

Research Report  
KTC -14-18/SPR-452-13-3F

# **Recommendations for KYTC's Railway/Highway At-Grade Crossing Management Practices**

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**Recommendations for KYTC's Railway/Highway At-Grade  
Crossing Surface Management Practices**

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## **A B S T R A C T**

An ideal Railway/Highway At-Grade Crossing Management program involves selecting cost-effective practices when designing new crossings and rehabilitating existing crossings. This report outlines two strategies to enhance KYTC's existing program. First, it describes a process that uses decision-option diagrams to optimize the assessment and implementation of engineering solutions in order to restore desired smoothness, minimize settlement in the post-construction phase, and foster acceptable long-term performance of crossings following their rehabilitation. Decision-option diagrams rely on assessments that are site-specific and based on historical performance, the present observed performance and condition, and the measureable parameters specific to particular crossings. To supplement this process, the second strategy that this report proposes is the establishment of an effective managerial structure at KYTC that streamlines decision-making to ensure that the selected design is properly applied and implemented. Taken together, these proposals will significantly improve the state's ability to systematically and cost-effectively repair deteriorated crossings.

<b>1. Report No.</b> KTC-14-18/SPR452-13-3F	<b>2. Government Accession No.</b>	<b>3. Recipient's Catalog No</b>	
<b>4. Title and Subtitle</b> Recommendations for KYTC's Railway/Highway At-Grade Crossing Surface Management Practices		<b>5. Report Date</b> December 2014	
		<b>6. Performing Organization Code</b>	
<b>7. Author(s):</b> Brett Malloy, Jerry Rose, and Macy Purcell		<b>8. Performing Organization Report No.</b>	
<b>9. Performing Organization Name and Address</b> Kentucky Transportation Center College of Engineering University of Kentucky Lexington, KY 40506		<b>10. Work Unit No. (TRAIS)</b>	
		<b>11. Contract or Grant No.</b> KYSPR-13-452	
<b>12. Sponsoring Agency Name and Address</b> Kentucky Transportation Cabinet 200 Mero Street Frankfort, KY 40622		<b>13. Type of Report and Period Covered</b> Final Report	
		<b>14. Sponsoring Agency Code</b>	
<b>15. Supplementary Notes</b>			
<b>16. Abstract</b> An ideal Railway/Highway At-Grade Crossing Management program involves selecting cost-effective practices when designing new crossings and rehabilitating existing crossings. This report outlines two strategies to enhance KYTC's existing program. First, it describes a process that uses decision-option diagrams to optimize the assessment and implementation of engineering solutions in order to restore desired smoothness, minimize settlement in the post-construction phase, and foster acceptable long-term performance of crossings following their rehabilitation. Decision-option diagrams rely on assessments that are site-specific and based on historical performance, the present observed performance and condition, and the measurable parameters specific to particular crossings. To supplement this process, the second strategy that this report proposes is the establishment of an effective managerial structure at KYTC that streamlines decision-making to ensure that the selected design is properly applied and implemented. Taken together, these proposals will significantly improve the state's ability to systematically and cost-effectively repair deteriorated crossings.			
<b>17. Key Words</b> Railway/Highway, At-Grade Crossings, Asphalt Underlayments, Railway Trackbeds, Trackbed Support		<b>18. Distribution Statement</b> Unlimited with the approval of the KY Transportation Cabinet	
<b>19. Security Classification (report)</b> Unclassified	<b>20. Security Classification (this page)</b> Unclassified	<b>21. No. of Pages</b> 30	<b>19. Security Classification (report)</b>

# TABLE OF CONTENTS

	<u>Page</u>
EXECUTIVE SUMMARY .....	1
CHAPTER 1. RECOMMENDATIONS FOR STANDARD PRACTICES .....	2
Assessing Crossing Rehabilitation Design and Construction Techniques .....	2
Adjustments/Improvements to the Highway Pavement Approach .....	3
Short Distance Correction of Pavement Roughness.....	4
Adjusting the Pavement Approach Geometry .....	4
Renewal of Crossing Surface .....	5
Determining Proper Surface Material for Surface Renewal.....	7
Complete Renewal of Crossing Surface, Track Panel, and Underlying Support.....	8
Considerations for Quality of Underlying Support .....	10
Assessing Recommendations for Improved Management Structure .....	11
Maintaining a District Representative .....	12
Maintaining a Central Rail Division .....	13

Developing a Designated Fund for Surface Renewal.....	13
Identification/Documentation of Material Costs.....	13
<b>CHAPTER 2. RECOMMENDATIONS FOR STANDARD PROCEDURAL PRACTICES.....</b>	<b>15</b>
Evaluate Proposals Based on Cost Effectiveness .....	15
Categorize/Separate Major Work and Cost Items .....	15
Review Historical Cost Data .....	16
Consult and Analyze Decision-Option Diagrams to Determine Extent of Rehabilitation.....	16
Evaluate Cost-Effectiveness of Various Alternatives .....	17
Select Alternate Design .....	18
Determine Cost per Track-Foot for Major Work Items and Total Cost .....	18
<b>CHAPTER 3. DISCUSSION AND FUTURE RESEARCH .....</b>	<b>19</b>
Discussion .....	19
Quantitative Assessment .....	19
Fuzzy Logic.....	20
<b>REFERENCES.....</b>	<b>22</b>
<b>ACKNOWLEDGEMENTS .....</b>	<b>22</b>



## **EXECUTIVE SUMMARY**

Cost-effective Railway/Highway At-Grade Crossing Surface Management programs integrate two critical practices – 1) performing an assessment of the prevailing conditions at a crossing and using the information gathered to select the procedure that will effectively rehabilitate the crossing economically, and 2) the establishment of an effective managerial structure that streamlines decision-making to ensure that the selected design is properly applied and implemented. To improve assessment, we describe a model decision-making process that uses decision-option diagrams to optimize the evaluation of engineering solutions, in order to restore desired smoothness, minimize settlement in the post-construction phase, and foster acceptable long-term performance. Assessments are site-specific and based on historical performance, the present observed performance and condition, and measureable parameters specific to particular crossings. These assessments can yield a number of solutions. A solution may be as simple as making adjustments or slight improvements to the Highway Pavement Approaches. However, other solutions are more complex, ranging from Renewal of the Crossing Surface to the Complete Renewal of the Crossing Surface, Track Panel, and Underlying Support. We describe different features of each option as well as methods to inform decisions. One key component of the decision-making process is considering the quality of underlying support. We recommend reviewing historical costs and performance data for the site under consideration; making cost effectiveness a central concern of the evaluation process; categorizing or separating major work and cost items to achieve comparative economies to obtain the optimum alternate design; and separating costs into finite units for comparison purposes. This report provides an in-depth discussion of these aspects of a crossing management program. To conclude, we advance suggestions for future research, which include using Fuzzy Logic Analysis to model and quantify the costs of various work items.

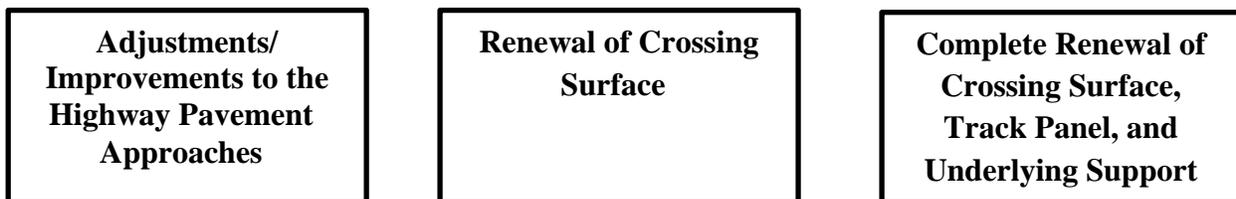
# CHAPTER 1

## Recommendations for Standard Practices

A review of state-level programs indicates that successful highway-railway at-grade crossing maintenance and rehabilitation programs integrate two critical practices. First, they develop a standard set of design and construction criteria. This is critical for achieving the desired crossing performance and extending a crossing's life. Second, the establishment of an effective managerial structure streamlines the decision-making process and ensures that the designated design is applied and implemented using appropriate construction techniques. When these practices operate in concert with one another, they constitute the foundation of a successful at-grade crossing maintenance and rehabilitation program. The following sections of this report discuss each of these practices in detail and advance recommended strategies to implement them.

### Assessing Crossing Rehabilitation Design and Construction Techniques

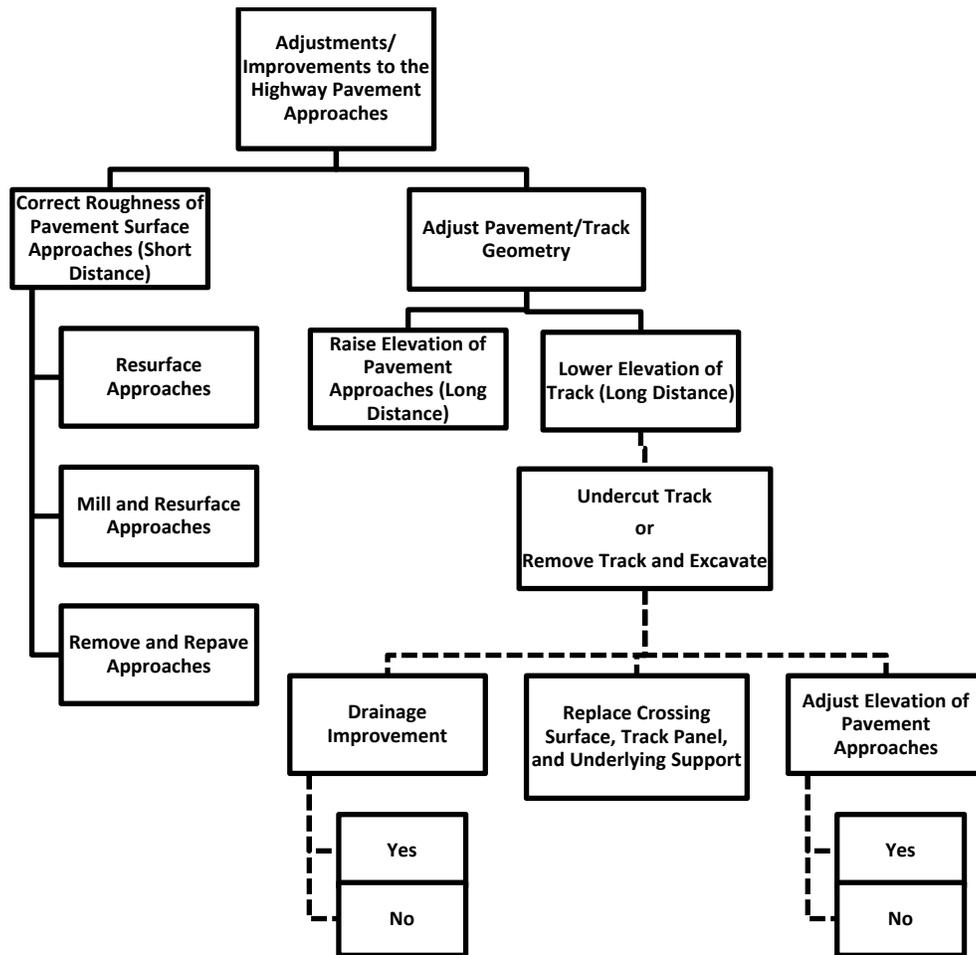
Crossing rehabilitation aims to restore, in an optimal manner, crossings to a desired level of smoothness while ensuring acceptable long-term performance. To decide on an appropriate course of action, three basic categories for assessing crossing rehabilitation techniques merit consideration. These techniques are site-specific and based on the present observed performance and condition of a particular crossing. The costs of the rehabilitation techniques, ultimately borne by a railroad company and/or public agency, can vary significantly depending on the solution selected following an engineering assessment. Other than cost, another important factor to account for is the inconvenience the traveling public experiences during rehabilitation projects. As such, it is advisable to minimize the length and frequency of crossing closures in order to avoid excessive highway traffic delays. Train traffic also experiences negative impacts until the affected track is restored to a condition that supports uninterrupted operations. Figure 1.1 shows the three categories of rehabilitation techniques that are commonly used. Each category varies in terms of the type and extent of rehabilitation it is ideally suited for.



**Figure 1.1.** Three Categories for Assessing Rehabilitation Techniques

## Adjustments/Improvements to the Highway Pavement Approaches

In many cases, it is the highway approaches to a crossing that are the primary – and sometimes only – factor contributing to its roughness and suboptimal performance. The needed solution can vary, and hinges on the scope and magnitude of the problem. For example, if the only problem is relatively simple (e.g. stemming from rough pavement surfaces), the solution is likely to be straightforward. However, if the cause is highly complex, such as the presence of a vertical geometrical incompatibility, the corrective action will be more involved. Figure 1.2 is a decision-option diagram that guides the selection of appropriate solutions when dealing with adjustments/improvements to the highway pavement approaches.



**Figure 1.2.** Adjustments/Improvements to the Highway Pavement Approaches Decision-Option Diagram

When the highway pavement approach adjustment has been chosen as the primary method to rehabilitate a crossing, there are two generally accepted solutions – 1) correcting the roughness of pavement surface approaches, and 2) adjusting pavement and track geometry. Each solution is discussed in turn below.

### *Short Distance Correction of Pavement Roughness*

The most economical and least complex solution is to merely correct the roughness of the pavement surface approaches that extend a short distance from the crossing. Corrective action focuses on areas 6-12 feet (1.8-3.6 m) from the crossings. Generally, these solutions are ideal if a pavement surface has been rippled, rutted, worn, or cracked such that the rideability is compromised. This solution has only minor impacts on railroad operations.

In some cases it may be possible to resurface the approaches with a thin lift of asphalt if the existing pavement is structurally sound. However, unless the pavement approaches have settled significantly, adding a layer of asphalt will result in a geometric incompatibility between the pavement approaches and the crossing. This may negatively influence crossing rideability. In most cases it is desirable to remove a portion of the pavement by milling off one to two inches (25-50 mm) of the surface before resurfacing the pavement to match the crossing surface. Another solution is to remove most, if not all, of the pavement and replace with a thicker lift of new paving material that matches up with the crossing surface.

Milling or excavating is optimal only if the existing condition of the approaches does not require the placement of a thin surface layer. This solution assumes that the crossing surface and track panel perform adequately and remain at the appropriate elevation. This relatively simple solution is based primarily on engineering judgment, knowledge of prior maintenance, and past performance. It assumes that minimal benefits would have accrued from renewing the crossing surface.

### *Adjusting the Pavement Approach Geometry*

The second solution is to adjust the vertical geometry of the pavement or track when there is an incompatibility with the crossing's geometric vertical gradients. In order to correct this incompatibility, it is possible to either raise the grade of the pavement approaches or lower the track's elevation. At crossings where the railroad is higher than the highway, raising the grade of the approaches on one or both sides of the track can remove the short crest or hump at the crossing. The vertical grades on the approaches must be transitioned for a reasonable distance beyond the crossing, generally 20 feet (6 m) or more depending on the site conditions. The grade must also meet the existing pavement at the selected distance from the crossing. Accomplishing this normally involves the use of thicker lifts of paving material near the crossing and gradually thinning the lift thickness to transition it to the existing pavement. Adjustments may be necessary to restore abutting highway intersections and drainage inlets. This is particularly the case in urban areas. At many crossings this solution can be very expensive and undesirable. Also, it is less likely to be practical for sag highway crossings or where the highway is on a continuous grade. This option is generally only considered for vertical crests in the highway profile.

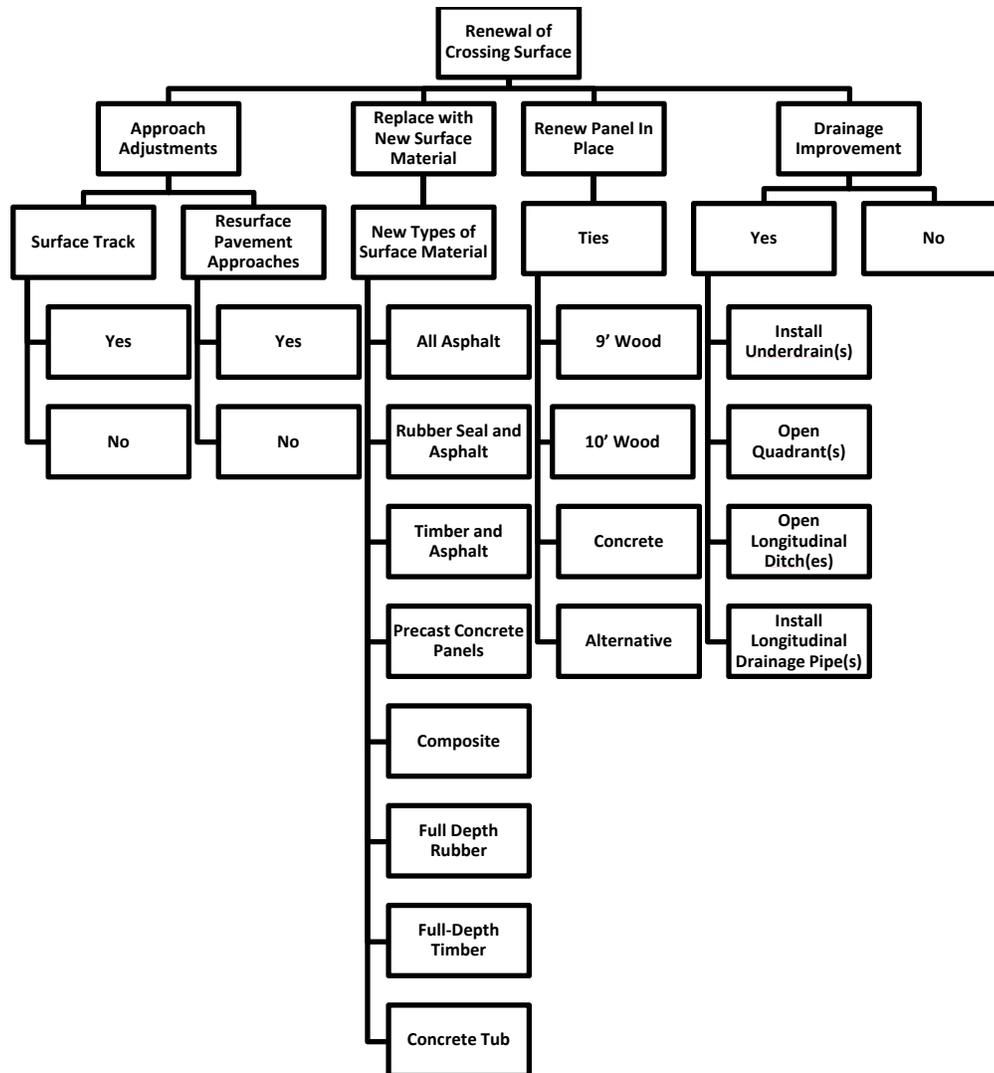
When elevating the grade of the pavement approaches is not viable or desirable, it is possible to correct the geometric incompatibility by lowering the elevation of the track within the

vicinity of the crossing. Lowering the track elevation effectively reduces the vertical difference between the railroad and highway. This fix applies only for sites where the railroad elevation is considerably higher than the highway, such that it creates a significant vertical offset in the profile. This solution is extremely expensive and involves considerable impact on railroad operations. One possible track lowering method is to use a typical track undercutter to remove granular material of a specified thickness within the trackbed, thus lowering the elevation of the track. The magnitude of the track elevation change can range from approximately one to four feet. Particular attention needs to be paid to ensure that significant sag does not develop along the track profile. Therefore, this solution requires modifying extremely long distances of track so it can transition to the existing grade beyond the crossing. This may also impact other track features within the affected area, such as turnouts, which will require re-positioning. Also, the integrity of the trackbed support may be compromised. An alternate procedure to consider where there is ample space along the track is to temporarily remove sections of track so that conventional excavating equipment can achieve the desired thickness. Once the excavation has been completed the track is reinstalled, producing the same result as undercutting.

Lowering a track's elevation is rarely the preferred method of matching railroad and highway elevations to upgrade the rideability and safety of a crossing. This procedure is complicated by the fact that the pavement approaches will need to be reconstructed to coincide with the lowered track. It also requires the installation of a new crossing surface. Benefit-cost analyses of this solution rarely justify its use, and it is generally viewed as an economically ineffective option.

### **Renewal of Crossing Surface**

If the only factor that contributes to crossing roughness and substandard performance is the deteriorated condition of the crossing surface material, the best solution is to renew the surface. Under this scenario little, if any, settlement may have occurred, so no adjustments to the railroad or highway profile are needed. However, it is typical that the highway approaches will be impacted for a short distance by the deterioration of the crossing surface, which necessitates repavement. Additionally, the track may need resurfacing – often to raise its elevation slightly – particularly if the approaches have settled. If the track is raised, a new lift of sufficiently thick asphalt must be applied to the highway approaches. These lifts must be correctly placed and adjusted to the installed crossing surface's height. Otherwise, the approaches will likely require milling or removal, often at an increased price, if the crossing is installed at precisely the same elevation. Figure 1.3 contains a decision-option diagram that outlines the primary considerations for crossing surface renewal.



**Figure 1.3.** Renewal of Crossing Surface Decision-Option Diagram

This procedure assumes the track panel can be left in place, and that none or only a portion of the ties will be renewed. The rail is also assumed to be in satisfactory condition. After the old crossing surface is removed, the selection of the replacement ties is made. Figure 1.3 provides a list of possible tie replacements. If surfacing and/or raising the track is an attractive option, the necessary quantity of ballast is distributed and the track in the crossing area and on the track approaches is surfaced. The next step is determining if the drainage in the immediate vicinity needs improvement. Once complete, the surface material is selected and installed. The final stage of this process is resurfacing the pavement approaches, if necessary, to align with the crossing surface's elevation.

We assume that sound engineering judgment is used to determine if the crossing can be renewed in place without removing support material below the ties. There should be signs of

trackbed pumping, excessive settlement, or excessive deterioration of the crossing and approaches. If this is the case, completely removing and replacing the crossing surface, track panel, and underlying support should be the selected rehabilitation technique.

### *Determining Proper Surface Material for Surface Renewal*

On surface renewal projects, the choice of surface material significantly influences project cost and the time required for completion. For this reason, determining the appropriate surface material is one of the most critical steps in any rehabilitation. Figure 1.3 lists a number of standard crossing surface materials. Selecting the proper surface material depends on a number of different factors. Typically, railroad companies and public agencies maintain a set of standards that define the type of surface material that will be used based on preset criteria. In some cases, public agencies require a specific surface material for all at-grade crossings. One agency with this requirement is the Iowa Department of Transportation, which requires the use of rubber or concrete panels for all crossings. In other cases, the set of built-in criteria define which type of surface can be used based on definable factors. The Illinois Commerce Commission uses AADT volumes to determine the type of surface material to use. For AADT volumes less than 500 vehicles per day, the ICC recommends a full-depth timber surface. For crossings that feature AADT volumes between 500 and 5,000 vehicles per day, a full-depth timber, rubber, or concrete surface is optimal. For those crossings that feature more than 5,000 vehicles per day, a full-depth rubber or concrete crossing surface is recommended. States that do not maintain standard criteria, or require a standard crossing surface for all projects, rely heavily on subjective judgment. DOT representatives or a local/district representative will recommend a surface material based on the crossing condition and corresponding factors. In Illinois, the district liaison is responsible for determining the materials used for surface renewal and this choice is based on a number of factors, including train volume and speed, AADT, and truck volume. Whether or not a standard set of criteria are maintained, it is important to maintain guidelines that help inform surface material selection. When standards are not applied, it is vital that the representative making suggestions possess an intimate knowledge of the crossing elements, and a comprehensive understanding of the railroad so that a proper recommendation can be made.

Different surface materials range widely in cost and required installation time. All-width hot-mix asphalt pavement is the least expensive material and takes the shortest amount of time to install. This material can be spread along with the pavement approaches to minimize the total installation time. The flangeway is readily formed, while the asphalt is still hot, with a hi-rail vehicle or locomotive. But this type of surface is rarely used except for roadways that have light traffic. Rubber seal/asphalt and timber/asphalt are commonly used, inexpensive surfaces. During installation, rubber seal strips or timber beams are positioned and attached along each side of the two rails, while asphalt is placed in the center of the track and on the field sides in the crossing area. If the pavement approaches require paving, it can be undertaken in concert with pavement

of the immediate crossing area. Compared to an all-asphalt surface, this surface is slightly more expensive and demands a bit more time to install.

There are four other types of crossing surfaces routinely installed – precast concrete, composite, full-depth rubber, full-depth timber, and concrete tub are considered premium surfaces. They are significantly more expensive than standard surfaces, often as much as three or four times more costly per track foot, and normally have a longer installation. However, these surfaces can have longer lives provided they are properly designed and set.

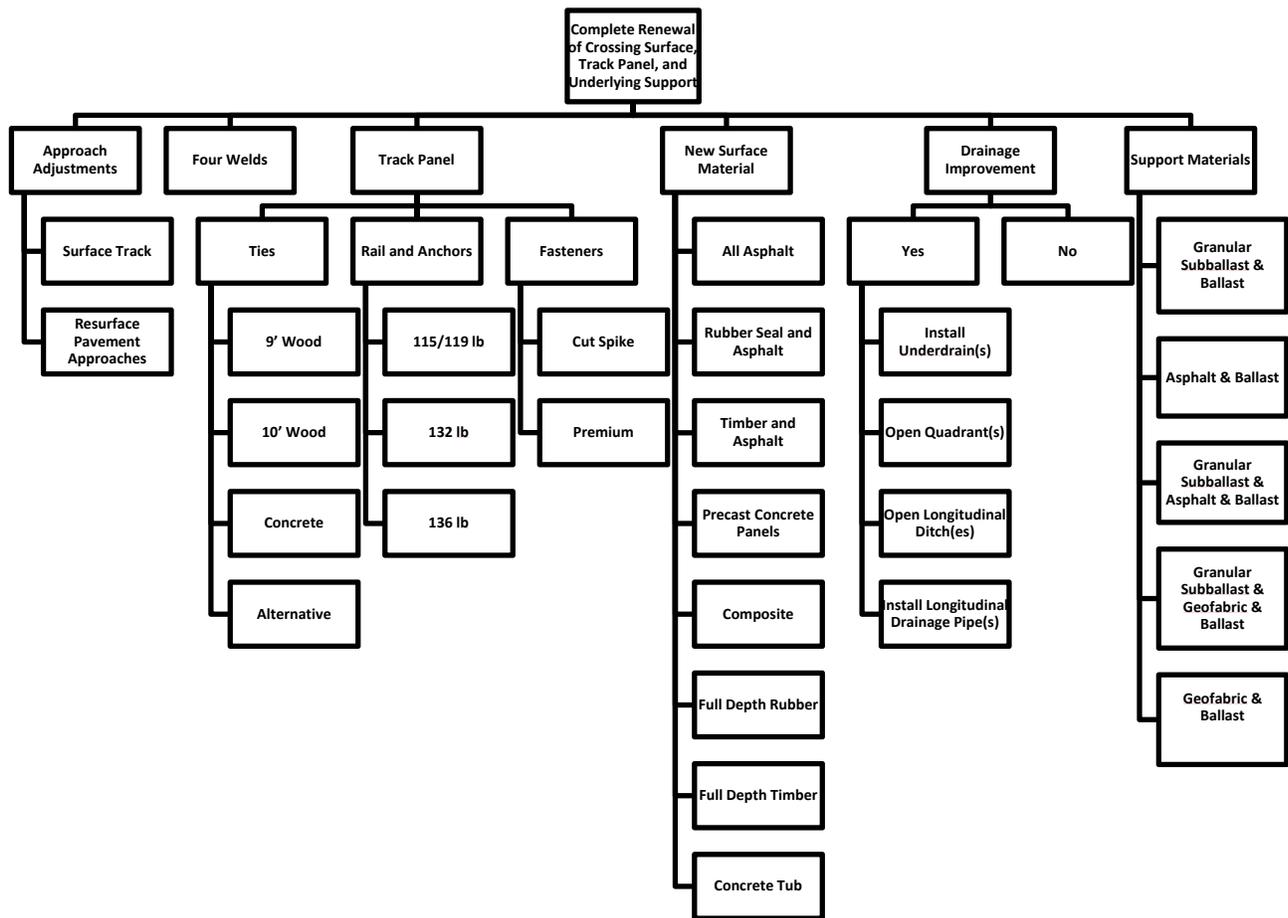
### **Complete Renewal of Crossing Surface, Track Panel, and Underlying Support**

Crossings commonly exhibit significant settlement due to the pumping of fines from the trackbed. This creates uneven, rough crossings for highway vehicles. Track settlement, in some cases, may be substantial enough to adversely impact train operations. One factor that can contribute to the failure of trackbed support, when fines are removed, is damage to the underlying drainage network. Often the underlying support has insufficient load carrying capacity further exacerbated by fines contaminating the ballast.

Figure 1.4 represents the decision sequence that is applied when the crossing surface, track panel, and underlying support are completely renewed. Under this scenario, all present elements are totally removed and replaced with new materials having increased and therefore adequate load-carrying properties. Also, the adequacy of the drainage should be addressed and appropriate improvements selected. Usually, this process entails assessing pavement approaches, and in many cases they will be raised to match the adjusted top-of-rail elevations of the track. The track approaches are typically adjusted vertically and elevated slightly, as the crossing area is surfaced before the new surface crossing is set into place.



**Typical Rubber/Asphalt Crossing Surface**



**Figure 1.4.** Complete Renewal of Crossing Surface, Track Panel, and Underlying Support Decision-Option Diagram

The length of the track panel is selected so that it reaches a specified distance along the track beyond the immediate common crossing area. Ten feet should be the minimum distance used, although it can be significantly longer depending on site context. The rail size and type of ties chosen for the new track panel must be able to support the anticipated traffic levels.

Two major decisions are particularly critical under the complete renewal scenario: 1) selecting the appropriate track support materials and 2) determining a suitable crossing surface. If the support system is comprised entirely of granular materials that have not performed satisfactorily, often engineers consider installing an improved support system. This support system often consists of a layer of asphalt positioned under the ballast. A layer of granular subballast may be included below the asphalt to protect the subgrade. This is a standard practice for an increasing number of railroad companies and governmental agencies, and is discussed in

detail later in this paper. Normally, this will involve excavating to a depth of 30-36 in. (760-910 mm) below the final top-of-rail elevation.

An alternative option requires setting down a layer of geofabric in combination with a layer of granular subballast to improve load-carrying capacity of the trackbed. The added cost to include a layer of asphalt or geofabric is minimal relative to the overall cost of completely rebuilding the crossing. Additional costs of five percent or less are common, particularly if more expensive premium surfaces are selected. As noted, the choice of the new surface material highly impacts the overall cost and time of rehabilitation.

The expectation is that premium crossing materials will last for a longer period of time and consequently perform better during the life of the crossing. This is not always the case as the quality of the support has significant bearing on the crossing surface's relative performance. Premium crossing materials may compensate for poor quality support because they provide a bridging effect – or an increase in bending strength – through the panels and their connections with the ties. However, these gains are realized through significant cost increases. Most often, improving trackbed support is a more economical and practical strategy. Another consideration to include is whether drainage improvements should be made. If necessary, improvement options include installation of underdrains, opening up quadrants, opening up longitudinal ditches, and/or installing longitudinal drainage pipes.

### **Considerations for Quality of Underlying Support**

The complete renewal of the crossing surface, track panel, and underlying support can often be avoided if there is proper support in place. Extensive rehabilitation projects that are costly and time-consuming are often the outcome of instances where the underlying support has broken down. When a vertical incompatibility exists because fines have been pumped from the trackbed, or due to improper drainage, highway vehicles are exposed to a dangerous situation. Train operations are likewise substantially influenced. If the support structure present is of sufficient quality, often engineers can choose more limited rehabilitation techniques, such as a highway approach adjustment or crossing surface replacement –reducing the total cost and installation time. Additionally, maintaining a resolute support structure eliminates the need to use premium materials to lengthen the crossing life. Standard crossing materials usually perform as well as premium materials over extended periods of time provided the standard materials receive the proper structural support. This calls for adding a structural layer to add strength, waterproofing, and confinement, which enhance the crossing support's structural adequacy.

The use of asphalt underlayments is increasingly becoming a standard for several Class I railroad companies and public agencies nationwide. The benefits of using asphalt underlayments to improve the quality of the subgrade support have been exhaustively documented. Affixing an additional asphalt layer provides the ideal sub-structural support for highway/railway at-grade crossings. The benefits of using asphalt underlayments include: (Rose, et.al, 2014):

- Production of adequate strength to resist the combined highway and rail loadings, thus minimizing stresses on the underlying subgrade
- Minimization of vertical deflections and permanent deformations of the crossings due to highway and rail loadings so that the wear and deteriorations of the crossing components will be minimized
- Creating a waterproof underlying subgrade so that its load carrying capability will not be sacrificed even when placed on marginal quality subgrades.

Additionally, asphalt underlayments positively contribute to the coveted fast-tracking approach during the rehabilitation process. It has been noted that the track can be placed back in service within four hours of asphalt installation, and highway traffic can resume within 8-12 hours depending on the approach installation procedures. Therefore, complete crossing renewal can be accomplished in a single day, which greatly reduces the effect on train operations and highway traffic disruptions (Rose, 2009).

Previous research has demonstrated the benefits of using asphalt to improve support quality and strength. In 2009, Rose, Swiderski, and Anderson monitored the long-term settlement of crossings that contained asphalt underlayment by establishing top-of-rail elevation profiles immediately after the rehabilitation of several crossings (Rose, et.al, 2009). Subsequent profile measurements were taken at varying times after rehabilitation to determine the rate of settlement. Crossings underlain with asphalt settled 41 percent less than all-granular trackbed crossings. Further, the crossing areas underlain with asphalt settled 44 percent less than those with all-granular track approaches. This study found the three-year settlements for the asphalt underlayment crossings averaged 0.57 in. (14 mm). Conversely, the all-granular crossings settled an average of 1.29 in. (33 mm). The crossings that were underlain with asphalt endured heavy highway traffic, while those featuring all-granular support were located in areas with significantly less vehicle activity.

### **Assessing Recommendations to Improve Management Structure**

Several states have developed strategies for completing crossing rehabilitation projects. These strategies usually begin with the management structure and drill down into the drivers that influence the selection of design criteria. Analysis of the programs in these states demonstrated that the benefits of developing a structured system are numerous. Project start-up becomes a much easier process, and projects are completed in a much more cost-effective, timely manner.

Developing a structured management system hinges largely on available resources, both funding and personnel. The lack of available resources often makes it difficult to implement an ideal management structure. After analyzing the program management techniques for several states, we have concluded that those with a defined structure have been most successful in

developing a strong crossing rehabilitation program. Several of the most successful aspects of these programs have been identified. The following sections highlight these procedures.

### **Maintaining a District Representative**

Indiana and Illinois have successfully utilized a designated representative in individual highway districts throughout the state who possesses extensive knowledge of the railroad industry. Not only do these representatives possess knowledge of the railroad industry, they are also thoroughly familiar with the highway district they represent. For this reason, coordination of projects throughout the state has become a much easier process, as these district representatives can administer and monitor rehabilitation projects within their corresponding jurisdiction. The presence of reliable district representatives relieves representatives in the central office of having to participate in detailed activities, which is beneficial as they often have multiple responsibilities to attend to.

If possible, we recommended that the district representative be present at the construction site throughout the entirety of project construction. When there is no such management structure in place and no district representative is on hand at the construction site, projects often do not proceed in a manner consistent with the department's vision. This increases the likelihood of project setbacks and an end product that underperforms expectations. The presence of the district representative helps ensure that departmental standards are observed and applied during construction. Employing multiple district representatives may also provide benefits beyond the scope of the DOT itself. The presence of a district representative can help forge improved relationships between the DOTs and the railroad companies. District representatives are more likely to develop bonds with local trainmasters employed by railroad companies, and therefore streamline interactions. As a result, it is more likely that railroad personnel adhere to standards set forth by the DOTs. This also positions the department to offer more input on the design specifications and construction methods used during project completion. This will yield financial benefits and improve the overall performance and longevity of crossings.

When finances or personnel availability do not permit the employment of representatives in each district, we recommend that a single representative be assigned to oversee the completion of rehabilitation projects. While this representative may not be responsible for administering all projects, they may provide assistance at critical project junctures, such as at their inception. Furthermore, a representative with extensive knowledge of the railroad industry is valuable because they can be relied upon to recommend mitigation procedures and design specifications. The State of Iowa has successfully installed a single representative to coordinate and oversee rehabilitation projects.

## **Maintaining a Central Office Rail Division**

Although in many cases, maintaining a separate rail division within the Department of Transportation is not possible, it still merits consideration. Iowa, Illinois, and Indiana designate a branch or division within their DOTs to deal solely with railroad operations. These branches are responsible for overseeing at-grade crossing rehabilitation projects. Maintaining a division that deals just with railroad work is important because, without a designated agency, administering program objectives becomes a more challenging endeavor. In all forms of management, it is desirable to maintain a small, centralized decision-making committee to improve coordination and program administration. Additionally, developing a railroad-specific branch translates into an increased concern for railroad operations within a state.

## **Developing a Designated Fund for Surface Renewal**

Iowa and Illinois each fund at-grade crossing rehabilitation projects primarily through funding resources designated purely to crossing surface renewal. The Grade Crossing Repair Fund in Iowa allocates \$900,000 for surface repair each year. Likewise, the Illinois Commerce Commission has adopted the Grade Crossing Protection Fund (GCPF) to pay for surface renewals. The GCPF allots \$750,000 per year, with the potential to increase this to \$1.5 million per year by 2015. Maintaining a designated fund used exclusively for surface repairs has been beneficial for both states. These case studies illustrate that developing a dedicated source of funding greatly improves project administration because funds are distributed more efficiently. Too often, rehabilitation projects are complicated or delayed because there is no access to a dedicated funding source. This results in fewer crossings being targeted for renewal. When funds for crossing rehabilitation projects are drawn from a diffuse network of sources, many of which are designated for other purposes, projects execution slows down.

Identifying a designated annual source of state funding for crossing surface renewals may assist in the procurement of additional federal funds. Federal funds are primarily administered for safety improvement projects only. Currently, MAP-21 allocates \$220 million for this purpose. The FHWA mandates that 50 percent of these funds be devoted to traffic control device improvement. As a result, the majority of federal funds go toward signaling at crossings rather than into improving the crossing structure itself. The designated annual source of state funding could be used to augment monies received from the federal government. The deterioration of crossing surfaces poses a significant safety risk to both highway vehicles and trains, justifying acquiring funding from a source dedicated entirely to surface renewal projects.

## **Identification/Documentation of Material Costs**

Maintaining an operating inventory that details the cost of select materials used on at-grade crossing rehabilitation projects can accelerate implementation. This summary provides a critical source to perform cost-benefit analyses for individual projects, and therefore assess

which projects should be prioritized. Rehabilitation projects are influenced by a number of factors, and thus selection of materials may vary widely. By maintaining a working inventory, selecting appropriate materials given the controlling factors and allocated funds becomes a much easier process.



**Typical Timber/Asphalt Crossing Surface**

## CHAPTER 2

### **Recommendations for Standard Procedural Practices**

Adopting a proactive approach, and supervising all phases of the project, will position KYTC to ensure at-grade crossing rehabilitation projects are carried out in a timely and cost-effective manner. This requires the development of standard design and management guidelines *and* setting policies for project procedures to develop better coordination between the Cabinet and the associated Railroad. This section presents recommendations to standardize the procedures followed when beginning an at-grade crossing rehabilitation project. These processes are highlighted below in chronological order (with respect to project implementation):

- Evaluate Proposals Based on Cost Effectiveness
- Categorize/Separate Major Work and Cost Items
- Review Historical Cost Data
- Consult and Analyze Decision-Option Diagrams to Determine Extent of Rehabilitation
- Evaluate Cost Effectiveness of Various Alternatives
- Select Alternate Design
- Determine Cost per Track-Foot for Major Work Items and Total Cost

#### **Evaluate Proposals Based on Cost Effectiveness**

Evaluating proposals is the first step in the rehabilitation process. After KYTC approves a rehabilitation project, a call for proposals should be made public. Any proposals received by KYTC should then be evaluated by select members of the Railroad Division; selecting projects in this way ensures the proposal chosen will offer the best fit based on the project goals and criteria. Proposal selection must emphasize the project's inherent needs; the proposal that is eventually chosen will, ideally, provide the greatest value to the public while being cost-effective. The proposal evaluation phase of the rehabilitation process allows KYTC to better influence the subsequent project process, and it establishes the Cabinet as the primary authority moving forward.

#### **Categorize/Separate Major Work and Cost Items**

Developing a method to categorize major work items helps maintain documentation of project costs and improve the efficiency of project completion. Separating the major work/cost items enhances documentation while also simplifying the allocation of costs and contributing favorably to a more streamlined, efficient rehabilitation process. The primary cost items for

rail/highway at-grade rehabilitation projects can be separated into five major categories. These categories are:

1. Labor and Equipment for Removal of Old Crossing and Replacement of New Crossing
2. Surfacing of Track Crossing and Approaches
3. Placement and Compaction of Highway Approaches
4. Materials
5. Traffic Control

The first category, which encompasses the labor and equipment needed to remove the old crossing and install the new crossing, includes an assortment of critical rehabilitative procedures. Procedures such as the removal and disposal of the old crossing surface and pavement approaches; removal and disposal of the old track panel; excavation of the roadbed to required depth; installation of drainage pipe; stabilization of the subgrade/roadbed; the placement and compaction of all-granular or asphalt subballast; placing and compacting ballast; positioning of the track panel and attachment to existing track using joint bars or welds; and installation of crossing flangeway material fall under this category. Likewise, the materials used during rehabilitation should be arranged in a designated category. These materials include drainage pipes, all-granular subballast, asphalt underlayment, ballast, the track panel, track fastening components, the crossing flangeway and surface, and asphalt or concrete for pavement approaches. Surfacing of the Track Crossing and Approaches, Placement and Compaction of Highway Approaches, and Traffic Control are separate primary cost elements that must be administered by the Railroad Division within the Cabinet.

### **Review Historical Cost Data**

Maintaining an accessible inventory of historical cost items is imperative for developing an efficient at-grade rail/highway rehabilitation process. Reviewing historical cost data from previous projects greatly improves KYTC's ability to estimate project costs and allocate funds. Developing designated categories for major cost items further augments this documentation procedure, creating an efficient method for dispersing work-related and financial responsibilities to the Cabinet and associated railroad. In addition, it is in the best interest of the parties involved to agree upon the scope of project work and financial responsibilities before the project gets underway. Any formal agreement would be structured using historical project cost data.

### **Consult and Analyze Decision-Option Diagrams to Determine Extent of Rehabilitation**

After selecting a proposal, members of the Cabinet may consult the decision-option diagrams to recommend the design and construction techniques most suitable for the project. Chapter 1 of this report presents these diagrams and provides an in-depth discussion of their components. The decision-option diagrams have been modeled to help streamline the decision-

making process. Additionally, they provide a baseline to identify optimal economic solutions for rehabilitating crossings and restoring desired crossing smoothness while maintaining acceptable long-term performance.

As Chapter 1 illustrates, there are three basic categories to consider when assessing appropriate rehabilitation techniques. The decision-option diagrams are organized in a manner that reflects these categories. The first and least comprehensive solution is the adjustment of highway pavement approaches. The second and third diagrams depict more comprehensive solutions, which include the renewal of the surface and the complete renewal of the crossing surface, track panel, and underlying support, respectively. Procedurally, that initial focus should be placed on selecting a diagram that aligns with project needs. Once the evaluation of proposals is finished, a thorough inspection of the crossing should reveal the magnitude of rehabilitation necessary. Members of the Cabinet may then consult the appropriate diagram to determine the subsequent procedures that provide the most economical solution.

### **Evaluate Cost-Effectiveness of Various Alternatives**

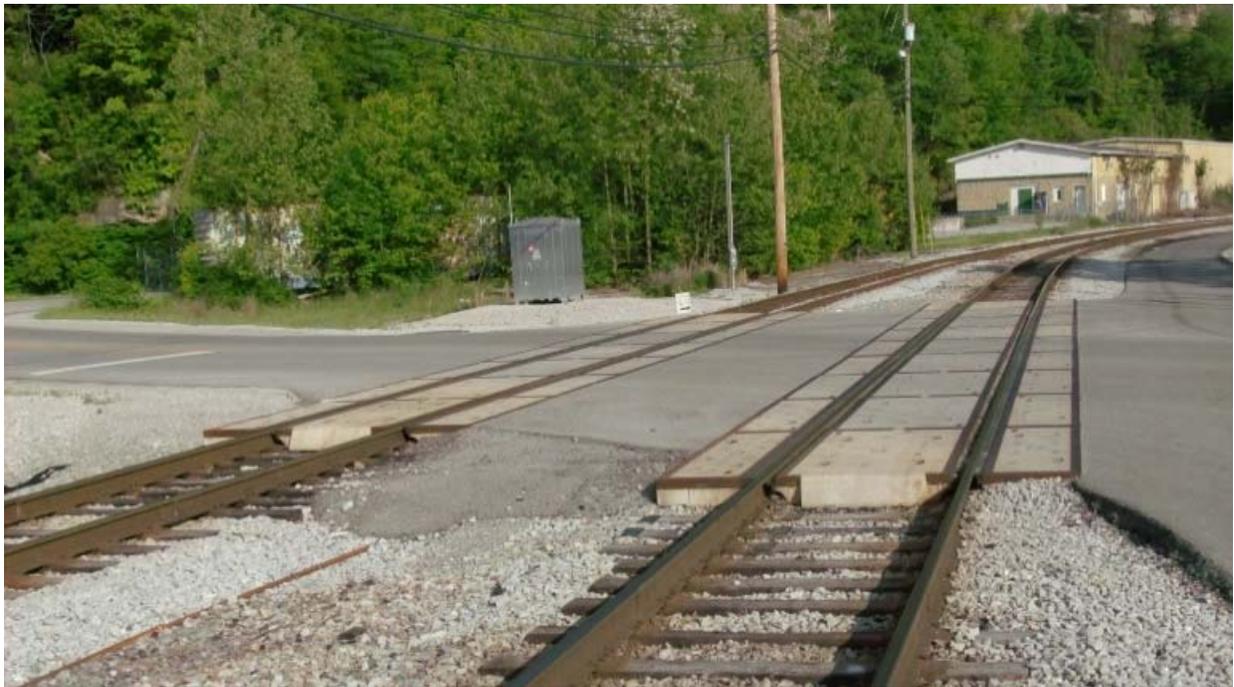
After consulting the decision-option diagrams to select an appropriate rehabilitation solution, it is necessary to generate a series of design alternatives. In addition to aiding in the selection of the appropriate rehabilitation method, the decision-option diagrams also guide the creation of design alternatives. Each decision-option diagram features various components relative to the crossing design. Selecting the various components for a particular project hinges on several factors and is contingent upon site characteristics. Chapter 1 details the components of each diagram, with particular attention focused on the evaluation of the crossing surface and underlying support. The selection of these elements of the crossing surface and underlying support material, in combination with rail size, tie material, and drainage treatment, can have a significant impact on the cost and performance of the rehabilitation procedure. For this reason, it is important to evaluate all of the possible alternatives that fit project needs. Under this scenario, members of KYTC would have an opportunity to evaluate several design alternatives and make an informed recommendation on the design choice. This recommendation will, ideally, combine cost-effectiveness and achieve desired performance longevity. Additionally, to avoid extended disturbances that inconvenience the traveling public, it is important to minimize construction work. While the selection of design components may vary significantly from project to project, specific components may be preferred in most scenarios. Rose and Malloy (2014a) discuss the status of ongoing evaluations that target several crossings throughout the state. The performance of specific crossing components has been documented, and the results of this research may assist during the recommendation process.

### **Select Alternate Design**

After a preferred design alternative has been recommended, KYTC should approve the design the Cabinet and the railroad have agreed on prior to construction. Assuming the power to authorize design alternatives establishes KYTC as *the* organization controlling the rehabilitation process; it also lets the Cabinet exert a more pronounced influence over the final design choice. As such, the Cabinet can guarantee that an emphasis is placed on developing cost-effective and timely alternatives that maximize long-term performance.

### **Determine Cost per Track-Foot for Major Work Items and Total Cost**

Occupying a more authoritative role during the procedural process would allow KYTC to better account and document the cost of rehabilitation. Several state DOTs have been successful in adopting cost-per-track foot methods that enable them to more expeditiously determine how costs will be allocated on a rehabilitation project. One DOT that has used this method with success is the Iowa DOT, which has been highlighted elsewhere (Malloy and Rose, 2014b). Adopting a cost-per-track foot-pricing scheme improves cost allocation while allowing for better documentation of project costs for future reference.



**Typical Concrete Panel Crossing Surface**

## CHAPTER 3

### Discussion and Future Research

#### Discussion

While this report has provided guidelines for developing an effective at-grade crossing maintenance and rehabilitation program, the need remains to establish a quantitative assessment of current and future at-grade crossing performance. Currently, standard methods for measuring crossing performance rely mostly on subjective judgment. Most states maintain an active crossing inventory that houses data on various aspects of crossings' performance, including crossing surface condition, highway approach condition, rideability, and profile. But these performance criteria are categorized qualitatively; the classifications conventionally used to grade performance are poor, fair, or good. While using qualitative classification can be sufficient to represent the present condition of the crossing, it does little to predict future performance and identify potential sources of failure. Further, qualitative assessment may not always capture the actual condition of the crossing, because subjective judgment is often constrained by a number of inherent factors that may alter the validity of the assessment.

#### Quantitative Assessment

Fortunately, there is ongoing research at the University of Kentucky that aims to develop a method for quantitatively assessing crossing performance. A form of three-dimensional imaging technology known as structured light 3D scanning is being used to develop three-dimensional models of at-grade crossings. This structured light technology, combined with a high-resolution 3D camera, can be used to measure the shape, depth, and surface information of the crossing (Wang, et.al, 2014a). The resulting three-dimensional point cloud can then be analyzed to identify defects in the crossing surface. Furthermore, crossings can be scanned several times over a specified period; the resulting models can then be analyzed to identify any temporal trends in their condition. This makes it possible to: 1) determine the extent to which the crossing has deteriorated over time and 2) pinpoint the source of deterioration.

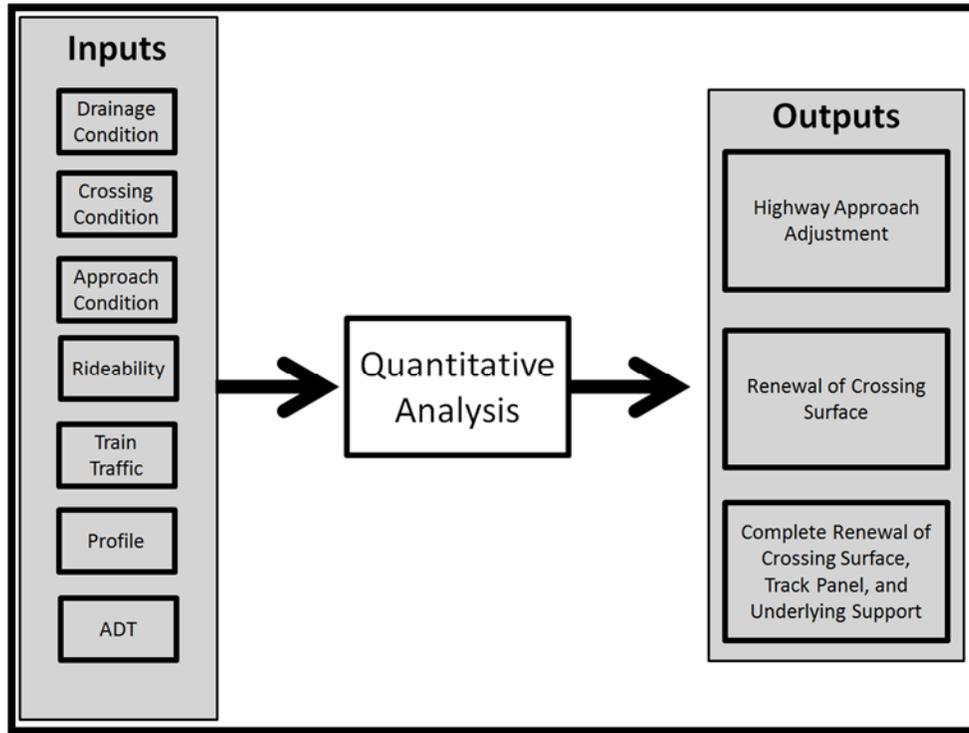
This modeling technique uses several approaches to quantify crossing performance. Using the corresponding crossing factors, including type of crossing surface, drainage condition, highway traffic volume, and train tonnage, a regression model based on a designated roughness index can be constructed for each type of crossing. The roughness index is assigned based on the comparison between an ideal crossing surface and the scanned surface. The regression model and analogous roughness index enable predictions of a crossing's future performance. Vehicle acceleration data can be used to measure crossing performance as well (Wang, et.al, 2014b). Vehicle acceleration data, combined with the 3D surface cloud and vehicle characteristic

information (weight, wheelbase, etc.), can be used to develop a vehicle dynamic simulation model as the first step to automate the crossing quantitative assessment (Wang, et.al, 2015).

Developing a quantitative method to determine at-grade crossing performance has the potential to significantly impact safety, rehabilitation and maintenance procedures. With the current crossing information supplied by inventories, which contain subjectively assigned performance measures for crossings, the framework for using this quantitative assessment is already in place. Those crossings that have been assigned a low score on the inventory list can be targeted first for 3D modeling. The 3D model can then be analyzed to determine the source of the crossing failure. Based on the information provided by the 3D model, the appropriate rehabilitation technique that will most effectively mitigate the problem can be chosen. This not only aids in streamlining the decision-making process, but also avoids unnecessary expenditures on maintenance. Depending on the quantitative assessment's outcome, the crossing can be rehabilitated using one of the three rehabilitation techniques that have been discussed in previous sections of this report. Too often, unnecessary rehabilitation and maintenance techniques have been applied to crossings that may not have needed such treatment. When unneeded treatments are applied, it results in needless financial expenditures, and the crossing's performance is not substantively improved in the long run. Therefore, quantitatively assessing crossing performance will lead to a more timely and cost-effective rehabilitation approach. Efforts are underway to improve the practicality of using a 3D scanner to model crossings. As the technique is refined, maintaining 3D models of all crossings, along with the information provided by the current inventories, is a reasonable possibility.

### **Fuzzy Logic**

The maintenance and rehabilitation process can be further improved using a modeling technique known as fuzzy logic. Researchers at the Kentucky Transportation Center (KTC) have used fuzzy logic modeling for various engineering applications. This technique analyzes a set of input variables and uses approximate reasoning to determine an appropriate solution. For the purpose of at-grade crossing rehabilitation and maintenance, fuzzy logic can be used to analyze the corresponding crossing data provided in the inventory, and, in combination with quantitative assessment, reveal the best possible rehabilitation procedure. If enough information about a particular crossing is provided, fuzzy logic could be used to recommend an appropriate surface material for a particular crossing. Figure 3.1 provides an illustration that documents the potential procedures for rehabilitating crossings that blends fuzzy logic and quantitative assessment.



**Figure 3.1** Fuzzy Logic Analysis

While the current rehabilitation and maintenance practices used in various states across the country have proven successful in some cases, much room for improvement still remains. Developing a structured management system and reliable design and construction criteria are important factors for establishing a successful at-grade crossing management program. However, as we have emphasized, determining a method to accurately quantify crossing roughness would make a significant contribution that could lead to a more robust maintenance and rehabilitation program.

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## ACKNOWLEDGEMENTS

This research was funded by the Kentucky Transportation Cabinet through the Kentucky Transportation Center.