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HOT MIX ASPHALT LONGITUDINAL JOINT DETERIORATION

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ABSTRACT

The notched wedge joint design has proven to be the preferred method of joint construction by research studies given the obvious benefits of higher density, reduced permeability and greater edge confinement when compared to traditional joint methods. Greater quality of joints and improved pavement performance is evident in states that specify the joint type, but not without careful quality control during the construction process. Pavements exhibit longitudinal joint cracking as early as three years into the service life of a roadway, exposing the pavement to damage and costly repairs, or total replacement. Workmanship determines the quality of the finished joint and good construction is the only means to reduce permeability caused by low densities. The notched wedge joint design seems to ensure higher densities and less potential for failure.

Prior to this study, contractor input was rarely solicited by the Wisconsin Department of Transportation (WisDOT) or by the industry as a whole. State roadway projects were chosen based on DOT collected information, and contractor representatives were surveyed to gain a greater understanding of the contractor perspective and process. The survey results exhibited many commonalities in method as well as differences in opinions and unique practices supported by industry research. This information was analyzed and used to propose specification revisions and to develop recommendations for a joint density testing process for performance data collection.

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CHAPTER 1

INTRODUCTION

1.1 PROBLEM CONTEXT

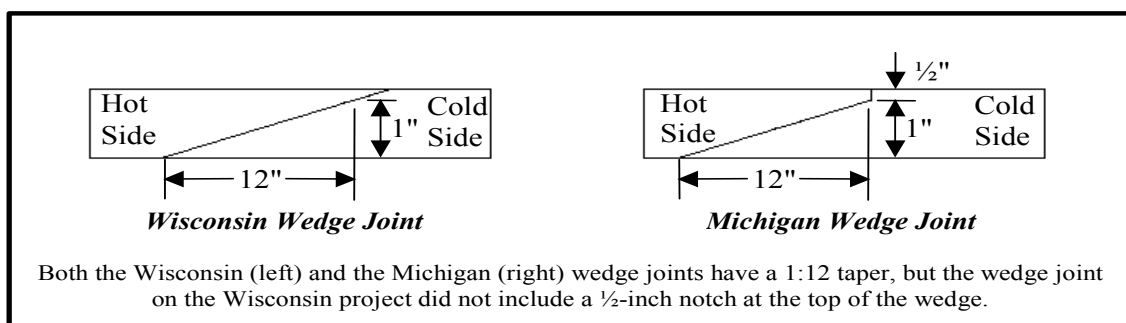
The notched wedge joint method is a common type of longitudinal joint construction between two adjacent hot mix asphalt (HMA) pavement mats. The joint is typically unavoidable because of the standard width of commonly used paving equipment, or even if the road is paved in echelon. Best practices dictate that the longitudinal joint is located at the centerline of a pavement, outside the wheel path of traffic. The joint provides a failure point if not built correctly, exposing the pavement to damage if a longitudinal crack forms or the joint opens over time.

The wedge method was first introduced as a tapered wedge joint in Arizona in the early 1980s and other states adopted it for use. It quickly became the preferred and specified joint construction method in Wisconsin, Michigan, Pennsylvania and New Jersey. Widespread use and early adoption of the method can be attributed to the ease of construction and positive results proven by good pavement performance. Implementing the wedge joint method required no significant change to equipment or schedule, and increased safety during construction over the vertical edge joint by providing a tapered drop off between lanes. Most important, it provides greater confinement of the free pavement edge at the first lane, thus increasing the density at the potentially weakest point of the pavement (Buchanan 2000). Increased density at the joint can prevent numerous problems, including two of the most common causes for pavement failure: cracking and raveling.

Pavement failure occurs when water permeates the surface through a crack or where aggregate base has been dislodged and expands in freezing temperatures, causing additional damage that becomes apparent after the pavement thaws. This damage increases safety concerns, particularly for cyclists, when ruts are formed. Multiple freeze-thaw cycles over the course of a single season or over a number of years only exacerbates the damage. The wedge joint method appeared to assure high performing pavements by reducing permeability and thereby preventing deterioration in freeze-thaw cycles, a reduction in repair and replacement costs, and simultaneous improvement of productivity and safety (Buchanan 2000).

A decade after implementing the wedge joint, the State of Michigan made a critical design change by adding a ½-in to 1-in notch to the top of the wedge as shown in Figure 1, which further improved joint performance.

Figure 1. Tapered Wedge Joint and Notched Wedge Joint Design



The method was renamed the “notched” wedge joint, but became more commonly referred to as the “Michigan joint.” The change showed vastly improved performance over states that

did not incorporate the notch in the design, particularly in Wisconsin (Kandhal and Mallick 1997; Toepel 2003). This distinguishing change and immediate improvement in performance was made through innovation in the choice of construction methods and equipment in the field. Other states, including Colorado and New Jersey, have modified the taper ratio and notch dimensions, but the notched wedge joint design and the benefits it provides are universal. In 1997, a National Center for Asphalt Technology (NCAT) study showed that the Michigan joint had greater densities than the Colorado joint, including the joints constructed on Wisconsin projects.

Following the NCAT study, Wisconsin studied the effects of eight different compaction methods on one project (Toepel 2003), but despite little difference in construction methods, could not duplicate the success achieved in Michigan. When directly compared to the results in Michigan, it became apparent that joint design, lack of experience and poor construction methods led to poor performance (Kandhal and Rao 1994). The poor performance led the Wisconsin state highway agency to refer to the longitudinal joint as the “most inadequate element of Wisconsin asphaltic pavements” in 1993 (Toepel 2003). After involvement in subsequent studies and further research, the notched wedge joint became the standard method of joint construction in the WisDOT specifications ten years later, despite performance that was not significantly better than other joint methods.

No single joint construction technique leads to consistent, long-term performance, but the notched wedge joint has been shown to perform better than other methods in the industry. Long-term performance is only achieved through good construction, and costs to construct good joints are similar to the costs of constructing a poor joint. However, if a pavement fails

prior to the designed life of 12 to 15 years and requires repeated repair or total replacement, the life cycle costs will be much higher for the life cycle of the pavement. An increasing number of HMA pavements have been shown to fail as early as within the first few years of service. Pavement repair by mill and fill techniques may prolong the life of the pavement, but also creates two new joints, or two possible failure points (Hutter 2003). Further research is necessary because notched wedge joint failure still occurs. Research specific to the construction of the joint in Wisconsin is necessary to improve technique and project performance within the state.

1.2 PROBLEM STATEMENT

Poor performing longitudinal construction joints are a workmanship issue, and determining success factors are completely controllable with sound planning and careful execution. Longitudinal joint failure can require 1) pavement repair, 2) overlay, or 3) complete replacement for an otherwise good performing pavement (Prowell 2007) and increase the total lifecycle cost of a pavement (Buncher 2010). Notched wedge joint failure is still a problem in states that use the method, including Wisconsin. Premature failure of HMA pavement caused by faulty longitudinal joints is occurring earlier than ever, sometimes as soon as three years after project completion (CMSC 2010).

Poor construction methods and lack of experience were determined as the primary causes for failure in 1992 (Toepel 2003) and remain the primary causes of failure today. Joint failure results in costly and repeated maintenance, due to extensive cost of replacing roadway as well as the social costs of constant repair, when combined, far exceed the original construction cost of the pavement.

Previous research has not focused on methods and equipment choices exercised by the actual road constructors, which ultimately lead to the failure or success of a pavement. This study identifies good and poor performing projects and determines the commonalities in practice and equipment that lead to either outcome. The results will be used to write specification revisions that lead to the good performing joints and contribute to extended pavement life with the least amount of repairs or replacement.

1.3 RESEARCH OBJECTIVES

The primary objectives of the study is to make recommendations for 1) revisions to the WisDOT specifications and 2) performance rating system. Clear specifications provide a prescriptive outline of notched wedge joint construction that are less prone to human error in interpretation and application. Further, a density testing process should be established and detailed in the specifications to ensure that the proper density has been achieved at the joint and expectations for performance can be determined.

Secondary objectives include 1) increased training focus, 2) improved quality, and 3) increased productivity in the field. Quality workmanship is imperative to correct notched wedge joint construction and performance and can prevent almost all potential problems with the finished pavement. Focused training guidelines can educate field foremen and crews in the correct methods, creating consistency in construction and outcomes, while improving quality and productivity.

1.4 RESEARCH SCOPE

The research scope extended to projects completed in the state within the last three years. The research data collected for analysis focused on methods used only by companies in Wisconsin.

The Wisconsin Department of Transportation (WisDOT) is divided into five regions as shown in Figure 2. Prior to the start of this study, company representatives in each of the regions of the state were asked to submit a list of five projects that had shown good performance and five projects that had shown poor performance in the first few years of service, subject to their opinion and experience. The response to this request was poor, so the researcher selected projects from the WisDOT archive database for analysis.

Figure 2. WisDOT Regions



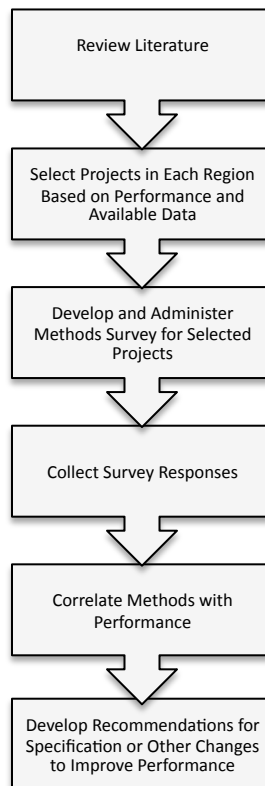
To maintain the relevance of the study and obtain accurate information, projects constructed between 2007 and 2010 were included in the study. Projects completed within

this time period and the associated severity listings were culled from the WisDOT files and compared to the projects submitted by the regions to create a list of 22 target projects. The projects selected were limited by the number of complete database entries that included severity ratings.

1.5 RESEARCH METHODOLOGY

A summary of the method used to conduct the study and accomplish the research objectives is shown in Figure 3.

Figure 3. Research Methodology



The notched wedge longitudinal joint deterioration study began with a literature review to determine 1) what is generally accepted as industry standard construction, and 2) if any state specifications include variations of the industry standard that could potentially lead to higher performance at the joint. This topic has been covered extensively in research since problems with the method were first documented in the mid-sixties, and State Highway Agencies (SHAs) that use the method have responded with revisions to the state specified construction methods, details, and density requirements.

A survey was developed by the researcher to examine the methods used on 22 projects completed in the preceding three years and compare these methods to the WisDOT rating of pavement performance. The collected data was used to make correlations between methods used, and whether it resulted in good or poor pavement performance. Variations in practices between companies was a secondary, unexpected finding used to develop specification revisions with greater clarity for consistency in construction.

1.6 REVIEW

The notched wedge longitudinal joint study focuses awareness on the methods of construction and their impact on project performance. The survey was created with the assistance of industry professionals and designed specifically to gain the insight of the contractors who actually utilize the methods and see the results firsthand.

SHAs have revised the notched wedge joint specifications when improvements in the field have shown to improve project performance. This study directly solicits those improvements that have proven successful for analysis and makes correlations between standard practice and good performance for inclusion in the specification revision. This

collaboration fosters a positive working relationship between WisDOT and contractors, which can lead to continuous future improvements.

The organization of this thesis is similar to the research methodology in achieving the objectives. Chapter 1 presents the problem statement, research goals, and a basic understanding of the topic. Chapter 2 is a comprehensive literature review of industry best practices, the importance of workmanship on quality, and studies of joint density testing methods in relation to quality control. Chapter 3 discusses survey development and methods utilized to collect the data used for analysis in addition to a summary of response characteristics. Chapter 4 uses the t-test statistical method to expose any correlations between method or means and pavement performance, as rated by the biannual photo survey. Results and responses are interpreted and discussed. Chapter 5 is the culmination of the research study; comprised of proposed specification revisions and joint density testing recommendations intended to improve the performance of longitudinal joints in the long term.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Construction of longitudinal joints is the continued focus of research studies because of the propensity for inducing pavement failure. Notched wedge joint design and installation best practices have emerged as a solution to construction and performance issues of preceding designs. Research has shown repeatedly that the added confinement when paving the second lane provided by the wedge and notch of the design is the reason for increased density (Bunchanan 2000; Kandhal and Mallick 1996,1997). A density gradient is created over the joint, with the highest density at the hot, confined side of the joint and lowest density at the free, cold edge. Pavements with the highest density joints show the best performance for the life of the roadway (Denehy 2005; Kandhal and Mallick 1997).

During construction, the HMA mix and lift thicknesses are dictated by the specifications. Typically, the finer the gradation of the mix, the lesser the chance of raveling caused by coarse aggregate dislodging during construction (Bognacki 2006). For the “Michigan Joint” used in the State of Wisconsin, a continuous notch of ½-in to 1-in in length and a taper of 12”:1” are created by a pre-manufactured or company fabricated edge-restraining device and installed in a straight line for the length of the pass. The first pass has an unconfined edge and is referred to as the “cold lane.” Lower density tends to occur on the cold side of the unconfined edge because the mix spreads unevenly when compacted. A second lane, or the “hot lane,” should be placed in a straight line along the previously placed cold edge. Compaction should always occur on the hot side of the joint using a vibratory

roller, at a recommended distance of 6-in over the joint. This practice applies to the compaction of both lanes, and a tag along steel roller is used universally among those surveyed in Wisconsin, after it was shown to perform best in previous studies (Toepel 2003).

If sufficient overlap of the mix at the joint is achieved by setting the screed to automatic, no bumping or raking of material should be required to fill in the joint or remove excess material. Higher density tends to occur on the hot side of the joint because both edges are confined during compaction; preventing lateral movement of material or “starving” of the joint (Brown 2006). The resulting increase in density combined with the wedge design creates a strong bond and theoretically, a better joint when built correctly.

Increased safety during construction is a secondary benefit of the notched wedge joint. Newly paved lanes are frequently reopened to traffic at the end of the work shift, and the tapered edge of the wedge joint provides a safer transition to the second lane rather than the abrupt drop of a vertical edge in the event a tire leaves the pavement. It has been argued that leaving new pavement open to traffic compromises quality because aggregate is broken off the edge by the introduction of traffic. This has been countered by research that showed an increase in density at the exposed joint by the added compaction of traffic tires (Zinke et al. 2008).

Adherence to best practices established by research and experience do not ensure a good performing joint. Rather, the longitudinal joint can contribute to the deterioration, repair, or replacement of an otherwise good performing pavement. If a crack forms at the interface of the two lanes, water infiltrates and widens the crack with each freeze-thaw cycle. Severe cracking poses a safety concern, particularly for motorcyclists, and it becomes costly for SHAs to repeatedly repair or completely replace the pavement. The performance of the

surrounding mat is irrelevant if the longitudinal joint fails, making construction of the joint critical.

Standard specifications vary by state, some basic and some prescriptive, but all allow for some innovation in construction driven by contractor preference or research. Innovation can improve joint construction, but it also can introduce variances that have not been tested and may negatively affect pavement performance. This literature review explains the importance of the interpretation of the specifications and good workmanship during construction. The review also explores the initiatives to include joint density measurements as an indicator of quality and predictor of performance. This focused examination of existing research may be used for future amendment of the WisDOT specifications as a means to improve joint construction and pavement performance, and measurement of both quality and performance.

2.2 DEPENDENCY ON WORKMANSHIP

Specifications are merely a guideline for construction, open to interpretation and change in the field. Notched wedge joints can provide distinct advantages unique to the design in terms of performance, such as reduced incidence of raveling and cracking, but quality of workmanship determines if these benefits will be fully realized. If workmanship is poor, the resulting joint will be milled out and converted to a standard vertical edge joint or left in place and susceptible to damage during subsequent freeze thaw cycles.

The most common joint problems are controllable during the construction process (Fleckenstein 2002) and can be addressed with planning and care in execution. Planning begins with joint location. If the project is an overlay to an existing pavement, the new

longitudinal joint should be offset from the existing joint by 6-in to avoid creating a shear plane (PennDOT 2007) but still be located at the centerline and away from the wheel path. A notched wedge joint eliminates the shear plane common to the vertical edge joint, but directly matching the existing and new joints can reintroduce the plane and create a failure point.

The notched wedge joint should only be used if each lift height is at least 1.5-in (greater than the maximum size of the aggregate), and allows for the correct dimensions of the notch and taper (Mansell 2008). Early test results showed that Wisconsin had success attributed to smaller lifts of 1-in because compaction of the wedge portion was less important due to the small size of the lift (Buchanan 2000). Quality in workmanship could be compromised if based only on the density test results in this single study, and could be put into service prone to raveling.

The notch size and ratio of the wedge dimensions need to be consistent and maintained for the length of the pass. It has been suggested that tapering to zero height at the edge of wedge could be disadvantageous and cause dragging of HMA at the end point of the wedge, which could be eliminated by tapering instead to a minimum height of approximately 3/8-in. (Kandhal and Mallick 2007). Pre-manufactured notched wedge joint attachments are available for use with paving equipment, but all of the survey responses indicated that devices were built in-house. Research supports this general practice of building devices rather than purchasing additional equipment, and the results are often similar (Fleckenstein 2002). Regardless of what type of device is used to form the notch and wedge, crews must take care to ensure that the notch is maintained for the length of the pass and raveling does not occur at the wedge portion.

All measures must be taken to guarantee that the first pass is straight, otherwise it is difficult to align the second pass and voids will form. The joint should always be located at the centerline and away from the wheel path, to minimize wear and tear caused by traffic. Even when precautions are taken to keep the lanes straight and aligned, the second lane is always at a slightly lower elevation prior to compaction, which can cause a slight depression, or inverted joint, if the correct lane overlap is not present.

Mix overlap should be in the range of 1-in to 1.5-in at the joint (Brown 2006; Mansell 2008; PennDOT 2007). This prevents crews from bumping or raking material in excess of 1.5-in into or out of the joint, eliminating potential for human error. The mix can move transversely during these tasks, and create a void that leads to a crack or failure point. Overworking the joint by hand can also result in segregation (Kandhal and Mallick 2007). At a minimum, gaps and depressions caused by insufficient material at the joint can be difficult to match in following passes. Raking can also create a ridge, exposing the pavement to two added issues. The roller could follow the path of the ridge, preventing the material adjacent to the ridge from being compacted (Benson and Sherocman 2006). The ridge can also appear as a crack in road photo surveys, and although it is not a longitudinal crack, it will appear as such and costs will be incurred to fill the ridge with sealant.

Material can be lost if the paver auger does not push the mix against the joint, and instead falls onto the pavement mat during the paving process. This results in excess material on the mat, insufficient material at the joint, and leaves coarser aggregate at the joint (Brown 2006). This creates air voids at the time of construction and increases the possibility of the raveling after the pavement is put into service, creating additional voids.

Placement and compaction of the second lane should occur as soon after compaction of the first lane as possible. Preferably, the second lane should be paved on the same day to maintain as high of a joint temperature as possible. This also prevents exposure to traffic and possible material breakage, particularly if left open for several days.

Approximately 96% of the maximum density is achieved by the time the pavement is compacted (Akpınar and Hossain 2004). Sufficient material is required for good compaction, and a good guideline is 1¼-in of material per 1-in of lift (Kandhal and Mallick 2007; PennDOT 2007), or approximately 20% more material should be on the hot side of the lane prior to compaction (Brown 2006). Essentially, the mix overlap has to be the same distance high as the amount of compaction that will occur (Benson and Sherocman 2006). Compacting a lesser amount of material may be easier for an operator, but insufficient material or if material is not pressed tight against the lane edge can result in air voids and permeability of the joint.

Amount of material overlap is still critical even if a notched wedge joint is milled out to leave a vertical joint. In this case, the overlap should be between ¼-in to ½-in maximum (Benson and Sherocman 2006) to prevent the same problems excess material poses for a notched wedge joint. Based on this literature review, the amount of material present at the joint and material handling is most likely the most important step in achieving high density.

During compaction, the drum of a steel roller should be located at the recommended distance of 3-in to 6-in over the joint and always rolled from the hot side (Brown 2006, PenDOT 2007). Compaction should always be done from the hot side to ensure that the material is pressed firmly against the existing cold joint (Buncher 2011; Benson and Sherocman 2006; Denehy 2006; Kandhal and Mallick 1997; Mansell 2008) Rolling with an

overlap over the joint prevents mix and aggregate from breaking off under the weight of the roller and on to the adjoining mat or surface if the roller is set inside the joint. Rolling at the recommended distance over the joint also prevents lateral movement that occurs when the weight of the wheel is applied directly on the joint. Compaction is done with a pneumatic roller or steel drum roller in static or vibratory mode. No research has shown a significant advantage to using a particular type of roller, but pneumatic tire rollers can effectively prevent bridging and non-compaction to which steel rollers are prone (Akpınar and Hossain 2004; Benson and Sherocman 2006). However, pneumatic (rubber) tire rollers exert too much pressure to be located within 6-in of the joint without breaking material (Benson and Sherocman 2006). Steel rollers can be used within, directly over, or overlapping the joint but only overlapping the joint is advisable. Further precautions can be taken through the use of a material transfer device (i.e. strike-off plate) on the compaction wheel to remove excess material overlap and prevent segregation of the aggregate and raveling (Fleckenstein et al. 2002, PennDOT 2007).

Consensus has not been reached regarding the benefits of applying tack coats to the joint prior to placing and compacting the second lane. Research has shown that tack coats, joint sealants, PG binders and adhesives can increase density and reduce pavement permeability (Brown 2006, Mansell 2008). Treated joints perform as well or better than untreated joints (Benson and Sherocman 2006; Fleckenstein et al. 2002) but the improvement is not significant (Daniel and Real, 2006). However, joint treatments have not been shown to reduce quality, and contractor should continue use has had good experience with a product.

Paving in echelon, or paving both lanes simultaneously, ensures that the joint remains hot and there is no cold lane for the duration of the paving process. This solution is not

possible for use with the notched wedge joint due to the design. The only advantage of paving in echelon is maintenance of temperature. This can be addressed by 1) limiting pass length in the specifications, 2) by planning to place the second lane as soon after the first lane is completed as possible, or by 3) using field knowledge to determine the pass length that allows for temperature maintenance. The New Jersey SHA limits passes to 1500' to minimize joint distress caused by loss of temperature (Baker 1990). It can be reasoned that good joint construction need not be limited to a particular distance and can be done well for any length of pass if temperature can be maintained. The use of infrared joint heaters has also gained popularity in the northeastern region of the United States, but they do introduce the possibility of human error. This can result in inconsistent joint temperatures or damage to the binder caused by overheating (Fleckenstein et al. 2002, Brown 2006) that could effect performance of the joint or require complete removal or mill out. Infrared heaters also add cost of equipment and manpower to operate, increasing the total cost of the pavement (Daniel and Real, 2006). Recreating the higher temperature of a hot lane at a previously cold lane does seem to improve compaction and the strength of the bond when done correctly (Daniel and Real, 2006). Infrared heating displays potential for a measured improvement in performance, such as a 17% incidence rate of cracking on the binder course versus a 36% incidence rate for unheated joints, and a mere 1.7% incidence of cracking for heated joints versus 93% for unheated joints on the surface course on a test section after a year of service (Daniel and Real 2006).

Fleckenstein et al. (2002) contends that the increased safety of the notched wedge joint at the time of construction offsets any future deterioration of the pavement, however this may not be a trade of equal value. It is possible to achieve maximum density through

good planning and control of common errors with construction technique to prevent future deterioration while still benefitting from the safety of design. Project planning, crew training, and use of automatic controls on equipment can allow for sufficient material to be placed at the joint and obtaining the correct density. Eliminating handwork and mistakes increases crew productivity and can reduce costs during construction and over the life cycle of the pavement.

2.3 SPECIFICATION OF PERFORMANCE

Results-based specifications tend to be very prescriptive and are intended to give contractors a density requirement to achieve their chosen means and methods. A specified density in the range of 92% maximum theoretical density at the mat and 90% at the joint (Kandhal and Mallick 2002), or mat density minus approximately 2% plus an allowable percentage of air voids, is typical. These requirements are often integrated with cost incentives or disincentives to motivate the contractor to meet or exceed the requirements or penalize for poor construction (Hand and Epps 2006). Although this type of specification can improve performance and quality at the joint, it can be difficult to set an attainable theoretical maximum density directly at the joint (Buncher 2011) and even more difficult to accurately verify joint density via most test methods. Erroneous density test results can lead to undeserved overpayments or penalties to contractors, as was the experience of the Minnesota state highway agency (MNRoad 2009).

Performance specifications are statistically based, accounting for multiple factors including mix design and gradation, with the greatest weight placed on in-place density and air voids (Hand and Epps 2006). Payments are determined by the results of data collection

and review, but differences in core size, sampling locations, testing method, and pavement engineer experience in obtaining samples can result in inconsistencies within the state and among other SHAs that enforce similar specifications.

Reliable density test data is dependent on experience of the tester and results vary by testing methods. The least destructive test method, nuclear gauges, tend to produce more variable results at the joint (Burati and Elzoghbi 1987) and can be the most difficult to use correctly. The gauge must be seated directly on the centerline of the joint (Kandhal and Mallick 1997) and cannot bridge the two pavement mats or a concise reading of the density at the joint cannot be obtained. The density gradient at the joint will show higher density at the hot side of the joint and lower density at the cold side of the joint, making centering the gauge critical to a good density reading. Placement is also an issue for the more destructive coring test method, as is size of the core removed from the joint. The core should be at least 5-in in diameter and located at the visible centerline of the joint (Prowell 2002). All cores will tend to contain more of the cold, less dense side of the joint, but this can be taken into consideration when reviewing data. Both of the most common test methods have degrees of variability in readings that make performance specifications difficult to enforce fairly if the results are not collected or interpreted correctly.

Cost incentive-based specifications are difficult to devise and enforce fairly, despite shown improvement in quality and associated cost savings. The Arizona SHA did not include bonus pay incentives when their specifications were first implemented, only using reduction of payments for pavements with low densities. After introduction of the specifications, air voids decreased significantly and it is thought that this has resulted in lower life cycle costs and improved performance for pavements (Nodes 2006). Payment

disincentives were not included in a revision of the Colorado SHA performance-based specifications with disastrous results. Contractors were not motivated to improve performance, no penalties were assessed for pavements with low density test results. The SHA estimates that this was a very costly mistake in respect to repair of poor pavements for the duration of their service life (Aschenbrenner 2001). Combining testing with cost incentives may be disadvantageous in execution and obscure the original intent of the specification to provide accurate data for use in measuring and improving pavement performance long-term.

2.4 SUMMARY

Research is unanimous that the construction of the notched wedge joint provides higher densities, less permeability, and improved performance when compared to traditional joint construction methods. Workmanship is crucial in achieving the high density made possible created by the confined edge of the joint design and is dependent on 1) having sufficient material at all points of the paving process, 2) working and compacting the material correctly, and 3) maintaining quality control at all times. Good workmanship is integral to meeting or exceeding density specifications.

Contractors appreciate opportunities for innovation in the field and will assume the risk of performance if left unbound by prescriptive specifications and SHA oversight. Improvements in notched wedge joint construction are the result of innovation in the field and experience. The survey conducted for this study showed that Wisconsin contractors are seeking to improve performance through use of joint sealants and infrared heaters, among other means and methods. This study gave contractors the rare chance to opine and provide

insight into the decision making process at the contractor level. This information can be compared to the best practices discussed in this literature review to determine if any changes to the specifications need to be proposed. The survey data is also used to determine if any correlations can be made between method and performance.

Joint performance can be measured by photographic survey analysis and direct density measurements. To effectively evaluate performance and make correlations with methods, long-term data must be collected and maintained. This process begins with obtaining accurate joint density test results during construction and again after the road has been put into service. Correlations cannot be made without measurable data and an established baseline. Testing should not be done to penalize contractors but to instead improve quality and performance of pavement in the state.

Participation in the research process fosters a positive working relationship between contractors and agency for this study and those in the future. Ideally, this collaboration encourages innovation in the industry and results in contractor understanding of the need for clear specifications and density testing.

CHAPTER 3

HMA LONGITUDINAL JOINT SURVEY

3.1 INTRODUCTION

WisDOT maintains records and photo logs of completed projects noted with design attributes and severity ratings, or Pavement Distress Index (PDI). Although this database contains project information that spans decades, it is not comprehensive and does not include all completed projects each year. Further, limits on time and resources means that not all pavements can be documented to assess performance after completion. A photo survey of one-tenth of a mile of each project is completed biannually, though if resources and funding were more readily available, a survey would be completed annually.

The aim of this research study was to collect a sample of projects completed between 2007 and 2009 with recorded WisDOT performance assessments, and then survey the project managers on the equipment, road designs, and methods deployed by each company to complete each project. This allowed for a minimum service life of 2 years and completion of a photo survey to determine if the pavement had formed any longitudinal cracks.

Surveys are a scientific means to collect data that cannot be observed. This study is concerned with the decision making process that leads to a desired outcome, or the selection of equipment and determination of methods to be utilized prior to the start of a HMA paving project. Contractors choose equipment and methods based on the belief that they will result in the best performance for the greatest amount of time. Careful construction of the WisDOT standard longitudinal joint, the notched wedge joint, has been shown to be critical to pavement performance. Correlation of the methods and performance results were used to

make recommendations for best practices and revisions to the specifications for improvements in consistency and quality.

3.2 SEVERITY RATING INDICES

The severity ratings for the projects surveyed were determined using the Pavement Distress Index (PDI), which was adapted for use by WisDOT as shown in Table 1. The rating index was used to assess pavement wear in Wisconsin beginning in 1980 before the more universal Pavement Condition Index (PCI) replaced it in 2009 (WisDOT 2010).

Table 1. Pavement Distress Index Severity (WisDOT)

0	No visible cracking
1	Slight cracks < 2" wide
2	Moderate cracks 2-4" wide
3	Severe cracks > 4" wide

The PDI index used a scale of 0 to 3 to rate pavement distress based on biannual photo surveys of the roadway. One-tenth of one mile of each project was photographed as part of the survey, capturing images at the mat and an overall road view of each section (see Appendix D). PDI rated longitudinal joint distress separate from other signs of distress such as transverse or alligator cracking for a distinct measurement directly at the joint.

The Pavement Condition Index (PCI) was originally designed by pavement engineers with the U.S. Corps of Engineers for assessment of airport runways, but was later revised to include parking lots and roadways and conforms to ASTM standards D6433-09 and D5340-11 (Greene and Shahin 2003). The index uses a scale of 0 to 100, with 100 signifying a good pavement. The rating scale is often grouped into three categories for improved understanding, but it is much more complex than the simple 0-3 PDI index.

The PCI has been adapted for use in the State of Wisconsin, but does not strictly adhere to the ASTM standards and extensive survey procedures (WisDOT 2010). The 2010 revision of the rating system no longer recognizes longitudinal cracks as a separate distress from transverse cracks, which makes attributing pavement failure to poor longitudinal joint construction more difficult than pavements rated by the previous PDI index revisions.

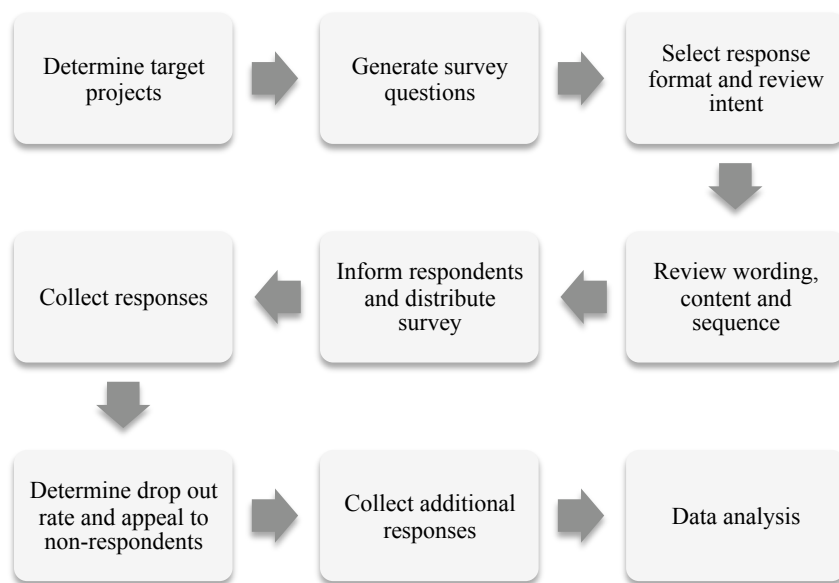
3.3 METHODOLOGY

A target project list of 22 projects of varying PDI severity, multiple contractors and locations in four of the five state regions were culled from the database and an individual survey for each project was sent to the responsible contractor for data collection. The target projects were the only examples of projects in the database that 1) were completed in the three-year timeframe and 2) had severity ratings assessed and documented. The majority of projects were completed in 2007, the first year designated for study, based on the availability of data for sampling.

Contractors who were not part of the sample group were encouraged to submit surveys for projects of their choice, both good and bad performers, to assist the study. The respondents were repeatedly made aware of the study, and moreover, the importance of

participation was stressed at multiple technical meetings prior to and during the study. The purpose of the study, as well as the risks and benefits, were clearly explained to the survey group prior to the release of the survey. Figure 4 shows the survey development and collection process.

Figure 4. Survey Process



The survey addressed topics in five major categories as they relate to notched wedge joint construction: 1) background, 2) materials, 3) notch construction, 4) equipment, and 5) joint overlap. Density, contractor opinion, and quality control items were included for both informational purposes and with the potential to form correlations with pavement performance. All of the questions were reviewed by multiple parties, including a university survey designer and the director of the Wisconsin Asphalt Paving Association (WAPA) for relevance, importance, wording, and intent. The finished survey administered to contractors is included in Appendix B.

The survey question was designed to incorporate questions answered with a yes or no, or by a Likert scale, which is a five-point bipolar measurement used for reliability. Yes or no questions are less reliable than the Likert scale, but are easy to complete and develop a rapport in the absence of a face-to-face interview. The Likert scaled questions establish relevance to the problem and operationalization, or translation of the results into practices that can be observed and recreated (Crano and Brewer 2002).

In the absence of direct observation of the actual construction of the joint for each project, the study relied on respondent recollection of project details including weather, methods, and equipment used at the time. Furthermore, the study relied on the contractor perspective on expected performance for each constructed joint. Depending on when the survey was completed, response bias could affect measurement validity based on the respondent's mood, social factors, or difficulty with survey language. Response bias was a concern, given the poor response to the request for voluntarily submitted projects from each region, which prompted the assignment of the surveys. Responses could also be affected by the number of choices per question or by the wording of questions, resulting in responding positively to positively worded questions or vice versa. Also, respondents could consistently choose responses in the middle of a scale (Crano and Brewer 2002), resulting in poor data. The researcher attempted to mitigate this threat by reviewing the question language with a University of Wisconsin-Madison survey developer for survey technicality, and the director of WAPA for industry specific input. Factors such as mood, or differences in gender or company role, could not be controlled but instead contribute to the generalizability of the results. The projects were chosen randomly based on the available data, and were completed by respondents of varying roles, for different companies in 4 of the 5 state regions. Thus, the

features of the sample group, albeit small, are typical of the state of Wisconsin, regardless of company size or location. This makes the results externally valid with a greater amount of precision.

Precision may have been affected by the seasonal nature of paving work, economic factors such as layoffs of employees who performed the work, apathy, or duration of time between project and survey completion. Overall, the surveys were only returned if an actual member of the project team could enter the data accurately or not returned at all.

3.4 SURVEY RESPONSE RESULTS

The total response rate for the survey was 73%, or 16 of the original 22 project surveys were returned. One respondent explained that three of the surveys were not returned because they were too small in size or there was no data available. The goal response for the study was 20 surveys or a 91% response rate to improve the reliability of the t-test of correlations used for data analysis. The returned surveys still provided measurable results that could be used to make correlations between practice and performance.

Table 2 shows the project surveys that were returned and used for analysis and pertinent information. Several of the projects denoted with a (-) did not have any biannual photo survey files or the photo did not contain the longitudinal joint, and thus was not rated by the SHA (photo surveys are found in Appendix D). The highway project denoted with a (*) represents a Superpave project, which had a different, specialized mix design than the other projects. The progression of longitudinal cracking does not directly compare to the typical cracking characteristics of a standard mix due to the difference in composition. This table also shows any differences between the database rating and the photo survey rating,

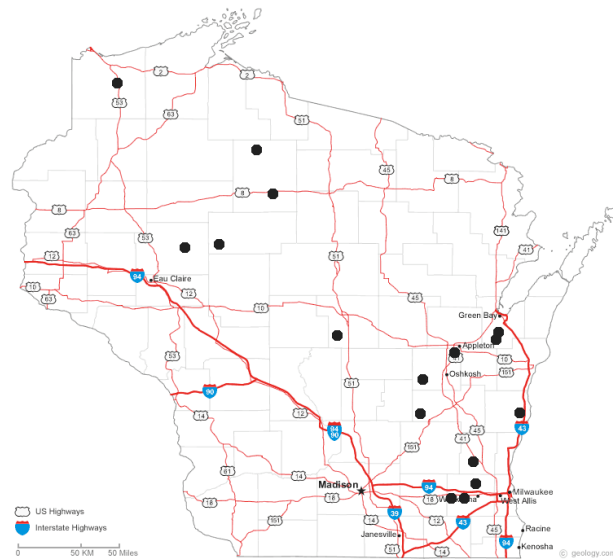
which was an unanticipated discovery during the research process. For analysis purposes, the visual and direct photo survey severity rating was used unless only a database severity was available for a particular project.

Table 2. Returned Project Surveys

Hwy No.	County	Region	Paving Year	PDI Severity Rating	
				Database	Photo Survey
STH 182	Price	North Central (4)	2007	1	-
STH 54	Portage	North Central (4)	2007	1	2
STH 44/49	Fond du Lac	North Central (4)	2007	1	3
STH 67	Sheboygan	North Central (4)	2007	1	0
STH 74	Waukesha	Southeast (2)	2008	0	0
STH 27	Douglas	Northwest (5)	2007	1	1
USH 53	Chippewa	Northwest (5)	2007	1	1
USH 8	Douglas	Northwest (5)	2007	1	-
STH 116	Winnebago	Northeast (3)	2007	0	0
STH 32/57	Brown	Northeast (3)	2007	3	0
STH 96	Outagamie	Northeast (3)	2007	1	1
STH 32/57	Brown	Northeast (3)	2007	1	0
194	Waukesha	Southeast (2)	2007	3	3
194	Waukesha	Southeast (2)	2007	1	0*
STH 60	Washington	Southeast (2)	2007	1	1
STH 64	Taylor	Northwest (5)	2008	0	-

Figure 5 shows the approximate locations of the returned survey projects on a Wisconsin state map. Four of the five state regions are represented by the survey responses, minus the Southeast region.

Figure 5. Returned Survey Project Locations



Prior to summarizing the responses, the research team coded the results to protect the confidentiality of the respondents and projects. Appendix C shows the summary of the results used for analysis in Chapter 4.

3.5 CHARACTERISTICS OF SURVEY RESULTS

Upon review of the survey responses, it was determined that the industry best practices are closely followed by Wisconsin contractors with some reported deviations. The specified notched wedge joint does not seem to add cost according to the contractors, which is also supported by the literature review as one of the benefits of the design, but judging by the responses, the confidence in the expected high performance is not as ensured. Some contractors have attempted to improve performance during joint construction with the use of

infrared heaters or tack coats, and the data analysis shows any correlations between innovation in the field and resulting pavement performance for the target projects.

Some unexpected data was collected during the survey process, including the number of non-specified, alternative longitudinal joint types that were actually constructed in the field. The assumption was that only the specified notched wedge joint was constructed, but the responses show that this is not always true. Furthermore, none of the contractors had any data to verify that the high density anticipated through the use of the notched wedge joint was achieved, making the prediction of future pavement performance more difficult.

3.6 SUMMARY

Survey of input from contractors is not standard practice in highway research, but this valuable source of information and expertise was critical to this study. The survey results were used to determine what practices are used in the field and their opinions of joint construction methods. The survey responses comprised the main purposes of the study: to determine what methods are utilized by companies in the state, differences between responding company practices, and the potential effects of these practices on longitudinal joint performance for HMA pavements.

CHAPTER 4

DATA ANALYSIS

4.1 INTRODUCTION

Data analysis methods were applied to the survey results to find correlations between the response data and the quality of the outcome, or rated pavement performance. Survey questions that did not address a method directly (e.g. job role of the respondent) or questions that had the same response for all returned surveys (e.g. type of extension used to create the notched wedge joint) are also interpreted and discussed in this chapter.

4.2 PROJECT DATA SUMMARY

The survey responses used for analysis and pertinent information including the year paved and severity rating, are shown in Table 3. All of the projects have been in service for at least 3 years, allowing for the biannual photo survey to be completed and determination if the pavement has failed early into the service life.

Surveys dependent on participation of human subjects are at risk for response errors, such as apathy or difficulty on the part of the respondent, which attribute for partial or total lack of completion of the survey. This survey was no exception to the threat of measurement validity, and not all questions were answered by all of the respondents, evident by the compilation of survey results (Appendix C). Precise results can still be obtained from small samples (Crano and Brewer 2002), but with a greater degree of uncertainty. During the response review, it was discovered that only 9 projects of the 16 returned surveys reported construction of a notched wedge joint, creating a smaller notched wedge joint response set

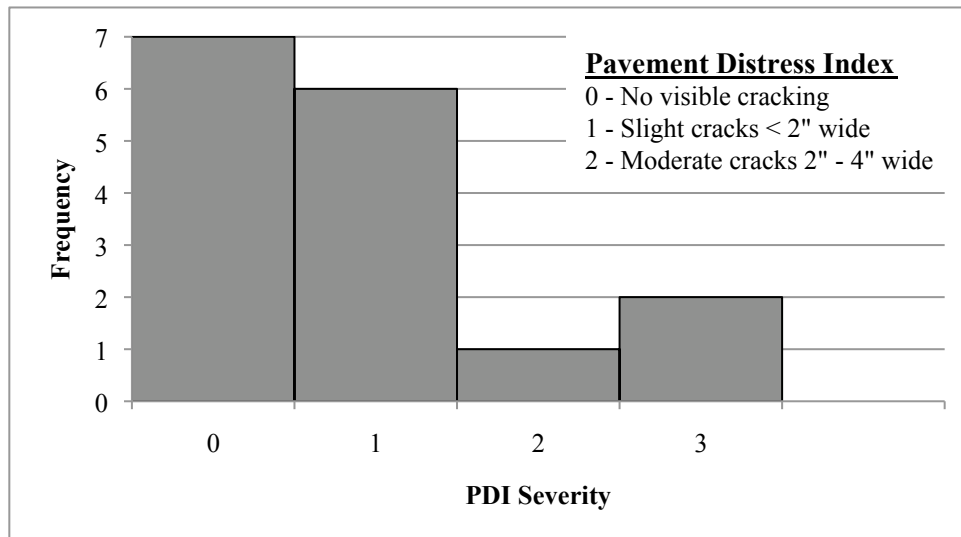
used to find any correlations between construction technique and premature failure of the notched wedge joint specifically.

Table 3. Responses for Analysis

Response Number	Paving Year	PDI Severity Rating
02060401	2007	1
02050401	2007	2
01020301	2007	3
01010301	2007	0
04040200	2008	0
02040501	2007	1
02010501	2007	1
02020501	2007	1
03040300	2007	0
03020301	2007	0
03010301	2007	1
03030303	2007	0
04010201	2007	3
04020203	2007	0
04030201	2007	1
02030500	2008	0

The frequency of severity for the project responses used in the study are shown in Figure 6, with the majority of the projects rated between 0 and 1. The photo survey rating was used for the purposes of analysis unless only a database rating was available.

Figure 6. Frequency of Severity Ratings



This distribution does not imply that longitudinal joint distress is not a significant issue, rather it is simply the results of the available data.

4.3 METHODOLOGY

A two-tailed t-test was used to analyze the results of the survey questions that can be used to draw inferences between method and the rated pavement performance. This statistical method is particularly effective for testing a null hypothesis (H_0) when using small sets of random samples. The null hypothesis asserts that there is no difference between the means (μ_1, μ_2) of a certain variable, for example, paving operations at night is not a factor on

paving performance ($H_0: \mu_1 \neq \mu_2$). The alternate hypothesis (H_A) would assert that conducting work at night does have an effect on paving performance ($H_A: \mu_1 \neq \mu_2$). The variable shared by the two sets is normally distributed within both populations, and the standard deviation is the same between the two sets.

The means of the two sets will always be different, caused by sampling error. The mean is only for a sample of data and provides an estimate of the population mean, and the t-test is necessary because a simple observation of the difference is not enough to form a conclusion.

The test will result in a p-value with a specified level of significance. For this study, a level of significance of 0.05 was chosen ($\alpha = 0.05$). If the p-value is greater than or equal to $\alpha = 0.05$, the null hypothesis (H_0) is determined to be true. If the p-value is less than α , it is concluded that the alternative hypothesis (H_A) is true, making the two means statistically significantly different. The p-value is the measure of the strength of the data that supports the null hypothesis, and the closer α is to zero, the more positive the observation of difference is the effect of the independent variable tested.

Responses that were universally agreed upon among respondents, otherwise deemed unsuitable for statistical analysis, or used for informational purposes are interpreted and discussed in this chapter.

4.4 CORRELATIONS BETWEEN METHOD AND PERFORMANCE

Survey questions were selected for data analysis based on the question content and corresponding response results. Responses for individual items shared by all of the respondents were not used for data analysis for lack of an independent variable. The

question order differs from the original survey and are instead grouped in the following categories: 1) background, 2) materials, 3) notch construction, 4) equipment, and 5) joint overlap.

Only 9 of the 16 returned surveys reported that the specified longitudinal joint type, the notched wedge joint, was actually constructed. This was an alarming discovery for the given sample size, yet it can be used to first determine if the notched wedge joint outperforms other joint types based on the response data.

Which type of longitudinal joint was actually constructed?

Notched wedge joints are specified by the Wisconsin state highway agency for use on all paving projects, but the responses show that this is not always the joint in place. Table 4 shows the responses used for analysis with the reported joint type included.

Table 4. Responses for Analysis by Joint Type

Response Number	Paving Year	Joint Type	PDI Severity Rating
02060401	2007	Notched Wedge (NWJ)	1
02050401	2007	Notched Wedge (NWJ)	2
01020301	2007	Combination (NWJ –binder, VE – surface)	3
01010301	2007	Combination (VE–binder, NWJ – surface)	0
04040200	2008	Vertical Edge (VE)	0
02040501	2007	Notched Wedge (NWJ)	1
02010501	2007	Flat Taper (FT)	1
02020501	2007	Vertical Edge (VE)	1
03040300	2007	Notched Wedge (NWJ)	0
03020301	2007	Notched Wedge (NWJ)	0
03010301	2007	Notched Wedge (NWJ)	1
03030303	2007	Vertical Edge (VE)	0
04010201	2007	Notched Wedge (NWJ)	3
04020203	2007	No Answer	0
04030201	2007	Notched Wedge (NWJ)	1
02030500	2008	Notched Wedge (NWJ)	0

Prior to the collection of the survey responses, it was unknown that any joint type other than the specified notched wedge joint was constructed. Table 5 shows the comparison of the performance of the notched wedge joint type versus the performance of the other types of joints constructed.

Table 5. Outcome by Joint Type

Shift	Number of Observations	Mean Severity	p-value
Notched Wedge	9	1	0.79
Other/Combined Joint	7	1	
H_0 : NWJ joint type does not make a difference in severity rating ($\mu_1 = \mu_2$) H_A : NWJ joint type does make a difference in severity rating ($\mu_1 \neq \mu_2$)			

By visual inspection of the mean severity, there appears to be no difference in joint type and resulting performance severity, which is confirmed by the t-test.

4.4.1 BACKGROUND DATA CORRELATIONS

The background data survey items requested general information about the projects including but not limited to weather and sequencing.

Was this project paved at night?

The majority of the responses indicated that they were paved during the standard day shift, and only 2 of the projects were constructed during night shifts. It is undetermined if quality of work changes based on shift.

Only one of the night paving projects was reported to be a notched wedge joint project. All 16 data results can be used to determine if night paving has an effect on severity for any joint type utilized in this study.

Table 6. Outcome by Shift

Shift	Number of Observations	Mean Severity	p-value
Night	2	2	0.51
Day	14	1	
H ₀ : night shift work does not make a difference in severity rating ($\mu_1 = \mu_2$)			
H _A : night shift work does make a difference in severity rating ($\mu_1 \neq \mu_2$)			

According to the data provided for this project, the two means are not statistically significantly different, so night shift work did not affect severity rating.

Were the weather conditions suitable for work when this project was in progress?

All of the responses indicated that the weather conditions were at least average to better than average.

Table 7. Outcome by Perceived Temperature

Perceived Temperature Range	Number of Observations	Mean Severity	p-value
Average	11	1	0.78
Better to Much Better than Average	5	1	
H_0 : perceived temperature does not make a difference in severity rating ($\mu_1 = \mu_2$) H_A : perceived temperature does make a difference in severity rating ($\mu_1 \neq \mu_2$)			

For the purposed of this study, perception of average or better than average temperatures does not statistically prove to have an impact on performance rating.

Did the joint location match the underlying joint location?

When overlaying a new HMA pavement, best practices recommend that the joint should be offset by 6" to prevent reflective cracking.

Table 8. Outcome by Joint Location

Notch Location	Number of Observations	Mean Severity	p-value
Offset to the left (min. 6")	3	1	0.91
Direct match	10	1	
H_0 : offsetting the joint does not make a difference in severity rating ($\mu_1 = \mu_2$) H_A : offsetting the joint does make a difference in severity rating ($\mu_1 \neq \mu_2$)			

Offsetting the overlay joint or directly matching the joint does not have a statistically significant relationship with pavement performance.

Approximately how many days was the joint exposed to traffic prior to final surfacing?

Traffic poses a concern to recently completed lanes left overnight because there is the potential for aggregate to break off at the joint. The amount of damage is thought to increase by the number of days exposed.

Table 9. Outcome by Exposure to Traffic

Number of Days Exposed	Number of Observations	Mean Severity	p-value
None	2	0	0.35
1-4 days	14	1	

The effect of traffic flow on unfinished lanes does not have a statistically significant influence on pavement severity rating.

4.4.2 MATERIAL DATA CORRELATIONS

The material survey questions were meant to find if any changes in mix design or composition impacted project performance.

Was binder grade used on the lower lift?

Was binder grade used on the final surface lift

Overall, most of the respondents used similar binder grade composition on both the lower and final surface lifts. However, 5 responses showed variation in binder grade use, which could possibly cause a change in performance severity.

Table 10. Outcome by Binder Grade on Lower Lift

Binder Grade	Number of Observations	Mean Severity	p-value
58-28	10	1	0.56
64-22	2	2	
H ₀ : change in binder grade on lower lift does not make a difference in severity rating ($\mu_1 = \mu_2$)			
H _A : change in binder grade on lower lift does make a difference in severity rating ($\mu_1 \neq \mu_2$)			

Table 11. Outcome by Binder Grade on Final Surface Lift

Binder Grade	Number of Observations	Mean Severity	p-value
58-28	11	1	0.55
64-22	3	1	
H ₀ : change in binder grade on final lift does not make a difference in severity rating ($\mu_1 = \mu_2$)			
H _A : change in binder grade on final lift does make a difference in severity rating ($\mu_1 \neq \mu_2$)			

The t-test verifies that there is no statistical difference evident between variation in binder grade on either the lower lift or final surface lift and pavement performance.

How much binder replacement was used?

Binder replacement has become more common in recent years, and it is very similar in composition to recycled asphalt pavement. The specifications have a predetermined limit on the percentage of replacement allowed, and as the mix approaches that limit, pavement performance may have been affected.

Table 12. Outcome by Amount of Binder Replacement

Amount of Binder Replacement	Number of Observations	Mean Severity	p-value
Less than specified limit	14	1	0.90
Equal to specified limit	2	1	
H ₀ : amount of binder replacement does not make a difference in severity rating ($\mu_1 = \mu_2$)			
H _A : amount of binder replacement does make a difference in severity rating ($\mu_1 \neq \mu_2$)			

The industry shift to the use of recycled materials like binder replacement does not show any statistical difference in pavement severity ratings.

Was any pre-overlay base patching required?

Patching is common measure to prevent cracks in the underlying pavement from migrating to the overlay, resulting in reflective cracks.

Table 13. Outcome by Pre-Overlay Patching

Amount of Binder Replacement	Number of Observations	Mean Severity	p-value
Patching	7	0	0.09
No Patching	6	1	
H_0 : patching does not make a difference in severity rating ($\mu_1 = \mu_2$) H_A : patching does make a difference in severity rating ($\mu_1 \neq \mu_2$)			

The benefit of doing pre-overlay patching to improve pavement performance is *almost* statistically significant.

4.4.3 NOTCH CONSTRUCTION DATA CORRELATIONS

Proper construction of the notch at the upper edge of wedge joint is critical to joint performance. The notch construction questions pertain to the construction and maintenance of the notch during the paving process for comparison to performance.

 Was the notched wedge joint formed in a 12:1 taper?

The purpose of this question was to establish if the specified taper ratio was maintained in the field or if changes have been made to the design, resulting in a change in pavement performance. 2 of the projects from a single company indicated that the taper varied as sketched on the survey responses and duplicated in Figure 7.

Figure 7. Wedge Taper Modifications

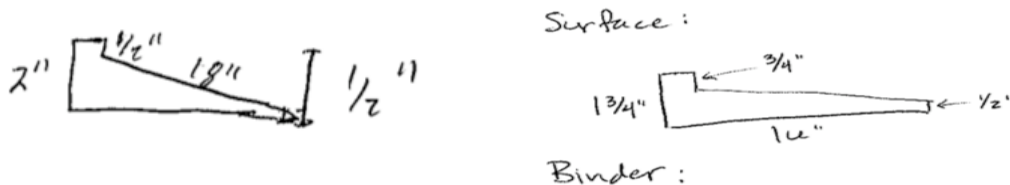


Table 14. Outcome by Taper Ratio

Amount of Binder Replacement	Number of Observations	Mean Severity	p-value
Modified Taper Ratio	2	2	0.43
Used 12:1 Taper Ratio	8	1	
H_0 : taper ratio does not make a difference in severity rating ($\mu_1 = \mu_2$) H_A : taper ratio does make a difference in severity rating ($\mu_1 \neq \mu_2$)			

The t-test confirms that the taper ratio is not statistically significant in determining pavement performance.

 Was a 1/2" notch formed?

As indicated in Figure 1, the Michigan state highway agency introduced the 1/2-in notch that improved the overall notched wedge joint design and increased density at the joint.

Table 15. Outcome by Notch Size

Amount of Binder Replacement	Number of Observations	Mean Severity	p-value
½" notch	7	1	0.58
¾" notch	2	1	
H ₀ : notch size does not make a difference in severity rating ($\mu_1 = \mu_2$)			
H _A : notch size does make a difference in severity rating ($\mu_1 \neq \mu_2$)			

The notch size is typically sized between ½-in and ¾-in, and this slight change from the standard Michigan joint ½-in notch is not statistically significant.

Did you mill out the joint before paving the second lane?

In some instances, the notched wedge joint can be milled manually or cut back entirely to create a vertical edge joint. This can be required to repair a joint or can be done out of contractor preference.

Table 16. Outcome by Milling First Lane

Amount of Binder Replacement	Number of Observations	Mean Severity	p-value
Milled	3	1	0.58
Not Milled	6	1	
H ₀ : milling the joint does not make a difference in severity rating ($\mu_1 = \mu_2$)			
H _A : milling the joint does make a difference in severity rating ($\mu_1 \neq \mu_2$)			

Milling of the notched wedge joint does not appear to have a statistically significant effect on pavement performance by conventional criteria.

4.4.4 EQUIPMENT DATA CORRELATIONS

Contractors tend to use similar equipment, but any variations can possibly affect pavement performance.

 What type of paver was used?

One of the aims of the study was to determine if equipment choice, in addition to methods deployed, led to a change in pavement performance. The survey responses showed that most of the equipment was of similar make and age, with some exceptions.

Table 17. Outcome by Age of Paving Equipment

Age of Equipment	Number of Observations	Mean Severity	p-value
Manufactured 2000+	6	1	0.84
Manufactured prior to 1999	5	1	
H ₀ : age of paving equipment does not make a difference in severity rating ($\mu_1 = \mu_2$)			
H _A : age of paving equipment on lower lift does make a difference in severity rating ($\mu_1 \neq \mu_2$)			

The age of paving equipment does not have a statistically significant influence on pavement performance.

 What types of rollers were used for the final surface on this project?

Every response indicated that steel drum rollers were utilized on the project, which is consistent with industry best practices. Some of the projects also supplemented the use of steel rollers with pneumatic rollers, which according to research and contrary to steel rollers, must be located within the joint during compaction.

Table 18. Outcome by Use of Pneumatics

Used Pneumatics in Addition to Steel Drum	Number of Observations	Mean Severity	p-value
Yes	5	1	0.44
No	10	1	
H ₀ : adding pneumatic rollers does not make a difference in severity rating ($\mu_1 = \mu_2$)			
H _A : adding pneumatic rollers does make a difference in severity rating ($\mu_1 \neq \mu_2$)			

The t-test shows that supplementing steel drum rollers with pneumatic rollers does not have a statistically significant influence on pavement performance.

Were infrared heaters used directly on the joint?

Infrared heaters are used to heat the joint to increase bond strength. This recreates a “hot lane” at a previously placed cold lane by raising the temperature after a lane cools between passes or overnight. The equipment requires a capital investment and increases labor cost by adding an operator, making the method more expensive than conventional means, but has been shown to increase density at the joint.

Table 19. Outcome by Use of Infrared Heaters

Amount of Binder Replacement	Number of Observations	Mean Severity	p-value
Used infrared heater	6	1	0.58
No infrared heater	10	1	
H ₀ : use of infrared heaters does not make a difference in severity rating ($\mu_1 = \mu_2$)			
H _A : use of infrared heaters does make a difference in severity rating ($\mu_1 \neq \mu_2$)			

Use of infrared heaters on the selected projects does not demonstrate a statistically significant difference on pavement severity.

Was a tack coat used directly on the joint?

This question was included to find if tack coats are commonly used, if there is repeated incidence of a particular product, or if they were being used at all.

Table 20. Outcome by Use of Tack Coats

Amount of Binder Replacement	Number of Observations	Mean Severity	p-value
Used Tack Coat	7	1	0.04
No Tack Coats	9	0	
H_0 : use of tack coats does not make a difference in severity rating ($\mu_1 = \mu_2$) H_A : use of tack coats does make a difference in severity rating ($\mu_1 \neq \mu_2$)			

Application of tack coat on the joint shows a statistically significant influence on pavement performance and severity rating.

4.4.5 JOINT OVERLAP DATA CORRELATIONS

The joint overlap questions refer the amount material available at the joint and any work performed manually to distribute that material.

Approximately how much mix overlap existed at the joint?

Mix overlap is of particular importance during construction of notched wedge joint because excess material leads to ridges or handwork, and insufficient material results in a “starved” joint. Material at the joint is less critical for other joint types by design. The response rate for this item was poor.

Table 21. Outcome by Amount of Mix Overlap

Amount of Binder Replacement	Number of Observations	Mean Severity	p-value
Up to $\frac{3}{4}$ -in	6	1	0.28
Greater than $\frac{3}{4}$ -in	2	2	
H ₀ : mix overlap does not make a difference in severity rating ($\mu_1 = \mu_2$)			
H _A : mix overlap does make a difference in severity rating ($\mu_1 \neq \mu_2$)			

The amount of mix overlap at the notched wedge joint does not show a statistically significant difference on performance for this range of data.

4.5 PROJECT DATA RESPONSE SUMMARY

Some survey questions could not be used for or were never intended for data intended for data analysis and development of correlations. Instead, the responses are summarized and discussed individually with the possibility of reader interpretation. A selected number of survey questions have been slightly rephrased for the purpose of general discussion. The survey questions are grouped in the same categories as the data analysis: 1) background, 2) materials, 3) notch construction, 4) equipment, and 5) joint overlap plus additional questions that address joint density, opinion, and quality.

4.5.1 BACKGROUND RESPONSE SUMMARY

The background questions served two purposes: 1) to obtain general information about the projects and 2) to develop rapport with the respondent. Survey research shows that particularly in the absence of a personal interview, inserting the least important and least difficult questions at the beginning of the survey encourages the respondent to complete the survey in full.

What was your role on this project?

Table 22. Summary of Respondent Roles

Title	Number of Responses
Project Manager	8
Foreman	3
Project Supervisor	1
General Manager	2

Table 22 shows that the respondents are employed in different roles among the companies that completed the surveys. Roles and responsibilities vary by company and are denoted by different titles depending on the organization. Field staff completed very few of the surveys; the majority of the respondents indicated that they served in a project management role, or the surveys were done as a group effort under the direction of a project manager. Surveys were not checked for completion prior to submittal, so interest in the study was limited by the willingness of the participants. This type of response bias is common in social surveys and depends on respondent mood or time available to complete a task. The response rate and role type most likely indicates that project managers were directed by those in upper management roles to assist in the research study.

List the dates the project paving started and completed.

Were the weather conditions suitable for work when this project was in progress?

All of the projects started and completed between May and October of their paving year, which is the ideal and typical construction season in the Midwest. The purpose of this

question was to distinguish if any of the projects were completed out of season or during months associated with adverse weather conditions.

Temperature ranges were addressed in the second question regarding suitability of the temperature to complete work. This response was highly dependent on the ability of the respondent to recall the information, so it was really intended to determine if there was anything unique or memorable about the weather conditions (e.g. heavy rains, extreme temperatures, etc.) Data analysis showed no correlation between perceived temperature and outcome of the pavement performance, which was expected because all of the responses were average to positive.

Was this project paved at night?

Day shift work typically requires keeping lanes open during construction to maintain traffic flow. Night shift work allows for paving of multiple lanes sooner and significantly less traffic over unfinished work because the lanes are often closed entirely. Common industry consensus is that bond strength is improved at higher temperatures best achieved by shorter time between passes. Further, traffic is considered detrimental to unfinished work because of the potential to break off aggregate, regardless of what type of joint is constructed.

Difference in quality of work between shifts is unknown and was the secondary purpose of this question. Inadequate lighting, different crew compositions and work conditions could affect the quality of pavement.

Although the projects were closed to traffic overnight for the two night projects, the quality of pavement was unaffected according to the analysis.

Did the joint location match the underlying joint location?

Research indicates that in overlay projects, the new joint should be offset from the existing joint by at least 6-in. This seems counterintuitive because the offset joint introduces a second failure point at the longitudinal joint, but research strongly supports the offset as a means to prevent reflective cracks.

The results of this study show that there is no difference in performance between overlay projects that offset or those that directly match the existing joint.

Did you pave multiple lanes at once (in echelon)?

This question was disregarded and not included in the analysis. None of the notched wedge survey responses indicated that lanes were paved in echelon. This is the obvious result because the design of the notched wedge joint does not allow for paving in echelon, and only served as a test of response validity.

Approximately how many days was the joint exposed to traffic prior to final surfacing?

Some research suggests that traffic can actually improve compaction at the joint (Zinke 2008), similar to the method of using a haul truck to compact a joint. Common industry consensus is that traffic causes damage to unfinished lanes, but the 2 projects closed

to traffic did not show any difference in performance than those projects open to traffic for up to 4 days.

4.5.2 MATERIAL RESPONSE SUMMARY

Mix design content is controlled by state specifications, but contractors or pavement engineers are allowed to modify mix designs to some extent. The modifications in amounts of recycled materials and changes in gradations must be within allowable limits in the specifications. The purpose of the material questions were to determine if any changes were made and their ultimate effect on the pavement performance, if any.

Did the gradation vary from the standard specifications?

The purpose of this question was to determine if the gradation of the mix design was different than that specified and if performance changed accordingly. All but 1 of the responses indicated that any variation in gradation was within the specified limits. The single response was unclear and not enough data to use for correlation to resulting performance.

Did the mix contain any Recycled Asphalt Material (RAM)?

All of the mix designs reported use of recycled asphalt material (RAM), which was anticipated by the researchers. Specifications typically limit the amount of RAM in the mix by a certain percentage. This question was included in the survey to test consistency of the answers and was not used for further data analysis because it was shared by all the projects.

Was binder grade used on the lower lift?

Was binder grade used on the final surface lift

The intent of this question was to determine if there was any variation in the amount of binder grade used on the lower and final surface lifts. The responses showed very similar responses in use of binder grade 58-28 on both lifts, indicating that the mix design is relatively uniform among contractors and the paving projects examined. Binder grade 64-22 was used on several projects, but did not appear to make a difference in performance according to the response analysis.

How much binder replacement was used?

Typical highway agency specifications dictate an allowable percentage of binder replacement between 20% and 40%, and the Wisconsin specifications are within this range. Binder replacement is recycled material that can lower material costs and use is becoming more common as pavement performance demonstrates similar results to those that use all virgin materials.

All of the survey responses indicated that the amount of binder replacement used was equal to or less than the specified limit. Those projects that used an amount equal to the limit did not show any significant difference than those projects that used less than the allowable limit of binder replacement.

Was any pre-overlay base patching required

Patching of preexisting pavement is a preventative measure used to deter reflective cracking from damaging new pavement. Judging by the responses of this study, it is used in a little more than half of the projects regardless of longitudinal joint type built.

The data results show that base patching is almost statistically significant and contractors should consider these results when determining if patching will be used on future projects.

4.5.3 NOTCH CONSTRUCTION RESPONSE SUMMARY

Premature pavement failure has been blamed on poor longitudinal joint construction, and the current specifications require construction of a notched wedge joint design. The following questions were included to establish if the specification is followed and if the integrity of the joint design is maintained in the field.

Which type of longitudinal joint was actually constructed?

Notched wedge joints are the specified joint type, but the survey responses show that of the 16 total surveys returned, only 9 indicated that a notched wedge joint was actually constructed. This result was surprising, as the assumption prior to the study was that only notched wedge joints are constructed as specified. This poses the question as to why contractors are choosing to use a different joint type or why the joint had to be altered in the field. It also prompts the question that for such a large incidence rate in a small sample, how widespread is this phenomenon?

Despite the high incidence of construction of unspecified longitudinal joint types, it does not appear to have a significant impact on pavement performance for this sample. Research does show that the notched wedge joint outperforms other joint types with higher density and reduced permeability industry-wide, which was the reason for the state specification change.

Was the notched wedge joint formed in a 12:1 taper?

The standard notched wedge joint used in Wisconsin has a 12:1 taper (other state highway agencies use different ratios) as shown in Figure 1. This ratio has shown great success in Wisconsin in published research.

2 of the surveys responded that the standard ratio was altered in the field, and sketches of the result were provided. Despite these changes, the alteration showed no significant difference in performance, likely because it is still similar to the original specifications.

Was a 1/2" notch formed?

The 1/2-in notch was the determining factor in the original design success in Michigan and inability of Wisconsin to duplicate the results during early testing of the notched wedge joint type. The notch provides the greater confined edge for increased density and less permeability. The standard notch dimensions are (1/2-in to 3/4-in), though the standard notch size is only 1/2-in.

Only 2 of the 9 notched wedge joint survey responses increased the size of the joint by 1/4-in, and no significant difference in performance was detected.

Were you able to maintain the notch?

During the construction process, the integrity of the notch can be compromised when the correct depth ($\frac{1}{2}'' - \frac{3}{4}''$) is not maintained. If the notch is damaged during construction, it can be remedied in part by milling out the notch, replacing with a different joint type, or worse, leaving the poorly constructed joint in-place. All of the survey respondents reported that the notch was maintained minus one exception. A correlation between maintenance of the notch and pavement performance cannot be determined with only one sample project. This survey prompted any respondent that did not maintain the notch to explain how the notch was reestablished or repaired, but no solution was provided in the response.

Did you mill out the joint before paving the second lane?

Milling of the joint is done in the field to repair a poorly constructed joint or to replace the joint completely with a conventional vertical edge joint. This can be completed at contractor discretion or as directed by a pavement engineer to maintain the quality of the pavement and better ensure future performance.

Of the 6 notched wedge joint respondents, 3 reported that the joint was milled out prior to paving the second lane, or at least one-third of the total notched wedge joint projects. The analysis resulted in no change on performance.

4.5.4 EQUIPMENT RESPONSE SUMMARY

The survey questions concerning equipment used on the project were more general interest items. The equipment choices and use proved to be mostly common among the contractors overall, but there were so differences for consideration.

What type of extension was used to create the notched wedge joint?

How was the joint compacted?

Research shows that although pre-manufactured extensions are available to create the notched wedge joint, the industry tends to fabricate extensions for use in-house, and contractors in Wisconsin are no exception. All of the respondents used their own fabricated extensions, so there is no variable for analysis.

It is standard practice in the state to use a tag along side roller to compact the notched wedge joint. This technique was proven to be successful in a WisDOT report (Toepel 2003) and used unanimously by the respondents, making it unfit for analysis.

Did you use a material transfer device?

A material transfer device feeds the HMA from the front of the paver to the rear, and spreads it to the desired width before compaction. This feed system is relatively standard, and it was expected that all of the responses would report use of the device.

What type of paver was used?

Ideally, the joint should be constructed well directly out of the paver with no need for manual adjustments. The purpose of this survey question was to determine if age of the paver changed the ultimate performance of the pavement, which could then be traced back to the paver used at time of construction. The analysis showed that age of the paver, even ten years or greater of a difference, showed no significant change in performance.

What types of rollers were used for breakdown on this project?

What types of rollers were used for the final surface on this project?

Steel drummed rollers were used by all of the respondents. Several projects also supplemented the steel rollers with pneumatic rollers on a single project. However, this addition in equipment showed no significant improvement in or detriment to pavement performance whether used on the breakdown or final surface of the projects surveyed.

Was the second lane rolled from the hot side or cold side?

All of the respondents rolled the second lane from the hot side, regardless of the type of joint constructed. This corresponds with industry recommended best practices and paving construction research. Because all of the respondents are conforming to the best practice, it could not be correlated with performance.

When the lanes are rolled, are they rolled from inside the joint, on the joint edge or over the joint?

Steel drum rollers are recommended for use with an overlap over the joint of 3-in to 6-in to prevent material from breaking off onto the adjacent lane caused by rolling on the joint, or to prevent transverse movement of the mix (“pinching”) by rolling inside the joint. According to research, pneumatic rollers should be operated within the joint by at least 6-in to 12-in due to the greater amount of pressure exerted by the rubber tires. Research prefers the use of steel vibratory drum rollers to pneumatic rollers; a preference shared by the respondents with the exception of those contractors that supplemented the use of pneumatics on their projects.

Were infrared heaters used directly on the joint?

Infrared heaters are used to recreate paving temperatures at the joint of a previously placed lane to increase bond strength. This practice shows proven results in increased joint density in research, particularly on the east coast where it is utilized heavily. This method requires purchase and operation of additional equipment, raising the unit cost of the joint versus conventional methods.

The 2 responding companies and 6 projects that did use an infrared heater on the joint did not show improvement in pavement performance when compared to projects that did not utilize the equipment.

Was a tack coat used directly on the joint?

Tack coats are another means to increasing bond and density at the joint that has shown some success in research. The added cost is minimal in terms of product and application time.

Similar to the results of research, the data from this study supports that the use of tack coats may improve pavement performance by improving bond strength and reducing permeability.

Were joint sealants or tapes used directly on the joint?

Were any other methods used directly on the joint?

Non-prescriptive construction specifications allow contractors some degree of innovation in the field to determine which methods work best for their own crews and result in the highest pavement and joint quality. Similar to tack coats, research indicates that some contractors apply joint sealants or joint tape to increase bond strength and density at the joint. However, none of the respondents chose to use joint sealants, tapes, or any other method directly at the joint.

4.5.5 JOINT OVERLAP RESPONSE SUMMARY

The amount of mix overlap at the joint determines how much handwork is necessary. Ideally, contractors should aim to create a joint that requires no raking or bumping. These activities increase the size of crews, add labor cost, and add the potential for human error that can lead to joint failure.

Approximately how much mix overlap existed at the joint?

Excess material at the joint distributed by handwork can create ridges at the joint. Some operators prefer excess material at the joint to make compaction less difficult. Ridges can make compaction less effective in achieving density, handwork is very imprecise, and good compaction should be the primary goal over operator ease.

It is also difficult to achieve the correct density if there is not enough material at the joint prior to compaction. Too little material can also result in an inverted joint, leaving a slight depression that can collect and hold water, possibly expediting damage during freeze-thaw cycles.

Best practices repeatedly stress a range of 1-in to 1.5-in amount of mix overlap at the joint prior to compaction. Of the 9 notched wedge joints, only 2 surveys were at the lower side of the range (1-in), 6 indicated an amount less than recommended by literature (0 to $\frac{3}{4}$ -in) and a single survey did not respond to the question. However, all of the projects complied with the suggested mix overlap of $\frac{1}{2}$ -in to 1-in recommended by the National Asphalt Paving Association. The results of the data analysis support that this difference in material does not have a significant affect on pavement performance and the NAPA recommendations may be sufficient.

Was raking required at the joint?

Was bumping required at the joint?

None of the respondents indicated that they did any raking or bumping at the joint. This could be an example of survey response acquiescence, or the tendency to answer a question with the perceived correct response. Best practices strongly discourage any handwork at the joint, instead recommending monitoring quality during construction of the joint to eliminate the need for raking or bumping.

The preceding question responses indicated that the mix overlap was less than the recommended range for at least 6 of the 9 notched wedge joints, which would mean that there was less material at the joint according to research standards but within NAPA standards. Raking and bumping is used to distribute excess material at the joint, and if the respondents had too little material at the joint, this would explain the responses. The unanimous answer does not allow for any further analysis.

4.4.6 JOINT DENSITY RESPONSE SUMMARY

The survey questions regarding density measurements at the joint were included to determine if the contractors or state agency had any knowledge of the density achieved at the joint or if any records were kept on density test results for reference.

Were any cores taken at the joint?

Were any density tests done directly on the joint for company records?

What density was achieved directly at the joint?

Based on the responses to these three questions, density was not tested by state pavement engineers or contractor staff at any point during or after construction. Therefore, neither the state nor the contractors are aware if density was actually achieved and there is no archival record of density testing data. The lack of test data makes predicting pavement performance in both the short- and long-term more difficult. Density test data could verify if the joint was constructed properly, and stronger correlations can be made by comparing methods to test data. These responses were not used for this study but do pose an interesting problem for future research.

4.5.7 CONTRACTOR OPINION RESPONSE SUMMARY

Contractors are rarely given the opportunity to contribute their opinions to research. The purpose of these questions was to request their unbiased perspective on perceived project challenges and their impacts, joint type performance and cost effectiveness. This also allowed the researcher to solicit their recommendations for improvement of the notched wedge joint based on their valuable field experience.

What challenges or problems occurred on this project?

Did these challenges possibly impact job performance?

The open responses to this question could not be used for data analysis and did not result in as much insight to field operations as hoped. One contractor indicated that a project experienced “cold and wet weather at gravel grade” and “soft edges where the soil type changed from clay to silty.” The contractor hypothesized that this may cause the heaving evident at the same locations each year.

Another contractor explained that the “underlying concrete” pavement was “unstable” and believes this condition was the cause for reflective cracking that appeared very soon after completion of the overlay.

Other responses noted some difficulty with a tender mix or staging, and two cited non-descript issues with weather, though none of these responses were thought to impact job performance.

The lack of or brief responses can be interpreted to mean either there were actually no challenges on the projects of note or the difficulties were not unique enough to recall.

How well does each type of joint perform?

The contractors were asked their perspective on joint performance by individual joint type. This opinion was requested to determine if the contractors expect better performance from the specified notched wedge joint or by other joints. This can lend insight to which joint type they would prefer to use or have the most experience constructing.

Table 23. Perception of Performance by Joint Type

	Not at All	Pretty Well	Well	Very Well	Extremely Well	Total Number of Responses
Flat Tapered Joint	2		4			6
Notched Wedge Joint	1	8	1			10
Vertical Edge Joint			7	4	2	13
Heated Joint					4	4

The quantities indicate the number of survey responses that chose each option of the Likert scale for each joint type.

The flat tapered joint is similar to original wedge joint design used in Wisconsin (Figure 1) and does not include a notch. The tapered joint design may result in a loss of density at the most vulnerable point of the joint and not provide as much of a confined edge as the notched design. The low response for this joint type can be attributed to some contractors who claimed to not use this joint at all or a general low preference for this joint.

The contractors appear to believe that the notched wedge joint performs well at best, with most of the responses indicating that performance is mediocre. This is contrary to all construction research, which repeatedly proves that the notched wedge joint outperforms all other joint types. These results can indicate a lack of training or experience with the notched wedge joint, or explain why other joint types were built despite the state specifications, particularly the conventional vertical edge joint. This negative response can also serve as evidence that joints may not be constructed correctly to achieve the correct density and why pavements are failing prematurely by current specifications.

The vertical edge joint had the most positive expected performance results in the survey. This joint type is conventional and simple to construct, and crews may have the greatest amount of experience with this type of joint. This acquiescence may translate to a reliance on building vertical edge joints instead of the specified notched wedge joint rather than improving training in the correct method, all based on a perception of performance.

The infrared heated joint was the only write-in answer submitted by two different contractors. Both contractors believe that a heated joint performs as well or better than other joints. Use of the infrared heater does not preclude a contractor from building a notched wedge joint, and such innovation in the field to improve performance should be encouraged.

How economical is each type of joint?

The contractors were then asked their perspective of the cost effectiveness of each joint type. The response could indicate if variations in cost prevented contractors from building a particular type of joint or if the specified notched wedge joint was more costly compared to other joints. Regardless of joint type, a bad joint costs the same as a good joint to construct, but will cost the contractor and the state much more over the life cycle of the pavement. It is assumed that all of the respondents based their answers below on initial construction costs.

Table 24. Perception of Cost Effectiveness by Joint Type

	Not at All Economical	Pretty Economical	Economical	Very Economical	Extremely Economical	Total Number of Responses
Flat Tapered Joint	2		2	5		9
Notched Wedge Joint		4		6	2	12
Vertical Edge Joint			7	4	2	12
Heated Joint	3					3

The quantities indicate the number of survey responses that chose each option of the Likert scale for each joint type.

The flat tapered joint responses varied from not at all economical to very economical, and it certainly requires less precision in execution than the notched wedge joint.

The notched wedge joint and vertical edge joint received somewhat similar responses, pointing to the idea that the costs are perceived to be similar by the contractors and should not influence which type of joint is actually constructed. Thus, if cost is not a prohibiting factor, the notched wedge joint should be constructed as specified.

As expected, the heated joint was the only joint to be dubbed “not at all economical” by the few respondents that utilize the technology. Though the contractors acknowledge the added costs of equipment and labor, the same contractors still use the method to improve pavement performance.

What can be done to improve notched wedge joint performance?

The response to the question was the most anticipated and some of the most interesting results for the researcher. Respondents were allowed to compose their response freely with no prompts or suggestions. Recommendations included:

- Bid item for infrared heaters
- Payment for heavy use of tack coats
- Cost incentives for performance
- Assurance of adequate joint tacking
- Milling out the wedge entirely
- Increased training and attention to detail

Cost incentives can be difficult to enforce fairly, particularly without accurate density data to verify that any density requirements are met. This item should be part of revision discussions if WisDOT decides to use a performance-based specification in the future.

The use of infrared heaters was recommended by three of the four contractor respondents. This may encourage future research on the pavement performance of infrared heaters compared to projects that do not utilize the method and determination if it should be included as a bid item.

Two of the contractors recommended increased use of tack coats and payment for what may currently be considered excess use. Application of tack coats to the joint is the only method that showed statistically significant improvement on pavement performance and may warrant future study and consideration.

4.5.8 QUALITY ASSURANCE RESPONSE SUMMARY

The quality assurance survey questions were written with the potential to be included in the data analysis, but at a minimum to provide insight into the quality control process in the field at the contractor level and how that procedure or lack thereof may influence pavement performance.

How many formal inspections of the joint were performed by job foremen during construction?

This question was disregarded and not included in data analysis. The intent of the question was to determine if quality control is a continuous, formal process for contractors and would be correlated with the pavement performance. In retrospect, the possible responses are vague and subjective and not useful for this study.

Should there be more DOT oversight during construction?

Overwhelmingly, 15 of the surveys stated that they did not want more state agency oversight during construction. However, a single survey did request additional pavement oversight by regulation agencies on the condition that they were well trained in HMA mix design and installation because the current feeling is that they avoid HMA mixes due to detractors like odor or mess. This perspective was echoed in part by a field foreman respondent, who would only be willing to work with state pavement engineers if they were “more qualified.” This question was included for informational purposes only, but as funding and resources allow, more training of state staff may be beneficial in improving notched wedge joint design and construction as well as HMA pavements overall.

Is there a company and/or project specific Quality Control Plan?

The responses to this question were not intended to be included in the data analysis, but instead to establish if there is a formal, written company procedure for pavement construction, particularly for notched wedge joints. Only 2 of the 4 responding companies were willing to share their company specific plan, which may be useful for future studies of quality control process influence on pavement performance.

4.6 DATA ANALYSIS SUMMARY

Surveys of human subjects are highly dependent on personal interest in the study and fidelity of recall on the part of the respondents. The response to the original request for

voluntarily submitted projects was poor, which was echoed in the response to the survey for assigned projects. The author acknowledges that it is difficult for any respondent to recall information from a project completed three to four years prior to the study, and the data may not be as accurate as more recent projects. Similarly, a small sample group allows for data analysis, but with a lesser degree of reliability .

This survey did show that contractor perspective of notched wedge joint performance is poor, and this may lend itself to poor execution in the field and a starting point for improvement. Several contractors strongly support the use of tack coats and infrared heaters, and this same kind of motivation to improve pavement performance should be applied to sound construction of the notched wedge joint.

CHAPTER 5

PERFORMANCE MEASURES, CONCLUSIONS, AND RECOMMENDATIONS

5.1 INTRODUCTION

Longitudinal joints are the primary cause for pavement failure, and this is a serious industry problem to which Wisconsin roadways are not immune. After intensive study and participation in industry research, WisDOT specified the notched wedge joint as the standard joint to be used for roadway construction. The joint design showed higher densities, lower permeability, and added safety benefits, all at the same cost of constructing a more conventional joint. In practice, pavements are failing as early as three years into their service life, making the 12-15 year expected design life almost unreachable using current construction methods. This results in costly repair and a dramatically shortened pavement service life for existing pavements, and no established means for improvement of future pavements.

The purpose of this study was to examine a sample of projects completed in the last three years to determine if the construction methods used are contributing to the roadway deterioration assessed by the WisDOT severity index. If construction methods were determined to be the cause for deterioration, the research team would 1) propose suggestions for revisions to the WisDOT specifications and 2) make recommendations for a coring program to assess density. Secondary objectives include 1) increased training focus, 2) improved quality, and 3) increased productivity in the field. The recommendations developed in this research study address each of these objectives.

This research study and the literature review that preceded it provides practical suggestions for specification revisions that allow for innovation and joint density test procedure recommendations with the intent of data collection without penalization.

5.2 SUMMARY OF RESEARCH

The primary objective of this research study was to form correlations between methods used to construct the notched wedge joint and the severity rating assessed by WisDOT pavement engineers after at least one year of service. A survey was written and distributed to contractors to analyze a selection of projects. The data collected on these projects represent common practices utilized in Wisconsin and examples of any other methods contractors are using to improve performance. The decision making process to produce quality joints prior to starting a project has not been examined from this perspective in past research.

A literature review of prior research easily accomplished the secondary objective of the study to compare industry and academia accepted best practices and determine if they aligned with practices currently used in Wisconsin highway construction. Any variations shown to improve performance or worse, cause future damage, were addressed with specification revisions if the potential effects were deemed significant.

Specification revisions must carefully consider freedom of the contractor to improve performance through innovation and proportionally assign risk and responsibility of work to the appropriate parties. Method-based specifications vary by state in that some are prescriptive and detailed, whereas others are left open to interpretation or serve only as a basic guideline. Overly detailed specifications can inadvertently assign too much

responsibility for pavement performance to the SHA, leaving the contractor with a disproportionate amount of risk or responsibility for their work. Performance-based specifications typically require a percentage of theoretical maximum density at the mat with a density measurement at the joint that is 2% less than that of the mat plus an air void specification. The density requirements must be reasonable to obtain in order to be successful, yet high enough to ensure a quality joint is enforced. A comprehensive density-testing program, including extensive training of pavement engineers in testing methods, must be developed to obtain accurate and fair results. Both method-based and performance-based specification revisions require careful consideration to achieve the desired results without limitation.

5.3 CONCLUSIONS

Longitudinal joint deterioration and contribution to pavement failure is an overt and unsolved issue for all of the paving industry, Wisconsin included. The notched wedge joint design and implementation into the WisDOT specifications offered a means to alleviate the problem and reduce pavement failure. Research review galvanizes that the notched wedge joint produces higher densities and reduced permeability when good workmanship and careful quality control are paramount.

Upon review of the WisDOT database and photo survey archives, the problem does not appear to be as prevalent as suggested by contractors and pavement engineers. This can be explained by the prompt repair of damaged joints by the Wisconsin SHA, a costly problem also too prevalent in the industry overall. The photo survey archives show the reason that the majority of the projects examined in this project has less than 2" of visible

cracking or none at all. Before joint damage progressed from a lower 0-1 PDI severity level to a more serious 2-3 PDI distress rating, the joints were sealed and repaired to prevent damage to the adjacent mat or complete pavement failure. The issue is disguised when the majority of the PDI ratings remained at the lower severity assessed prior to repair. This phenomenon creates a false sense of confidence in current construction methods and undeservedly calls the proven notched wedge joint design into question. This is particularly true based on the survey results that only 9 of 16 projects actually constructed a notched wedge joint in accordance with the specifications. The SHA may erroneously conclude that the notched wedge joint is not performing as shown in research based on the results of pavement severity assessments, when in reality the joints are not built as specified.

The survey used in this study depends on human fidelity of recall, which is fallible and increasingly faulty over time. The research team was able to make a positive correlation between the use of tack coats and improvement in joint performance, and nearly make a correlation between the application of pre-overlay patching and prevention of reflective cracking in the new pavement. Although contractors appear to be building the notched wedge construction joint in accordance with industry best practices, the results exposed some lack of compliance with the WisDOT specifications.

The survey results also showed that neither the contractor nor the SHA has any numerical evidence of the density achieved at the joint, and there is no target density set to be achieved at either the joint or the mat. Long-term data collection would certainly prove valuable in strengthening correlations between construction methods and pavement performance.

5.4 RECOMMENDATIONS

The authors provide the following recommendations for successful construction of a notched wedge joint in Wisconsin and evaluation of joint performance.

5.4.1 SPECIFICATION REVISIONS

One of the objectives of this study was to propose specification revisions to address any poor construction methods that did not align with industry best practices or were shown to contribute to pavement deterioration. The survey results and data analysis correlations showed that with two exceptions, contractors are in working in compliance with both best practices and WisDOT specifications: 1) construction of the notched wedge joint and 2) application of tack coat.

The WisDOT highway specification *Section 450.3.2.8 Jointing* designates that only the notched wedge joint should be constructed at the centerline of all mainline paving operations that meet pavement thickness requirements. The correct taper and notch dimensions of 12:1 and ½-in, respectively are also outlined in this section. The tag along side roller used by all of the surveyed contractors and proven by Wisconsin specific research (Toepel 2003) is defined. This section provides clear expectations that align with best practices without being prohibitive for contractors and should remain as written. Only 9 of the 16 survey responses indicated that the notched wedge joint was actually constructed, and the results showed a distinct preference for the more conventional vertical edge joint. Pavement engineers should strictly enforce the construction of the notched wedge joint

according to the existing specifications, and contractors should provide a formal submittal to the SHA for review if the joint type is to be changed or modified in design for any reason.

Application of tack coat is clearly indicated in *Section 450.3.2.7 Tack Coats* and *Section 450.3.2.8 Jointing* to be applied to the “tapered surface before placing the adjacent lane.” Yet, the survey responses showed that less than half of the total responses used tack coats on their project. Utilization of tack coats has been shown by industry research to contribute to higher densities, including by this study, which made the only positive correlation between application of tack coats and effect on performance of all of the survey items.

The current revision of method-based specifications used by WisDOT and the Wisconsin contractors are comprehensive and well-written. The survey results demonstrate that contractors are aware of and abide by many of the industry best practices and SHA requirements. However, pavement engineers should be vigilant in enforcement of the WisDOT specifications and assess penalties for nonconforming work that per specification *Section 450.5 Payments*. If alternatives are not preapproved prior to placement or nonconforming work is left in place, payments should be adjusted as an incentive for contractors to build the notched wedge joint correctly.

5.4.2 JOINT DENSITY TESTING

Joint density data records currently do not exist and must be collected to evaluate performance perpetually. Without baseline information and repeated evaluations of performance beyond surface layer evaluation, it can never be fully known by the contractor

or the SHA if a joint has been constructed well and which methods lead to joint success or failure.

Baseline information collected at time of construction can be used to predict how the pavement will perform and if the contractor is building joints correctly on other projects. This information would allow for stronger correlations between construction methods and performance to be made and adjusted continuously. Progress can be made with consistent iterative improvement of methods when compared to joint density measurements and observation of performance over time.

The author recommends development of a detailed density-testing program for implementation. The SHA should choose a density testing method, either destructive or non-destructive, that best suits their needs and produce results within tolerable limits of reliability. All field staff and contractors should be trained on the accuracy of the selected testing methods and how to properly collect data results. In the early stages of implementation, the purpose of the density-testing program should be the collection of valuable data to be used for comparison and pavement improvement. It should not be used for development of performance-based specifications until it can be proven that the contractors are diligently abiding to the existing method-based specifications, and until accurate test results can be obtained to expand the program in a manner that is fair to the contractors.

Documentation of joint density data should be formally archived with the results of pavement distress severity assessments for each project. This information should be made available and easy to access for staff, contractors, and researchers, and reviewed periodically at technical meetings to continuously compare and improve performance.

5.4.3 JOINT METHOD TRAINING

The final recommendation is formal training in the notched wedge joint construction method to reinforce the SHA expectations outlined in the specifications and to galvanize the importance of contractor adherence to the standards. Training should be implemented on multiple levels from individual crew members to SHA pavement engineers for overall improvement.

The seasonal nature of the work makes training of crew members difficult, particularly during the busy summer construction season. However, the specifications should be reviewed as part of quality control program prior to the start of work for a new employee. A brief orientation would stress the importance of proper construction, and establish expectations for quality of work. Employers should recognize a secondary benefit to this type of training in the form of improved productivity and reduced learning curve. Veteran employees could also benefit from additional training to sever reliance on other conventional methods or prevent avoidance of the notched wedge joint method. It would also equip foremen with the tools to train their crew members and execute a greater amount of quality control during construction.

Nearly all of the survey respondents agreed that no additional DOT oversight was warranted, but one project manager was willing to offer that review by a pavement engineer would be valuable with increased training. In their opinion, there was a tendency to avoid HMA mixes entirely. Training in mix designs and proper construction of the notched wedge joint would allow pavement engineers to 1) review any requests for alternatives, 2) provide

detail-oriented quality control during construction and 3) rigorously enforce the WisDOT specifications as they are currently written for the best joint performance.

5.4.4 SUMMARY OF RECOMMENDATIONS

The following is a simplified summary of the recommendations presented as a result of this research, categorized by each of the parties responsible for implementations: 1) State Highway Agency, 2) Contractors and collaborative effort of 3) SHA and Contractors.

- **State Highway Agency**
 1. Maintain the current distress rating index with the following changes:
 - a. Identify longitudinal cracking separately from transverse cracking to isolate the issue and devise appropriate solutions as needed.
 - b. Notify contractors of distress rating assessments.
 - c. Maintain detailed records of severity for future study and comparison.
 - d. Train pavement engineers in HMA mix designs and notched wedge joint construction methods.
 - e. Enforce the WisDOT specifications as written.
 - f. Develop a density-testing program as a means to collect data for comparison and improvement.
 - a. Notify contractors of density test results so methods can be addressed if necessary.

- **Contractors**

1. Conduct formal notched wedge joint training for all crews and field staff annually before the start of construction season.
2. New crew members should receive training immediately prior to the start of work to maintain consistency and quality, and to ease the learning curve.
3. Prepare a quality control program specific to notched wedge joint construction for review with crew members and WisDOT pavement engineers.
4. Abide by WisDOT specifications in the construction of notched wedge joint and methods.

- **SHA and Contractor**

1. Cooperate in density testing program implementation.
2. Enforce training requirements.
3. Work collaboratively to foster a positive working relationship and facilitate progress through pavement performance improvement

5.5 RECOMMENDATIONS FOR FUTURE RESEARCH

No single study can prove or disprove the theory that construction means and methods are the primary contributors to joint performance or failure. However, this study does contribute to a greater understanding of joint construction, the performance that may result from those choices, and assists in determining the next step towards improvement of performance.

The element human error of the study could certainly be improved in future studies. Reliance of the study on participation from contractors could also be partly or completely eliminated by direct observation by a researcher. False consensus bias could be reduced by directly observing the means and methods during construction of a sample of projects in each county and performance could be assessed a predetermined number of years later to make a direct cause and effect observation. This would also address bias caused by respondents who want to confirm the research theory and adjust their answers accordingly or fear repercussions for what could be interpreted as the wrong answer. A researcher could watch construction in progress and determine firsthand if the notch of the joint was maintained or if any raveling occurred at the lower part of the wedge, and note the equipment and methods used.

The vast majority of project data received in this study is for projects completed in 2007 (see Appendix C). The amount of time between project completion and this study is significant, and the original project team members could possibly no longer work for the company or simply not accurately recall the details of the project. Future studies on pavement performance could identify projects to review for the next construction season, the researcher could observe construction and send a questionnaire immediately upon project completion, followed by an evaluation of the pavement. This would ensure that the data provided by the actual project team members is accurate and comparisons could be made by direct observation for increased reliability of results. A survey would be easier for participants to complete and minimize the threat of apathy towards the process. Moreover, the identified number of projects could be a manageable size such that the pavements could be measured annually rather than biannually for the purposes of the study.

The survey showed that some contractors favored joint treatments such as infrared heating or thick application of tack joints. By identifying projects for observation and taking joint density samples, the outcome of these unique construction methods on joint density and permeability could be more readily analyzed, similar to the studies performed by Huang et al. in Tennessee in 2006.

Many of the projects surveyed showed that joints were located directly over the pre-existing longitudinal joints on overlay projects. Best practices suggest that the joint is offset by 6-in to the left or right of the original joint. Density cores could determine if reflective cracking occurs despite construction of a good joint on the surface layer, similar to studies performed in Colorado (Hutter 2003).

In the interim, projects completed in recent years could be collected from willing contractor participants or from any returned surveys distributed at the WAPA Conference held in November, 2011. Pavement distress can be determined from the photograph archives on the submitted projects rather than relying on the department database for complete and accurate entries for comparison.

Future studies may want to determine why vertical joints are still constructed and seem to be the preferred method among contractors despite the notched wedge joint specification. A surprising number of surveys received indicated that the actual joint constructed was not the specified notched wedge joint. Potential reasons for reliance on the conventional method could be quality control, warranty concerns, lack of experience, or poor construction methods.

Researchers may also want to examine the determining factors prior to milling a notched wedge joint in favor of a vertical joint. This information could be used to establish a

consistent quality control process to determine if a notched wedge joint has been poorly constructed or otherwise compromised and how it should be remedied.

Researchers Kandhal and Mallick (2007) have proposed that the tapered portion of the wedge should end with a small, approximately 3/8" notch at the base of the joint rather than tapering to zero to discourage raveling. This design modification could be incorporated into another study or independently to determine if this contributes to a better performing joint. Similarly, contractors in this study strongly supported the use of infrared heaters as a means to improve joint density and quality. This should be studied more extensively and validated with density test results directly at the joint to determine if density is improved and the added costs are justified.

Finally, joint density and how to obtain accurate density test results directly at the joint would be a valuable research topic. This information could be used to establish baseline data for density immediately upon completion of the project and used as a comparison for future performance measurements. These measurements could be used in conjunction with the observed data results and photo surveys to determine precisely which construction methods build the notched wedge joint with the highest density and best performance.

APPENDIX A: GLOSSARY

(Source: Pavement Interactive 2011 unless noted otherwise)

Asphalt Binder - the principal binding agent in Hot Mix Asphalt (HMA), which includes asphalt cement as well as any material added to modify the original asphalt cement properties.

Bumping – Manually spreading excess material over a joint with hand tools (also see *raking*).

Cold Lane – Previously paved lane, or the first lane paved.

Compaction – process by which the volume of air in an HMA mixture is reduced by using external forces to reorient the constituent aggregate particles into a more closely spaced arrangement (used interchangeably with *rolling*).

Core – circular sample taken from a pavement for *density testing*.

Cracking – Series of interconnected cracks caused by fatigue failure of the HMA surface (or stabilized base) under repeated traffic loading.

Density Testing – field test performed to measure the density of a pavement at a given location (e.g. by nuclear density gauge).

Department of Transportation (DOT) – also see State Highway Agency (SHA).

Echelon – Paving multiple lanes at once.

Extension - An attachment on the paver screed that forms the mat edge into a tapered section.

Filler – A finely divided mineral aggregate added to asphaltic mixtures to improve mixture properties (WisDOT 2009)

Gradation – particle size distribution of the aggregate.

Hot Lane – The lane currently being placed, or second lane placed.

Hot Mix Asphalt (HMA)

Joint Overlap – The width that the hot lane extends past the cold lane.

Longitudinal Joint – A longitudinal joint is the interface between two adjacent and parallel HMA mats.

Lower Layer – Any asphaltic pavement layer that will not be exposed to traffic when the pavement structure is complete. A pavement structure may have multiple lower layers (WisDOT 2009).

Material Transfer System - accepts the HMA at the front of the paver, moves it to the rear and spreads it out to the desired width in preparation for screed leveling and compaction.

Notched Wedge Joint – an extended joint taper placed on the first paved lane that helps reduce joint air voids. The notches are at least as deep as the nominal maximum aggregate size of the mix and the taper is usually spread out over about 1 foot (12:1 taper).

Overlay – Laying HMA mats over an existing surface after the damaged layer is ground or milled off.

Pavement Distress Index (PDI) – Rating system used to assess the condition of pavement on a scale of 0-3 based on the size and number of cracks observed.

Quality Management Program (QMP) – developed by WisDOT and contractors in 1990 in a cooperative effort to provide structured process control and quality assurance for various construction processes (Schmitt et al. 1996).

Raking – manually spreading excess material over the joint with hand tools, typically when the overlap is greater than 1.5” (also see ***bumping***).

Raveling – The progressive disintegration of an HMA layer from the surface downward as a result of the dislodgement of aggregate particles.

Rolling – see ***compaction***.

Reclaimed Asphalt Material (RAM) – Generally contains between 3 and 7 percent asphalt by weight or about 10 to 20 percent asphalt by volume.

State Highway Agency (SHA) – also see Department of Transportation (DOT).

Tack Coat – A thin bituminous layer applied between HMA pavement lifts to promote bonding.

Upper Layer – The asphaltic pavement layer that exposed to traffic when the pavement structure is complete. A pavement structure has only one upper layers (WisDOT 2009).

Vertical joint – Joint where the two mats abut at right angles (also standard joint, butt joint).

APPENDIX B: HMA LONGITUDINAL JOINT STUDY SURVEY

Introduction

This study attempts to collect information about construction methods and equipment used to complete selected HMA projects between 2008 and 2010. The intent is to use the results to form correlations between best longitudinal joint construction practices and high performance and development of overall recommendations.

Procedure

You will be given a questionnaire for each of the projects selected for study. Questions are designed to determine what construction methods and equipment were used on the specified project. Please compile the data requested and be prepared to discuss the questions in person during the technical meeting at the Truax campus on July 25, 2011.

Risks/Discomforts

Risks are minimal for involvement in this study. The responses collected will not be identified or shared with any individuals, firms, or WISDOT.

Benefits

There are no direct benefits for participants. However your participation definitely fosters a positive working relationship between contractors and agency. It also encourages innovation in the industry and pushes overall progress through best practices in the field.

Confidentiality

All data obtained from participants will be kept confidential and will only be reported in an aggregate format (reporting only combined results and never reporting individual ones). Only the investigator will have access to the surveys and will retain their confidentiality. The data will not be shared with any firms, organizations, or inspection agencies.

Compensation

There is no direct compensation for participation in this study.

Participation

Participation in this research study is completely voluntary. You have the right to withdraw at anytime or refuse to participate entirely. If you desire to withdraw, please notify the principal investigator in person or via email at jalund3@wisc.edu. Your participation is greatly appreciated and it is our sincere hope that your responses will help lead to improvement of this industry problem.

If you have questions at all at any point regarding this study, please do not hesitate to contact Jen Lund at 773/551-1818, jalund3@wisc.edu.

If you have questions you do not feel comfortable asking the researcher, you may contact Gary Whited, 608/262-7243, whited@enr.wisc.edu.

Project ID:

Highway No:

Region:

County:

Description:

Paving Year: 2007 - 2008 - 2009 - 2010 (circle one)

Project Length:

Respondent Name:

Contact Information:

1. I understand the purpose of the study and am willing to participate.

- Yes

2. What role did you have on this project?

- Project Manager
 Project Foreman
 Technical Advisor
 Other, please specify: _____

3. List the dates the project paving started and completed:

Start Month/Dates: _____

End Month/Dates: _____

4. Was this project paved at night?

- Yes
 No

5. Were the weather conditions suitable for work when this project was in progress?

- Much Worse than Average
 Worse than Average
 Average
 Better than Average
 Much Better than Average

6. Did the gradation vary from the standard specifications?

- Yes
- No, the gradation varied as follows:

7. Did the mix contain any Recycled Asphalt Material (RAM)?

- Yes
- No

8. Was binder grade used on the lower lift?

- Yes
Grade used _____
- No

9. Was binder grade used on the final surface lift?

- Yes
Grade used _____
- No

10. How much binder replacement was used?

- None
- Less than the specified limit _____ %
- Equal to the specified limit
- More than the specified limit _____ %

11. Did the joint location match the underlying joint location?

- Offset to the left _____ “ (approximately)
- Direct match
- Offset to the right _____ “ (approximately)

12. Was any pre-overlay base patching required?

- Yes
- No

13. Which type of longitudinal joint was actually constructed?

- Notched Wedge Joint
- Flat Taper
- Vertical Edge
- Please tell us what kind: _____

If the notched wedge joint was not used, skip to Question #40

14. Was the notched wedge joint formed in a 12:1 taper?

- Yes
- No, the joint design was modified in the field as follows:

15. Was a 1/2" notch formed?

- Yes
- No, the joint design was modified in the field as follows:

16. Were you able to maintain the notch?

- Yes
- No, but it was remedied or reestablished by:

17. Did you mill out the joint before paving the second lane?

- Yes
- No

18. Was type of extension was used to create the notched wedge joint?

- Premanufactured extension
- In-house fabricated extension

19. How was the joint compacted?

- Haul Truck Tires
- Without Truck Tires (No Roll)
- Steel Side Roller Wheel
- Rubber Side Roller Wheel
- Tag-along Roller on the side of the HMA paver
- Other, please specify: _____

20. Did you use a material transfer device?

- Yes
- No

21. What type of paver was used?

Manufacturer _____

Year _____

22. Did you pave multiple lanes at once (in echelon)?

- Yes
- No

23. Approximately how many days was the joint exposed to traffic prior to final surfacing?

- None
- 1-2 days
- 3 days
- 4 days
- More than 4 days

24. What type of rollers were used for the breakdown on this project?

- Pneumatic
- Steel Wheeled Static
- Steel Wheeled Vibratory

25. What type of rollers were used for the final surface on this project?

- Pneumatic
- Steel Wheeled Static
- Steel Wheeled Vibratory

26. Did you use any of the following methods directly on the joint?

Method	Yes	No
Infrared heater	<input type="radio"/>	<input type="radio"/>
Tack Coat Please specify brand: _____	<input type="radio"/>	<input type="radio"/>
Joint Sealants or Tapes Please specify brand: _____	<input type="radio"/>	<input type="radio"/>
Other Please specify brand: _____	<input type="radio"/>	<input type="radio"/>

27. Approximately how much mix overlap existed at the joint?

_____“

28. Was raking required at the joint?

- Yes
- No

29. Was bumping required at the joint?

- Yes
- No

30. Was the second lane rolled from the hot side or the cold side?

- Hot side
- Cold side

31. When lanes are rolled, are they rolled from inside the joint, on the joint edge or over the joint?

- Inside the joint by 3-6”
- Directly on the edge
- Over the joint by 3-6”

32. How many formal inspections of the joint were performed by a job foreman during construction?

- No inspections
- Few inspections
- Frequent inspections
- Very frequent inspections

33. Were any cores taken directly on the joint?

- Yes
- No
- Unknown

34. Were any density tests done directly on the joint for company records?

- Yes
- No

35. What density was achieved directly at the joint?

_____ %

36. What challenges or problems occurred on this project?

(examples: weather, manpower problems, material issues, etc)

37. Do you think these challenge may have impacted joint performance?

- Yes

- No

38. How well do you think each joint type performs?

	Not at all	Pretty well	Well	Very well	Extremely well
Flat tapered joint	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Notched wedge joint	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Vertical Edge	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Other Please specify: _____	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

39. What joint type do you think is the most economical?

	Not at all	Pretty well	Well	Very well	Extremely well
Flat tapered joint	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Notched wedge joint	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Vertical Edge	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Other Please specify: _____	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

40. What do you think could be done to improve notched wedge joint performance?

(examples: more training, better equipment, revised specifications, cost incentives, etc)

41. Would you like to see more DOT oversight during construction?

Yes

No

Please explain (optional)

42. Does your company have a company and/or project specific Quality Control Plan?

Yes, my company has a formal Quality Control Plan

No, my company does not require a formal Quality Control Plan

If yes, would you be willing to share a copy of the plan? Yes - No

43. Are there any other projects you think should be reviewed and why?

Yes

No

APPENDIX C: SUMMARY OF SURVEY RESULTS

Survey Response Tally

(N=16)

Q2. What role did you have on this project?					
	<i>Project Manager</i>	<i>Project Foreman</i>	<i>Technical Advisor</i>	<i>Project Supervisor</i>	<i>General Manager</i>
01010301					Joe Kyle/Ron?
01020301					Joe Kyle
02010501				1	Neil Bakke- Monarch
02020501	1				Mike Byrnes- Monarch
02030500					1
02040501	1				Richard Forsythe- Northwoods
02050401					1 Tom Burch
02060401	1				Jerid Baranczyk
03010301	1				Brett Stanton
03020301	1				Brett Stanton
03030303	1				Brett Stanton
03040300	1				Brett Stanton
04010201		1			Andy Klokow
04020203		1			Andy Klokow
04030201	1				Roni LaMarche
04040200		1			Andy Klokow
Total	8	3	0	1	2

Q3. When did this project occur?

01010301	5/31/07 - 6/11/07
01020301	June - July
02010501	5/2007 - 7/2007
02020501	10/2/07 - 10/26/07
02030500	05/08 - 09/08
02040501	8/07 - 10/07
02050401	5/10/07 - 5/21/07
02060401	8/07 - 9/07
03010301	6/28/07 - 7/20/07
03020301	8/1/07 - 8/29/07
03030303	8/30/07 - 9/27/07
03040300	5/31/07 - 6/12/07
04010201	7/30/07 - 10/23/07
04020203	7/30/07 - 10/23/07
04030201	6/7/07 - 8/19/07
04040200	6/3/08 - 11/4/08

Survey Response Tally

(N=16)

Q4. Was this project paved at night?			
	Yes	No	Not a NWJ
01010301		1	1
01020301		1	1
02010501		1	1
02020501		1	1
02030500		1	
02040501		1	
02050401		1	
02060401		1	
03010301		1	
03020301		1	
03030303		1	1
03040300		1	
04010201	1		
04020203	1		
04030201		1	
04040200		1	1
Total	2	14	6

Q5. Were the weather conditions suitable for work when this project was in progress?							
	Much Worse Than Average	Worse Than Average	Average	Better Than Average	Much Better than Average	Unknown/No answer	Not a NWJ
01010301					1		1
01020301				1			1
02010501			1				1
02020501			1				1
02030500			1				
02040501			1				
02050401			1				
02060401				1			
03010301			1				
03020301			1				
03030303			1				1
03040300				1			
04010201			1				
04020203			1				
04030201				1			
04040200			1				1
Total	0	0	11	4	1		6

Survey Response Tally

(N=16)

Q6. Did the gradation vary from the standard specifications?			
	Yes	No	Notes
01010301		1	
01020301		1	
02010501	1		25 mm lower layer, 14 mm intermediate, 12.5 upper
02020501		1	
02030500		1	
02040501		1	Varied within allowable WisDOT specifications
02050401		1	
02060401		1	
03010301		1	
03020301		1	
03030303		1	
03040300		1	
04010201		1	
04020203		1	
04030201		1	Varied within allowable WisDOT specifications
04040200		1	
Total	1	15	

Q7. Did the mix contain any Recycled Asphalt Material (RAM)?				
	Yes	No	Unknown/No answer	Not a NWJ
01010301	1			1
01020301	1			1
02010501	1			1
02020501	1			1
02030500	1			
02040501	1			
02050401	1			
02060401	1			
03010301	1			
03020301	1			
03030303	1			1
03040300	1			
04010201	1			
04020203			1	
04030201	1			
04040200	1			1
Total	15	0	1	6

Survey Response Tally

(N=16)

Q8. Was binder grade used on the lower lift?					
	Yes	No	Unknown/No answer	Grade Used	Not a NWJ
01010301	1			PG 58-28	1
01020301	1			PG 58-28	1
02010501	1			PG 58-28	1
02020501	1			PG 58-28	1
02030500	1			PG 58-28	
02040501	1			PG 58-28	
02050401	1			-	
02060401	1			PG 58-28	
03010301		1		Overlay project	
03020301		1		Overlay project	
03030303	1			PG 58-28	1
03040300	1			PG 58-28	
04010201	1			PG 64-22	
04020203	1			PG 64-22	
04030201	1			PG 58-28	
04040200			1		1
Total	13	2	1		6

Q9. Was binder grade used on the final surface lift?					
	Yes	No	Unknown/No answer	Grade Used	Not a NWJ
01010301	1			PG 58-28	1
01020301	1			PG 58-28	1
02010501	1			PG 58-28	1
02020501	1			PG 58-28	1
02030500	1			PG 58-28	
02040501	1			PG 64-22	
02050401	1			PG 58-28	
02060401	1			PG 58-28	
03010301	1			PG 58-28	
03020301	1			PG 58-28	
03030303	1			PG 58-28	1
03040300	1			PG 58-28	
04010201	1			PG 64-22	
04020203	1			PG 64-22	
04030201	1			PG 64-28	
04040200			1		1
Total	15	0	1		6

Survey Response Tally

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Q10. How much binder replacement was used?

	<i>None</i>	<i>Less than Specified Limit</i>	<i>Equal to Specified Limit</i>	<i>More than Specified Limit</i>
01010301		1		12-14%
01020301		1		16-20%
02010501		1		12.5-29%
02020501		1		21%
02030500		1		16%
02040501			1	
02050401		1		22%
02060401		1		16%
03010301			1	
03020301		1		16%
03030303		1		16%
03040300		1		17%
04010201		1		0-16%
04020203		1		16%
04030201		1		0-7%
04040200		1		8%
Total	0	14	2	0

Q11. Did the joint location match the underlying joint location?

	<i>Offset to the Left</i>	<i>Direct Match</i>	<i>Offset to the Right</i>	<i>Unknown/No answer</i>	<i>Distance</i>	<i>Notes</i>	<i>Not a NWJ</i>
01010301				1			1
01020301		1					1
02010501		1					1
02020501		1					1
02030500	1				6"		
02040501		1					
02050401				1			
02060401		1					
03010301		1				Which resulted in reflective cracking	
03020301		1					
03030303		1				Which resulted in reflective cracking	1
03040300	1				6"		
04010201	1				12"		
04020203				1			
04030201		1					
04040200		1					1
Total	3	10	0	3			6

Survey Response Tally

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Q12. Was any pre-overlay base patching required?					
	Yes	No	Unknown/No answer	Notes	Not a NWJ
01010301	1				1
01020301			1		1
02010501		1		PCC was rubblized	1
02020501		1			1
02030500		1			
02040501	1			Numerous soft spots in the first curve area south of USH 2	
02050401		1			
02060401		1			
03010301	1			+/- 6000 sf	
03020301	1			Some culvert patching	
03030303	1			On existing concrete	1
03040300	1			Very little	
04010201		1			
04020203			1		
04030201	1				
04040200			1		1
Total	7	6	3		6

Q13. Which type of longitudinal joint was actually constructed?						
	Notched Wedge	Flat Taper	Vertical Edge	No Answer	Combination	
01010301					1	NWJ - upper, VE - lower
01020301					1	NWJ - binder, VE - surface
02010501		1				
02020501			1			Mil/Fill
02030500	1					
02040501	1					
02050401	1					
02060401	1					
03010301	1					
03020301	1					
03030303			1			
03040300	1					
04010201	1					
04020203				1		
04030201	1					
04040200			1			
Total	9	1	3	1	2	16

Survey Response Tally

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Q14. Was the notched wedge joint formed in a 12:1 taper?				
	Yes	No	Not a NWJ	Unknown/No answer
01010301	1		1	
01020301	1		1	
02010501			1	
02020501			1	
02030500	1			
02040501	1			
02050401	1			
02060401	1			
03010301	1			
03020301	1			
03030303			1	
03040300	1			
04010201		1		*See sketch
04020203				1
04030201		1		*See sketch
04040200			1	
Total	9	2	6	1

Q15. Was a 1/2" notch formed?				
	Yes	No	Not a NWJ	Unknown/No answer
01010301	1		1	
01020301	1		1	
02010501			1	
02020501			1	
02030500	1			
02040501	1			
02050401	1			
02060401	1			
03010301	1			
03020301	1			
03030303			1	
03040300	1			Up to 3/4" notch
04010201	1			
04020203				1
04030201	1			Up to 3/4" notch
04040200			1	
Total	11	0	6	1

Survey Response Tally

(N=16)

Q16. Were you able to maintain the notch?				
	<i>Yes</i>	<i>No</i>	<i>Not a NWJ</i>	<i>Unknown/No answer</i>
01010301	1		1	
01020301	1		1	
02010501			1	
02020501			1	
02030500	1			
02040501	1			
02050401		1		
02060401	1			
03010301	1			
03020301	1			
03030303			1	
03040300	1			
04010201	1			
04020203				1
04030201	1			*except through intersections
04040200			1	
Total	10	1	6	1

Q17. Did you mill out the joint before paving the second lane?				
	<i>Yes</i>	<i>No</i>	<i>Not a NWJ</i>	<i>Unknown/No answer</i>
01010301		1	1	
01020301		1	1	
02010501			1	
02020501			1	
02030500		1		
02040501		1		
02050401		1		
02060401	1			
03010301	1			
03020301		1		
03030303			1	
03040300	1			
04010201		1		Should have (!)
04020203				1
04030201		1		
04040200			1	
Total	3	8	6	1

Survey Response Tally

(N=16)

Q18. What type of extension was used to create the notched wedge joint?

	<i>Premanufactured</i>	<i>In-house Fabricated</i>	<i>Not a NWJ</i>	<i>Unknown/No answer</i>
01010301		1	1	
01020301		1	1	
02010501			1	
02020501			1	
02030500		1		
02040501		1		
02050401		1		
02060401		1		
03010301		1		
03020301		1		
03030303			1	
03040300		1		
04010201		1		
04020203				1
04030201		1		
04040200			1	
Total	0	11	6	1

Q19. How was the joint compacted?

	<i>Haul Truck Tires</i>	<i>Without Truck Tires (No Roll)</i>	<i>Steel Side Roller Wheel</i>	<i>Rubber Side Roller Wheel</i>	<i>Tag-along Roller</i>	<i>Not a NWJ</i>	<i>Unknown/No answer</i>
01010301					1	1	
01020301					1	1	
02010501						1	
02020501						1	
02030500					1		
02040501					1		
02050401					1		
02060401					1		
03010301					1		
03020301					1		
03030303						1	
03040300					1		
04010201					1		
04020203							1
04030201	1				1		
04040200						1	
Total	1	0	0	0	11	6	1

Survey Response Tally

(N=16)

Q20. Did you use a material transfer device?				
	Yes	No	Not a NWJ	Unknown/No answer
01010301	1		1	
01020301	1		1	
02010501			1	
02020501			1	
02030500	1			
02040501	1			
02050401	1			
02060401		1		
03010301	1			
03020301	1			
03030303	1		1	
03040300		1		
04010201	1			
04020203				1
04030201		1		
04040200			1	
Total	9	3	6	1

Q21. What paver was used?		
	<i>Not a NWJ</i>	
01010301	CAT 2002	1
01020301	CAT 2002	1
02010501	-	1
02020501	-	1
02030500	Cedar Rapids 552	
02040501	Cedar Rapids 2003	
02050401	Blaw Knox PF200	
02060401	Blaw Knox PF200 1991	
03010301	Roadtec 1997	
03020301	Blaw Knox 2000	
03030303	Blaw Knox 2000	1
03040300	Blaw Knox 1999	
04010201	Blaw Knox 1999	
04020203		
04030201	Blaw Knox 2000	
04040200	Blaw Knox 1999	1
Total		6

Survey Response Tally

(N=16)

Q22. Did you pave multiple lanes at once (in echelon)?				
	Yes	No	Not a NWJ	Unknown/No answer
01010301		1	1	
01020301		1	1	
02010501		1	1	
02020501		1	1	
02030500		1		
02040501		1		
02050401		1		
02060401		1		
03010301		1		
03020301		1		
03030303		1	1	
03040300		1		except some turn lanes
04010201		1		
04020203				1
04030201		1		
04040200		1	1	
Total	0	15	6	1

Q23. Approximately how many days was the joint exposed to traffic prior to the final surfacing?							
	None	1-2 days	3 days	4 days	More than 4 days	Not a NWJ	Unknown/No answer
01010301		1				1	
01020301		1				1	
02010501						1	
02020501						1	
02030500		1					
02040501		1					
02050401		1					
02060401		1					
03010301		1					
03020301		1					
03030303	1					1	
03040300		1					
04010201				1			
04020203							1
04030201		1					
04040200	1					1	
Total	2	10	0	1	0	6	1

Survey Response Tally

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Q24. What type of rollers were used for the breakdown on this project?					
	<i>Pneumatic</i>	<i>Steel Wheeled Static</i>	<i>Steel Wheel Vibratory</i>	<i>Not a NWJ</i>	<i>Unknown/No answer</i>
01010301			1	1	
01020301			1	1	
02010501				1	
02020501				1	
02030500			1		
02040501			1		
02050401			1		
02060401			1		
03010301			1		
03020301			1		
03030303			1	1	
03040300			1		
04010201	1		1		
04020203					1
04030201			1		
04040200			1	1	
Total	1	0	13	6	1

Q25. What type of rollers were used for the final surface on this project?					
	<i>Pneumatic</i>	<i>Steel Wheeled Static</i>	<i>Steel Wheel Vibratory</i>	<i>Not a NWJ</i>	<i>Unknown/No answer</i>
01010301			1	1	
01020301			1	1	
02010501				1	
02020501				1	
02030500			1		
02040501	1		1		
02050401			1		
02060401			1		
03010301	1				
03020301	1		1		
03030303	1		1	1	
03040300			1		
04010201		1			
04020203					1
04030201	1		1		
04040200			1	1	
Total	5	1	11	6	1

Survey Response Tally

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Q26a. Did you use an infrared heater directly on the joint?				
	Yes	No	Not a NWJ	Unknown/No answer
01010301	1		1	
01020301		1	1	
02010501			1	
02020501			1	
02030500				1
02040501		1		
02050401		1		
02060401		1		
03010301	1			
03020301	1			
03030303	1		1	
03040300		1		
04010201	1			
04020203				1
04030201		1		
04040200	1		1	
Total	6	6	6	2

Q26b. Did you use a tack coat directly on the joint?				
	Yes	No	Not a NWJ	Unknown/No answer
01010301	1		1	
01020301	1		1	
02010501			1	
02020501			1	
02030500		1		
02040501	1			SS1h
02050401	1			
02060401	1			
03010301		1		
03020301		1		
03030303		1	1	
03040300		1		
04010201	1			
04020203				1
04030201		1		
04040200	1		1	
Total	7	6	6	1

Survey Response Tally

(N=16)

Q26c. Did you use joint sealer or tape directly on the joint?				
	Yes	No	Not a NWJ	Unknown/No answer
01010301		1	1	
01020301		1	1	
02010501			1	
02020501			1	
02030500				1
02040501		1		
02050401		1		
02060401		1		
03010301		1		
03020301		1		
03030303		1	1	
03040300		1		
04010201		1		
04020203				1
04030201		1		
04040200		1	1	
Total	0	12	6	2

Q26d. Did you use any other method directly on the joint?				
	Yes	No	Not a NWJ	No Answer
01010301		1	1	
01020301		1	1	
02010501			1	
02020501			1	
02030500		1		
02040501		1		
02050401		1		
02060401		1		
03010301		1		
03020301		1		
03030303		1	1	
03040300		1		
04010201		1		
04020203				1
04030201		1		
04040200		1	1	
Total	0	13	6	1

Survey Response Tally

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Q27. Approximately how much mix overlap existed at the joint?		
	<i>Not a NWJ</i>	<i>No Answer</i>
01010301	1 1/4" max	1
01020301	1 1/4" max	1
02010501		1
02020501		1
02030500		1
02040501	1/2"	
02050401	0"	
02060401	0" - 1/2"	
03010301	3/4"	
03020301	3/4"	
03030303	3/4"	1
03040300	3/4"	
04010201	1"	
04020203		1
04030201	3/4" - 1"	
04040200		1
Total	6	2

Q28. Was raking required at the joint?				
	<i>Yes</i>	<i>No</i>	<i>Not a NWJ</i>	<i>No Answer</i>
01010301		1	1	
01020301		1	1	
02010501			1	
02020501			1	
02030500		1		
02040501		1		
02050401		1		
02060401		1		
03010301		1		
03020301		1		
03030303		1	1	
03040300		1		
04010201		1		
04020203				1
04030201		1		
04040200			1	1
Total	0	12	6	2

Survey Response Tally

(N=16)

Q29. Was bumping required at the joint?				
	Yes	No	Not a NWJ	Unknown/No answer
01010301		1	1	
01020301		1	1	
02010501			1	
02020501			1	
02030500		1		
02040501		1		
02050401		1		
02060401		1		
03010301		1		
03020301		1		
03030303		1	1	
03040300		1		
04010201		1		
04020203				1
04030201		1		
04040200			1	1
Total	0	12	6	

Q30. Was the second lane rolled from the hot side or the cold side?				
	Hot Side	Cold Side	Not a NWJ	Unknown/No answer
01010301	1		1	
01020301	1		1	
02010501			1	
02020501			1	
02030500	1			
02040501	1			
02050401	1			
02060401	1			
03010301	1			
03020301	1			
03030303	1		1	
03040300	1			
04010201	1			
04020203				1
04030201	1			
04040200			1	1
Total	12	0	6	2

Survey Response Tally

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Q31. When lanes were rolled, were they rolled from inside the joint, on the joint edge, or over the joint?						
	<i>Inside the joint by 3-6"</i>	<i>Directly on the edge</i>	<i>Over the joint by 3-6"</i>	<i>Not a NWJ</i>	<i>Unknown/No answer</i>	<i>Used a pneumatic?</i>
01010301			1	1		
01020301			1	1		
02010501				1		
02020501				1		
02030500			1			
02040501			1			Yes
02050401			1			
02060401	1					
03010301	1					Yes (by 12"-18")
03020301	1					Yes (by 12"-18")
03030303	1			1		Yes (by 12"-18")
03040300	1					
04010201	1					Yes
04020203					1	
04030201	1					Yes
04040200				1	1	
Total	7	0	5	6	2	

Q32. How many formal inspections of the joint were performed by a job foreman during construction						
	<i>No inspections</i>	<i>Few inspections</i>	<i>Frequent inspections</i>	<i>Very Frequent Inspections</i>	<i>Not a NWJ</i>	<i>Unknown/No answer</i>
01010301			1		1	
01020301		1			1	
02010501					1	
02020501					1	
02030500		1				
02040501			1			
02050401			1			
02060401		1				
03010301			1			
03020301			1			
03030303			1		1	
03040300			1			
04010201			1			
04020203						1
04030201	1					
04040200					1	1
Total	1	3	8	0	6	2

Survey Response Tally

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Q33. Were any cores taken directly on the joint?					
	Yes	No	Unknown	Not a NWJ	Unknown/No answer
01010301		1		1	
01020301		1		1	
02010501				1	
02020501				1	
02030500		1			
02040501		1			
02050401		1			
02060401		1			
03010301		1			
03020301		1			
03030303		1		1	
03040300		1			
04010201		1			
04020203					1
04030201		1			
04040200		1		1	
Total	0	13	0	6	1

Q34. Were any density tests done directly on the joint for company records?				
	Yes	No	Not a NWJ	Unknown/No answer
01010301		1	1	
01020301		1	1	
02010501			1	
02020501			1	
02030500		1		
02040501		1		
02050401		1		
02060401		1		
03010301		1		
03020301		1		
03030303		1	1	
03040300		1		
04010201		1		
04020203				1
04030201		1		
04040200		1	1	
Total	0	13	6	1

Survey Response Tally

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Q35. What density was achieved directly on the joint?		
	<i>Unknown/No answer</i>	<i>Not a NWJ</i>
01010301	1	1
01020301	1	1
02010501		1
02020501		1
02030500	1	
02040501	1	
02050401	1	
02060401	1	
03010301	1	
03020301	1	
03030303	1	1
03040300	1	
04010201	1	
04020203	1	
04030201	1	
04040200	1	1
Total	14	6

Q36. Any unique job challenges on this project?			
	<i>Yes</i>	<i>No</i>	<i>Responses</i>
01010301		1	
01020301		1	
02010501		1	
02020501		1	
02030500			Soft shoulders
02040501	1		Cold and wet weather at gravel grade; many soft edges and areas in the first curve south of USH 2; transition of soil type from clay to silty
02050401		1	
02060401		1	
03010301	1		Curb and gutter tie-in was difficult to achieve while meeting requirements; unstable underlying concrete
03020301		1	
03030303	1		Size and staging made continuous paving impossible.
03040300		1	
04010201	1		Weather (non-descript)
04020203		1	
04030201	1		Material - tender mix, issues with pushing
04040200	1		Weather (non-descript)
Total	6	9	

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Q37. Do you think unique job challenges may have impacted joint performance?			
	Yes	No	Unknown/No answer
01010301			1
01020301			1
02010501			1
02020501			1
02030500		1	
02040501	1		Pavement has heaved upwards every winter at the the soft area at the first curve south of USH 2.
02050401			1
02060401		1	
03010301	1		Concrete was very unstable, so reflective cracks appeared within hours and days!
03020301		1	
03030303		1	Possibly
03040300			
04010201		1	
04020203		1	
04030201		1	
04040200			1
Total	2	7	6

Q38a. How well do you think a flat tapered joint performs overall?						
	Not at all	Pretty well	Well	Very well	Extremely well	No Answer
01010301	1					
01020301	1					
02010501						1
02020501						1
02030500						1
02040501			1			
02050401						1
02060401			1			
03010301						1
03020301						1
03030303						1
03040300						1
04010201			1			
04020203						1
04030201						1
04040200			1			
Total	2	0	4	0	0	10

Survey Response Tally

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Q38b. How well do you think a notched wedge joint performs overall?						
	<i>Not at all</i>	<i>Pretty well</i>	<i>Well</i>	<i>Very well</i>	<i>Extremely well</i>	<i>No Answer</i>
01010301		1				
01020301		1				
02010501						1
02020501						1
02030500					1	
02040501					1	
02050401					1	
02060401			1			
03010301		1				
03020301		1				
03030303		1				
03040300		1				
04010201		1				
04020203						1
04030201	1					
04040200		1				
Total	1	8	1	0	3	3

Q38c. How well do you think a vertical edge joint performs overall?						
	<i>Not at all</i>	<i>Pretty well</i>	<i>Well</i>	<i>Very well</i>	<i>Extremely well</i>	<i>No Answer</i>
01010301			1			
01020301			1			
02010501						1
02020501						1
02030500					1	
02040501				1		
02050401					1	
02060401			1			
03010301			1			
03020301			1			
03030303			1			
03040300			1			
04010201				1		
04020203						1
04030201				1		
04040200				1		
Total	0	0	7	4	2	3

Survey Response Tally

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Q38d. How well do you think other joint types perform overall?							
	<i>Not at all</i>	<i>Pretty well</i>	<i>Well</i>	<i>Very well</i>	<i>Extremely well</i>	<i>No Answer</i>	<i>Type Specified</i>
01010301						1	
01020301						1	
02010501						1	
02020501						1	
02030500						1	
02040501						1	
02050401					1		Heated
02060401						1	
03010301						1	
03020301						1	
03030303						1	
03040300						1	
04010201					1		Vertical heated
04020203						1	
04030201					1		Vertical heated
04040200					1		Vertical heated
Total	0	0	0	0	4	12	

Q39a. How economical do you think a flat tapered joint is overall?						
	<i>Not at all economical</i>	<i>Pretty economical</i>	<i>Economical</i>	<i>Very economical</i>	<i>Extremely economical</i>	<i>No Answer</i>
01010301	1					
01020301	1					
02010501						1
02020501						1
02030500						1
02040501						1
02050401						1
02060401				1		
03010301				1		
03020301				1		
03030303				1		
03040300				1		
04010201			1			
04020203						1
04030201						1
04040200			1			
Total	2	0	2	5	0	7

Survey Response Tally

(N=16)

Q39b. How economical do you think a notched wedge joint is overall?						
	<i>Not at all economical</i>	<i>Pretty economical</i>	<i>Economical</i>	<i>Very economical</i>	<i>Extremely economical</i>	<i>No Answer</i>
01010301		1				
01020301		1				
02010501						1
02020501						1
02030500					1	
02040501				1		
02050401					1	
02060401				1		
03010301				1		
03020301				1		
03030303				1		
03040300				1		
04010201		1				
04020203						1
04030201						1
04040200		1				
Total	0	4	0	6	2	4

Q39c. How economical do you think a vertical edge joint is overall?						
	<i>Not at all economical</i>	<i>Pretty economical</i>	<i>Economical</i>	<i>Very economical</i>	<i>Extremely economical</i>	<i>No Answer</i>
01010301			1			
01020301					1	
02010501						1
02020501						1
02030500					1	
02040501						1
02050401					1	
02060401			1			
03010301					1	
03020301					1	
03030303					1	
03040300					1	
04010201					1	
04020203						1
04030201					1	
04040200					1	
Total	0	0	2	0	10	4

Survey Response Tally

(N=16)

Q39d. How economical do you think a other joint types are overall?							
	<i>Not at all economical</i>	<i>Pretty economical</i>	<i>Economical</i>	<i>Very economical</i>	<i>Extremely economical</i>	<i>No Answer</i>	<i>Type Specified</i>
01010301						1	
01020301						1	
02010501						1	
02020501						1	
02030500						1	
02040501						1	
02050401						1	
02060401						1	
03010301						1	
03020301						1	
03030303						1	
03040300						1	
04010201	1						Vertical heated
04020203						1	
04030201	1						Vertical heated
04040200	1						Vertical heated
Total	3	0	0	0	0	13	

Q40. What do you think could be done to improve NWJ performance?

<i>Responses</i>	
01010301	No answer
01020301	Bid item for seam reheat
02010501	No answer
02020501	More training and better equipment has been done since this project
02030500	No answer
02040501	Spray tack coat heavy at the joint (0.035 - 0.5 gallons/sqyd). WisDOT has penalized contractors who spray tack heavy by not paying for gallons over 0.02 - 0.025 gallons/sqyd. Stop this!
02050401	Use of joint heater
02060401	Cost incentives
03010301	
03020301	
03030303	Ensure adequate tacking at joint; increased use of joint heaters; training and attention to detail is crucial
03040300	
04010201	Mill out the wedge
04020203	No answer
04030201	Already done, vibratory notch wedge add on
04040200	

Survey Response Tally

(N=16)

Q41. Would you like to see more DOT oversight during construction?			
	Yes	No	No Answer
01010301		1	
01020301		1	
02010501			1
02020501		1	
02030500		1	
02040501			1
02050401		1	
02060401	1		Field personnel need a little understanding of HMA mixes and placement to provide quality oversight during construction. Many field personnel do not like dealing with HMA (too hot and smells).
03010301		1	
03020301		1	
03030303		1	
03040300		1	
04010201		1	*Adding only if qualified to do so
04020203			1
04030201		1	
04040200		1	*Adding only if qualified to do so
Total	1	12	3

Q42. Does your company have a formal company and/or project specific Quality Control Plan?			
	Yes	No	No Answer
01010301	1		* Quality Plan is available (see note on Response #1)
01020301	1		
02010501			1
02020501	1		
02030500	1		*Contact Erv Dukatz (Mathy)
02040501	1		*Yes
02050401	1		
02060401	1		
03010301	1		
03020301	1		
03030303	1		* No to request for copy
03040300	1		
04010201	1		
04020203			1
04030201	1		*No to request for copy
04040200	1		
Total	14	0	

APPENDIX D: PHOTOGRAPHS OF PDI RATED PROJECTS

APPENDIX D: PHOTOGRAPHS OF SURVEYED PROJECTS

PHOTOGRAPH SET 1.	PROJECT NO. 04010201	#
PHOTOGRAPH SET 2.	PROJECT NO. 04020203	#
PHOTOGRAPH SET 3.	PROJECT NO. 02010501	#
PHOTOGRAPH SET 4.	PROJECT NO. 04030201	#
PHOTOGRAPH SET 5.	PROJECT NO. 04040200	#
PHOTOGRAPH SET 6.	PROJECT NO. 03010301	#
PHOTOGRAPH SET 7.	PROJECT NO. 03030303	#
PHOTOGRAPH SET 8.	PROJECT NO. 03020301	#
PHOTOGRAPH SET 9.	PROJECT NO. 01010301	#
PHOTOGRAPH SET 10.	PROJECT NO. 01020301	#
PHOTOGRAPH SET 11.	PROJECT NO. 03040300	#
PHOTOGRAPH SET 12.	PROJECT NO. 02050401	#
PHOTOGRAPH SET 13.	PROJECT NO. 02040501	#
PHOTOGRAPH SETS 14-16	NOT AVAILABLE	

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