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Evaluation of Guardrail Needs and Update of Guardrail Rating Program

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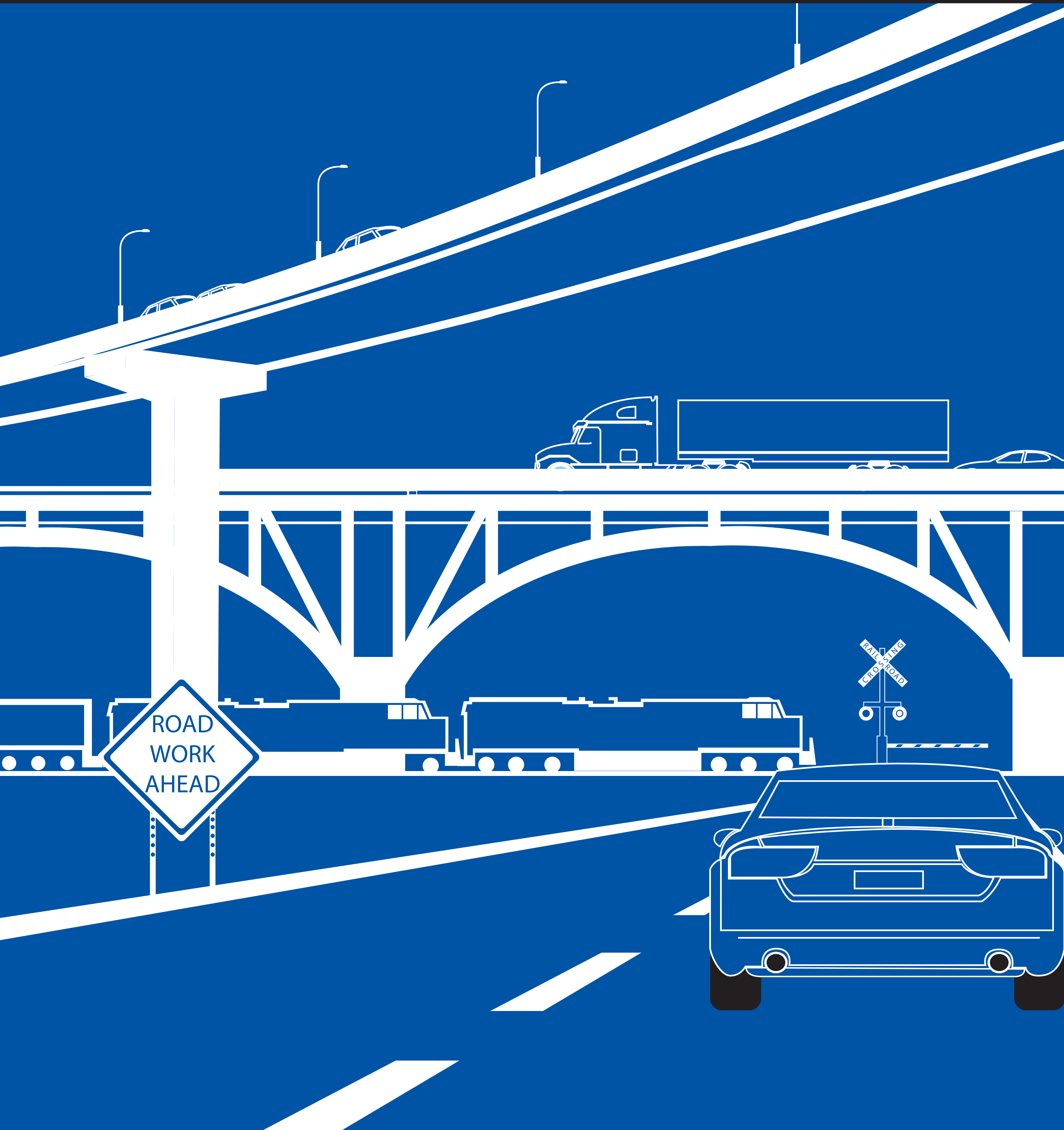

Kentucky Transportation Center
College of Engineering, University of Kentucky, Lexington, Kentucky

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University of Kentucky

Research Report

KTC-19-28/SPR19-577-1F

Evaluation of Guardrail Needs and Update of Guardrail Rating Program

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The Kentucky Transportation Cabinet (KYTC) seeks to reduce the frequency of roadway departure crashes, which often prove fatal. Roadside barriers such as guardrail have proven effective at mitigating these crashes, however, the demand for installations is high throughout the state. KYTC must prioritize prospective guardrail locations to match available funds with the most critical, or unsafe, sites. The current guardrail rating program (GRP) was established in 1989 to identify and prioritize guardrail needs. Despite periodic updates, the existing program no longer meets the transportation industry's safety guidelines and policies. The Kentucky Transportation Center (KTC) studied national and state guardrail practices and developed a new methodology for prioritizing guardrail installations. The new GRP model focuses on two main factors: crash frequency and crash severity, with the goal of maximizing safety outcomes for roadway departure crashes.</td></tr>
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Executive Summary

Roadway departure crashes represent some of the most severe crashes for vehicle occupants. In 2016, these crashes comprised approximately 65 percent of all fatalities and 54 percent of serious injuries throughout Kentucky. The Kentucky Transportation Cabinet (KYTC) seeks to mitigate roadside departure crashes through various means, particularly the installation of roadside barriers such as guardrail. Each year, district offices submit their requests for guardrail needs, including new installations. Due to high volume, KYTC must prioritize prospective guardrail installations to match available funds with the most critical, or unsafe, sites. The KYTC guardrail rating program (GRP) was established in 1989 as a process for identifying and prioritizing all guardrail needs. Despite periodic updates, the program no longer meets the transportation industry's safety guidelines and policies. As a result, the Kentucky Transportation Center (KTC) developed a new GRP methodology incorporating transportation best practices.

KTC researchers conducted a literature review of national and state guardrail practices and assessed the AASHTO Roadside Design Guide, the Manual for Assessing Safety Hardware, and the Highway Safety Manual. The manuals did not provide clear guidance on prioritizing guardrail needs. They did establish warrants for establishing guardrail needs, which researchers used to further refine the proposed methodology. FHWA has issued various documents over the years related to guardrail, but most focus on structural components and testing. The research team also performed an online search query across 23 state DOTs to examine their guardrail programs. While all states had internal guardrail programs, the research team identified two states, California and Virginia, with methodology useful for KYTC's program. California's use of run-off-road (ROR) crashes and Virginia's cost-based guardrail measures both provided insights into the development of the new GRP methodology for Kentucky.

KTC examined the existing GRP, including all 32 rating elements. The newly developed GRP model focused on two main factors: crash frequency and crash severity. Crash frequency indicated the probability of a vehicle departing the roadway, while crash severity measured the impact to the vehicle's occupants after a crash, most notably, crashes involving injury or death. Rankings for guardrail need locations should maximize safety outcomes for run-off-road crashes, and crash severity was the primary condition indicating the need for guardrail. However, where many highly-ranked sites across the state had roadside hazards commonly associated with severe crashes, crash frequency became increasingly important to consider in reducing the overall number of severe crashes.

With a focus on crash frequency and severity, the research team and study advisory committee chose 8 individual rating elements and assigned scoring attributes. All scored rating elements met three criteria: (1) influenced crashes through crash severity, crash frequency, or both per published research studies; (2) allowed for quantitative determination; and (3) remained comparable across different projects. The research team developed four initial weighting models using the criteria. Along with KYTC input, the team developed a final model with the following assigned rating elements and weighted percentages (totaling to 100 per project):

1. Speed Limit (5%)	2. Lane Width (5%)
3. Maximum Embankment Slope (18%)	4. Maximum Embankment Height (18%)
5. Empirical Bayes Expected Crashes (18%)	6. Excess Expected Crashes (18%)
7. Horizontal Distance from the Edge of Through Traveled Lane to the Nearest Fixed Object (18%)	
8. Horizontal Distance from the Edge of Through Traveled Lane to the Critical Slope (18%)	

The proposed model combined crash severity and crash frequency concepts through scored rating elements to identify the most at-risk locations for run-off-road crashes. Overall, the new GRP model did not differ significantly from the previous version but there were ranking changes amongst the project sites. Overall, the research team identified five recommendations for KYTC:

- Adopt the new GRP model methodology for use in ranking guardrail need projects across the state
- Provide KYTC personnel, including district offices, with the newly revised guardrail survey form to collect the necessary data
- Provide information and training sessions to KYTC personnel on the development rationale for the new model and its subsequent implementation
- Update the GRP online application and back-end IT architecture to match the new model data collection and processing requirements

1. Background

1.1 Introduction

Roadway departure crashes occur when vehicles leave the roadway, encroach upon the shoulder, and then crash at some distance from the travel lane. The most serious crashes occur when the vehicle strikes a roadside fixed object or overturns due to steep slopes found alongside the road. Roadside objects may include trees, utility poles, rocks, embankments, and bridge walls. Highway design engineers and planners often seek to mitigate roadside hazards through established safety criteria outlined in the AASHTO Roadside Design Guide. Guardrail and other types of longitudinal barriers are used to deflect and protect vehicles from encountering roadside hazards.

Kentucky Transportation Cabinet (KYTC) District Offices identify their guardrail needs and submit them to the KYTC Division of Maintenance. The Division of Maintenance is responsible for prioritizing guardrail needs across the state and choosing the sites for new installation. Maintenance officials prioritize guardrail needs using the guardrail rating program software. The Kentucky Transportation Center (KTC) originally developed KYTC's guardrail rating methodology through a 1989 research study (Report KTC-89-39, "Warrants and Guidelines for Installation of Guardrail"). KTC, in conjunction with KYTC, periodically refined the guardrail program, most notably in 2002 and 2009. The 2002 effort created an online database and software user interface to allow district offices to input their guardrail preference locations. The 2009 updates included: (1) revised crash data reflecting the most recent statistics of roadside departure crashes, (2) the critical rate calculator as the mechanism for obtaining crash data, and (3) hazard rating descriptive text and template photographs. For the third update, the text and photographs informed end users on the appropriate hazard rating to use when assigning subjective hazard ratings to guardrail locations.

1.2 Problem Statement

The Division of Maintenance is responsible for identifying and prioritizing guardrail needs along KYTC roads. The current KYTC system used to assess and rate guardrail needs—known as the guardrail rating program (GRP)—last received an update in 2009. Since that time, the Highway Safety Manual (HSM) has adopted a more rigorous methodology involving crash/accident data elements. KYTC's "accident rate" element within the current rating system uses legacy critical crash numbers and rates as the foundation. However, the HSM's "Potential for Crash Reduction" factor has largely replaced critical crash numbers and rates due to increased statistical reliability. Therefore, KYTC is exploring the adoption of HSM's updated crash factor into their GRP.

The research team also reviewed elements of KYTC's GRP and compared them to national guardrail best practices to find additional improvements to the current system. Finally, since the user interface and data inputs into the guardrail rating software directly influence the final ranking results, researchers examined the guardrail need survey form. Differing backgrounds and experience levels for district personnel responsible for entering the data may introduce subjectivity into the process.

1.3 Objective

The Kentucky Transportation Center (KTC) evaluated KYTC's GRP and recommended updates to improve the methodology behind prioritizing guardrail installations. The research team also evaluated and improved the statistical reliability and user interface for the guardrail rating software, thereby maximizing safety outcomes. The project objectives are as follows:

- Conduct literature review of state DOT best guardrail practices
- Evaluate the current KYTC GRP
- Update the GRP to suit KYTC's current needs
- Draft report of results and improvements to the GRP

2. Literature Review

The KTC research team conducted a comprehensive literature review on guardrail standards and other state's best guardrail practices. The literature review focused on procedures and policies used to prioritize guardrail site placement, as well as methodologies that maximize safety within an established budget. This chapter discusses the guidance on guardrail prioritization provided by various technical and regulatory authorities, including AASHTO, Federal Highway Administration (FHWA), and state departments of transportation.

2.1 American Association of State Highway and Transportation Officials

The American Association of State Highway and Transportation Officials (AASHTO) is a non-profit advocacy organization that promotes transportation. In this role, it fosters research and education programs serving technical practitioners, policy-makers, and the public. AASHTO has led many efforts in developing transportation best practices, including roadside hardware. The KTC research team reviewed current AASHTO manuals for information regarding guardrail infrastructure. The findings are described further below.

2.1.1 Roadside Design Guide

The AASHTO Committee on Design, Technical Committee on Roadside Safety published its most recent Roadside Design Guide (4th edition) in 2011. [1] This synthesis manual provided highway officials and engineers with best practices relating to roadside safety. Researchers reviewed this edition for factors warranting possible updates to Kentucky's existing guardrail prioritization program. The Kentucky Transportation Cabinet (KYTC) originally adopted criteria from the first-released Roadside Design Guide, then called "Highway Design and Operational Practices Related to Highway Safety"[2], as the basis for its GRP.

The research team reviewed the latest manual and found the most relevant changes in Chapter 5, Roadside Barriers. This chapter provides technical requirements on different roadside barriers (e.g., guardrail, cable barrier, etc.) and recommendations on their placement to minimize the severity of roadway departures. The majority of factors that impact safety remained unchanged from the 1988 Roadside Design Guide, to include: embankment height, embankment side slope, roadside obstacles (i.e., culvert inlets and trees), speed, and annual average daily traffic (AADT). Therefore, these factors remain valid for roadside safety.

The Roadside Design Guide also contains an independent safety analysis program, called the Roadside Safety Analysis Program (RSAP). While useful, KYTC has adopted the practices in the Highway Safety Manual for all of its safety program analysis. The RSAP uses a different approach to estimate crash frequency than the Highway Safety Manual. Yet, many contributing factors are the same in both analyses. Consequently, the RSAP program was not considered for determining guardrail rating criteria.

2.1.2 Manual for Assessing Safety Hardware

Researchers reviewed the AASHTO Manual for Assessing Safety Hardware, better known as MASH,[3] for potential guardrail rating factors that could be added to Kentucky's existing guardrail prioritization program. The MASH primarily focuses on crash testing procedures used to evaluate roadside barriers, including guardrail and guardrail end-treatments, and authorizes their use on the federal highway system. In fact, the MASH describes several guardrail systems that meet crash testing standards. One such system, the Midwest Guardrail System (MGS), was adopted by KYTC in 2017. The MASH also provides guidance on conducting in-service performance evaluations (ISPE) for highway maintenance programs. Yet, the MASH does not provide warrants or recommendations for identifying optimal guardrail locations. Therefore, it could not provide additional insight into KYTC's guardrail prioritization methods.

2.1.3 Highway Safety Manual

Next, the research team assessed AASHTO's Highway Safety Manual (HSM)[4] for guardrail placement guidelines. The HSM provides highway officials with methods and statistical tools to evaluate highway safety, particularly in estimating crashes and assessing countermeasures to reduce them. The HSM does not specifically address the issue of guardrail placement. In this context, it did not provide additional guidance on prioritizing guardrail installation needs. Yet, it did provide detailed safety methodologies used in today's state of practice. Therefore, HSM concepts have been adopted into KYTC's current policies and processes and were used within the new GRP. Additional details on KYTC's use of HSM methodologies are discussed further below.

KYTC uses the HSM as the basis for implementing safety concepts into its policies and procedures. The critical rate factor (CRF) compares a segment's actual crash rate to a crash rate that is considered critical, or much greater than the average crash rate for a segment of that roadway type. KYTC defines critical crash rates as those rates greater than or equal to three standard deviations above average for a given roadway type. [5] Yet, recent research has shown that CRF is not the most accurate or reliable method to compare a segment's crash performance to similar type segments. CRF assumes that crashes and traffic volume have a linear relationship, which may not always be true. The CRF does not address regression to the mean bias, meaning it does not account for temporal crash fluctuations. [6]

The HSM improves safety performance evaluations of segment-based crash frequencies through statistically rigorous methodologies. This peer-reviewed manual determines excess expected average crash frequencies with an Empirical Bayes adjustment.[7] Kentucky's Strategic Highway Investment Formula for Tomorrow (SHIFT) model uses the same HSM methodology to evaluate safety across all statewide proposed projects.[8] KYTC has adopted the term Excess Expected Crashes, or EEC, for this analysis. The EEC relies on two safety metrics: predicted crashes from a safety performance function (SPF) and expected crashes from the empirical Bayes (EB) method.

SPFs are models that predict crashes, typically using the variables of segment length and traffic volume. SPFs must be calibrated to local crash conditions for specific crash types in order to accurately predict crash frequencies on a given roadway. The Empirical Bayes method adjusts the SPF predicted crash frequency for a site using the location's observed crash history (i.e., observed frequency) to account for regression to the mean bias, resulting in the EB expected crashes (i.e., expected frequency). Next, the EEC is calculated as the difference between the EB adjusted crash estimate and the SPF crash prediction. This means positive EEC locations experience higher crashes, on average, than expected based on similar-type, similar-volume locations. Conversely, negative EEC locations experience fewer crashes, on average, than expected based on similar-type, similar-volume locations. The SPF graph below illustrates these terms in relation to one another:

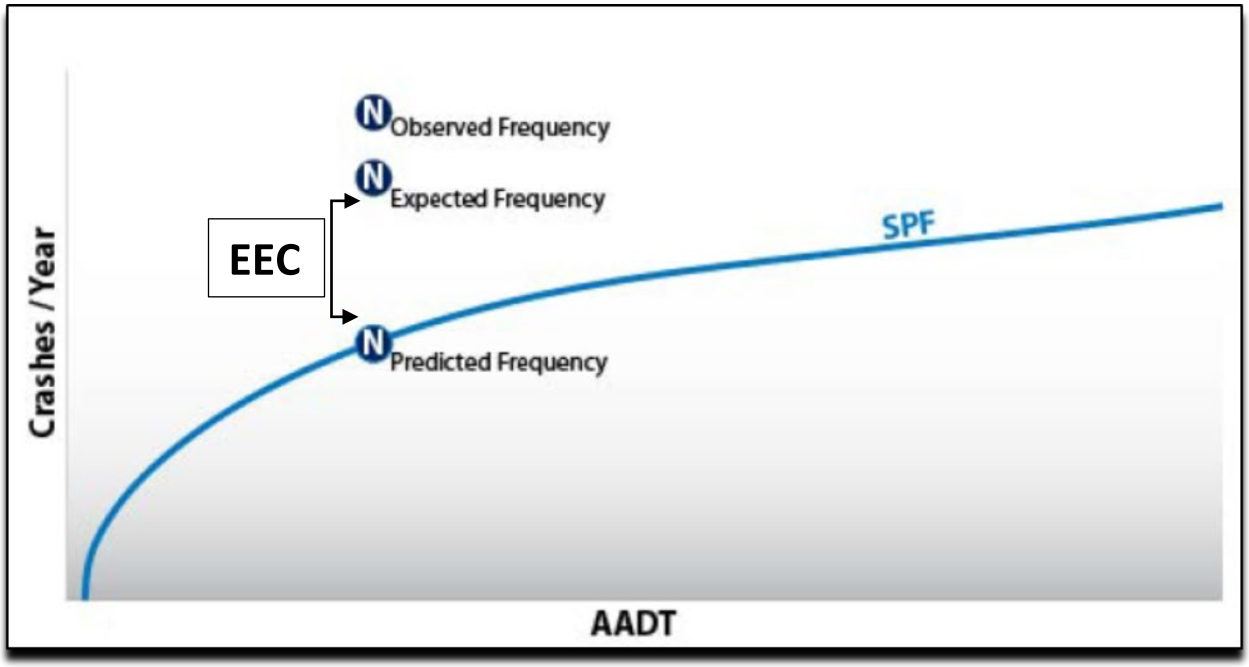


Figure 1 Crash Frequencies[9]

2.2 Federal Highway Administration

Upon completion of the AASHTO review, the research team assessed federal standards and guidelines for guardrail placement. This analysis investigated the following documents from FHWA's Roadway Departure Safety website[10]:

- FHWA Roadway Departure Strategic Plan[11]
- An open letter to all in the highway safety hardware and roadside design community dated May 26, 2017[12]
- FHWA Memorandum on the subject of In-service Performance Evaluation and Continuous Monitoring of Roadside Safety Features dated November 17, 2005[13]
- Guardrail 101[14] is a document on FHWA's Roadway Departure website that outlines the purpose and function of guardrail. This document does not address where guardrail installation may be warranted.
- Report to Congress – Roadside Safety Hardware ID methods[15]
- FHWA Memorandum on Federal-aid Reimbursement Eligibility Process for Safety Hardware Devices[16]

These documents focus on testing infrastructure components, rather than warrants. Essentially, the FHWA guidance provided the "how" on guardrail installation, but less on the "where". Similar to other literature reviewed, the FHWA guidance did not provide prescriptive guidance on prioritizing guardrail site placement.

2.3 State Departments of Transportation

KTC researchers evaluated policies and practices for guardrail site selection and installation across various state departments of transportation (DOTs). This was performed through an online guardrail program survey, whereby researchers conducted online search queries for guardrail warrant programs and prioritization procedures for state DOTs. They ultimately selected and examined 23 individual state DOT websites for their policies, manuals, and guidance. The reviewed states included: Alabama, Alaska, Arizona, California, Colorado, Connecticut, Georgia, Illinois, Indiana, Maine, Minnesota, Montana, Nebraska, New York, Ohio, Oregon, Pennsylvania, Rhode Island, South Carolina, Virginia, Washington, West Virginia, and Wyoming.

During this process, researchers noted that all 23 state DOTs made their guardrail installation procedures and material specifications available through their public websites. Each state also had an internal guardrail warrant plan—an established process indicating when guardrail installation is required at a given location. Yet, some states relied solely on national guidance for their guardrail warrant program, primarily, the AASHTO Roadside Design Guide. Fourteen states actually established their own guardrail warrant programs tailored to the needs of their state. These programs sometimes included guardrail prioritization procedures. While useful, the individual guardrail warrant programs varied significantly across their scopes and the years they were enacted. The research team evaluated all 14 programs to determine if any programs or components might be suitable for adoption in Kentucky. The summarized results are shown below:

Table 1 State DOT Guardrail Warrants & Prioritization

State	Guardrail Warrants or Prioritization Procedure	Established Policy Year
Alaska	Spreadsheet tool to determine if guardrail is a cost-effective countermeasure for a location	1999
Arizona	Minimum 75' guardrail installations, state warrants for guardrail installation with curbs	2018
California	Crashes, alignment, volume, speed, merge/weave areas, climate and roadside recovery areas to determine guardrail need	2017
Georgia	Developed a warranting standard above the RDG. No prioritization	2018
Illinois	Rigid objects that are more than 4" above surrounding ground warrant guardrail	1998
Indiana	Prioritize location guardrail installations based on crash rate and AADT	1999
Maine	Guardrail is warranted where adequate vehicle recovery area cannot be provided	2017
Minnesota	Uses AASHTO guides to check for warrants in addition to personnel evaluation. No Prioritization	1999
New York	Guardrail is installed if clear zone is insufficient or hazards cannot be made crash worthy, and if funding is available	1999
Ohio	If warrants are met, guardrail is installed without prioritization	1999
Rhode Island	Install guardrail in conjunction with scheduled projects if it is warranted	1999
Virginia	Risk-based comparison tool is used to prioritize locations needing guardrail installation or upgrade	2001
Washington	Guardrail is prioritized based on benefit-to-cost ratio	1999
Wyoming	Uses RDG to check for clear zone warrants with no prioritization of installations	1999

Based on this research, the research team narrowed down this list to two states of interest: California and Virginia. Both states had robust guardrail programs that warranted further analysis. The Caltrans and Virginia DOT guardrail policies and procedures are discussed below.

2.3.1 Caltrans

The California Department of Transportation (Caltrans) establishes uniform practices for roadside barrier installation and maintenance through their Division of Traffic Operations. Caltrans lists five major criteria in selecting locations for their guardrail installation: collision history, roadway alignment, operating characteristics, climate conditions, and roadside recovery area. First, they analyze a site's collision history to determine the incidence of run-off-road (ROR) crashes. Elevated ROR crash rates help justify guardrail installation. Challenging roadway alignment characteristics, such as isolated or short-radii curves represent another potential guardrail need. Traffic volume, speed, and merge/weave areas are three distinct operating characteristics that may require guardrail installation. All three characteristics are frequently associated with ROR crash types, which guardrail helps prevent. Caltrans evaluates the frequency and/or severity of climate conditions such as fog, rain, snow, or ice as contributing factors to ROR crashes. Finally, any fixed object placed within the recovery zone represents a hazard warranting mitigation, with guardrail used as one possible countermeasure.[17]

Conversely, other factors may prevent guardrail installation from further consideration. The availability of resources (i.e., funding) and the roadway type occasionally limits the opportunity to install guardrail. For instance, the agency may not install guardrail per routine warrants (e.g., fixed object found in the recovery zone) if multiple driveways are located nearby.

The Caltrans guidance describes explicit conditions and exceptions for guardrail installation, but remains limited in its usefulness as a prioritization methodology. The research team did not find any tools designated for new guardrail installation. However, for existing guardrail, Caltrans prioritizes and schedules repairs for damaged guardrails based on several risk factors: highway type, extent of damage, and probability of second vehicular strike prior to repair. The damaged guardrail receives a rating of High, Medium, or Low to indicate its repair priority. [18]

2.3.2 Virginia DOT and Multistate Survey

The Virginia Department of Transportation provides several tools for selecting and prioritizing guardrail installation locations. Its hazard database tool logs roadside hazards on roadways that merit guardrail installation and notes any locations already possessing guardrail. The hazard database tool also stores traffic volumes, crashes, guardrail strikes in existing installations, and recorded citizen complaints. The second tool, the guardrail screening tool, determines a monetary value associated with crashes at a given location. This tool uses traffic volumes, crash history, crash severity, and crash costs as the variables. A third tool also helps prioritize locations for new guardrail installation. Users must provide inputs across a range of parameters to use the tool. The inputs for each location include:

- Hazard length: length of hazard parallel to roadway
- Severity index: 1-10 based on site characteristics
- Annual average daily traffic (AADT)
- Daily vehicle-miles traveled (DVMT)
- main run cost: cost of linear portion of guardrail
- run-on cost: end treatment cost
- run-off cost: end treatment cost
- removal cost: cost to remove any existing guardrail
- other costs: additional improvements such as paint or reflectors
- total site improvement cost: total site cost

The tool uses provided inputs to calculate five separate statistical measures for each site: total guardrail mileage, severity, vehicle-miles, severity-miles, and severity-vehicle-miles. Each site is ranked across the five categories, essentially resulting in five distinct ranked columns. Users may choose any individual list, or a combination thereof, to produce their own overall ranking. The tool also allows users to evaluate installation costs in conjunction with these ranks. For example, the tool can calculate a cost ratio for each category, such as total guardrail mileage per installation costs at that location. These cost ratios provide officials with another analysis tool in prioritizing between new guardrail installations. It should be noted that this tool does not draw from a statewide requested guardrail installation database such as Kentucky has. Rather, the tool is used to compare new guardrail installations across a limited number of site candidates across the state.[19]

While developing these tools, the Virginia DOT reviewed and assessed other state DOT guardrail installation and prioritization practices for possible inclusion into their program. Their survey cited guardrail procedures and best practices across the nation, including KYTC's GRP. Virginia claimed that Kentucky's GRP helped them identify factors for guardrail need. However, they were uncertain how KYTC developed its weighting assignments for each guardrail factor, which hindered their ability to fully adopt it. The list below summarizes the results of Virginia's guardrail survey: [20]

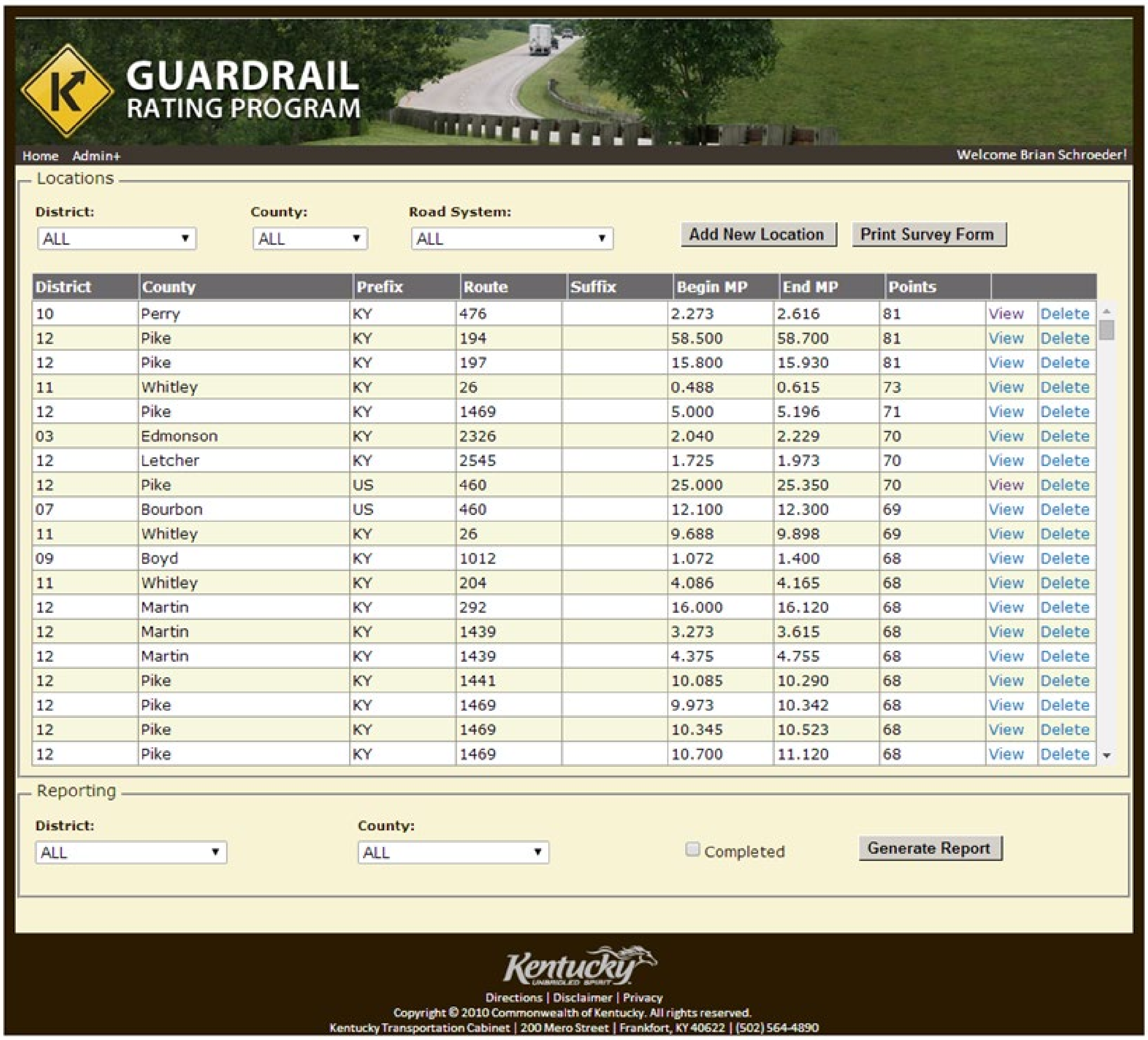
- Washington uses a benefit/cost ratio to compare guardrail locations.
- Rhode Island recommends upgrading/installing guardrail in conjunction with other scheduled projects.
- Indiana evaluates potential locations with high crash rates and prioritizes installations using traffic volume.
- New York evaluates potential locations to determine if clear zone is sufficient and installs guardrail if it is insufficient. Guardrail is also installed when hazards cannot be made crash worthy. No prioritization performed, although funding limits the number of installations.
- Ohio uses warrants to determine when guardrail is needed, but does not prioritize installation locations.
- Minnesota and Wyoming use AASHTO guides to determine when guardrails are warranted. No prioritization is used.
- Alaska uses a spreadsheet to perform cost-effectiveness analysis using traffic data, grade, number of lanes, lane width, highway type, slope, obstacles, severity of hazard, and cost factors to determine if guardrail is economical, but did not state if the spreadsheet is also used to prioritize locations.

The Virginia DOT conducted their survey in 1999. Due to the time elapsed, the research team investigated the originally surveyed states' procedures and practices to determine if they were still current. In this effort, the research team reviewed the public-domain websites and any guardrail reports/manuals for the state DOTs listed on the survey. They found no additional evidence in the form of updated policies, procedures, or best practices that deviated from the original survey findings.

3. Guardrail Rating Program

KYTC's Division of Maintenance is responsible for identifying and prioritizing guardrail needs across the state. They receive requested guardrail projects from each district office. Similar to most transportation programs, the infrastructure demands greatly exceed the resources available to fund them. Consequently, KYTC relies upon their GRP to assess and prioritize new guardrail installations for all requested locations. KYTC's GRP currently uses the methodologies developed by KTC in 1989, with 2002 and 2009 updates (see Background section). KYTC employees use a guardrail survey form to collect information and assign attributes to their potential guardrail site, and submit this information through their online GRP. A copy of their current guardrail survey form is provided in Appendix A. The below provides an illustration of the GRP output with project rankings.

Table 2 KYTC Guardrail Rating Program



District	County	Prefix	Route	Suffix	Begin MP	End MP	Points		
10	Perry	KY	476		2.273	2.616	81	View	Delete
12	Pike	KY	194		58.500	58.700	81	View	Delete
12	Pike	KY	197		15.800	15.930	81	View	Delete
11	Whitley	KY	26		0.488	0.615	73	View	Delete
12	Pike	KY	1469		5.000	5.196	71	View	Delete
03	Edmonson	KY	2326		2.040	2.229	70	View	Delete
12	Letcher	KY	2545		1.725	1.973	70	View	Delete
12	Pike	US	460		25.000	25.350	70	View	Delete
07	Bourbon	US	460		12.100	12.300	69	View	Delete
11	Whitley	KY	26		9.688	9.898	69	View	Delete
09	Boyd	KY	1012		1.072	1.400	68	View	Delete
11	Whitley	KY	204		4.086	4.165	68	View	Delete
12	Martin	KY	292		16.000	16.120	68	View	Delete
12	Martin	KY	1439		3.273	3.615	68	View	Delete
12	Martin	KY	1439		4.375	4.755	68	View	Delete
12	Pike	KY	1441		10.085	10.290	68	View	Delete
12	Pike	KY	1469		9.973	10.342	68	View	Delete
12	Pike	KY	1469		10.345	10.523	68	View	Delete
12	Pike	KY	1469		10.700	11.120	68	View	Delete

3.1 Guardrail Rating Elements

KYTC has an established guardrail rating system that evaluates potential guardrail installations across 32 site conditions. Devised in 1989, the *Warrants and Guidelines for Installation of Guardrail* report provides the original methodology KYTC used to prioritize guardrail installations.[21] The report describes the guardrail rating elements used when evaluating locations for guardrail need. Elements #1-13 help KYTC assign objective attributes to proposed guardrail locations. These attributes characterize a site location by road name, route, latitude, and longitude, among others. Because these elements are objective, they do not receive a score to be used in determining overall rankings.

The remaining elements (#14-32) correlate with safety conditions — primarily run-off-the-road crashes — at a given site. The current GRP assigns numerical values to ten elements in the set, identified as the hazard-index point system. These ten determine how the guardrail need at a given site will be prioritized, or ranked. The hazard point index elements and the maximum number of points allowed per category include:

- Typical Embankment Slope (10 points)
- Typical Embankment Height (10 points)
- Average Existing Roadside Recovery Distance from Edge of Traveled Way (10 points)
- Are there any Culvert Headwall or Culvert Openings within 5 Feet of Travel Lane? (5 points)
- Lane Plus Shoulder Width (10 points)
- Speed Limit (10 points)
- Average Daily Traffic (10 points)
- Number of Accidents (15 points)
- Accident Rate (15 points)
- Subjective Hazard Rating (5 points)

The combined total from these ten elements calculates the score at any given location (see Appendix B for the original guardrail hazard-index point system and accompanying descriptions). In the final step, the prioritization process sorts all guardrail need sites by their single assigned score. KYTC selects those locations with the highest scores for future guardrail installations. All guardrail rating elements, both the scored elements and non-scored, are shown in Table 3. Note that all ten elements used in the hazard-index point system are indicated by double asterisks (**).

Table 3 Current KYTC Guardrail Rating Elements

Item No.	KYTC Guardrail Rating Elements
1	Highway District
2	County
3	Route
4	Road System
5	Terrain
6	Road Name
7	Rural/Urban
8	Road Type
9	Latitude
10	Longitude
11	Mile Post - Begin
12	Mile Post - End
13	Length (miles)
14	Typical Embankment Slope**
15	Typical Embankment Height**
16	Average Existing Roadside Recovery Distance From Edge of Traveled Way**
17	Distance From Edge of Pavement to a Fixed Object in Recovery Zone
18	Are There Any Culvert Headwall or Culvert Openings within 5 Feet of Travel Lane?**
19	Select Existing Barrier Type
20	Existing Barrier Condition
21	Lane Plus Shoulder Width**
22	Lane Width
23	Speed Limit**
24	ADT**
25	Number of Accidents (if Available)**
26	Accident Rate (if Available)**
27	Indicate Subjective Hazard Rating**
28	Remove Linear Length of Guardrail
29	Install Linear Length of Guardrail
30	Will Any New Guardrail Section be more Hazardous than Existing Unshielded Condition?
31	Can Hazard be Corrected by Relocation of the Obstacle?
32	Additional Comments

3.2 Guardrail Rating Evaluation

Since the original GRP methodology was derived by KTC in 1989, it may contain terms or practices that are no longer used in today's methodologies. The research team subsequently evaluated each guardrail rating element to determine if updates or removal were required. The evaluative process occurred through the framework of qualitative and quantitative criteria.

3.2.1 Guardrail Rating Criteria

The evaluation process involved a line-by-line analysis across all 32 rating elements through four criteria: appropriateness, weighting, consistency, and scalability. The research team selected these four criteria to examine the rating elements through different perspectives, and ultimately, to improve the overall methodology for selecting proposed guardrail locations. The definitions for these criteria are as follows:

- Appropriateness - The degree of usefulness for an element within the guardrail rating program.
- Weighting - The degree of importance or emphasis placed on an element if it retains the ability to disproportionately affect the outcome.
- Consistency – A measure of the ability to clearly define data elements for the end user, minimizing the probability that data elements may be misinterpreted to affect outcomes.
- Scalability – The degree to which a rating element can be assigned a flexible numerical value across a given range.

The first criterion, appropriateness, represents the very foundation for each rating element's inclusion into the guardrail prioritization process. A rating element must be relevant to the selection process, and if not, it could become a strong candidate for removal. In this context, all rating elements must be appropriate in terms of either: (1) usefulness as an assigned attribute for the guardrail site and therefore, provide a unique identifier (e.g., location, length, etc.) or (2) usefulness as a guardrail selection factor contributing to enhanced safety at that location (e.g., embankment slope, speed, etc.). The team evaluated each rating element's level of appropriateness by low (L), medium (M), or high (H).

The second criterion, weighting, assigns points to each rating element based on the current process, also known as the hazard-index point system. As previously stated, the current system only assigns weighting points to ten elements. The other elements were considered non-scoring elements, and may be used as defined attributes or conditions for the site. During this evaluation phase, the research team simply used KYTC's current weighting scheme with their defined point system. Chapter 4 describes how the research team developed and analyzed different weighting schemes for the final, approved guardrail rating elements and assessed how they performed.

The third criterion, consistency, measures how clearly defined data elements are for end users (e.g., district personnel) and how they promote a shared understanding. Consistently defines the probability that data elements may be misinterpreted, or even manipulated, so that the prioritization process could become skewed. For example, KYTC officials noted that one particular rating element, the roadside hazard rating, appeared to be more subjective than others. This meant that district personnel may not be assigning values to their individual site's roadside hazard rating in a consistent manner. The research team evaluated each rating element's level of consistency by low (L), medium (M), or high (H).

The fourth and final criterion, scalability, provides numerical scaling assignments to those elements, where appropriate, in order to improve the final safety outcome. This initial evaluation simply assigned numerical ranges based on KYTC's current scale. Since only ten rating elements were scored, those same ten elements were the only elements assigned a numerical value corresponding to this metric. In the next phase of the project (see Chapter 4), the research team developed and analyzed different scalability schemes for the final, approved guardrail rating elements to promote improved flexibility in numerical prioritization. For example, some elements employed the use of a step or jump function in their numerical rating (e.g., critical number of crashes). These situations were assessed to determine if a sliding or continuous numerical rating definition may be more appropriate. The full results from the guardrail rating element evaluation for all four evaluation criteria is shown in Table 4.

Table 4 Evaluation of Guardrail Rating Elements

Item No.	KYTC Guardrail Rating Elements	Original Evaluation Criteria			
		Appropriate[a]	Weighting[b]	Consistency[c]	Scalability[d]
1	Highway District	H	0	H	NA
2	County	H	0	H	NA
3	Route	H	0	H	NA
4	Road System	H	0	H	NA
5	Terrain	L	0	M	NA
6	Road Name	H	0	H	NA
7	Rural/Urban	M	0	M	NA
8	Road Type	M	0	H	NA
9	Latitude	H	0	H	NA
10	Longitude	H	0	H	NA
11	Mile Post - Begin	H	0	H	NA
12	Mile Post - End	H	0	H	NA
13	Length (miles)	H	0	H	NA
14	Typical Embankment Slope*	H	10	M	0-10
15	Typical Embankment Height*	H	10	M	0-10
16	Average Existing Roadside Recovery Distance From Edge of Traveled Way*	H	10	H	0-10
17	Distance From Edge of Pavement to a Fixed Object in Recovery Zone	M	0	H	NA
18	Are There Any Culvert Headwall or Culvert Openings within 5 Feet of Travel Lane?*	H	5	H	0, 5
19	Select Existing Barrier Type	M	0	H	NA
20	Existing Barrier Condition	L	0	M	NA
21	Lane Plus Shoulder Width*	H	10	H	0-10
22	Lane Width	M	0	H	NA
23	Speed Limit*	H	10	H	0-10
24	Average Daily Traffic (ADT)*	H	10	H	0-10
25	Number of Accidents (if Available)*	M	15	H	0, 15
26	Accident Rate (if Available)*	L	15	H	0, 15
27	Indicate Subjective Hazard Rating*	M	5	L	1-5
28	Remove Linear Length of Guardrail	L	0	H	NA
29	Install Linear Length of Guardrail	H	0	H	NA
30	Will Any New Guardrail Section be more Hazardous than Existing Unshielded Condition?	H	0	L	NA
31	Can Hazard be Corrected by Relocation of the Obstacle?	H	0	M	NA
32	Additional Comments	H	0	L	NA

* Rating Elements identified by present KYTC methodology as "Hazard Rating Points"

3.2.2 Guardrail Rating Analysis

The KTC research team used the result from the evaluation criteria matrix to propose changes to the GRP. The majority of rating elements received a high mark for appropriateness; 21 received a High rating, while 7 were rated Medium and 4 were rated Low. The results for consistency followed a similar trend: 23 were rated High, 6 rated Medium, and 3 rated Low. Rating elements that received either Medium or Low warranted additional investigation by the research team, including the possibility of removal or modification. The weighting and scalability criteria were only applicable to the original hazard index rating elements. For these, the research team simply assigned the current weighting and scalar ranges to each scored rating element.

After analyzing the scores for all the rating elements, the KTC research team presented their recommendations to the KYTC study advisory committee. During a February 26, 2019 meeting, KTC and the committee collectively decided upon the final changes to the existing guardrail rating elements. Those results are shown in Table 5 below.

Table 5 Guardrail Rating Element Recommendations

Item No.	KYTC Guardrail Rating Elements	Status		
		No Change	Remove	Modify
1	Highway District	X		
2	County	X		
3	Route	X		
4	Road System	X		
5	Terrain		X	
6	Road Name	X		
7	Rural/Urban	X		
8	Road Type	X		
9	Latitude	X		
10	Longitude	X		
11	Mile Post - Begin	X		
12	Mile Post - End	X		
13	Length (miles)	X		
14	Typical Embankment Slope[a]			X
15	Typical Embankment Height[a]			X
16	Average Existing Roadside Recovery Distance From Edge of Traveled Way[b]			X
17	Distance From Edge of Pavement to a Fixed Object in Recovery Zone[b]			X
18	Are There Any Culvert Headwall or Culvert Openings within 5 Feet of Travel Lane?[b]		X	
19	Select Existing Barrier Type		X	
20	Existing Barrier Condition		X	
21	Lane Plus Shoulder Width[c]			X
22	Lane Width	X		
23	Speed Limit	X		
24	ADT	X		
25	Number of Accidents[d]			X
26	Accident Rate[d]			X
27	Indicate Subjective Hazard Rating		X	
28	Remove Linear Length of Guardrail		X	
29	Install Linear Length of Guardrail[e]			X
30	Will Any New Guardrail Section be more Hazardous than Existing Unshielded Condition?		X	
31	Can Hazard be Corrected by Relocation of the Obstacle?[b]			X
32	Additional Comments	X		

4. GUARDRAIL RATING REVISIONS

The KTC research team and the KYTC study advisory committee collaborated to identify changes to the existing guardrail rating system. Guardrail rating elements were placed into four categories: no change, remove existing condition, modify existing condition, and propose new condition. Rating elements were assessed through the four criteria — appropriateness, weighting, consistency, and scalability — to strengthen the rating system. For example, changing the score for consistency of an element would ensure field personnel all interpreted or processed a condition in the same manner. In other instances, a condition was updated to reflect current transportation safety practices, such as implementing the Empirical Bayes method of crashes. Per the original guardrail condition matrix shown in Table 5, the full list of proposed revisions and descriptions of those changes follow.

4.1 Description of Revisions

4.1.1 Modified/Revised Rating Elements

Item No. 14 – Typical Embankment Slope
“Typical embankment slope" lacked consistency in its implementation. Field personnel may see typical as the average roadway embankment slope, or as a worst-case scenario, steep slope. The main purpose for guardrail installation is to reduce crash severity along a roadway corridor. The maximum embankment slope (or steepest) that occurs along a segment would likely result in the most severe crashes. Therefore, the guardrail rating element was changed to “Maximum Embankment Slope”.

Item No. 15 – Typical Embankment Height
“Typical embankment height" was the vertical height associated with the original typical embankment slope. Since the latter term was changed, its associated counterpart, typical embankment height, was updated to “Maximum Embankment Height”.

Item No. 16-17 – Average Existing Roadside Recovery Distance From Edge of Traveled Way/ Distance from Edge of Pavement to a Fixed Object in Recovery Zone
Both elements listed here incorporated concepts related to the clear zone and embankment slope. Per the Roadside Design Guide, the clear zone is "the unobstructed, traversable area provided beyond the edge of the through traveled way for the recovery of errant vehicles".[1] The two main factors impeding a clear zone include adverse slope conditions and immovable, fixed objects in the runoff road area. It is critical to know the horizontal distance available within the clear zone prior to a vehicle encountering a roadside hazard such as adverse slopes and/or fixed objects. Therefore, this guardrail condition was split into two similar elements addressing each roadside hazard. They are: “Horizontal Distance from the Edge of Through Traveled Lane to the Nearest Fixed Object” and “Horizontal Distance from the Edge of Through Traveled Lane to the Critical Slope”. It is important to note that only one of these elements will apply to a given location. This determination will use a worst-case scenario comparing the location of the fixed object with the critical slope. The hazard located nearest to the edge of through traveled lane will constitute the worst-case scenario.

Item No. 21 – Lane Plus Shoulder Width
“Lane width" was captured as a distinct category, while "lane plus shoulder width" were two factors coupled together. Since both lane and shoulder widths were found to be key factors for roadside departures, both elements should each have their own category. Therefore, this element was revised to "shoulder width".

Item No. 25-26 – Number of Accidents / Accident Rate
The "number of accidents" and "accident rate" elements represent outdated safety performance metrics not aligned with recent Highway Safety Manual (HSM) guidance. Consequently, new elements aligned with national best practices and KYTC approved policies were required. The new elements “Empirical Bayes expected crashes” and “excess expected crashes” would replace “number of accidents” and “accident rate” using a series of derivations (described below).

Researchers developed a Safety Performance Function (SPF) to predict run-off-road crashes for all the segments in the guardrail database. This SPF was developed using a statewide road dataset with similar characteristics to those in the guardrail database, and calibrated to use only run-off-road crashes. This calibration allowed SPF to be used in any location in the guardrail database to predict run-off-road crashes. The resulting SPF model was as follows:

$$ROR\ SPF = L * e^{-4.365} * AADT^{0.851}$$

Where,

- ROR SPF is the predicted run-off-road crashes on a segment for a five-year period,
- L is the segment length, and
- AADT is the annual average daily traffic on the segment.

This model was developed using crash data over the 2013-2017 time period. The theta parameter was 2.436, indicating the data had a strong fit within the model.

Next, the team calculated the empirical Bayes (EB) expected crashes. This process combined SPF predicted crashes with historical crashes using a weighted parameter. The model’s parameter was based on the degree of correlation between its expected crashes and the historical crashes. This resulted in an expected crash value that was weighted between the empirical model and the historical crashes. The weight parameter was calculated using the following equation:

$$Weight = \frac{1}{1 + \frac{\left(\frac{ROR\ SPF}{Length}\right)}{Theta}}$$

Where,

- Weight is the resulting weight parameter that will balance between the SPF and the historical crashes,
- ROR SPF is the predicted crashes from the run-off-road SPF,
- Length is the length of the segment, and

- Theta is the parameter describing how well the SPF correlates to the dataset (2.436 for this model).

The weight was then used to calculate the EB expected crashes using the following equation:

$$EB\ Expected\ Crashes = ROR\ SPF * Weight + Historical\ ROR\ Crashes * (1 - Weight)$$

Where,

- EB Expected Crashes is the empirical Bayes expected crashes,
- ROR SPF is the predicted crashes from the run-off-road SPF (a five-year value),
- Weight is the parameter calculated using the previous equation, and
- Historical ROR Crashes is the actual number of run-off-road crashes on the segment in the last five years.

Finally, to calculate EEC, the following equation was used:

$$EEC = EB\ Expected\ Crashes - ROR\ SPF$$

Where,

- EEC is the excess expected run-off-road crashes,
- EB Expected Crashes is the empirical Bayes expected run-off-road crashes, and
- ROR SPF is the SPF predicted run-off-road crashes.

Item No. 29 – Install Linear Length of Guardrail

“Install linear length of guardrail" element was expanded upon to reflect several important cost factors associated with the installation of new guardrail. The research team consulted with the study advisory committee and found that several factors contribute to new guardrail installation costs: length of guardrail to be installed, number of end treatments installed, shoulder preparation, cribbing, embankment in place, additional post length required, and guardrail connectors to a bridge. All these factors were included in the new rating analysis, however, they will not be weighted for scoring within the proposed rating system. Rather, KYTC will consider the new cost factors when determining their guardrail budget and installation project cut-offs. Furthermore, the combination of new cost factors may also assist KYTC decision makers when deciding upon two similarly-ranked projects in terms of safety.

Item No. 31 – Can Hazard be Corrected by Relocation of the Obstacle?

The "hazard relocation" element was appropriate for mitigating risk, but lacked a clear and comprehensive definition. Hence, the definition was expanded to address all risk mitigation options: relocation, removal, and redesign. In addition, this rating element was rarely utilized by respondents in their guardrail submittals. For the 4,602 data described previously, respondents answered affirmatively to this question for only 0.5 percent of submitted sites. The modified guardrail element became “Can the Fixed Object/s be Removed, Relocated, or Redesigned to Mitigate Risk (Y/N)?”. Any of these options can satisfactorily address risks associated with roadside hazards.

4.1.2 Removed/Deleted Rating Elements

Item No. 5 – Terrain
The "terrain" element scored low in the criteria for appropriateness. It was neither a unique roadway attribute used for identification, nor was it a rigorously defined characteristic used in safety analysis. Rather, the elements related to embankment slopes provide a clearly defined, measurable attribute helpful in safety analysis. Terrain was often inconsistently applied across districts.

Item No. 18 – Are There Any Culvert Headwall or Culvert Openings within 5 Feet of Traveled Lane?
The "culvert" element was removed since a culvert meets the definition of a fixed object. Therefore, a culvert would be identified through the new "fixed object" element category.

Item No. 19-20 – Select Existing Barrier Type/Existing Barrier Condition
The "existing barrier" and the "condition" elements were removed because they received medium-to-low rankings for appropriateness. Each district office is responsible for selecting and submitting their proposed guardrail needs. To this extent, any existing barriers should be evaluated by the district to see how they might be upgraded or improved prior to submitting a guardrail need. Consequently, the study advisory committee deemed these elements as unnecessary for the rating process.

Item No. 27 – Indicate Subjective Hazard Rating
The "subjective hazard rating" was not clearly defined. Each district submitting a proposed guardrail need must rely on his or her own background, judgment, and expertise in determining what this element truly means. Therefore, it leaves the rating up for interpretation and introduces inconsistency into the process, as indicated in its low consistency ratin). Therefore, it was removed from the list of rating elements.

Item No. 28 – Remove Linear Length of Guardrail
The "remove linear length of guardrail" element was removed due to its low rating for appropriateness. Similar to the removal of the "existing barrier" element described earlier, each district should assess their individual site location and determine new guardrail needs. If existing guardrail no longer meet specifications, then the district may submit the site as a new project.

Item No. 30 – Will Any New Guardrail Section be more Hazardous than Existing Unshielded Condition?
This element was not clearly defined. Similar to the subjective hazard rating, this condition relied upon the background of the individual submitting the guardrail need project for its interpretation and was subject to inconsistency. Furthermore, KYTC provided GRP data to the research team, which contained all 4,602 guardrail sites under consideration. The research team analyzed this data and found that only 1.1 percent of site submittals answered affirmatively to this question. Due to this lack of clarity and low-response rate, this element was removed. The proposed GRP fully addresses the concept of roadside hazards and risk within other elements and ensures that proper warrants are used prior to any barrier installation, including guardrail.

4.1.3 New Rating Elements

Route Suffix
"Route suffix" was added as another unique identifier for roadway locations, to be used as needed.

Describe Fixed Object/s (e.g., headwall, bridge end, etc.)
Fixed objects should not be placed within the clear zone. This is defined as a roadside hazard, and was addressed in guardrail condition #17. However, the original methodology did not indicate the nature of the fixed object. This element will allow Central Office decision-makers to understand the type of fixed object present when making any evaluative determinations. It will also provide additional context on the roadside hazard and allow for further discussions.

4.1.4 Proposed Guardrail Rating Element Matrix

The newly proposed guardrail rating element list includes 34 distinct categories, and includes the changes discussed within this section. See Table 6 below, for a list of the proposed guardrail rating elements.

Table 6 Proposed Guardrail Rating Element Matrix

No.	Proposed KYTC Guardrail Rating Elements
1	Highway District
2	County
3	Route Prefix
4	Route Number
5	Route Suffix
6	Road System
7	Road Name
8	Rural/Urban
9	Road Type
10	Latitude
11	Longitude
12	Beginning Milepoint
13	Ending Milepoint
14	Length (miles)
15	Speed Limit
16	ADT
17	Lane Width (ft)
18	Shoulder Width (ft)
19	Maximum Embankment Slope[a]
20	Maximum Embankment Height (ft)[b]
21	Horizontal Distance from the Edge of Through Traveled Lane to the Nearest Fixed Object (ft)
22	Horizontal Distance from the Edge of Through Traveled Lane to the Critical Slope (ft)
23	Describe Fixed Object/s (e.g., headwall, bridge end, etc.)
24	Can the Fixed Object/s be Removed, Relocated, or Redesigned to Mitigate Risk (Y/N)?[d]
25	Empirical Bayes Expected Crashes[e]
26	Excess Expected Crashes[f]
27	Linear Length of Guardrail (ft)
28	Number of End Treatments
29	Other Cost Factors - Shoulder Preparation
30	Other Cost Factors - Cribbing
31	Other Cost Factors - Embankment in Place
32	Other Cost Factors - Additional Post Length Required
33	Other Cost Factors - Guardrail Connector to Bridge
34	Additional Comments

Definitions for Proposed Modifications

a The steepest slope, or drop in elevation, occurring at the shoulder break along the identified roadway segment.

b The vertical height measured from the bottom of the maximum embankment slope to the edge of the through traveled lane.

c The fixed object occurs multiple times along a roadway segment and maintains similar horizontal offsets from the edge of through traveled lane (i.e., not highly irregular offsets), such as utility poles. Otherwise, the fixed object is categorized as a single, unique occurrence or incident.

d Refer to the AASHTO Roadside Design Guide, chapter 4, for risk mitigation options involving roadside hazards within the clear zone. Any "Yes" responses will merit further evaluation.

e Weighted crash estimate based on historical crash data and the safety performance function crash prediction.

f The difference between the Empirical Baye's expected crashes and the safety performance function's predicted crashes.

4.2 Guardrail Rating Models

Guardrail ratings should maximize safety outcomes for vehicles departing the roadway, or run-off-road (ROR) crashes. The probability of a crash occurring at a given location is known as crash frequency. Locations considered prone to a high number of crashes might require increased focus if roadside hazards are prevalent. Still, the primary purpose for installing guardrail is to reduce crash severity for ROR crashes. A guardrail will not reduce the probability of a crash occurring. Rather, it mitigates the severity of ROR crashes when they occur.

4.2.1 Crash Frequency Factors

Crash frequency provides insight into the probability that a ROR crash may occur at a location. By itself, crash frequency does not justify the installation of guardrail. However, it may provide additional understanding into the likelihood of crashes occurring when prioritizing locations in the most need of guardrail repair or installation. Studies have shown several factors contributing to crash frequency including AADT, speed, lane width, and shoulder width.

The annual average daily traffic (AADT) counts represent traffic volume along a given corridor. As research studies have shown, the frequency of crashes increase as AADT increases. Excess vehicle speeds have been tied to an increasing number of crashes, as well as crash severity.[22] Several research studies have shown connections between crash frequency and the widths of roadway lanes and shoulders, respectively. In both cases, decreasing widths contributed to an increasing number of crashes. Fitzpatrick et al., demonstrated narrower lane widths increased roadway departures for lanes less than 12 feet.[23] Similarly, several researchers have examined the relationship between shoulder width and crash frequency. Most of these studies demonstrated that decreasing shoulder width led to increases in the crash rate. For instance, Zegeer and Deacon found that shoulder widths had a significant effect on crash rates.[24]

4.2.2 Crash Severity Factors

Guardrail represents a safety countermeasure that reduces crash severity for vehicles departing the roadway, or run-off-road (ROR) crashes. The Roadside Design Guide specifically recommends the installation of roadside hardware barrier devices, such as guardrail, to reduce the severity of ROR crashes.[1] However, guardrail does not reduce the probability of a crash occurring, otherwise known as crash frequency. Due to close proximity to the edge of pavement, the installation of guardrail may lead to an increased frequency of ROR crashes. Crashes may occur as vehicles departing the roadway have less free space to maneuver and may inadvertently strike the guardrail prior to navigating back onto the roadway. Nevertheless, guardrail is an effective device to reduce crash severity for vehicles leaving the roadway, thus serving its intended purpose.

Crash severity measures the effect of a crash on vehicle occupants. The Federal Highway Administration uses a KABCO injury classification scale to assess crash severity, ranging from non-severe to extremely severe crashes. The Kentucky Transportation Cabinet similarly employs the KABCO acronym as defined by the following terms:[25]

- K – Fatality
- A – Incapacitating Injury
- B – Non-Incapacitating Injury
- C – Possible Injury

- O – Property Damage Only

Many researchers have examined crash severity over the years and shared their results with the transportation safety community. In these studies, they have evaluated many different factors associated with ROR crashes and examined their influence on fatalities and injuries. Collectively, research studies have demonstrated a few factors that have the most direct impact on crash severity: steep slopes, fixed objects in the clear zone, and excessive speeds.

Roadside slopes are found on the roadway's adjacent embankment. The slope of primary concern, the foreslope, begins at the shoulder break. For fill sections, foreslopes decline in elevation from the roadway surface at different rates. The Roadside Design Guide categorizes foreslopes into three distinct categories: recoverable, non-recoverable, and critical. Recoverable slopes are flat slopes (1V:4H or flatter) that allow the vehicle to recover and readily reenter the roadway following departure. Non-recoverable slopes are steeper (between 1V:3H and 1V: 4H) slopes that are traversable but do not allow the vehicle to easily reenter the roadway following departure. Typically, the vehicle will continue down this slope until it reaches the toe. The steepest slopes are critical slopes and include any slope at 1V:3H or steeper. Vehicles will continue down these steeps slopes and are at increased risk for overturning, a leading factor in fatalities.[1]

Critical slopes represent the greatest danger to vehicle occupants during ROR crashes. Roadside departures occurring along flat slopes with soils that support tires (and without fixed objects) usually result in minimal crash severity.[26] Similarly, FHWA and the National Cooperative Highway Research Program have published studies demonstrating slope flattening reduces severe crashes, particularly fatalities and injuries.[27,26] On the other hand, extreme slopes leading to overturned vehicles can result in the most dire outcomes. Neuman, et al. found that overturned vehicles comprised nearly 42 percent of all ROR single-vehicle fatalities.[26] A Texas Transportation Institute (TTI) study discovered overturned vehicle crashes occurring on two-lane, rural roads in Texas were twice as likely to result in a fatality.[28]

Fixed objects located in the clear zone are another significant roadside hazard impacting crash severity. Fixed objects are non-crashworthy objects that can disproportionately impact the vehicle's trajectory (e.g., snagging) or speed (e.g., rapid deceleration) and will injure the vehicle's occupants in the process. The FHWA and the National Cooperative Highway Research Program have shown that removing fixed objects in the clear zone will reduce crash severity for roadside departures.[29,26] When fixed objects are not removed, the consequences may be severe. For instance, Zegeer et al. demonstrated that fixed objects frequently led to injury-producing crashes, such as those involving utility poles (49.7 percent).[30] Neuman, et al. found that fatalities occurred when vehicles struck fixed objects, including trees (25.4 percent) and utility poles (7.2 percent).[26]

Many research studies have examined vehicle speeds and their association with crash outcomes. Speed is a factor that has been shown to be a contributing factor for both crash frequency and crash severity. In the former, Liu and Subramanian examined single-vehicle ROR crashes and found that nearly 90 percent of those crashes involved speeding vehicles.[31] The Institute for Road Safety Research discovered a similar finding that crash rates increased as speeds increased.[32] Excessive speeds also are highly correlated with severe crash outcomes. Past FHWA studies investigated crash severity involving utility poles. They found a 50 percent chance of injury for collisions with poles with impact speeds as low as 6 mph.[33] A TTI study demonstrated a higher frequency of fatalities for vehicles traveling at excessive speeds, at 10 percent, versus 7.6 percent for those not speeding.[28]

4.2.3 Weighting Analysis

The research team developed a weighting scheme using the new guardrail rating elements. Similar to the original methodology, only specific rating elements were used to evaluate, or score, the benefits of guardrail installation in particular locations. The team initially selected 10 scored rating elements from the newly developed 34 rating element list. These elements were identified by their ability to meet defined, relevant characteristics for guardrail need. At a minimum, all scored rating elements possessed the following attributes:

- Influence crashes—both frequency and severity—based on various research studies
- Allow for quantitative determination
- Provide project-by-project comparison

Per the first criteria, some rating elements primarily correspond to crash frequency, while others correspond to crash severity. The research team determined an appropriate crash basis determination for each rating element using the research literature review discussed in sections 4.2.1 and 4.2.2. The full list of scored rating elements and their corresponding crash element role (i.e., frequency, severity, or both) are shown in Table 7.

The remaining 24 attributes from the approved guardrail rating element list (Table 6) did not meet scoring conditions for various reasons. Several attributes did not receive scoring because they served strictly as project site unique identifiers, such as highway route name, location (e.g., longitude, latitude), and road type. Consequently, they did not demonstrate the ability to influence crashes or allow for direct comparisons. In fact, rating elements #1-14 on the list met this definition. Other attributes (#23, #24) simply described a roadside hazard description, or a means to mitigate the roadside hazard. These attributes did not quantify the existing hazard or provide a basis for comparison. Therefore, they were not scored. Finally, the remaining rating elements #27-34 described the factors that determined overall guardrail project costs. These include the overall length of guardrail, number of end treatments, and various special cost cases (e.g., cribbing or embankment in place). While useful for comparison purposes, the primary intent for the new methodology was to focus on safety, and allow for comparisons in that perspective.

Table 7 Scored Rating Elements by Crash Frequency and Severity

Item No.	KYTC Guardrail Rating Elements	Rating Element Role	
		Crash Frequency	Crash Severity
15	Speed Limit	X	X
16	AADT	X	
17	Lane Width (ft)	X	
18	Shoulder Width (ft)	X	
19	Maximum Embankment Slope		X
20	Maximum Embankment Height (ft)		X
21	Horizontal Distance from the Edge of Through Traveled Lane to the Nearest Fixed Object (ft)? [a]		X
22	Horizontal Distance from the Edge of Through Traveled Lane to the Critical Slope (ft)? [a]		X
25	Empirical Bayes Expected Crashes***	X	
26	Excess Expected Crashes****	X	

4.2.4 Weighting Models

Once the scored rating elements were identified, the research team developed four guardrail rating models, each with different weighting assignments placed on crash frequency and crash severity. To represent different guardrail prioritization methodologies, certain models assigned higher weighting scores to either frequency or severity. The team initially developed a total of four working models, described further below.

Model #1

All rating elements were weighted equally. This model assumed all guardrail rating elements associated with roadway characteristics, clear zone characteristics, and crash characteristics were no more or less important than other elements.

Model #2

Rating elements associated with crash characteristic (e.g., Empirical Bayes Expected Crashes and Excess Expected Crashes) were weighted slightly higher than the other elements. This model placed increased emphasis on the likelihood (or frequency) of a crash occurring at a given location.

Model #3

Rating elements associated with clear zone and crash characteristics were weighted significantly higher than those involving roadway characteristics. This model balanced crash frequency with crash severity.

Model #4

Rating elements associated with clear zone characteristics were weighted most heavily. This model placed increased emphasis on elements most directly associated with crash severity.

On May 15, 2019, the research team and study advisory committee met and evaluated all four models. The two groups assessed the advantages and disadvantages of each working model and decided upon model #3 as their preferred option, but with a few minor changes. For purposes of discussion, this new model will be referred to as model #5. The changes from the previous model included removing scoring consideration for AADT and shoulder width while simultaneously boosting numerical scoring for other categories. Overall, model #5 weighted clear zone and crash characteristics heavily. The full list of changes to this model are shown below:

Model #5

- Speed limit: decreased percentage from 14% to 5%
- AADT: removed this element from receiving a weighted score (but will retain as a non-scored rating element used as an attribute)
- Lane width: no change to weighted percentage of 5%
- Shoulder width: removed this element from receiving a weighted score (but will retain as a non-scored rating element used as an attribute)
- Maximum embankment slope: increased percentage from 14% to 18%
- Maximum embankment height: increased percentage from 14% to 18%
- Horizontal distance from the edge of through traveled lane to the (nearest fixed object) OR (critical slope)—use whichever is closer to the traveled lane: increased percentage from 14% to 18%
- Empirical Bayes expected crashes: increased percentage from 14% to 18%
- Excess expected crashes: increased percentage from 14% to 18%

The rationale for removing AADT as a standalone variable was its inclusion into other scored factors already used in the methodology. For example, AADT is used as a component of five separate elements: (1) Maximum Embankment Height, (2) Maximum Embankment Slope, (3) Distance from Edge of Through Traveled Lane to the Nearest Fixed Object, (4) Empirical Bayes Expected Crashes, and (5) Excess Expected Crashes. The concern among the research team and study advisory committee was that including AADT as a standalone variable would significantly overweight it as the "super" factor among all factors. Therefore, for the reasons listed here, the decision was made to remove it as a standalone element.

The shoulder width element was also removed as a scoring factor for consideration. Similar to the removal of AADT, shoulder width was removed due to its inclusion into other rated elements—Horizontal distance from the edge of through traveled lane to the (nearest fixed object) or (critical slope). The horizontal distance rating element allowed planners to determine if minimum clear zone requirements were met and rendered the need for shoulder width unnecessary.

The remaining elements either decreased or increased in value commensurate with their importance to guardrail need. Speed limit and lane width each decreased to 5 percent weighted values for the new model, respectively. The research team reduced their percentages due to each element's general overall uniformity amongst competing guardrail projects. For example, many guardrail projects have similar speed limits thereby rendering the use of this metric for comparison purposes less useful. The remaining elements all increased proportionately to 18 percent. This list includes: (1) maximum embankment slope, (2) maximum embankment height, (3) horizontal distance from the edge of through traveled lane to the nearest fixed object or critical slope, (4) Empirical Bayes expected crashes, and (5) excess expected crashes. These rating elements received increases in their value due to their strong influence on crash outcomes, most notably crash frequency and severity, which has a direct link to guardrail need. Collectively, the summation of these rating elements is equal to 100.

4.2.5 Rating Element Scores

After weight assignments, each rating element received a score corresponding to select attributes. Each rating element was scored on a scale of 0-10 points, which assigned a consistent scale for each element. Maintaining this scale across all rating elements allowed for a simple scoring application before the follow-on weighting assignment. For example, if a location received a score of 10 for its EEC, that rating element would be multiplied by 18% to determine how much it contributed to the overall project score.

The Empirical Bayes (EB) expected crashes and excess expected crashes (EEC) each received an assigned point score based on their distribution within subdivided categories. In this methodology, the aggregated EB and EEC rating elements were assigned categorizations within 5 distinct value ranges, or bins. Each bin contained approximately the same number of rating element values distributed across the entire 4,600 projects currently identified in the KYTC GRP database. Rating elements assigned to low-value bins were less likely to occur and consequently received lower point values. For example, an EB less than one meant that less than one crash was expected to occur at a location within the next 5 years. Therefore, that category received zero points. Similarly, an EEC value less than zero meant fewer crashes were occurring than expected, also earning a score of 0. The remaining four bins for EB and EEC were based on the distributions of the two metrics for each project found in the GRP database. The point distributions for EB and EEC are shown in Tables 8 and 9 below.

EB	Points
<1	0
1<x<=5	3
5<x<=10	5
10<x<=15	7
>15	10

Table 8 EB Points

EEC	Points
<0	0
0<x<=1	3
1<x<=5	5
5<x<=10	7
>10	10

Table 9 EEC Points

Using the same approach, the next rating element, lane widths, divided bins into a nearly equal number of projects for each bin. The speed limit rating element adopted a slightly different approach to rating element categorization. The research team assigned point values across this range based on common speed limits for guardrail site locations, although the majority of sites fall into the 55 mph bin. Both lane width and speed limit distribution are shown in Tables 10 and 11 below.

Lane Width (ft)	Points
<8	10
8<=x<9	7
9=<x<10	5
10<=x<11	3
>=11	0

Table 10 Lane Width Points

Speed Limit (mph)	Points
<=25	0
26-35	3
36-45	5
46-55	7
56-70	10

Table 11 Speed Limit Points

The remaining rating elements tiered into 5 distinct categories as before, but also relied upon AADT as a distinguishing factor. Therefore, the maximum embankment height, maximum embankment slope, and distance from the edge of through traveled lane to the (nearest fixed object) or (critical slope) used a matrix table to account for both ranges. The AADT bins also reflected nearly equal portions of guardrail sites within each bin, similar to the development of the other bins.

The rationale for including AADT into the point matrix was to assess the risk of crash frequency for each rating element. A higher AADT meant an increased volume of vehicles traveling and a greater potential for a run-off-road crash. Therefore, the point assignment increased both as AADT increased and as the rating elements became more severe. All three rating element matrices are shown below, in Tables 12, 13, and 14.

Table 12 Embankment Height Points

Embankment Height (ft)	AADT				
	0-250	251-500	501-1000	1001-2000	>2000
<=5	0	0	0	0	0
5<x<=10	1	2	3	4	5
10<x<=15	2	3	4	5	7
15<x<=20	3	4	5	6	8
>20	4	5	6	8	10

Table 13 Embankment Slope Points

Embankment Slope	AADT				
	0-250	251-500	501-1000	1001-2000	>2000
Flatter than 5:1	0	0	0	0	0
5:1 to 4:1	2	3	4	5	7
Steeper than 4:1	4	5	6	8	10

Table 14 Horizontal Distance (Fixed Object/Critical Slope) Points

Fixed Object/ Shoulder (ft)	AADT				
	0-250	251-500	501-1000	1001-2000	>2000
<=7	4	5	6	8	10
7<x<=10	3	4	5	6	8
10<x<=12	2	3	4	5	7
12<x<=14	1	2	3	4	5
>14	0	0	0	0	0

4.2.6 Comparison of Old and New GRP Models

Researchers applied the new guardrail rating model #5 to current locations in the guardrail database, and directly compared the ranking of elements to the previous GRP model. Researchers quantified the significance in ranking changes between models using the statistical measure Spearman's Rho. This non-parametric test measures the strength of the association between two variables. In this case, the two associated variables were a site's ranking in the previous GRP system and its corresponding ranking using the new GRP model. One limitation in this analysis is that the current GRP method does not collect data on "Horizontal Distance from the Edge of the Through Traveled Lane to the Critical Slope". Therefore, this element was not incorporated into this analysis and all project scores and rankings were calculated using "Horizontal Distance from the Edge of Through Traveled Lane to the Nearest Fixed Object".

After running both models, project rankings were tabulated for all sites, both old and new. Higher rankings for guardrail need were associated with lower numerical values (e.g., rank #1 received the highest assigned priority for guardrail need). Both lists with full rankings were compared using the correlation function found in Microsoft Excel to determine a Spearman's Rho value of 0.708. In Spearman's Rho, an R-value equal to 1 is interpreted as a perfect positive correlation while an R-value equal to -1 is a perfect negative correlation. In other words, a positive 1 value means each set of corresponding variables between two datasets are identical. Thus, a Spearman's Rho value of 0.708 demonstrated a high positive correlation between the old rankings and the new rankings. Essentially, the new model improved upon the old model but did not significantly alter the overall guardrail need rankings as an aggregate. In Table 15 below, the top-10 rankings found in the previous GRP model are shown with their newly assigned rankings using the new model.

Table 15 Top 10 Locations by Old Method

RT_Unique	BMP	EMP	Length	Old Score	New Score	Old Rank	New Rank
016-KY-0070 -000	11.117	11.226	0.109	89	86	1	9
098-KY-0194 -000	54	55	1	87	59.1	2	324
010-KY-0005 -000	3.959	4.794	0.835	86	80.6	3	18.5
055-US-0421 -000	4.73	5.16	0.43	85	84.2	5	11
058-KY-1107 -000	0	0.28	0.28	85	82.7	5	13.5
049-KY-0036 -000	12.4	12.5	0.1	85	64.4	5	172.5
043-US-0062 -000	26.499	26.705	0.206	84	72.6	7.5	52.5
036-KY-1428 -000	11.867	11.931	0.064	84	71.9	7.5	60
098-KY-1499 -000	0	0.117	0.117	83	79.1	11.5	20.5
105-US-0025 -000	10.2	10.39	0.19	83	75.5	11.5	31.5

As shown here, only one project retains its top 10 ranking in the new model (i.e., #1 old rank transitioned to a #9 new rank). The remaining sites decreased in ranking value. Three sites slightly decreased in rankings moving to #11, #13.5, and #18.5, respectively. In total, eight sites stayed within the top 100 list, while only two fell outside the top 100 (i.e., #172.5 and #324).

The total guardrail need database contained over 4,000 locations. An examination of the entire dataset revealed that only 23 sites in the original top 100 rankings decreased significantly in priority. Those sites were ranked greater than 500 with the new model. Further examination of these 23 sites demonstrated that only six of them had five or more crashes within the last five years. All 23 sites experienced a relatively low Expected Excess Crash value meaning they were not experiencing more crashes than expected. In addition, only seven of these sites had AADT values exceeding 2,000, indicating relatively low traffic volumes. Therefore, the model demonstrated its emphasis on road departure crashes, including AADT, comprising a key component to modeling potential crash exposure. In Table 16 below, the newly assigned top-10 rankings are shown with model #5.

Table 16 Top 10 Locations by New Method

RT_Unique	BMP	EMP	Length	Old Score	New Score	Old Rank	New Rank
093-KY-0053 -000	0	0.87	0.87	50	95	962.5	1
106-KY-0053 -000	2.3	2.5	0.2	75	90.6	79	2
093-KY-1694 -000	0.376	0.654	0.278	48	89.6	1141.5	3
010-KY-0168 -000	6.711	7	0.289	72	87.6	113.5	4
056-KY-2052 -000	0.693	0.729	0.036	47	87.1	1247	5
081-US-0062 -000	10.5	11	0.5	77	87	58	6.5
035-KY-0032 -000	10	10.615	0.615	53	87	776.5	6.5
019-US-0027 -000	18.961	19.16	0.199	43	86.1	1671.5	8
016-KY-0070 -000	11.117	11.226	0.109	89	86	1	9
103-US-0060 -000	1.892	2.077	0.185	82	84.5	17	10

Several sites on this list were ranked rather low using the previous methodology. In fact, six of the ten did not even make the top 500 rankings with the previous methodology. Expanding this analysis, the new model listed 37 sites now ranked within the top 100 that previously were ranked greater than 500. Researchers examined these 37 sites and found that all of them possessed an AADT greater than 2,000. Moreover, 14 of the 37 sites had an EEC equal to or greater than 5. These high EEC values demonstrate that the new model targets locations experiencing more run-off-road crashes than expected. Many of these sites demonstrated high-risk factors related to crash severity including speed limits equal to or greater than 55 miles per hour, fixed objects closer than 7 feet, embankment heights equal to or greater than 15 feet, and embankment slopes equal to or greater than 3:1. Combining these crash severity and crash frequency factors provides a strong rationale for why these locations moved up significantly in the new ranking structure, and demonstrates the efficacy of the new model.

5. Conclusion

The KTC research team employed best practices in safety analysis, including key concepts from the Highway Safety Manual, to improve upon the existing KYTC guardrail rating program (GRP) model. In this study, the team collaborated with the KYTC study advisory committee to understand how they collect, process, and prioritize their guardrail need rankings at sites across the state. The primary factors impacting run-off-road crashes were examined across a comprehensive literature review and incorporated into the model's analysis. Most notably, all guardrail ranking elements used in scoring were connected with crash severity and/or crash frequency. Severe crashes are most commonly associated with the presence of roadside hazards, such as steep slopes or fixed objects, and are the primary reason why roadside barriers such as guardrail are initially considered. Furthermore, crash frequency measures the probability that a run-off-road crash will occur at a location. In the model that was developed, locations that demonstrate severe crash risk and have a high probability of run-off-road crashes receive higher priority than other locations.

5.1 Findings

The KTC research team developed the newest rating model (model #5) using assigned weightings and scores of certain elements. Eight elements comprised the final scored list used to assigned guardrail rankings. The final weighting structure included:

- Speed Limit – 5%
- Lane Width – 5%
- Maximum Embankment Slope – 18%
- Maximum Embankment Height – 18%
- Horizontal Distance from the Edge of the Through Traveled Lane to the (Nearest Fixed Object) or (Critical Slope) – 18%
- Empirical Bayes Expected Crashes – 18%
- Excess Expected Crashes – 18%

When researchers compared the new guardrail rating model to the previous model, they analyzed the rankings of current guardrail need locations in the database. The new model #5 improved upon the old model but did not significantly alter the rankings of guardrail needs. For example, 23 of the guardrail sites originally ranked as high-need fell in the rankings with the new model. An evaluation of the 23 sites demonstrated that only six of them had five or more crashes within the last five years, and all 23 sites had low EEC values, meaning they were not experiencing more crashes than expected. AADT, a key component in modeling potential crash exposure, scored high in only seven sites, which indicates lower traffic volumes.

Many of the 23 sites had high-risk factors related to crash severity such as: speed limits above 55 miles per hour, fixed objects closer than 7 feet, embankment heights equal to or greater than 15 feet, and embankment slopes of 3:1 or greater. By emphasizing crash frequency and crash severity, the new model targets locations with a higher number of road departure crashes than would be expected. These higher-risk locations moved up significantly in the new ranking structure, demonstrating the effectiveness of the new guardrail prioritization model.

5.2 Recommendations

The KTC research team recommends the following items for implementation based on the results of this research study:

- Adopt the new GRP model #5 methodology for use in ranking guardrail need projects across the state
- Provide KYTC personnel, including district offices, with the newly revised guardrail survey form to collect the necessary data
- Provide information and training sessions to KYTC personnel on the development rationale for the new model and its subsequent implementation
- Update the GRP online application and back-end IT architecture to match the new model data collection and processing requirements

Appendix A – Current Guardrail Survey Form

Guardrail Survey Form

District: ________ County: ______________________ Road Name: ____

Route Prefix: ________ Route: ____________ Route Suffix: ________

Beginning MilePoint: ______________ Ending MilePoint: ______________

Terrain: ☐ Flat ☐ Mountainous ☐ Rolling Latitude: ____________________________

Lane Width: ______________ ft. Longitude: ____________________________

Lane Plus Shoulder Width: ______________ ft.

Average Existing Roadside Recovery Distance From the Edge of the Traveled Way: ______________ ft.

Distance From the Edge of Pavement to a Fixed Object in the Recovery Zone: ______________ ft.

Type of Fixed Object: ____

Can the Hazard Be Corrected By Relocation of the Obstacle: ☐ Yes ☐ No

Existing Barrier Type: ☐ Cable ☐ W-Beam ☐ None

Existing Barrier Condition: ☐ Good ☐ Fair ☐ Poor ☐ N/A

Guardrail Length to Remove: ______________ ft. Guardrail Length to Install: ______________ ft.

Embankment Height: ______________ ft. Embankment Slope: ______________ : 1

Will Any Section of the New Guardrail Be More Hazardous Than Existing Unshielded Condition: ☐ Yes ☐ No

Are There Any Culvert Headwall or Openings Within 5 Feet of the Travel Lane: ☐ Yes ☐ No

Indicate Subjective Hazard Rating: ☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
(0=Virtually None to 5=Extremely Hazardous)

Place any additional comments on the back of this form.

Surveyed By: ____________________________________ Survey Date: ____________________________________

Appendix B – Current Hazard-Index Point System

DEVELOP A HAZARD-INDEX POINT SYSTEM

Prior to conducting a field survey, there was a need to develop a system for relating the operational and geometric characteristics of highway sections with their accident history to determine which sections exhibited the greatest need for guardrail. In addition to accident statistics, there are several characteristics which can be associated with the potential for accidents. The following characteristics were selected to represent a hazard-index rating of highway sections.

CHARACTERISTICS	RATING POINTS POSSIBLE
1) Number of run-off-road accidents	15
2) Run-off-road accident rate	15
3) Traffic volume	10
4) Speed limit or prevailing speed	10
5) Lane and shoulder width	10
6) Roadside recovery distance	10
7) Embankment slope	10
8) Embankment height	10
9) Culvert Presence	5
10) Subjective Roadside Hazard rating	5

An attempt was made to include characteristics representative of accidents and accident potential, operations, and cross section. Point-system weightings of each characteristic were determined by subjective evaluation (the rating form is presented as Figure 10). It can be seen that the combination of number of accidents and accident rate made up 30 of a possible 100 points. Traffic volume and speed limit, considered to be operational characteristics, totaled 20 of the possible 100 points. Cross-section characteristics made up an additional 40 points. Because of their frequency of occurrence and the hazard associated with culvert headwalls or openings near the roadway, a special category was created to represent this condition. For a culvert present within five feet of the road, 5 points were assigned. Also included was a general category representing a subjective roadside hazard rating with 5 points possible. This rating was based on a visual observation that was compared to photographic documentation of roadway sections depicting various degrees of roadside hazard.

Appendix C – New Guardrail Survey Form

Guardrail Survey Form

Roadway Characteristics

District: __________ County: ____________ Road Name: ____________________

Rural or Urban (circle one): Rural/Urban

Route Prefix:_____________________

Route Number:__________________

Route Suffix:____________________

Beginning Milepoint: ____________

Ending Milepoint:_______________

Latitude:________________________

Longitude:______________________

Posted Speed Limit: _______mph

Lane Width: _______ft.

Roadside Characteristics

Maximum Embankment Slope[1] (V_1:H_1):____: 1

Maximum Embankment Height[2]: ____ft.

Horizontal distance from the edge of through traveled way to nearest fixed object(s): ______ft.

Horizontal distance from the edge of through traveled way to critical slope: _____________ft.

Describe fixed object/s (e.g., headwall, bridge end, etc.) ______________________________

Can the fixed object(s) be removed, relocated, or redesigned to mitigate risk (circle one)? Yes/No

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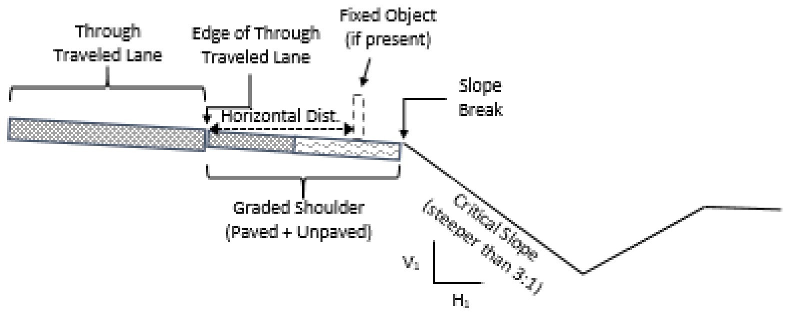
[1] The steepest slope, or drop in elevation, occurring at the shoulder break along the identified roadway segment.
[2] The vertical height measured from the bottom of the maximum embankment slope to the edge of the through traveled lane.

Figure A: Diagram of Roadside Characteristics



Guardrail Estimates

Length of Guardrail to be Installed: _______ft.

Number of End Treatments Needed: ______

Other Cost Factors (check all boxes that may apply):

- ☐ Shoulder Preparation
- ☐ Cribbing
- ☐ Embankment in Place (Backfill)
- ☐ Additional Post Length Required
- ☐ Guardrail Connector to Bridge

Additional Comments

Surveyed By: ______________________________ Survey Date: _____________

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