulders.

• Sim's (2012) study of design exceptions was inconclusive because the study did not focus only on segments where exceptions had been used. Even so, he concluded that safety performance may have benefitted from the use of design exceptions.

Despite published studies calling for more investigations of how design exceptions impact safety, there has not been a great deal of research engagement. This may be due to the methodological challenges involved in designing studies and there being insufficient data to make firm conclusions. But keep in mind that no research to date has uncovered evidence of design exceptions significantly harming safety performance.

1.3 Report Structure

We have divided the rest of the report into three chapters. Table 1.3 summarizes their contents.

Table 1.3 Report Contents

Chapter	Content
2	• Axioms that designers can put into practice to create more practical and context-adapted projects
3	• Case studies illustrating the use of design exceptions and variances in multiple project contexts
4	• Brief, real-world examples of situations in which challenges can be addressed through creative or no-build solutions

CHAPTER 2 - Axioms for Highway Design

During our research for this project we spoke with KYTC designers whose combined experience in highway design is upwards of 150 years. The axioms presented below have been pieced together from our conversations. Although the ideas may feel intuitive or self-evident, they attempt to synthesize lessons learned that are too often forgotten in day-to-day practice. Although this wisdom is likely to confer the greatest benefit to early-career designers, even the most seasoned practitioners can benefit.

1. Analyze Problems with a Diagnostic Mindset

The purpose of a highway design project is to solve a need (e.g., high crash rates, traffic congestion). To determine an appropriate corrective action, designers must first understand what factors contribute to a problem. In medicine and other fields, practitioners use a process called differential diagnosis to pinpoint the cause of an issue. Diagnostic information is then used to formulate a treatment. For example, suppose a road segment has elevated crash rates compared to adjacent segments. Your first step is to brainstorm potential causes. There could be many — geometric characteristics, variability in traffic volumes throughout the day, behavioral factors, anything that may contribute to high crash rates. With a set of potential explanations in hand, empirical analysis becomes your focal point. This means looking at data and figuring out which explanations are the most persuasive and best supported by the evidence. Your investigation should be wide-ranging — crash reports, crash statistics, site visits, mapping the spatial distribution of incidents, and conversations with members in the local community are valuable for understanding what is going on. Using this knowledge, you can devise a treatment or set of treatments to address the problem's underlying causes that meld with the site and any project constraints.

2. Design to the Context

As a designer your foremost goal is to thoroughly understand the project context and create a design that is adapted to that context. Designers must take an expansive view of context. Understanding the biophysical and built environments of a project is imperative. Equally important is having knowledge of the demands imposed by different transportation modes. Historical performance (for reconstruction or spot improvements) and anticipated user trends are also a part of context. Taking these factors under consideration, your goal is to design a facility that effectively balances the needs of different user groups, fits within the environmental constraints, is cost-efficient, and will deliver acceptable performance into the future.

3. Do Not Fear Design Exceptions and Variances

Never fear design exceptions or variances. To some, the words exception and variance suggest that these options should be reserved for extraordinary circumstances. But in reality all design exceptions and variances require is that you provide a little extra justification for your design choices. Remember, the goal is to design a project that is adapted and responsive to its context — not design a project that is adapted to baseline values listed in the Green Book or KYTC's *Highway Design Manual*. Adhering to printed guidance is not mandatory. Delivering a project that fulfills the purpose and need in a cost-efficient, effective manner without significantly compromising on performance is.

4. Understand When Design Exceptions and Variances Are Needed

A former director of KYTC's Division of Highway Design observed that about half of all requests for design exceptions did not actually require an exception. Keep in mind the circumstances under which you need to ask for an exception or variance. On roads with design speeds ≥ 50 mph, design exceptions are required when the design departs from minimum suggested values for the 10 controlling criteria. If design speeds are < 50 mph, design exceptions are only required when the design departs from the minimum suggested values for (a) design speed and (b) design loading structural capacity. A variance is needed on these roadways if for the remaining eight controlling criteria the design uses design values that depart from typical values. Variances are also needed when a design diverges from common geometric practices (e.g., median widths, interchange spacing, ditch width, guardrail end treatments) that do not fall under the 10 controlling criteria, regardless of design speed.

5. Embrace Creativity and Cost-Efficient Solutions

Designers sometimes fall into the trap of over-designing projects. But often the most elegant and effective solutions are the simplest. Some problems may not even warrant complex designs. For instance, imagine a road segment has elevated crash rates and you are asked to correct inadequate sight distance upstream and throughout a horizontal curve believed to be driving up those rates. Your first step should be to think critically and creatively about the existing site conditions and determine what steps can be taken to solve the problem. Perhaps close investigation of the roadway indicates that poor sight distance can be mitigated by simply removing overhanging trees and roadside obstructions. Rather than instinctively jumping to a solution which entails reconfiguring highway geometrics, it pays to immerse yourself in the site conditions, explore a problem from multiple angles, and reflect critically on all of your potential options.

6. Adopt a Multidisciplinary Perspective in Communication and Problem Solving

Approach every project using a multidisciplinary lens. Not only does this mean appraising the influence of factors like environmental constraints, utilities, railroads, and right of way on the design process, it calls for collaborating with construction, traffic operations, and maintenance personnel to understand their perspectives and seek their input. The project you design has to be built, operated, and eventually maintained, so it is important to craft a design which facilitates all of these activities. Removing silos that have separated divisions and departments from one another encourages a more holistic method of design and a more reciprocal approach to problem solving.

7. Don't Fall in Love with A Single Solution

It is easy to become enamored of a design solution, or countermeasure, after seeing it perform well on projects. This is understandable — designers and project managers want to implement solutions that work! And there is no better evidence of a solution's potential to work than it having a proven track record. But it is a mistake to approach a fresh design challenge with an entrenched bias, one that compels a designer to think a solution must deliver improved performance merely because it has elsewhere. For example, high friction surface treatments (HFSTs) have proven incredibly effective in Kentucky and elsewhere at reducing crashes on ramps and curves on two-lane roads. Crash reductions have exceeded 90 percent in some cases. The early returns on HFSTs led some agencies across the US to go a bit overboard with their use, thinking they would automatically lower crash rates irrespective of context. But in some instances crash reductions have been disappointing. Why? Because the underlying drivers of crashes are sometimes unrelated to pavement friction. Harkening back to Axiom #1, it is critical to assume the role of a diagnostic designer — a sort of detective who approaches each project introspectively, as a puzzle that needs to be solved and which requires an investigation of the problem from multiple perspectives. Fidelity to a single design strategy hinders the diagnostic process and can result in designers opting for a solution when it does not fit with the context.

8. Be Intellectually Curious and Pose Questions

It is tempting to sit down in front of a computer and develop a paint-by-numbers design that meets minimum criteria and move onto the next project. But two of the most significant obstacles to creating good designs are failing to engage design questions at a conceptual level rooted in a deep knowledge of the underlying physics and geometry, human factors and behavior, as well as project context, and treating received knowledge as unimpeachable and authoritative. Computers are an aid to design — they cannot tell you how to become a competent designer. Similarly, tables full of minimum values and criteria offer a starting point, not an ending point. Accumulating conceptual knowledge, poring through case studies, and quizzing experienced designers will help you build up your design intuition. As your intuition sharpens you will develop a more critical eye, become a more skilled practitioner who can translate concepts and project goals into a functional design, and — most importantly — develop a better grasp of when to adhere to guidance and when to leave it behind.

CHAPTER 3 - Case Studies in Design Exceptions and Variances

Looking at previous applications of design variances and exceptions is the best way for designers and project managers to get a handle on how they are used in real-world settings to solve design challenges. Recognizing this, we scoured the KYTC project archives to identify projects that would provide useful case studies. Projects were selected with input from Cabinet project managers and designers. This chapter presents eight case studies drawn from around the state. Write-ups for each case study identify the project and location, provide an overview of the purpose and need, describe existing site characteristics, review the design solution, and briefly summarize the design exceptions and/or variances obtained by the project team. At the end of each write-up we provide illustrations of typical sections as well as photos taken before and after construction. Image availability varied. For some sites we were able to retrieve on-the-ground photos. For others we rely on captures from Google Earth to illustrate the magnitude of changes.

What these case studies highlight is that design exceptions and variances do not require sacrificing mobility or safety performance — they help designers create a context-adapted, cost-effective solution that dovetails with the templates of existing facilities as well as the built and biophysical landscapes. The most common design variances and exceptions include narrowing lane and/or shoulder widths and selecting design speeds below those specified by guidance. Highway design requires creativity, imagination, the willingness to take informed and judicious risks, and a commitment to forging solutions that meld with the context they will be constructed in. Design exceptions and variances are merely tools in the designer's everyday toolkit which facilitate problem solving. Of course, neither tool should be used indiscriminately. As our axioms emphasized, they should not be feared or avoided. Remember, design exceptions make for exceptional designs.

Table 3.1 Case Study Information

Route	Location (County)	Project Objectives
KY 378	Breathitt	• Bridge replacement • Modify bridge approaches
KY 144	Daviess	• Road widening
KY 4 / US 60	Fayette	• Interchange reconstruction
KY 163	Metcalfe	• Bridge replacement • Modify bridge approaches
KY 172	Morgan	• Road widening and reconstruction
KY 461	Pulaski	• Road widening • Interchange construction
KY 101	Edmonson	• Road reconstruction
KY 90	Barren	• Road reconstruction

Project Name & Location: Breathitt County, KY 378 — Bridge Replacement over Frozen Creek
Item # 10-1110.00

Overview of Purpose and Need

The goal of this project was to replace a two-span bridge that traversed Frozen Creek. The original structure was built in the 1930s or 1940s and had a substructure constructed of stone masonry. In 1976, KYTC reconstructed the bridge superstructure and reinforced existing abutments with concrete. Over the next 40 years, the bridge underwent significant deterioration. Concrete reinforcements weathered and peeled away from the original stone masonry, while a stone masonry pier in the channel degraded in response to weathering and impacts by debris.

Pre-Project Site Characteristics

At the bridge site, Frozen Creek drains a watershed that measures 23 square miles. KY 378 is designated a rural minor collector that sees fewer than 300 vehicles per day and has a statutory speed limit of 55 mph. Existing roadway widths ranged between 18 feet and 20 feet while shoulders were between 0 feet and 2 feet. The original bridge had a curb-to-curb deck width of 24 feet and a sufficiency rating of 24.5. On the roadway's southern approach, cribbing had been installed along a 0.1-mile segment to stabilize the slope above Frozen Creek and mitigate debris slides.

Design Considerations and Solutions

Needing to avoid impacts to slide-prone areas and minimize earthwork, the project team concluded that fulfilling criteria for the 55-mph statutory speed limit was neither feasible nor cost-effective. Designers elected to (1) create an improved roadway template and (2) develop alignments to match or improve existing geometrics. The new roadway layout consists of two 11-foot driving lanes with 2-foot paved shoulders. The new structure is a 98-foot single span bridge with a vertical breast-wall abutment to the south and a spill-through abutment to the north.

Exceptions and/or Variances

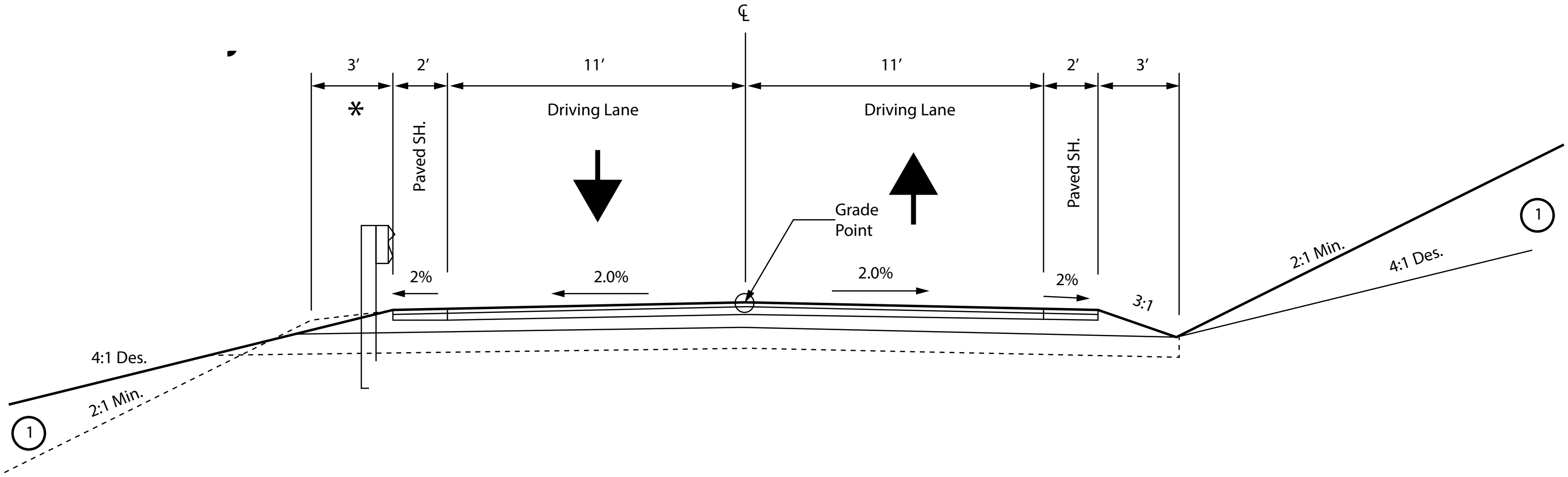
• Due to site constraints, the project team obtained a design exception for design speed. Although the selected 20-mph design speed was consistent with AASHTO and *Highway Design Manual* guidance, it was significantly less than the 55-mph statutory speed limit.

• A design variance for stopping sight distance was also approved. AASHTO's *Guidelines for Geometric Design of Very Low-Volume Local Roads* suggests a 95-foot stopping sight distance, but stipulates that designers can match existing conditions. A 95-foot stopping sight distance would have demanded raising the vertical alignment significantly, in turn raising the bridge grade and obligating designers to lengthen the southern approach. Extending this approach would have infringed upon slide-prone areas, increased earthwork, and drove costs above the project budget.

Exception/Variance	Typical Design Criteria	Adopted Design
Design Speed (E)	55 mph	20 mph
Stopping Sight Distance (V)	95 feet	56.45 feet

Figure 3.1 KY 378 — Breathitt County

Example Cross Section



Project Name & Location: Daviess County, Widening of KY 144
Item # 2-194.00

Overview of Purpose and Need

This project attempted to correct deficiencies related to highway geometrics and safety on KY 144 while improving the connectivity between Owensboro and Knottsville and incorporating improvements at the KY 144 / Pleasant Valley Road intersection. Several factors influenced unsafe conditions, including narrow lanes, limited shoulder widths or the absence of shoulders, drop-offs at the edges of pavements, inconsistent horizontal geometry, and restricted clear zones. A Data Needs Assessment (DNA) study found that improving curves near Pleasant Valley Road would significantly reduce crash rates.

Pre-Project Site Characteristics

Passing through level topography, KY 144 is a rural collector that accommodates roughly 2,200 vehicles per day. Along portions of the existing roadway, horizontal and vertical alignments did not meet AASHTO design standards for the traffic volumes and posted speed limit (55 mph). The existing lanes had a width of 10 feet, while shoulder widths ranged between 0 feet and 2 feet. Safety concerns were exacerbated by the presence of coal trucks and school busses. Design speeds for the eight horizontal curves along the project segment varied between 20 mph and 45 mph.

Design Considerations and Solutions

The project team was keen to design improvements that were consistent with the roadway's overall character. The selected alternative adopted a design speed of 45 mph along the project segment, used as much of the existing roadway as possible, and minimized property and utility impacts. Construction alternated between opposing sides of the existing roadway so that traffic could be maintained. Both lanes were widened from 10 feet to 11 feet and designers adopted 6-foot shoulders (two feet of which are paved). The horizontal curves which posed the greatest safety challenges were also eliminated.

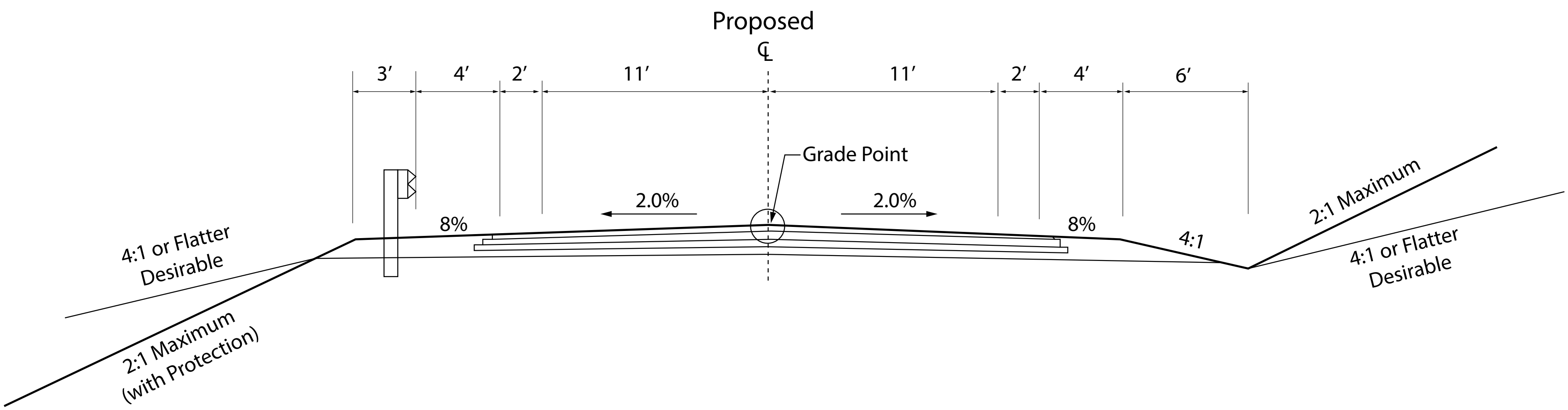
Exceptions and/or Variances

- The project team obtained design exceptions for design speed, lane width, and shoulder width. Guidance recommends 12-foot lanes and 8-foot shoulders; the design incorporated 11-foot lanes and 6-foot shoulders. These exceptions provided cost savings, allowed the project team to maximize use of the existing roadway, and yielded a design consistent with KYTC's 2008 directive on practical solutions. Lowering the design speed from 55 mph to 40 mph let designers mitigate impacts to adjacent residential properties and maintain the character of KY 144 found throughout Daviess County.
- Through a design variance, the clear zone was set at 12 feet. Establishing a 12-foot clear zone preserved consistency with improvements made elsewhere on KY 144 while minimizing the effects on property owners and utilities which run parallel to the existing roadway.

Exception/Variance	Typical Design Criteria	Adopted Design
Design Speed (E)	55 mph	45 mph
Paved Lane Width (E)	12 feet	11 feet
Shoulder Width (E)	8 feet (4 feet paved)	6 feet (2 feet paved)
Clear Zone Width (V)	7 feet – 10 feet	12 feet

Figure 3.2 KY 144 — Daviess County

Example Cross Section



Project Name & Location: Fayette County, Reconstruction of KY 4 (New Circle Road) and US 60 Interchange
Item # 7-279.00

Overview of Purpose and Need

The goal of this project was to reconstruct the cloverleaf interchange that links KY 4 and US 60 to improve safety and reliability. To accomplish this objective, the design needed to resolve four issues:

- Unsafe weaving by vehicles entering northbound KY 4 from eastbound US 60 as well as by vehicles exiting KY 4 onto westbound US 60
- Unsafe weaving by vehicles entering eastbound US 60 from southbound KY 4 as well as by vehicles exiting eastbound US 60 onto northbound KY 4
- Acceleration taper by vehicles entering westbound US 60 from northbound KY 4
- Perceived sight distance impacts for vehicles turning left across westbound US 60 to enter southbound KY 4,which increased crash frequencies

Pre-Project Site Characteristics

US 60 is an urban/rural arterial that connects the city of Lexington to the Blue Grass Airport, Versailles, and eventually Frankfort. It services approximately 50,000 vehicles per day and has a posted speed limit of 45 mph at the US 60 / KY 4 interchange and 55 mph to the west. The cloverleaf interchange linking US 60 and KY 4 opened in 1965. As traffic volumes grew, the interchange became more and more unsafe. Weaving proved especially troublesome. Vehicles exiting southbound KY 4 to travel east on US 60 shared a lane with vehicles exiting eastbound US 60 to enter northbound KY 4. This created a hazardous situation as the lane used for both merging onto and exiting US 60 was approximately 500 feet long. A similar dynamic afflicted northbound KY 4 as vehicles merging onto KY 4 entered an approximately 700-foot lane traveled by vehicles exiting onto US 60 westbound. The interchange had one non-continuous movement, where vehicles entering southbound KY 4 from westbound US 60 had to turn left across eastbound US 60 traffic. Even though the sight distance for vehicles turning onto KY 4 was adequate for speeds of up to 70 mph, perceived issues with sight distance materialized when eastbound vehicles passed through a sag vertical curve. Crash frequencies at this location were high and the public voiced concerns about the sag vertical curve.

Design Considerations and Solutions

The project team developed a context-adapted design that melded with the surrounding landscape. Dubbed the Left Overloop the new interchange eliminates shared lanes for vehicles merging onto and exiting both KY 4 and US 60. To address issues with the sag vertical curve, designers raised the grade for stopped vehicles, shifted the stop bar 75 feet to the west so it would be closer to the vertical curve's crest, and reduced the superelevation of eastbound lanes from 5.8 percent to 2 percent, increasing the elevation along the pavement's outside edge by 1.9 feet. Raising the pavement and moving the stop bar eliminated the sight distance challenges perceived by drivers of left-turning vehicles.

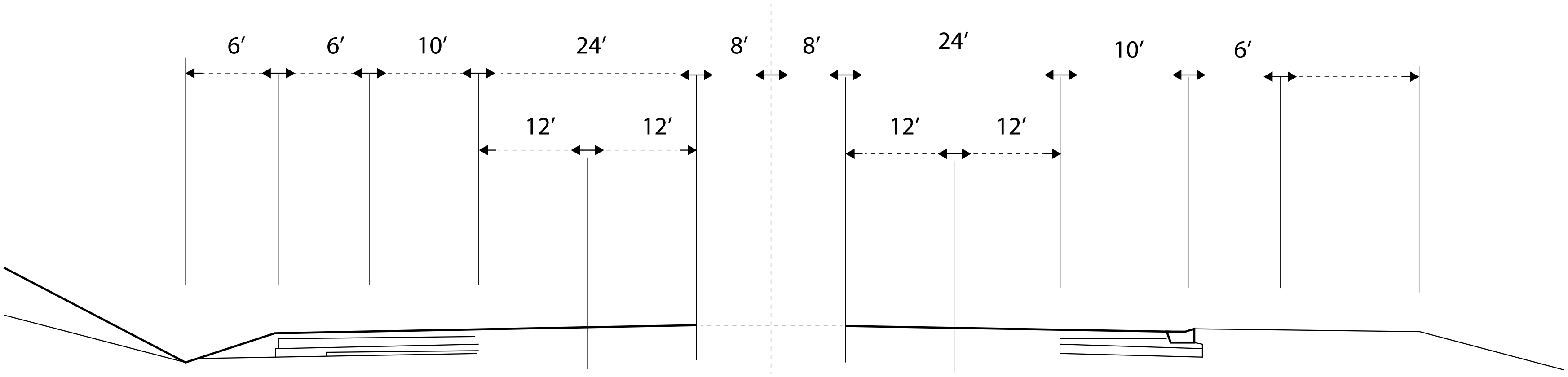
Exceptions and/or Variances

- The project team obtained a design exception for superelevation on eastbound US 60. Lowering the superelevation from 5.8 percent to 2.0 percent raised the outside pavement edge of US 60 by 1.9 feet. Along with other geometric modifications, drivers turning left onto southbound KY 4 retain full visibility of eastbound US 60 traffic. The existing horizontal curve radius when paired with a 2.0 percent cross slope can safely accommodate vehicles traveling up to 71 mph — far above the posted speed limits, which transition from 55 mph to 45 mph along the curve.

Exception/Variance	Typical Design Criteria	Adopted Design
Superelevation (E)	5.8 percent	2.0 percent

Figure 3.3 KY 4 — Fayette County

Example Cross Section



Project Name & Location: Metcalfe County, Replace Bridge over Rogers Creek and Adjacent Approaches on KY 163
Item # 3-8506.20

Overview of Purpose and Need

This project sought to improve the safety and mobility of KY 163 near Edmonton by replacing the functionally obsolete bridge over Rogers Creek and modifying bridge approaches. A 2007 study found that 36 crashes occurred on the roadway segment from 2003 to 2006; 10 crashes were recorded from 2013 to 2017 (two injuries). Contributing factors to these incidents included narrow lane widths and shoulders as well as unforgiving roadside conditions. The existing bridge over Rogers Creek was built in 1940 and exhibited many problems — joint failure, horizontal cracking in external beam web faces, fractures in exterior beams, spalling, and horizontal cracking. The local community viewed this as the highest priority spot improvement project on KY 163.

Pre-Project Site Characteristics

At the bridge site, Rogers Creek drains an 8.56-square mile watershed. KY 163 is designated a rural major collector that also functions as a school bus route. The posted speed limit is 55 mph and the facility services between 1,600 and 2,400 vehicles per day. Existing lane widths were between 10 feet and 11 feet, while earthen shoulders had widths of 2 feet or less. The two-lane bridge over Rogers Creek consisted of five reinforced concrete deck girder spans and measured 241 feet in length. On the bridge, curb-to-curb width was 19 feet, while lanes were 9.5 feet wide and lacked shoulders. This configuration resulted in a mismatch between the structure width and existing approach roadway width (21 feet).

Design Considerations and Solutions

The project team determined that widening and rehabilitating the existing bridge was not a cost-effective option as it would require KYTC to maintain a structure with elements approaching 80 years of age. The selected alternative involved building a new bridge upstream of the existing bridge so that traffic would not be impacted during construction. Lanes on the approach roadways are 11 feet wide to match existing site conditions, and shoulders generally have a width of 8 feet (two feet of which are paved). Along a segment in the northern part of the project area, designers elected to use 4-foot shoulders (two feet paved) in response to site constraints.

Exceptions and/or Variances

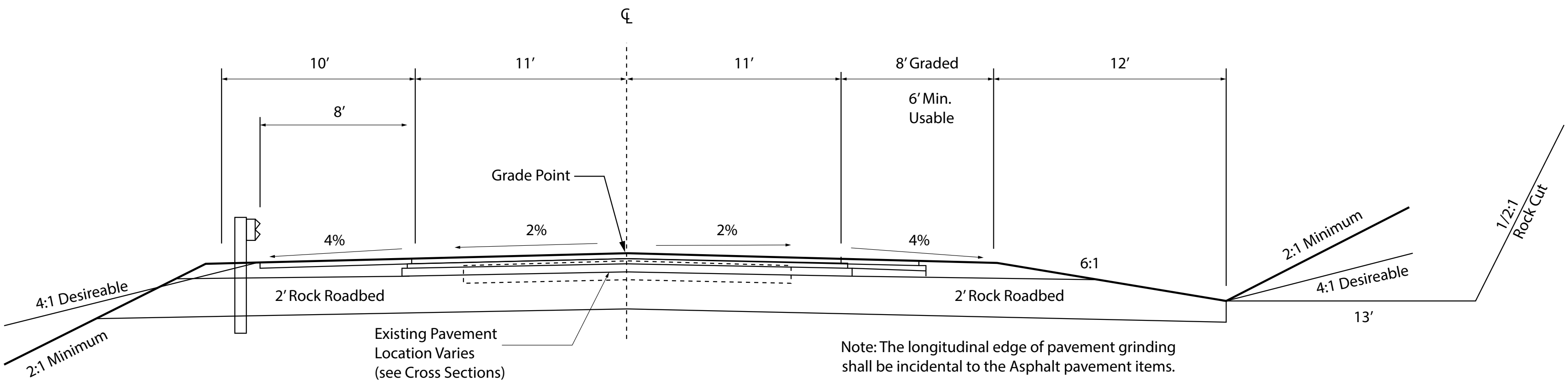
• The project team obtained an exception for lane width. Guidance calls for installing 12-foot lanes on rural collector roads that service more than 2,000 vehicles per day. Justifications for using 11-foot lanes included design consistency with KY 163's 10-foot lanes; cost savings realized by reducing bridge width, paved width, and earthwork and embankment work; and the use of partially paved shoulders.

• A second exception dealt with minimum usable shoulder length. Guidance advocates the use of 8-foot shoulders. But in response to challenges with right-of-way acquisition, 4-foot shoulders (2 feet paved) were adopted along a short segment. Narrowing the shoulders saved money by reducing paving widths, as well as earthwork and embankment work, and lowering right-of-way costs. Four-foot shoulders are also more consistent with KY 163's existing layout and driver expectations.

Exception/Variance	Typical Design Criteria	Adopted Design
Lane Width (E)	12 feet	11 feet
Shoulder Width — Minimum Usable (E)	8 feet usable (minimum 6 feet usable)	4 feet (2 feet paved)

Figure 3.4 KY 163 — Metcalfe County

Example Cross Section



Project Name & Location: Morgan County, Widen and Reconstruct KY 172 from MP 2 to MP 10.4
Item #s 10-8100.00, 10-8300.00, 10-8301.00

Overview of Purpose and Need

The objective of this project was to improve the safety and mobility of KY 172 and enhance the connectivity of traffic flowing between West Liberty and Paintsville. It was divided into three sections. Targeted purpose and need statements were generated for each (see below). Each section contained multiple segments for which multiple alternatives were developed.

Segment	Purpose and Need
MP 2 – MP 5	• Enhance safety by correcting narrow roadway widths, substandard curves, and inappropriate grades
MP 5 – MP 8	• Improve roadway alignment by increasing lane widths and ameliorating hazardous curves and poor sight distances
MP 8 – MP 10.4	• Correct substandard horizontal and vertical curvature, widen lanes, address narrow shoulders and drop-offs

Pre-Project Site Characteristics

KY 172 is a rural major collector situated atop rolling terrain and has a posted speed limit of 55 mph. Traffic volumes vary along the roadway, from 2,500 vehicles per day at MP 2 to 1,000 vehicles per day at MP 10. Across all sections, existing roadway widths were between 9 feet and 10 feet, while shoulders ranged from 0 feet to 2 feet. Substandard curves were found along the entire project length, with design speeds as low as 20 mph. The project area includes one bridge, over Straight Creek. The absence of shoulders and/or steep drop-offs from the pavement edge were factors in most recorded crashes.

Design Considerations and Solutions

KYTC retained three design consultants for the project, one for each section. All design teams embraced the Cabinet's 2008 guidelines on practical solutions in their work and adopted measures to reduce costs while addressing the purpose and need. Maintaining consistency across all three sections was a priority. The selected alternatives used 11-foot lanes, 4-foot shoulders (2 feet paved), and, with the exception of one curve, a 45 mph design speed. Cost savings were also realized by maximizing use of the existing alignment and salvaging existing pavement where feasible. Estimates indicate that adopting practical solutions saved KYTC over $30 million.

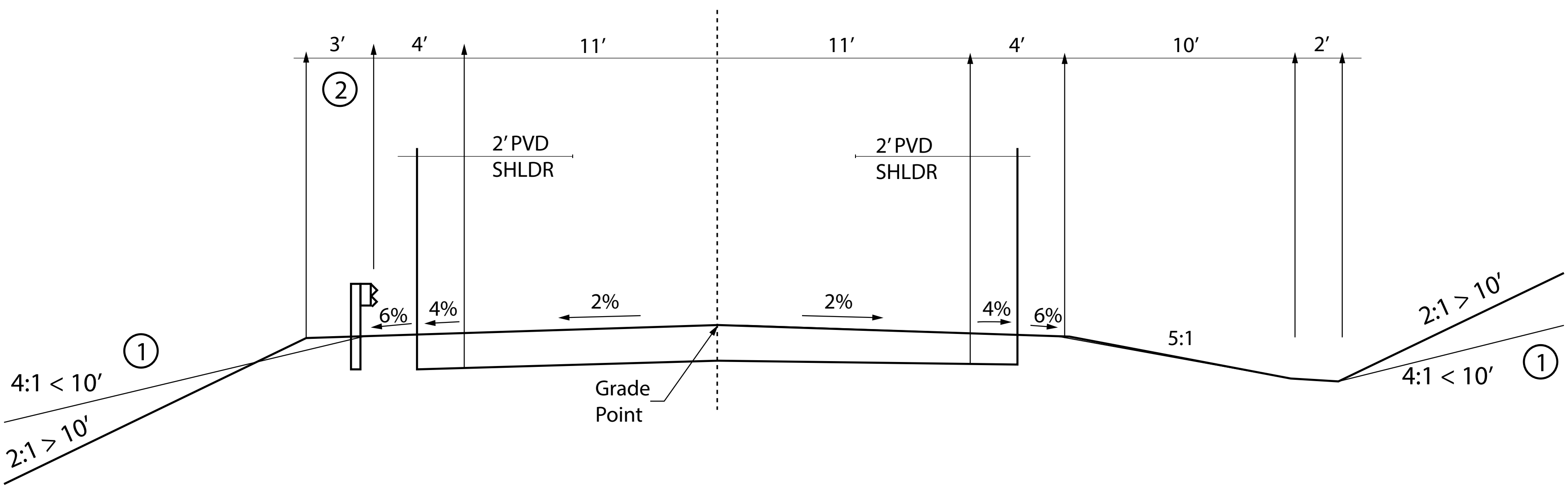
Exceptions and/or Variances

• Design exceptions were granted for lane width, shoulder width, and design speed. However, these design choices were consistent with KYTC's 2008 practical solutions guidance. In addition to being cost-effective, 11-foot lanes and 4-foot shoulders represented significant improvements over the existing conditions, mitigated sharp drop-offs, and provided the best fit within the project context. Using a 45-mph design speed improved curvature in several locations.

Exception/Variance	Typical Design Criteria	Adopted Design
Lane Width (E)	12 feet	11 feet
Shoulder Width — Minimum Usable (E)	8 feet usable (minimum 6 feet usable)	4 feet (2 feet paved)
Design Speed (E)	55 mph	45 mph

Figure 3.5 KY 172 — Metcalfe County

Example Cross Section



Project Name & Location: Pulaski County, Widen KY 461 and Construct Interchange with KY 80
Item # 8-59.25

Overview of Purpose and Need

The goal of this project was to improve regional mobility while creating a safer, more streamlined connection between Interstate 75, the Cumberland Parkway, Hal Rogers Parkway, and the planned Somerset Northern Bypass. From 2013 through 2018, 40 crashes occurred on KY 461 (two fatalities, 30 injuries) and 50 crashes took place on KY 80 (24 injuries). Sixteen incidents occurred at the KY 461 / Coin Road at-grade intersection, where safety was negatively impacted by commercial vehicles turning across KY 461 as well as high traffic volumes generated during shift changes at the Valley Oak Industrial Complex.

Pre-Project Site Characteristics

Both KY 461 and KY 80 are partially access controlled rural principal arterials on the National Highway System that cut through rolling terrain. Posted speed limits are 55 mph. Average daily traffic for KY 461 is 11,500 vehicles (17 percent trucks), while Coin Road services 7,700 vehicles per day (6 percent trucks). Before the project, Coin Road was a two-lane facility with lane widths that varied between 10 feet and 12 feet. Minimum usable shoulder widths ranged between 0 feet and 2 feet. Common crash types were lane departures, angle collisions, rear ends, and intersection collisions.

Design Considerations and Solutions

To improve safety and mobility at the KY 461 / Coin Road interchange, designers selected a jug handle intersection configuration, increased the lane width to 12 feet, and enlarged the usable shoulder width. When devising a solution, a key consideration was the traffic which flows into and out of the Valley Oak Industrial Complex. This hub of industrial activity is important for spurring local economic growth, and it was critical that the chosen alternative not impede traffic to or from the industrial park.

Exceptions and/or Variances

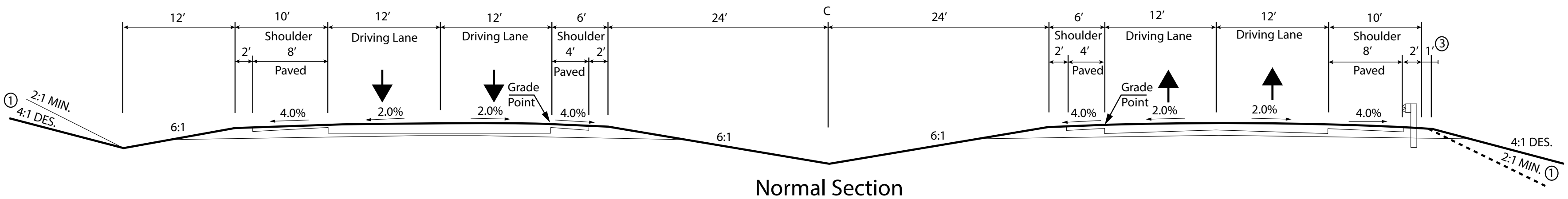
• The project team obtained an exception for design speed. Guidance recommends a design speed of 40 mph for facilities in rolling terrain which accommodate more than 2,000 vehicles per day. However, the speed limits of Coin Road and in the adjacent Valley Oak Industrial Complex are 25 mph. Because the primary purpose of Coin Road is to connect the industrial park to KY 461, designers concluded that the horizontal curves and minimum grades needed to support a 40-mph design speed would have negatively impacted facilities in the industrial park. Adopting a 25-mph design speed let designers minimize impacts and match existing roadway conditions.

• The project team also obtained a variance for minimum usable shoulder length. Guidance suggests 8-foot shoulder widths. To minimize impacts on industrial facilities, designers opted for a 4-foot graded shoulder (2 feet are usable). This represented an upgrade over existing conditions.

Exception/Variance	Typical Design Criteria	Adopted Design
Design Speed (E)	40 mph	25 mph
Shoulder Width — Minimum Usable (V)	8 feet usable	4 feet graded (2 feet usable)

Figure 3.6 KY 461 — Pulaski County

Example Cross Section



Normal Section

Project Name & Location: Edmonson County, Reconstruction of a 2.5-Mile Segment of KY 101 at Chalybeate
Item # 3.117.00

Overview

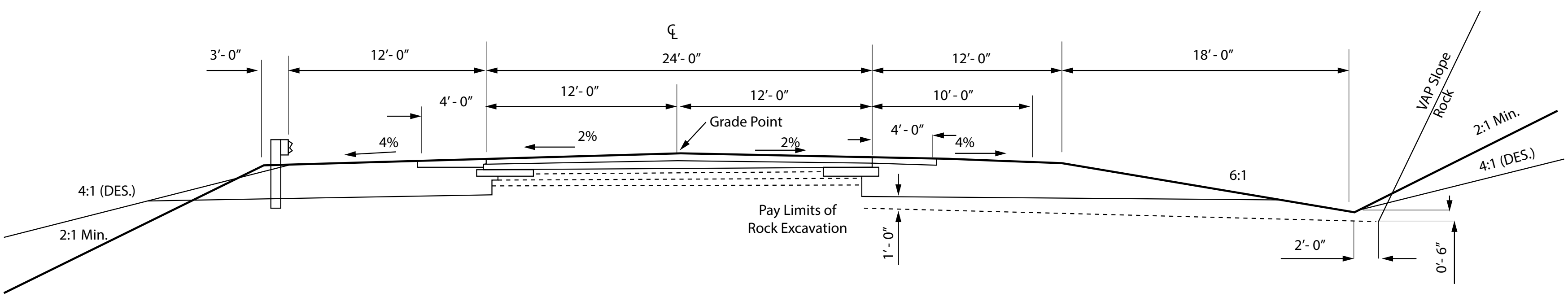
This case study provides a nice example of taking lessons learned from a previous project to improve the design philosophy implemented on a later project. Item # 3.117.00 — our main focus — was a project that reconstructed a 2.5-mile segment of KY 101 to strengthen connectivity between Interstate 65 and the Wendell Ford Western Kentucky Parkway and improve the prospects for economic development in Edmonson County. Constructed in 2011, this project was preceded by an earlier project that reconstructed an adjacent segment of KY 101 in 2006 – 2007. KY 101 is a rural arterial which services 4,800 vehicles per day and has posted speed limits that vary between 45 mph (in the town of Chalybeate) and 55 mph. The 2006 – 2007 project adopted 8-foot paved shoulders, citing their safety and operational benefits (e.g., leaving room for bicyclists and pedestrians). In hindsight, designers concluded 8-foot paved shoulders were unnecessary and that narrower shoulders would accommodate all user demands while achieving adequate safety performance. When the 2.5-mile reconstruction project was done in 2011, designers had the opportunity to put this knowledge into practice. The target segment had 11-foot lanes and 2-foot shoulders. Rather than opting for 8-foot shoulders, 4-foot shoulder were used for the reconstruction — Figure 3.7 illustrates the clear contrast between the 2006 – 2007 project and 2011 project. Installing narrower shoulders proved more efficient and minimized construction costs by reducing expenses related to materials and right-of-way acquisition.

Figure 3.7 KY 101 — Edmonson County

Figure 3.14 KY 101 After Construction

Note the differences shoulder widths between adjacent roadway segments. The segment with wider 8-foot shoulders (visible in both panels) was constructed as part of a project completed in 2006 – 2007. A project completed in 2011 adopted narrower 4-foot shoulders.

Example Cross Section



Project Name & Location: Barren County, Reconstruct KY 90 from MP 11.2 to MP 22.1
Item # 3.108.00

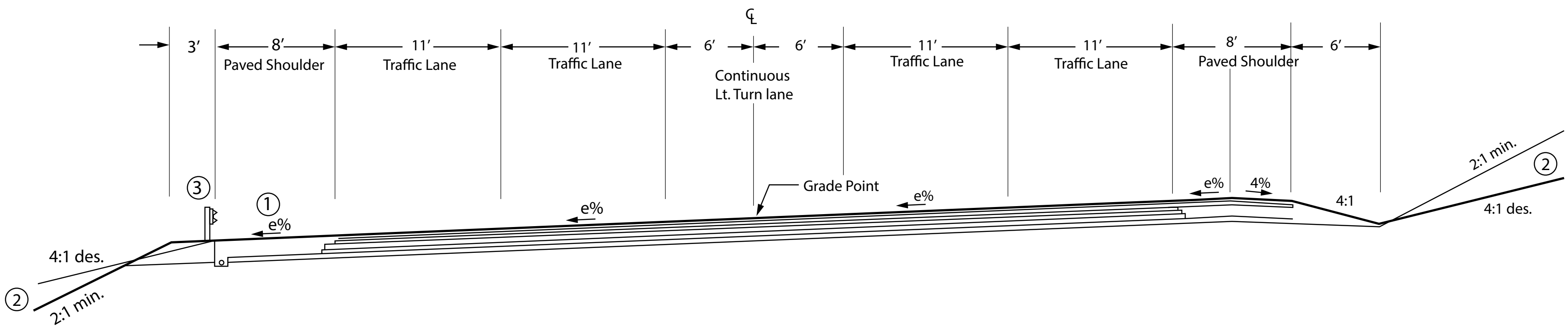
Overview

This project addressed safety and mobility issues along KY 90 in the vicinity of Glasgow. Key objectives included roadway widening, reducing curves, and installing passing lanes where feasible. KY 90 transitions from an urban arterial to a rural arterial at MP 12.6 as it exits Glasgow. Posted speed limits vary between 45 mph and 55 mph. Near Glasgow the roadway carries 9,500 vehicles per day, while more rural segments service 5,400 vehicles daily. Designers sought a solution that would alleviate demands on the transportation network leading into and out of Glasgow, improve sight distances, and minimize impacts to commercial and residential property owners. The corridor has dense commercial and residential development as well as numerous utility lines that run parallel to the roadway. Another requirement for the design solution was that it implement typical sections consistent with existing spot improvements. Ultimately the project was divided into five segments. The project team obtained design exceptions for lane width, shoulder width, and bridge width as well as variances for ditch width and fill slope. Although exact details vary from segment to segment, in general the design used 11-foot lanes and 8-foot shoulders. However, narrower shoulders were used where the roadway assumed a 2 + 1 configuration (Figure 3.8). Bridge widths for structures on the segments from MP 16.2 – MP 17.1 and MP 17.1 – 22.1 were reduced to 49 feet and 56 feet, respectively. Ditch widths were considerably narrower than typical guidance, while the threshold for switching from a 4:1 (minimum) to 2:1 (minimum) fill slope was increased from 4 feet to 10 feet. This project demonstrates the importance of using design exceptions and variances to create a context-adapted design that blends in with the highway template(s) established by earlier projects.

Exception/Variance	Typical Design Criteria	Adopted Design
Lane Width (E)	12 feet	11 feet
Shoulder Width (E)	10 feet	8 feet
Bridge Width (E)	68 feet	49 feet – 56 feet
Ditch Width (V)	12 feet — 18 feet	6 feet
Fill Slope (V)	• 0′ – 4′; 4:1 min., 6:1 or flatter desired • > 4′; 2:1 min., 4:1 or flatter desired	• 0′ – 10′; 4:1 min., 6:1 or flatter desired • > 10′ ; 2:1 min., 4:1 or flatter desired

Figure 3.8 KY 90 — Barren County

Example Cross Section



CHAPTER 4 - From Diagnosis to Solution

The goal of this chapter is to present some brief case studies that demonstrate how an engineer can move from diagnosis to solution. Our primary emphasis is HSIP projects, the purpose of which are to mitigate traffic injuries and fatalities. Often these involve a low-cost, minimally invasive solution to improve roadway safety performance. Some of the most successful HSIP projects have entailed making small modifications to facilities where it is not possible to comply with design values found in published guidance, such as installing centerline and edge line rumble strips. When complying with design guidelines is not possible, the designer's job is to figure what solutions can improve driver safety and mitigate the effects of possible geometric issues. It is also important to bear in mind that many factors which influence crashes lie beyond the control of engineers. Although designers can control geometry, they cannot engineer variables such as human behaviors, choices, and interactions between drivers that are implicated in many crashes. Which again speaks to why we should not be overly preoccupied with hitting a particular set of design values. Ultimately, the engineer's job is to diagnose the problem by understanding it from multiple perspectives and figuring the different ways in which things can go awry for a motorist. As two of the examples below show, the most effective and cost-efficient solution is sometimes one that does not require KYTC to build or reconstruct a facility. Engineers should always be on the lookout for economical solutions that solve the problem at hand as this can help the Cabinet stretch its limited funding. The case studies here are shorter than in the previous chapter as specific location information has been redacted. But they still contain the information readers need to make sense of the projects and grasp why the solution was chosen and how it was implemented.

Locating Rumble Strips

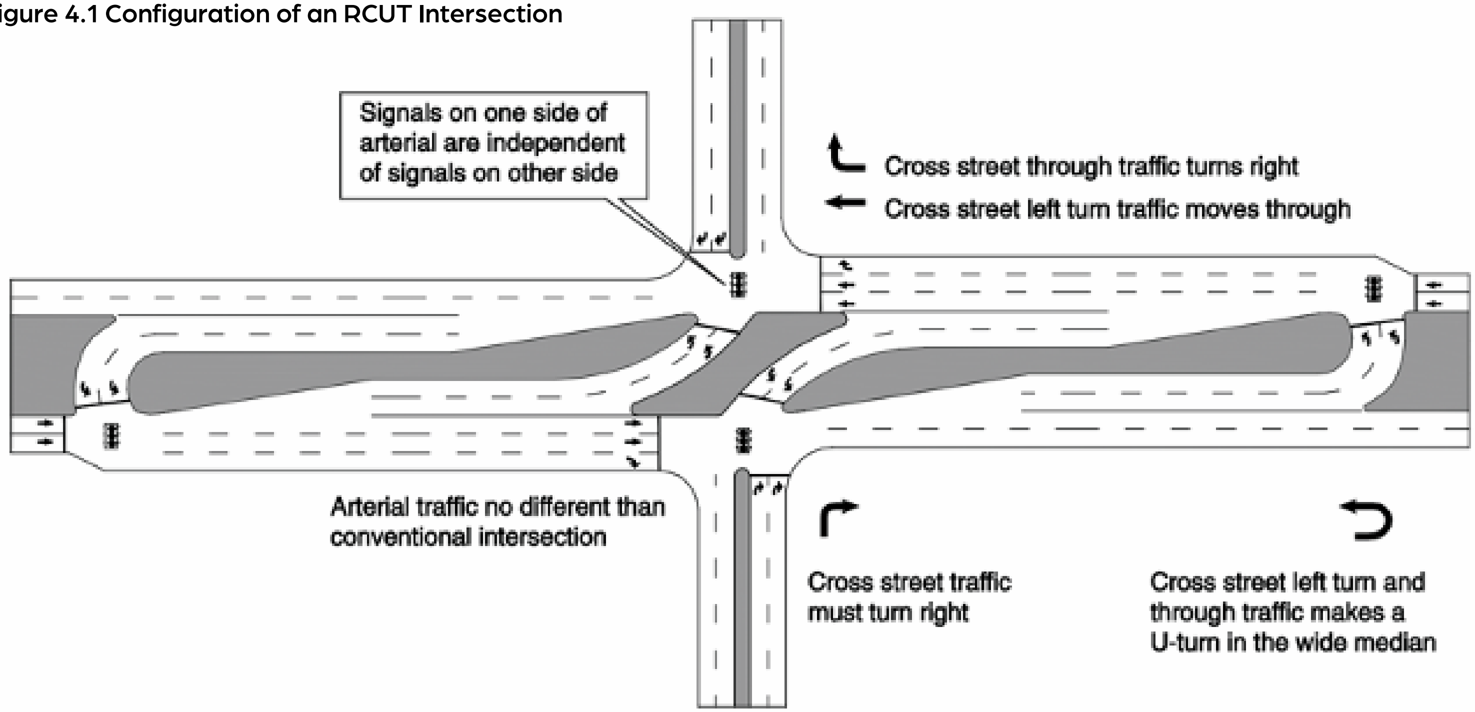
Route DD is a two-lane rural roadway that saw a large number of roadway departure crashes. Engineers noticed that while edge rumble strips were located along much of the roadway their positioning was spatially uneven — some segments of the road lacked them. Attempting to determine why a large number of crashes were occurring, engineers decided to examine the relationship between crashes and the placement of rumble strips to see if any meaningful correlation existed. Detailed mapping revealed that 80 percent of the crashes recorded on Route DD happened along the 20 percent of the road that lacked rumble strips. This demonstrated a clear relationship between rumble strips and crash frequency and suggested the most cost-effective countermeasure was not to redesign and reconstruct the facility, but to merely install rumble strips where they were absent. Looking closely at crash patterns in relation to roadway features, or the lack of features as this example illustrates, is critical for detecting the underlying drivers of crashes and developing a context-adapted solution that has the potential to maximize crash reductions. Installing rumble strips where they had been missing resulted in a more uniform facility consistent with driver expectations.

Reducing Crashes at Intersections

Safety problems occasionally arise even when a roadway conforms to every standard in the *Highway Design Manual*. This was the case with Route BB, a rural highway that experienced excessive crashes at one of its intersections. Engineers first installed a flashing beacon to alert motorists they needed to use caution at the intersection, but this did not appreciably lower crash rates. Looking for another strategy, engineers decided to convert the beacon to a traffic signal. But this produced an unexpected effect — crashes increased by over 65 percent and injury crashes went up 30 percent. Perplexed, engineers needed to take a closer look at why an intersection whose geometric layout mirrored idealized *Highway Design Manual* criteria, and where drivers had completely unobstructed views of cross traffic and oncoming traffic, was becoming less safe. Examining the intersection's surrounding context and how this influenced driver expectations offered much-needed clues. Nestled in an isolated location, the newly installed signal was quite far away from the closest signals — approximately 5 miles in one direction and 10 miles in the other direction. Motorists on this stretch of roadway were not expecting to encounter a signalized intersection (even with signage alerting them to the impending signal). This impacted driving behaviors. Recognizing the problems posed by the intersection, especially with turning vehicles, engineers installed a restricted crossing U-turn intersection (RCUT). RCUTs eliminate left turns and through movements from the side street at intersections by requiring drivers to turn right and then make a U-turn at a one-way median opening downstream of the intersection (Figure 4.1; FHWA 2014).

The RCUT significantly improved safety. This example offers persuasive evidence that complying with standards does not automatically translate into exemplary safety performance. Designers must be attuned to driver expectations and idiosyncrasies to create solutions that produce the intended outcome. If a road is a perfect representation of by-the-book design and is in flawless condition yet still has poor safety performance, it is important to reflect on how drivers interact with the facility and whether behavioral factors or expectations degrade safety. That knowledge is essential for pursuing corrective action. We cannot engineer driver behavior, but we can design facilities that accommodate drivers and minimize the risk of unsafe interactions between drivers, roadways, and other users.

Figure 4.1 Configuration of an RCUT Intersection



Curve Widening and Vegetation Obstruction

Route CC is a low-speed, two-lane road in a rural portion of eastern Kentucky. The route saw abnormally high lane departure crash rates along a horizontal curve. Many crashes involved motorists drifting across the centerline into the opposite lane. Due to the low posted speed limits, most crashes only resulted in property damage, however, a safety problem was evident. A review of crash reports and narratives found that several drivers commented they had difficulty seeing around the curve to identify obstructions and oncoming traffic and left their lanes to obtain a better view. Initially, engineers thought widening the horizontal curve would remedy issues with sight distance. A closer inspection indicated that the primary culprit of reduced visibility was the encroachment of tree limbs and other vegetation. This made sense because the site's crash history also indicated that crash frequencies declined during the late-fall and winter months. This knowledge changed how engineers approached the problem. Rather than opting for a reconstruction project, they chose to trim back vegetation to see what the effect was. Getting rid of overhanging branches and shrubs impinging on the shoulder improved sight distance and ultimately reduced crash rates. This example illustrates why close attention to site conditions and crash histories when deciding on a course of action is critical as it let KYTC avoid a costly — and unnecessary — design project. It also demonstrates that a key aspect of the diagnostic mindset is formulating multiple hypotheses to address a problem. This simply means coming up with a range of causal explanations for the observed conditions and implementing a solution that best responds to underlying drivers of the problem.

The School Bus Problem

Sometimes projects require extensive planning before implementation, which is problematic if existing conditions are hazardous. Consider Route LL, a sharply curved rural highway that winds through extremely rugged terrain. The combination of horizontal and vertical curvature made it difficult for vehicles with longer wheelbases to navigate the road safely. Work to improve the geometric trouble spots accelerated following a school bus crash that resulted in a fatality, but the local community expressed great concern over continuing to have school buses traverse this section of road while design work was ongoing and before construction was finished. Brainstorming short-term solutions to address safety concerns, KYTC hit upon the idea of buying for the local school district a few school buses with shorter wheelbases. Shorter buses could safely navigate the highway, protect passengers, and address community concerns. Although purchasing shorter buses was not a permanent solution, it temporarily mitigated safety issues, affording the Cabinet time to finish the design and reconstruction of wider curves. This example illustrates the importance of stepping back and thinking about what intermediate steps can be taken to ameliorate a problematic situation while a more lasting solution is developed and implemented.

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