IMPACT OF NIGHTTIME RESURFACING

OPERATIONS ON ASPHALT

ROUGHNESS BEHAVIOR

by

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ABSTRACT

The relationship between nighttime construction scheduling and future road quality in terms of roughness was investigated. Research was three-phased: interviews with local leaders in paving, on-site observations, and historical data analyses. Interviews and on-site observations served to explore potential differences in the paving practices and general opinions in the paving industry regarding daytime versus nighttime paving, while the bulk of empirical research took place in the historical data analyses. Differences in road quality, defined as pavement roughness in this study, between day-scheduled construction and night-scheduled construction were determined by an analysis of the International Roughness Index over the pavement lifecycle as made available to researchers by the Alabama Department of Transportation. Results showed that the roughness values of pavements laid at night were significantly higher than those of pavements laid in the day. Analyzed in 3 30-month intervals beginning at project completion, night and day roughness values were equal in the first interval, but differences in means and variances expanded in the second and third intervals, with increasing significance over time. The research and results are furthered discussed in this report.

DEDICATION

This thesis is dedicated to my family, friends, and especially my advisor, Dr. David Grau-Torrent, without whom I would have lost my mind. Before any of you make the joke—yes, I am aware that I may have lost it a long time ago.

LIST OF ABBREVIATIONS AND SYMBOLS

FHWA	Federal Highway Administration
UTCA	University Transportation Center for Alabama
DOT	Department of Transportation
QCS	Quarter-Car Simulation
IRI	International Roughness Index
DGNC	Daywork/Nightwork General Checklist
SC	Safety Checklist
WPC	Worker Productivity Checklist
POPQC	Pavement Operation Productivity and Quality Checklist
EV	Exposure Value
LVS	Longitudinal Visibility Survey
ESAL	Equivalent Single-Axle Load
HPMS	Highway Performance Monitoring System

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I would mostly like to thank my parents, Bob and Pat McElvy, for staying on my case and sacrificing so much for me to go to graduate school at the University of Alabama. Roll Tide.

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CHAPTER 1

MOTIVATION

The demand from state and federal transportation agencies for nighttime construction scheduling for roadway and highway projects has grown steadily over the past several years. This demand is the result of the need to alleviate increasing congestion. According to the 2011 Urban Mobility Report, "congestion caused urban Americans to travel 4.8 billion hours more and to purchase an extra 1.9 billion gallons of fuel for a congestion cost of $101 billion" (Schrank, Lomax, & Eisele, 2011). The construction industry has attempted to answer this demand with increases in projects implementing nighttime scheduling for highway maintenance projects. State transportation agencies have substantially increased the resources and expenditures on nighttime operations to alleviate the problem (El-Rayes & Hyari, 2005). As of 1995, the New York Department of Transportation has considered nighttime construction in its development of project specifications, and has also legally bound contractors and agencies to consider nighttime scheduling for urban projects in downstate New York (FHWA, 2007b). New Jersey performed an estimated 25% of highway construction primarily at night according to survey data from 2001 (Holguín-Veras et al., 2003). At this point, however, populations are expanding and congestion is suffocating to the point that nearly all major cities fail to keep pace.

The primary force pushing nighttime construction is, indeed, congestion. This problem is affecting urbanized areas of all sizes in some way. Birmingham, Alabama, considered only to be a medium-sized urban area, ranked 31st out of 101 areas analyzed for increased delay due to congestion since 1982 (Schrank, Lomax, & Eisele, 2011). In that span, Birmingham's urban area demand has increased more than 30% faster than its roadway growth, and the auto-commuters of Birmingham, Alabama, suffered an increase from 7 hours of delay per year per auto commuter to 27 hours. While this number may sound staggering, it is little more than one-third the 74 hours of delay for each Washington, D. C., resident. By scheduling these paving projects at nighttime, when there is little to no congestion, traffic delays are minimized and even eradicated. Keep in mind, still, that users are not the only ones who are affected by the costs of congestion. Businesses surrounding the congested area can suffer tremendously from unmitigated heavy-traffic and high traffic delay. After comparing the economic effects of congestion in Chicago, Illinois, and Philadelphia, Pennsylvania, the National Cooperative Highway Research Program, found that “industries with higher levels of truck shipping absorb higher costs associated with congestion and thus benefit more from congestion reduction” (Weisbrod, Vary, & Treyz, 2001). The report also determined that industries and businesses with non-specialized inputs are not hurt as greatly by congestion as businesses with specialized inputs, because the former can more easily adjust to congestion substituting closer suppliers.” Although alleviating congestion is a good reason to utilize nighttime scheduling, it is not the only factor that should be considered when scheduling projects at night.

Examples of common projects completed at night to alleviate congestion include resurfacing, surface treatment, milling and removal, concrete pavement works, pavement marking, reworking shoulders, or installation of highway signs. Nighttime operations can also include subgrade or concrete compaction, paving, crack sealing, or tack coating, among others. The most common project given nighttime scheduling consideration is asphalt concrete paving

(Hinze & Carlisle, 1990). Unfortunately, there is not a uniform set of guidelines on a national level regarding nighttime construction operations. The simple explanation for this lack of best practices is one or a combination of a lack of experience in nighttime construction on the state and federal level, and the relatively low volume of research regarding nighttime construction operations.

According to a survey by Hinze and Carlisle, the six most important factors when deciding on nightime construction contracts are congestion, safety, noise, work time available, user cost, and quality (Hinze & Carlisle, 1990). A study published in 2001 found this list to be the top five factors in decreasing significance: safety, traffic control, congestion, lighting, and quality (Park, Douglas, Griffith, & Haas, 2002). One glaring issue is that in both studies, contractors seemingly admitted that quality takes a backseat to other issues with regard to nighttime paving projects. This discrepancy in percieved importance of quality should not be taken lightly, for it is possible that such discrepancies in the mind could translate into work quality deficiencies in nighttime construction projects. If this is the case, the current literature on the impact of nighttime construction on work quality makes it difficult to make conclusions supporting or opposing the notion of a difference in quality. Several criticisms can be made regarding the literature.

The first criticism is that there is a lack of empirical evidence available to determine whether or not nighttime construction has an impact on the quality of the finished work. While there may be a “common perception that work quality is compromised during nighttime,” a perception is not enough to validate an argument (Rebholz et al., 2004). The FHWA echoes this sentiment and calls for a push in research of nighttime's impact, claiming that the "current conclusions to date are inconclusive regarding the comparison of productivity and the quality of daytime and nighttime projects on roadways" (Abraham, Spadaccini, Burgess, Miller, & Valentin, 2007). Even though the literature is limited, there have been some studies performed on the impact of nighttime construction on work quality, but most of these studies used "inadequate research methods or incomplete data sets" (U.S. Cong., 2007). One widely used research method for investigating construction quality is grading scale surveys, which are subjective in their nature and can lead to skewed results due to a "perceived question threat" (Northrup, 1996). For example, a contractor or government agency may feel influenced by this perceived threat to answer positively when asked a question regarding the quality of their work regardless of the actual quality. Also, even these survey-based studies have produced confusing and inconclusive results.

One such example is the survey from *Variables Affected by Nighttime Construction Projects* (Hinze & Carlisle, 1990). The survey reports that seventy-six percent of the project and resident engineers believed that "the quality of asphalt concrete paving work performed at night was lower than the quality of similar work performed during the day." However, one question from the survey asked if there were any tasks performed better at night. While no task mentioned received constituted a majority, the most-mentioned enhanced operation was asphalt concrete paving with six responses—making up one-sixth of the respondents' answers (Hinze & Carlisle, 1990). So, in a study where an overwhelming majority in the study believes that paving quality is affected negatively by nighttime operations, roughly seventeen percent believe that the quality is positively affected by the same circumstances. To only add to the confusion, Hancher and Taylor found that state DOT's and highway contractors see “quality” as the top problem encountered during nighttime construction; resident engineers rated quality third in the same study (Hancher & Taylor, 2001). The difference of opinions among engineers shows that empirical data is crucial for any conclusive research on the subject, but even the existing empirical studies have had shortcomings.

Several empirical studies have tried to produce data to analyze nighttime construction's effects on quality, but doing so is a “challenging task due to the […] lack of quantitative tools” with which to assess the impact (Al-Kaisy & Nassar, 2009). Also, in some cases, the sample size was too small to adequately draw any conclusions from data sets (U.S. Cong., 2007). For example, the Washington Department of Transportation was involved with a study that compared surface smoothness between daytime and nighttime shifts' work (Dunston, Savage, & Mannering, 2000). The results showed no significant difference in quality between the two operation durations. There are, however, two evident faults with this study: the sample size was very small—six day profilograph readings, and two night readings; and the study simply compared surface smoothness in the early life of the pavements, but did not investigate the surface smoothness later in life when pavement distresses and difference might be more observable. Moreover, a number of studies have utilized organized anecdotal and observational methods to assess the impact of nightwork relative to daywork. The results of several of these studies claimed defects in the nightwork road samples such as unevenness in the paving surface due to construction, but failed to validate their observations through statistical analysis (Hossain

& Parcells, 1995). Furthermore, the overall lack of empirical data supporting or disputing the notion that nighttime construction impacts work quality (either negatively or positively) does not prove that there is not an impact, but, rather, it begs for further investigation.

The second criticism is that the current construction literature revolves around a binary focus on the issue of daytime versus nighttime construction, which would be perfectly acceptable if every project was the exact same with no variability from job-site to job-site. Even though this is not the case at all, this method of comparison is especially prevalent in the studies researching differences in quality (Hinze & Carlisle, 1990; Hossain & Parcells, 1995). In order to fully understand the impact of nighttime construction in some regard, one must know the impacts of individual factors on the night projects themselves. Four major factors have been identified to affect the quality of the finished work during nighttime versus daytime hours: visibility; lighting, inclusive of glare; supervision and inspection; and worker morale (Rebholz et al., 2004). Traffic volumes and temperature can also have an impact on the quality of projects built under nighttime operations. While some studies have found anecdotal or other type of evidence indicating a higher, equal, or lower quality of the finished work at nighttime when compared to daytime, a study of the influence of the previous factors on nighttime construction has never been considered. Thus, it is important to compare not only the quality of nighttime paving projects relative to similar daytime paving projects, but also the quality of similar nighttime projects.

Criticism three is that the current literature fails to explain the long-term cost effects derived from the quality of finished work at nighttime. Much of the cost-analysis literature for night versus day studies only examine the immediate costs, as in what the owner pays per the contract for the project. Consensus among the literature is that the extra costs generally come from extra lighting and administrative expenditures. For example, one study reported a nine percent rise in total costs, including a sixty-three percent spike in lighting costs, to have an asphalt paving project performed at night instead of during the day (Hinze & Carlisle, 1990). A survey from *Nighttime Construction: Evaluation of Construction Operations* showed that seventy-eight percent of the transportation departments contacted claimed a zero to twenty-five percent increase in project costs for working at night (Rebholz et al., 2004). One reason that studies generally exclude or do not calculate a lifetime cost-analysis could be that to this point, research has not proven beyond a doubt that the pavement quality of a night-scheduled project is any better or worse than that of a day-scheduled project. Considering that the main reason for implementation of nighttime construction operations is to alleviate congestion and the costs associated with it, it is crucial to compare the lifetime cost analysis of a night project with the money saved by the mitigated congestion. This lifetime analysis should include the repair costs, maintenance costs, and the vehicle operating costs for roadway users. As of now, the nighttime construction literature does not include such comparisons; therefore, to say that the potential costs saved by alleviation of congestion provide ample reason to work at night is to support an idea that may or may not be entirely correct.

CHAPTER 2

BACKGROUND

2.1 Defining Pavement Quality for This Study

One glaring issue in investigating the quality of highway construction is that "there is no single definition of construction quality for transportation projects" (Rebholz et al., 2004). To form a definition of quality for the sake of this study, one can begin by looking at the general business definition. In general, quality is defined as "the totality of features and characteristics of a product or service that bear on its ability to satisfy stated or implied needs" (Joint Technical Committee, 1994). With respect to roadway construction, the product, of course, is the highway infrastructure provided by the project. The service is the use of that infrastructure by all commuters. The needs, as stated by President Nixon in 1954, are safety enhancement, congestion alleviation, traffic court relief, economic efficiency and growth, and military defense system enhancement (Weingroff, 2011). The features and characteristics can be grouped into what is called the pavement condition.

The concept of pavement condition with respect to the users revolves around two key interrelated components: serviceability and ride ability (Hoque, 2006). According to *Nighttime Construction: Evaluation of Construction Operations*, "the most notable quality aspect […] is surface smoothness or ride ability." (Rebholz et al., 2004). Serviceability is the ability of a pavement to provide the "desired level of service to the user" while ride ability refers to the subjective comfort as experienced by the user (Hoque, 2006). The importance of rideability and surface smoothness is evidenced by the fact that agencies and owners are now including financial incentives and disincentives to have pavement conditions meet certain intervals of acceptability (Boeger & Crowe, 2002). These intervals are based on roughness measurements, which show the “deviation of a surface from a true planar surface with characteristic dimensions that affect vehicle dynamics and ride quality” (FHWA, 2005). Roughness readings worsen over time for roads due to deterioration of the pavement condition, which is caused by one or more of the following factors: design inadequacies, traffic loading, material aging, construction deficiencies, and environmental factors (Hoque, 2006). There are many types of deteriorations, also known as pavement distresses, but the following can be caused by construction deficiencies: depressions, rutting, shoving, crocodile (alligator) cracks, longitudinal cracks, crescent shape cracks, delamination, flushing or bleeding, raving, stripping, edge breaks, and edge drop-offs (Hoque, 2006). With so many types of distresses caused by poor construction methods, it is easy to assume that variables that diminish effectiveness of construction methods would result in poorer work quality and higher roughness scores. This potential variability in road quality makes it crucial not only to periodically assess pavement conditions to determine when and if maintenance is needed, but also to assess the issues that may cause this variability.

2.2 Regarding Effects of Nighttime Scheduling

In order to cope with increasing traffic and congestion, nighttime scheduling is being used on more paving projects. This collective decision across paving contractors and agencies is essentially based on subjective reasoning and engineering experience, but not on objective analysis (Hinze & Carlisle, 1990). Although there have been several suggestions and supportive tools for making a decision to work at night, these are mostly weighted decision methods based on how clients, contractors, and agencies perceive the effects of nighttime construction, rather than the effects themselves.

In order to investigate the potential effects of nighttime construction, one must investigate the variables self-imposed by contractors when working at night. In general, working at night inherently affects the following variables in some way: visibility, worker fatigue, material and equipment availability, and weather and environmental changes (Hinze & Carlisle, 1990). Visibility and worker fatigue seem to be a more consistent focus in literature. Essentially, this focus implies that poor visibility and worker fatigue, due to difficulties in quantification and mitigation, are largely affected by the decision to work at night.

First, the visibility issue could easily affect not only the work of paving laborers, but also the machine operators and inspectors. In order to combat the potential problems due to lack of visibility, several studies have investigated lighting levels and arrangements for both minimum requirements and optimal lighting for construction tasks performed at night (Ellis, 2001; Hyari & El-Rayes, 2006). For example, R.D. Ellis suggests a minimum illumination level of 108 lux for paving and milling, as well as any activity involving the "performance of visual tasks of medium size, or low to medium contrast, or medium required accuracy" (Ellis, 2001). Many state agencies, such as New York and Florida have determined their own lighting requirements in an effort to ensure quality nighttime construction as best as possible (Shane, Kandil, & Schexnayder, 2012). Often, though, agencies do not necessarily set standards for lighting and, thus, leaves the lighting tools and standards to the contractors' discretions, which can lead to less than optimum lighting arrangements (Shane, Kandil, & Schexnayder, 2012). If lighting is not adequate, and sometimes even when it is, mistakes in construction and operation could easily go unnoticed by inspectors, and emerge as problems in pavement quality at some point in the life of the pavement.

Secondly, worker fatigue always has the potential to affect the quality of finish products of any industry. Physical and mental fatigue can cause workers to be less productive, more distracted, and more prone to making mistakes (Barton, 2009). Generally, when fatigued, workers tend to exhibit a loss of concentration, the need to repeat tasks, and slower work paces (Barton, 2009).This is due to the inversion of natural sleep cycles, which are based on circadian rhythms. According to the American Psychological Association, “All the sleep in the world won’t make up for circadian misalignment” (Price, 2011). Adolfo Ramirez, focal point of a *Los Angeles Times* piece on nighttime pavement workers, claimed that workers “don't do [night work] enough to get used to it, so you feel kind of sick all the time, like you're hung over” (Catania, 1993). Although research directly studying fatigue on the construction site is not thorough in current literature, studies focusing on fatigue in other industries can be related to construction worker fatigue due to the similarities in “repetitive work tasks, use of heavy equipment and complex work processes” (Hallowell, 2010). Therefore, when a study of 200 production workers reveals that 52% admitted to making mistakes on the job due to fatigue from abnormal shift hours (Deros, Khamis, Ismail, & Ludin, 2009), it is a red flag for the construction industry, considering two-thirds of nighttime construction workers get less than six hours of sleep before their shifts (Holguín-Veras et al., 2003). Other effects of consecutive nightshift on workers have been studied, but only fatigue as it pertains to quality of work is necessary for this study. In short, worker fatigue, if occurring on a construction site, could easily cause mistakes in paving operations and inspection, as well as decision making for engineers on-site.

Several research teams have developed decision-making tools to aid in determining whether night-work is conducive to the success of individual construction projects, based on the aforementioned effects and many other parameters that may be affected. One such study surveyed state agencies, contractors, and resident engineers and determined that two of the three groups believed that quality was the biggest problem encountered during night operations (Hancher & Taylor, 2001). This study also asked what specific activities were negatively affected in terms of quality and productivity. Asphalt paving happened to fall into the negatively affected quality category (Hancher & Taylor, 2001). The final result of that study was a list of parameters to rate, average, weight, and sum subjective values in order to decide if nighttime construction was appropriate. Another study surveyed 30 people ranging from project engineers to laborers, and proposed several suggestions to help combat worker fatigue and cost problems associated with nighttime construction, including shorter work weeks, better pay differentials for night workers, temporary accommodations, and better evaluation of when to perform nighttime construction (Holguín-Veras et al., 2003). A 2004 study with the Illinois Department of Transportation showed that all surveyed participants believed work quality was negatively impacted at night for all construction practices listed in the study, including resurfacing, surface treatment, milling and removal, and even pavement marking (Rebholz et al., 2004). In fact, resurfacing was ranked as most negatively impacted by nighttime construction. Still, there is not strong objective evidence to support a difference in quality to corroborate the valued perception of engineers and workers.

Although this study will investigate nighttime paving practices, visibility, and worker fatigue on jobsites, the focus is on the utilization of the International Roughness Index, and the understanding of all the information aforementioned to determine the difference in roughness, if any, between the finished products of daytime and nighttime paving construction. Determining whether there is a difference through objective statistical analysis is crucial to settling this debate. In order to analyze such statistics, one must have an understanding of both the pavement resurfacing process and the pavement condition assessment data being investigated.

2.3 The Pavement Resurfacing Process

There are several types of asphalt pavement maintenance techniques that contractors utilize to keep roadways performing adequately. Normally these include asphalt resurfacing, rejuvenation, crack sealing, infrared repair, and fog seal ("Maintenance and resurfacing techniques," 2013). Of these five, only asphalt resurfacing projects were investigated in this study. Resurfacing projects require the following steps according to Nashville Public Works ("Maintenance and resurfacing techniques," 2013):

1. Adjustment (lowering) of utilities to allow milling machines to traverse the roadway without damaging utility assets (Illustration 1).

Illustration 1. Manhole lowering
(North Chicago, 2010a).

2. Removal (milling) of old surface using a milling machine. All milled surfaces must be cleaned by the milling contractor and marked appropriately to safely direct traffic. Milling may not be required on streets with no curb and gutter; however, the edges of streets with no curb and gutter may be trimmed prior to milling in order to provide a more uniform milled surface (Illustration 2).

Illustration 2. Milling machine (HAPI, 2012).

3. Re-adjustment (raising) of utilities so that they will again be flush with the new surface that will be applied (Illustration 3).

Illustration 3. Reconstruction of manhole
(North Chicago, 2010b)

4. Application of a tack coat to milled surface to serve as a binder for the new surface that will be applied (Illustration 4).

Illustration 4. Application of tack coat
(Pavement Interactive, 2010).

5. Application of new paving surface by paving machines (Illustration 5)

Illustration 5. Asphalt paving crew
(George White Location Photography, 2009).

6. Application of thermal plastic pavement markings on new pavement surface (Illustration 6).


Illustration 6. Striping paved road
(Safety Marking Inc., 2012).

In each of these six steps, visibility and mental acuity of the workers, engineers, and inspectors are of the utmost important to ensure that quality work is being done. Mistakes in any of the first five steps could easily cause construction-related deterioration in the pavement in both the short and long run. Since nighttime can indeed affect the visibility and alertness of everyone on the site, it is very perceivable that night quality could falter relative to day work quality. This would easily lead to rougher roads in the future.

2.4 Brief History of Pavement Assessment

Manual roadside inspection was the original mode of quality assessment for roads, and is still used today for in select occasions. The general goal of this was to attempt to estimate and ensure roads met the expectations and “general opinion of the travelling public” (Sayers & Karamihas, 1998). This method is still considered to give the most precise data on pavement quality (Hoque, 2006). In order to somewhat standardize the manual inspection assessments, the Panel Rating Methods of the 1950’s were utilized (Sayers & Karamihas, 1998). A group of experts graded the quality of the roads after travelling over them. This panel scored the roads on a 0 to 5 scale—0 meaning very poor and 5 meaning very good. These grades were based on visual inspection, driving experience, and general profile measurements. The rating that was attributed to the strip of road was known as that stretch’s Present Serviceability Rating, or PSR. Considering two of three criteria for the PSR were based on human judgment, the rating lacked objectivity and sustainability over time, which is true of most visual condition surveys (TxDOT, 2011). A rating of 3 or 4 might not have referred to the same level of quality from panel to panel, year to year. This was especially true with several years in between surveys.

Understanding the subjectivity involved, the Present Serviceability Index (PSI) was developed through the utilization of the PSR data from 1958 through 1960 (Pavement Interactive, 2006). The purpose here was not to simply grade the pavement conditions, but to have a panel-free, objective rating method that was also a tool that could successfully predict and match the PSR accurately (Carey & Irick, 1960). Therefore, the outputs for the formulae for flexible and rigid pavements match the 0 to 5 scale of the PSR. The formulae for PSI are as follows:

For Flexible Pavements:

$$\text{PSI} = 5.03 - 1.91[\log(1 + S_v)] - .01\sqrt{C_l + P_a} - 1.38R_d^2 \quad \text{(Eq. 1)}$$

For Rigid Pavements:

$$\text{PSI} = 5.41 - 1.8[\log(1 + S_v)] - .09\sqrt{C_l + P_a} \quad \text{(Eq. 2)}$$

For these two formulae S_v is slope variance, C_l is crack length in inches, P_a is patching area in feet squared, and R_d is rut depth. By adding a statistical error value, E_r, to the PSI, the equation gives a value comparable to the PSR for the same road (Hoque, 2006).

As technology progressed, advancements made it possible to automate pavement condition assessments. The most notable advancement was the creation of the quarter-car simulation (QCS), which when first invented was a "specialized analog computer designed to analyze road profiles measured by profilometers" (Burchett, Rizenbergs, & Moore, 1977). After gathering pavement profile information by vehicle-mounted profilers (Illustrations 7 and 8), the absolute sum of vertical displacements of the road were used to determine "vehicle body deflection and acceleration" which is highly representative of passenger ride comfort (Ahmadian, 1997). Essentially, the pavement profile information gathered was inputted into the computer system, and the QCS used simulated values for the vehicle mass, tire mass, suspension spring rate, tire spring rate, suspension damping coefficient, and simulation speed (Burchett et al., 1977).

Illustration 7. Front-mounted laser profiler
(Michigan Scientific Corporation, 2005).

Illustration 8. Rear-mounted Inertial Profiler (FHWA, 2012).

Using these two sets of information, the QCS determined the vertical displacement, velocity and acceleration of the sprung and unsprung mass. Agencies used the relative displacement between the two masses to form a roughness index (Burchett et al., 1977). The output for roughness index was in units of slope—inches per mile, for example.

Although the system was accurate and served its purpose on a wide scale in pavement assessment, the results of the system were velocity dependent. One study cited noticeable differences in the final results of roughness indices of the same road due to velocity changes; however, when velocity was held constant among trials, the results were both reproducible and comparable (Burchett et al., 1977). Because of this variability, a more standardized system was needed to relate all roughness measurements and ensure this reproducibility.

The movement toward a standardized roughness assessment method was realized by the World Bank with their development of the International Roughness Index (IRI) in 1982 (Sayers, Gillespie, & Paterson, 1986). The IRI is a quarter-car simulation system with a standard algorithm that calculates passenger and vehicle response in terms of roughness using a hypothetical travelling velocity of 49.7 miles per hour (80 kilometers per hour). It can be expressed as an "accumulation of the motion between the sprung and unsprung masses in the quarter-car model, normalized by the length of the profile" (Loizos & Plati, 2008). Figure 1 shows a simple illustration depicting how the system works. The equation for IRI was essentially a roughness index equation combined with a velocity-standardized QCS equation (Loizos & Plati, 2008):

$$IRI = \frac{1}{l}\int_{0}^{l/s} |z_s - z_u| \, dt \qquad \text{(Eq. 3)}$$

Where:

IRI = International Roughness Index, in/mi

l = Length of profile in mi

s = simulated speed, 49.7 mph

z_s = time derivative of the height of the sprung mass

z_u = time derivative of the height of the unsprung mass

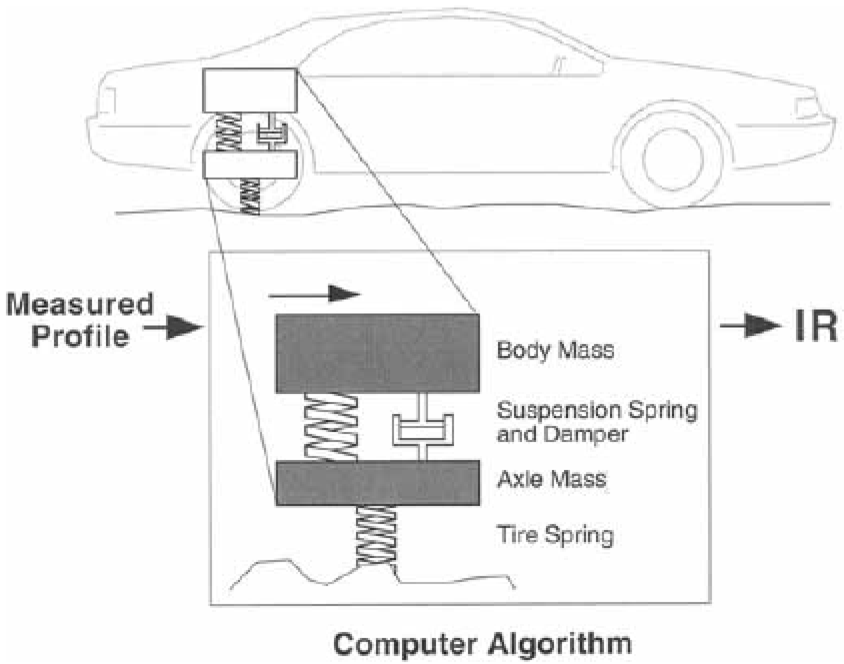


Figure 1. Representation of IRI Algorithm Calculation
(Sayers & Karamihas, 1998).

According to the 2005 HPMS Field Manual, the advantages of utilizing IRI for pavement assessment are:

1. It is a time-stable, reproducible mathematical processing of the known profile.
2. It is broadly representative of the effects of roughness on vehicle response and user's perception […] and thus relevant to the definition of roughness.
3. It is a zero-origin scale consistent with the roughness definition
4. It is compatible with profile measuring equipment available in the U.S. Market.

5. It is independent of section length and amenable to simple averaging.
6. It is consistent with established international standards and can be related to other roughness measures (FHWA, 2005).

Since low IRI values depict smoother roads, higher IRI values depict extremely rough roads with many of the distresses discussed earlier. Also, these higher IRI values can be indications of "significant distress in [the roadway's] underlying foundation" which makes it a helpful indicator of quality (AAHSTO & TRIP, 2009). Early in the pavement lifecycle, these distresses are sometimes not evident, and the IRI values remain constant; however, eventually there is a rapid increase in IRI values due to compounding distresses (FHWA, 1998). Therefore, IRI is measured several times by transportation agencies over the life of a road. State and Federal agencies categorize individual roadways into one of five pavement condition groups based on the IRI values as shown in Table 1 (WSDOT, 2012):

Table 1. FHWA Pavement Condition Designations. (WSDOT, 2012)

Road Quality	IRI Interval
Very Good	≤60
Good	61-95
Fair	96-120
Poor	121-170
Very Poor	>170

Since guidelines for the calibration, collection, and interpretation of IRI data were published in 1986, IRI has become the most widely used roughness measurement tool (Sayers et al., 1986). In fact, all state transportation agencies have been required to submit IRI data to the Federal Highway Administration for inclusion in the HPMS (Harrison & Park, 2008). The information sent to the FHWA includes, but is not limited to the road section identification, the IRI for two wheelpaths in inches per mile, the average IRI for the road section, the data collection date, and the length of the road section in feet (FHWA, 2005). The wheelpaths are simply the areas over which vehicle wheels travel consistently. After periods of wear and tear, the wheelpaths are made visible by longitudinal distresses in the pavements, as exemplified by Illustration 9. The information is stored in a pavement management system so that agencies can better monitor road roughness over time, schedule maintenance, and check against standards and requirements following maintenance.

Illustration 9. Highway Wheelpaths (Pavement Interactive, 2008).

CHAPTER 3

OBJECTIVES AND SCOPE

3.1 Research Objectives

Keeping in mind the aforementioned criticisms of nighttime construction literature, and the background of the research itself, this study's purpose consists of the following objectives:

1. to observe the influence of nighttime construction factors likely to impact the quality of the construction work in ways that could lead to increased roughness,
2. to investigate the impact of nighttime versus daytime construction on the pavement quality of the work with respect to roughness over the service life.

3.2 Data Collection Scope

Project information and data used research needed to be from the same or similar entities to ensure comparability among different sets of the information. All historical data in this study came from the Alabama Department of Transportation (ALDOT). More exactly, the general project data, which included, but was not limited to project number, locations, mix types used, and level of service, came from 7 participating divisions of ALDOT, and the related International Roughness Index (IRI) data came from the Materials and Test Bureau of ALDOT. The general data was to reflect projects that did not use multi-shift day/night scheduling, neither in series or parallel. Also, the projects needed to be between 1 and 15 years old as of 2011 (completion between 1996 and 2010, inclusively). Project data from ALDOT was required to consist of only highway and interstate resurfacing projects, while excluding projects containing lane additions or other changes to the infrastructural set-up originally in place. While there was not strict guideline requiring hot or warm mix asphalts only, hot mix was preferred. Most projects used in research consisted of hot mix asphalt paving. Projects with drastically incomplete data were discarded from the provided sets.

Using the project numbers, completion dates, route designations, and mileposts, the Materials and Test Bureau of ALDOT in Montgomery, Alabama, retrieved all the corresponding IRI data for those projects. This data included pre-resurfacing IRI and all IRI calculations since the resurfacing projects along with their respective calculation dates. By collecting and analyzing this data, objective 1 was satisfied.

Observational data was to be recorded only while on active construction site visits. These projects could not be simultaneously scheduled for both night and day construction, but, instead, could only be either night or day construction for an extended period of time. Therefore, like the requirement for historical data collection, no multi-shift projects were considered. One observed project involved day paving for the first half of the schedule and night paving for the other half of the project schedule, but these two shift schedules did not run daily; therefore, it was still acceptable for observation. Only resurfacing projects were observed, and they must have required said resurfacing on at least 2 lanes throughout the project. Lastly, projects qualifying for observation had to cover at least one mile in length so that ample time for observation of practices could be performed. With this observational data scope, the second objective could be completed.

CHAPTER 4

METHODOLOGY

The purpose of this study is to determine whether or not there is any difference in pavement quality as defined by roughness that can be attributed to nighttime work. As discussed in previous sections, the majority of literature on the subject of nighttime pavement quality focuses on decision-making tools or the initial roughness results of these projects, but rarely the differences in practices and roughness later in the pavement life. In order to address all the objectives of this study, a three-phase research methodology was developed—interviews with members of the construction team; observations and field data from active paving site visits; and analysis of historical International Roughness Index data from the Alabama Department of Transportation.

4.1 Phase 1: Interviews

The first of these phases was the interview phase. The purpose of the interview phase was to obtain a spectrum of views on the variables and issues facing nighttime paving projects, personal opinions regarding nighttime paving, and evidence and anecdotal instances that shaped those opinions. While the majority of current literature utilizes the survey method here, we opted for a more informal approach. Therefore, the interviews conducted were generally informal, with the exception of a thorough interview with a paving subcontractor from Tuscaloosa. All other interviews were conducted semi-casually, understanding that the breadth and depth of paving knowledge might be less for some than others. Indeed, with a less formal guideline of questioning rather than a regimented barrage, the interviewer can utilize the "grouping of topics and questions [to] ask in different ways for different participants," depending on the interviewee and setting (Lindlof & Taylor, 2002). Therefore, an open-ended conversation took place more often than not, and qualitative notes were recorded. Obtaining the opinions from a range of titles offered different insights on the same problem.

4.1.1 Data Collection

Interviews were conducted on-site, with the exception of the subcontractor interview, which was in the confines of the University of Alabama campus. The list of notable interviewees include a subcontractor, a project supervisor; an engineer with a government transportation agency, a superintendent, and an asphalt foreman. A project manager; traffic control, and inspectors, were also interviewed. When considered together, these interviews, found in Appendix J, could help shed light on reasons for potential differences in pavement quality between night and day projects, if such differences should appear in later phases of research. While interviews and the accounts of professionals are both interesting and useful, a first-hand look at day projects and night projects was deemed necessary to further research.

4.2 Phase 2: On-site Observations and Field Data

The second phase of research consisted of on-site observations and gathering of field data. For this phase, the primary researcher travelled to several daytime and nighttime paving job sites and observed, for several hours at a time, the practices and procedures used, problems encountered, and methods of overcoming those problems. Inasmuch as best practices do not always translate into actual practices, on-site data collection was necessary to find interesting similarities and, if any, differences between daytime and nighttime practices. Also, collecting on-site data provides an opportunity for recording happenings that otherwise might be left out of an interview, questionnaire, or survey.

4.2.1 Data Collection

The procedure for phase two ultimately began with the selection of various job sites to visit. In order to ensure that our on-site data was comparable among several sites, a list of criteria was used for site selection. First, the site to be observed had to be that of a resurfacing project, guaranteeing the collection of relevant, comparable data. No lane-addition projects were visited. Secondly, in order to be selected, the projects had to span at least one mile. This criterion ensured that observations would not be skewed by short procedure times or extreme changes in paving pace. Lastly, in order to be considered for observation, the project duration had to be at least one month long, including weekends. This was to make sure that enough sites could be visited over the time allotted to on-site observations.

After much research, the tools to be utilized in data collection in the field were determined. In order to check for unseen pavement failures and mistakes in newly poured pavement, the LumaPower MRV-SIDEKICK Ultra III Turbo Force Flashlight was used. Its 1000 Lumens provided enough light to examine the milled areas and newly paved asphalt. Secondly, for visibility measurements, the Sekonic L-308S Flashmate, Flash and Ambient, Incident &

Reflected Exposure Meter was used to examine visibility along the jobsite and in specific work areas. Lastly, in order to examine the cooling rate of freshly poured asphalt and the compaction thereof, a Flir i7 Compact Infrared Camera was used. These pieces of equipment were used on every visit upon receipt of them. On visits prior to the arrival of the equipment, general observations were made about the on-goings of the project.

4.2.2 Checklists and Surveys

With all equipment in place, a full set of data could be collected. With regards to on-site data collection, there were two broad categories of data. The first data collection category consisted of standardized checklists and surveys. In order of execution on the job site, the documents were the Daywork/Nightwork General Checklist, Safety Checklist, Worker Productivity Checklist, Paving Operation Productivity and Quality Checklist, and, lastly, the Longitudinal Visibility Survey. All checklists were developed through research of common paving practices and safety standards (FHWA, 2007a; FHWA, 2009; Hyari & El-Rayes, 2006; Abraham et al., 2007; Hoque, 2006; Reckard & Ryer, 1990; Blades & Kearney, 2004; *Hot-Mix Asphalt Paving Handbook*, 1991). The second category consisted of observations and anecdotes. This included any information, events, special situations, problems, advantages, or disadvantages that were not explicitly inquired about in the checklists. These two categories served to provide a wide enough research net to cast and hopefully find a solution to the original inquiry: is the quality of night work any different that day work, and, if so, why?

4.2.2.1 Daywork/Nightwork General Checklist

The first of the five research documents, all of which were filled out solely by the researchers, was the Daywork/Nightwork General Checklist (DNGC). This checklist can be found in Appendix A. The purpose of this checklist was to obtain general site information including location, work to be done, head counts, equipment counts, and general inspector engagement. This survey was performed one time as soon as the researchers arrived on the site. General site questions were asked of the highest person in charge on the site whenever the DNGC was performed. Immediately upon completion of the DNGC, the researchers moved on to the next research document.

4.2.2.2 Safety Checklist

The next step in on-site data collection was to check that safe conditions were ensured and appropriate safety measures were taken by the contracting company and all the workers. This Safety Checklist (SC), a copy of which is located in Appendix B. helped the researcher to investigate the hazards and prevention thereof on the job site. The majority of the items on the checklist came from sections of multiple versions of the *Manual on Uniform Traffic Control Devices* (FHWA, 2007a; FHWA, 2009). SC topics included public traffic, signage, illumination and reflectors, lane closures, lighting, shoulder conditions, channeling devices, attenuators, travelling equipment, and employees. Although only a few of these subjects could really have an effect on nighttime paving quality, we did not want to waste this opportunity to gather night and day safety data to compare. The SC was only completed one time per project site visit, so as to not interfere with more pertinent data collection, such as the data gathered with our third research document.

4.2.2.3 Worker Productivity Checklist

The third research document was the Worker Productivity Checklist (WPC), as seen in Appendix C. Completed once per hour during the site visit, the WPC aided in the investigation of worker patterns during projects. The WPC was used to examine signs of worker fatigue and apathy, and also to categorize on-site employees into one of the following three labor categories: direct, indirect, and idle. A classification of "direct work" means that is a part of the "actual construction work performed on the project including labor, materials, [and] equipment" which in this case would be shoveling asphalt, driving the asphalt truck, and anything else directly affecting the asphalt pavement (NREL, 2008). Alternatively, someone classified as indirect is not directly affecting the construction—the pavement or paving process. Instead, they may simply be making it run more smoothly via hauling, overseeing crews, looking at plans, and any other administrative work on-site. This category includes supervisors discussing plans, inspectors checking asphalt truck temperatures and milling depths, and foremen instructing labor crews. Finally, idle refers to anyone doing neither direct nor indirect work, and thus adding no value to the job at hand. Looking at fatigue, apathy, and worker classification all together could yield interesting results between night and day projects.

4.2.2.4 Paving Operation Productivity and Quality Checklist

The next checklist created was the Paving Operation Productivity and Quality Checklist (POPQC). Like the WPC, this checklist was performed once per hour while on the job site. The POPQC, shown in Appendix D, serves to investigate not only the implementation of, or changes to, best practice procedures, but whether or not conditions around the paving area are acceptable and conducive to efficient, quality paving operations and finishes. The POPQC covers equipment behavior (such as headlight activity and rollers on the asphalt), pre-paving area visibility, post-paving area visibility, surface preparation, asphalt placement techniques, and asphalt cooling and compaction. A large portion of this checklist was made of binary questions, with yes or no as the only possible answers to questions such as "Are there uneven layers that have not been leveled by milling or placement of asphalt level course?" and "Is there supplemental lighting on the sides of the asphalt truck?" These questions were answered by simply observing the paving processes and preparation. There were however two portions of this checklist that required a systematic approach using the aforementioned equipment.

The section of the POPQC titled "Illumination around Direct Work-Related Vehicles" was completed by implementing the procedure found in Appendix E, repeating twice for a total of three rounds of checks. This procedure allowed us to observe how much incident light is made available around the fresh pavement by the balloon lights on pavement spreaders and how much light reaches the laborers' eyes working behind the pavement spreader. The light meter used read illuminance in terms of exposure value (EV) which is a mathematical simplification of shutter-speed and aperture ("Exposure value," 2013). Although EV is not a direct measurement of illuminance, which would actually be lux (1lumens/m^2), it can be converted easily to lux using the following equation:

$$y = 2.4866e^{.6935x} \qquad \text{(Eq. 4)}$$

Where:

y = illuminance in lux (lumens/m^2)

x = Exposure value from light meter

This equation was derived from the chart provided on the light meter manufacturer's website which converted EV values in .5 increments into lux values (Sekonic Control Light, 2013). After the "Visibility around Direct Work-Related Vehicles" section was complete, the research shifted to the pavement itself.

The section of the POPQC that focuses on the cooling and treatment of the pavement is labeled "Asphalt Cooling and Compacting Over Time". By using the Flir i7 Compact Infrared Camera, researchers we able to observe not only how fast the pavement was cooling at night, but also if rollers were compacting the pavement below general workability temperatures. The procedure for this section can be found in Appendix F. Upon finishing the "Asphalt Cooling and Compaction Over Time" chart, the POPQC was completed.

4.2.2.5 Longitudinal Visibility Survey

After carrying out the WPC and the POPQC, only the Longitudinal Visibility Survey (LVS), as seen in Appendix G remained. Inasmuch as the POPQC was utilized to find the level of visibility directly around the work area, the LVS used the same Sekonic L-308S Flashmate to find the visibility across entire lanes of work. This was important because the work being performed in paving projects is not always immediately next to the paving truck. Essentially, the LVS was the measurement of incident light every five feet along the job site, taken from five feet, five inches, vertically from the ground, which is just above the average male eye level ("Ergonomics data and mounting heights," 2010). The light meter used to take these readings was angled forty-five degrees down to the pavement so that the incident values would represent the amount of light absorbed by the workers' eyes when looking down to perform their paving tasks. Not only were there columns in the LVS for illuminance values, there were spaces to record project stations, extra light sources, activity versus non-activity area, objects causing shadows, and general comments. Activity areas were simply areas in which work such as paving, compacting, working with a backhoe, milling, or any other work was being executed. Non-activity areas were areas in which no work was occurring. With the values obtained, uniformity ratios, which is a description of the illuminance range across a given distance, could then be determined and compared to literature guidelines. This final document concludes the first part of the phase two of research.

The recording of on-site observations—any information, events, special situations, problems, advantages, or disadvantaged that were not explicitly inquired about in the checklists—closed phase two of the research. This section for observations serves to allow subjective judgments that may be relevant to the research. These anecdotal obvservations can be found in Appendix K. Phase two essentially serves as a chance to witness any differences in procedures and practices between day and night paving projects. If phase three was to discover that there is some difference in quality it will be crucial that this phase sheds some light on what aspects of the projects to which the differences can be attributed.

4.3 Phase 3: Historical Data Analysis

Phase 3 of the research refers to the accumulation and statistical analysis of historical data. Because the International Roughness Index (IRI) is so widely used across the entire country as the primary measurement of quality of a paving surface, IRI values from the Alabama Department of Transportation (ALDOT) were utilized as our historical data. This section was especially crucial to the research in as much as it is the only truly quantitative comparison between a substantial sample of night and day projects.

For the sake of this study, and studies performed afterwards, it is important to know how Alabama conducts the surveys that produce the IRI data. According to engineers in the Material and Test Bureau of ALDOT, Alabama's IRI data is collected by a private vendor, most recently Pathway Services, Inc. According to the company website, IRI values are computed via the "PathRunner collection system" which essentially is a van with a front-bumper attached "South Dakota type laser profiler manufactured based on active class 1 ASTM E950 standards" (Pathway Services, Inc., 2010). These standards ensure that the vehicle used "provides a satisfactory method for acquiring traveled surface profile data" (ASTM, 2009). In Alabama, the Pathrunner vans have front-bumper profilers on both the right and left wheel path. The laser profiling equipment attached to the Pathway van takes a reading every three-fourths of an inch. Using this profiling data, two quarter-car IRI values are then reported in 52.8 feet intervals using both sets of profile data. These two quarter-car IRI values are then averaged to produce the Mean Roughness Index (MRI). According to engineers at ALDOT, this method is “less forgiving” than the half-car IRI method in which profile data is averaged before computing the IRI. The result is an accurate depiction of road roughness in inches per mile, which can be related to the Federal Highway Administration’s pavement condition categories as stated earlier. This category structure is very helpful for agencies, such as the Alabama Department of Transportation, when deciding between alternatives regarding pavement rehabilitation. “Very Good” and “Good” pavements need no maintenance other than preventive measures. “Fair” and many “Poor” pavements need patching and overlay procedures (FHWA , 2011). “Very Poor” pavements generally are in need of structural repairs, replacement, or complete reconstruction (FHWA, 2011). Because of this ranking system’s usefulness, these categories served as a reference datum to compare night and day IRI values.

4.3.1 Data Collection

Before we could gather any IRI data, of course, we first needed to gather a random sample of night and day paving projects’ general information from ALDOT. The initial requests were sent via email to the State Maintenance Engineer, George Conner, P. E. This request email included three document attachments: the official UTCA description of the study, a pre-designed excel spreadsheet for data input, as seen in Appendix H, and explicit directions for inputting data into the spreadsheet Appendix I. The following information for each project was requested by researchers: Project Number, Daywork or Nightwork, Project Beginning and Ending Dates, Project Type, State Route, Beginning Milepost, End Milepost, Mix Type, Layer Type, Maximum Aggregate Size, ESAL Range (level of service), and Asphalt Pour Rate. When multiple mixes were used, as often was the case, the applicable sections were to be filled out for each mix. The request for project information limited the data field to resurfacing projects performed through either daytime construction or nighttime construction, but not both. No projects involved in the study were to be brand new roadway construction projects, but instead only resurfacing projects. Also, the projects could be no more than 15 years old at the time of the request sent in the Fall of 2011. With the approval of both the researchers and Mr. Conner, the requests were ready to be sent to the nine divisions of the Alabama Department of Transportation. Specifically, the division engineers, division maintenance engineers, and division construction engineers all received the request email. At this point, the researchers waited for replies.

Upon receiving the completed spreadsheets from the divisions, the next step of Phase 3 could ensue. This step required sending the project numbers along with respective project beginning and ending dates to Frank Bell of the Materials and Test Bureau of the ALDOT. Frank Bell was able to retrieve all the IRI data that correlated to the project data sent to him by the research team. This new data set included the pre-resurfacing IRI value and date of collection, and all post-resurfacing IRI collections to date or prior to another resurfacing. This allowed us to look at IRI over the current life of projects through statistical analysis comparing several different groupings of the data. The groupings included but were not limited to grouping by age of project at IRI collection, grouping of collection number, overall night project values versus overall day project values, and linear regression of the night and day values in an attempt to predict values of future IRI collections. This statistical analysis served as the final and most crucial part of the research, inasmuch as it would empirically show any difference in quality over time for night and day projects.

CHAPTER 5

ROUGHNESS DATA ANALYSIS AND RESULTS

The most crucial element of this study was the historical IRI data analysis. Since this study has defined quality as roughness and rideability, the IRI metric was the perfect reflection of the road quality. The longitudinal aspect of this data relative to index change over time was the basis of the historical data analysis for this study. With the data from ALDOT reflecting only resurfacing projects and no new road construction projects, researchers analyzed the data thoroughly.. The results of day versus night IRI-value comparisons are contained in this section, as well as discussions of the implication of significant findings.

5.1 Origin of the Data Set

Of the nine divisions, seven divisions replied sufficient data for the study: 1st, 2nd, 3rd, 4th, 5th, 8th, and 9th. Project data was never received from the 6th or 7th divisions. In all, the seven participating divisions submitted 99 resurfacing projects for research. University researchers then partnered with ALDOT's Material and Test Bureau to obtain International Roughness Index data for each of the 99 projects. The expanded data set matched the general project information to the IRI prior to resurfacing, the date associated with that collection, and post-resurfacing IRI collections and respective date. Eleven projects, however, were discarded for one or a combination of the following reasons: incomplete project data, no IRI data attributed to the projects, large drops in project IRI signifying maintenance was performed without updating the database. After removing the eleven projects from the data set, there were 49 day resurfacing projects and 39 night resurfacing projects.

5.1.1 Project Mix Types

In order to ensure adequate sample sizes, the mix types were not factored into the statistical approach; however, we requested that all projects be resurfacing projects, as stated earlier, and we mentioned that hot mix asphalt mixes were the preferred mix for the study. Although we did not base study differences in IRI values relative to mixes, we still investigated the mix type proportions in the data set. Table 2 shows all the mix codes used in the day and night projects and the corresponding mix according to the 2012 list of active U.S. customary items (ALDOT, 2012). Table 3 then shows the different mix types and the percentage of total mix types that each category represents in the day and night projects.

Table 2. Mixes and Mix Types.

Day		Night	
Mix	Mix Type	Mix	Mix Type
416A-021	Bituminous Concrete (Butim Conc)	404D-003	Paver-Laid Surface Treatment
420A-011	Open Graded Friction Course	420A-011	Open Graded Friction Course
420A-015	Open Graded Friction Course	420A-015	Open Graded Friction Course
423A-002	Stone Matrix Asphalt	420A-361	Open Graded Friction Course
423A-003	Stone Matrix Asphalt	423A-001	Stone Matrix Asphalt
423B-000	Stone Matrix Asphalt	423A-002	Stone Matrix Asphalt
424A-240	Superpave Bituminous Concrete	423A-003	Stone Matrix Asphalt
424A-241	Superpave Bituminous Concrete	423B-001	Stone Matrix Asphalt
424A-261	Superpave Bituminous Concrete	424A-240	Superpave Bituminous Concrete
424A-276	Superpave Bituminous Concrete	424A-241	Superpave Bituminous Concrete
424A-280	Superpave Bituminous Concrete	424A-260	Superpave Bituminous Concrete
424A-281	Superpave Bituminous Concrete	424A-276	Superpave Bituminous Concrete
424A-300	Superpave Bituminous Concrete	424A-280	Superpave Bituminous Concrete
424A-340	Superpave Bituminous Concrete	424A-281	Superpave Bituminous Concrete
424A-341	Superpave Bituminous Concrete	424A-360	Superpave Bituminous Concrete
424A-356	Superpave Bituminous Concrete	424A-361	Superpave Bituminous Concrete

Table 2 (Continued)

Day		Night	
Mix	Mix Type	Mix	Mix Type
424A-360	Superpave Bituminous Concrete	424B-261	Superpave Bituminous Concrete
424A-361	Superpave Bituminous Concrete	424B-281	Superpave Bituminous Concrete
424A-366	Superpave Bituminous Concrete	424B-288	Superpave Bituminous Concrete
424A-367	Superpave Bituminous Concrete	424B-289	Superpave Bituminous Concrete
424B-280	Superpave Bituminous Concrete	424B-301	Superpave Bituminous Concrete
424B-281	Superpave Bituminous Concrete	424B-581	Superpave Bituminous Concrete
424B-288	Superpave Bituminous Concrete	424B-650	Superpave Bituminous Concrete
424B-321	Superpave Bituminous Concrete	424B-651	Superpave Bituminous Concrete
424B-441	Superpave Bituminous Concrete	424B-655	Superpave Bituminous Concrete
424B-461	Superpave Bituminous Concrete	424B-659	Superpave Bituminous Concrete
424B-585	Superpave Bituminous Concrete	424C-280	Superpave Bituminous Concrete
424B-621	Superpave Bituminous Concrete	424C-280	Superpave Bituminous Concrete
424B-622	Superpave Bituminous Concrete	429A-260	Bituminous Concrete
424B-636	Superpave Bituminous Concrete	429B-261	Bituminous Concrete
424B-648	Superpave Bituminous Concrete		
424B-650	Superpave Bituminous Concrete		
424B-651	Superpave Bituminous Concrete		
424B658	Superpave Bituminous Concrete		
424B-659	Superpave Bituminous Concrete		
424B-662	Superpave Bituminous Concrete		
424B-681	Superpave Bituminous Concrete		
424B-693	Superpave Bituminous Concrete		
424C-280	Superpave Bituminous Concrete		
424C-360	Superpave Bituminous Concrete		
424C-370	Superpave Bituminous Concrete		
429A-261	Bituminous Concrete		
429B-261	Bituminous Concrete		

Table 3. Mix Type Proportions. SP = Superpave. OGFC = Open Graded Friction Course. Bitum = Bituminous Concrete, Surf. Trt. = Paver-Laid Surface Treatment. SMA = Stone Matrix Asphalt.

	SP	OGFC	BITUM	SURF. TRT.	SMA
Day Projects	96%	9%	4%	0%	2%
Night Projects	85%	23%	3%	3%	23%

Research indicates that the SMA mix can have an effect on initial IRI values while there was no significant difference among other mix types (Wen, 2011); however, in this study, the initial IRI values were similar. Once researchers saw the initial values were similar, we decided to not include asphalt type as a potential difference cause over time, since the literature showed initial IRI difference was the main concern relative to mix types. Still, further research should take mix types into account.

5.2 Statistical Approach

In the statistical analysis of the IRI data for these 88 remaining projects and subsamples, only findings with P-values less than or equal to the standard .05 P-value were considered significant. A result meeting the .1 P-value was considered noteworthy, but not significant. When studying project ages, collection ages and ESAL ranges, either the 2-tailed z or Welch's t-tests was performed in concordance with the appropriate sample size assumptions. The z-test was used when sample sizes were larger than 30, while the Welch's t-test, which assumes unequal variance, was utilized when sample sizes were less than or equal to 30. The 2-tailed F-test was used for all age variance comparisons. The same tests were conducted for the IRI values; however, these tests were only one tailed, with a null hypothesis of equality, and an alternative hypothesis of day project IRI-value means being less than the night means. The one-sided F-test for variance differences was used for IRI values as well. The remainder of this section lays out the order and findings of the IRI statistical analysis conducted in this research study.

5.3 Comparisons of Entire Day and Night Data Sets

In order to ensure than the populations were comparable, it was important to make sure that the ages of the projects, the ages at the times of collection, and the ESAL ranges were similar in mean and variance. If the project ages compare, that means that generally the IRI calculations were performed with the same procedures and margin of error. Comparisons of collection ages could show that the IRI values were gathered at similar times. Comparing ESAL Ranges of the entire data sets serves to show that similar traffic levels commuted on the roads, and extra traffic would not be a cause of increased IRI values. Ideally, these three compared values would indeed be statistically equal; however, it was noted counter-intuitive findings in the IRI, such as higher roughness ratings in a younger data set or lower ESAL range, would be a significant point of emphasis as well, because that would be incredibly suggestive of a difference in quality.

5.3.1 Project Ages

A comparison of the overall age of day projects (n=49, μ = 6.67 years, σ^2 = 14.06) and night projects (n=39, μ = 5.59 years, σ^2 = 10.35) showed than there was no difference in means (P = .148) and no difference in variances (P = .332). The histogram in Figure 2 shows the distribution of day projects and night projects. Knowing that the ages of the projects are comparable implies that a general similarity in the care, methods, and acceptable margin of error for the collection of data was adhered to for the two samples.

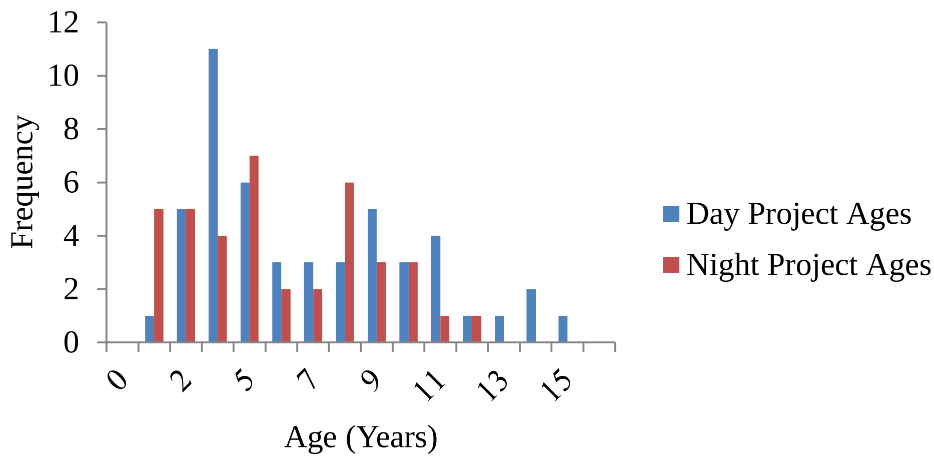


Figure 2. Histogram: Day and Night Project Ages

5.3.2 Project Ages Relative to Time of Collection

Even though the ages of the projects are comparable, and thus the methods and acceptable error are comparable, it is still crucial to know when the IRI values were collected in each data set. The difference in ages, or lack thereof is essential information for comparing the IRI data. For the 49 day projects and 39 night projects, totals of 123 and 111 IRI values were collected, respectively. The 123 day collection times (μ = 52.25 months, σ^2 = 1570.57) did not differ from the 111 night collection times (μ = 46.78 months, σ^2 = 1097.10) in terms of mean collection age (P = .252). However, the day collection age variance was between 1.05 and 1.94 times greater than that of the night projects (P=.028) with 95% significance. Figure 3 shows that this discrepancy in variances is due to the more expansive third and fourth quartiles of the day collection ages. Inference would have it that the higher variance in ages would lead to a higher variance of IRI values for the day projects; however, this is not the case. Before studying the IRI values, though, an analysis of the ESAL ranges was performed.

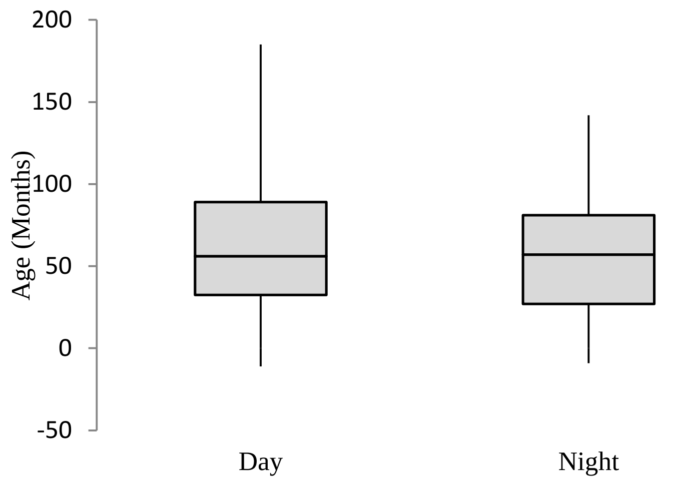


Figure 3. Boxplot: All Day and Night Collection Ages.

Table 4. Descriptive Statistics for Figure 3.

Description	Collection Ages		
	n (collections)	μ (months)	σ (months)
All Day Collections	123	52.25	39.63
All Night Collections	111	46.78	33.12

5.3.3 ESAL Ranges Comparison

Because many projects had multiple ESAL ranges attributed to them due to multiple mixes in the design, the highest ESAL range listed for each project was used for analysis for the sake of being conservative with our approach. An ESAL Range ranking technique was used to compare the data set’s average ESAL range.

Using intervals of .5, a range of 1 through 6 was assigned to all possible ESAL ranges as shown in Table 5. The number of collections in each project was multiplied by each respective project's ESAL range rank to create a weighted ESAL value for each project. These values were summed and divided by the sum of collections, which resulted in a weighted ESAL average for the data set. This average took into account the frequency of ESAL ranges with respect to how many collections in the data set could be attributed to them, rather than how many projects were attributed to the ESAL ranges. The latter would have produced skewed ESAL data, non-reflective of the collections. This procedure was done for all ESAL comparisons in this study.

Table 5. ESAL Range Rank System.

A	A/B	B	B/C	C	C.D	D	D/E	E	E/F	F
1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6

According to the ranking technique show in Table 5, an average ESAL Rank of 4.75 shows that the projects in the data set, on average, are between the D/E and E ESAL ranges.

Out of the entire data set, one day and two night projects lacked ESAL data. Analysis of the remaining data showed that with 119 day collections (μ = 3.96 ESAL Rank, σ^2 = 1.248) had an average ESAL Rank just under the D ESAL Range. The night collections (n=103, μ = 4.31 ESAL Rank, σ^2 = .531) had an ESAL Rank between D and D/E. A difference in means analysis shows that the night mean is greater than the day mean (P=.003) by at most over half an ESAL Ranking, 99% CI = (.05, .64). Interestingly, the day variance is greater than the night variance (P = .000007) at an incredibly significant level. Essentially, this proves the data is incomparable in terms of level of service at the population level. Even still, we looked at how the two sets of IRI data compared.

5.3.4 IRI Value Comparison

Knowing that the ESAL ranges were different for the night and day project sets, this section is not conclusive regardless of results. Regardless, comparisons showed that the 123 day IRI values (μ = 70.02 inches per mile, σ^2 = 452.49) and the 111 night IRI values (μ = 74.66 inches per mile, σ^2 = 731.80) had no significant difference in mean, but the night variance was greater than the day variance (P=.005) by a factor between 1.05 and 2.50. There were, however, 2 extreme outliers (≥3 standard deviations from the mean) in the day collections, and 1 in the night collections. Removing these extreme outliers resulted in a difference in means (P=.042, CI = .25, 10.08) between the 121 day IRI values (μ = 68.67 inches per mile, σ = 18.51 inches per mile) and the 110 night IRI values (μ = 73.84 inches per mile, σ = 25.75 inches per mile). Also, the night variance was still significantly higher (P = .0003, CI = 1.42, 2.63). It was interesting that both the day collection age and ESAL variance were higher than the night counterparts, but the night IRI variance was significantly higher. The discrepancies in the base data (ages and ESAL ranks) made it difficult to conclude anything based solely on the IRI value means, but the difference in variance initially shows that there is much more predictability with day IRI values, regardless of the age and ESAL range of the projects. Figure 4 shows the IRI values for the entire day and night data sets—there is no real discernible difference in the data when perceived as a whole, so in order to further investigate the data, the comparisons had to take into account the longitudinal nature of the data.

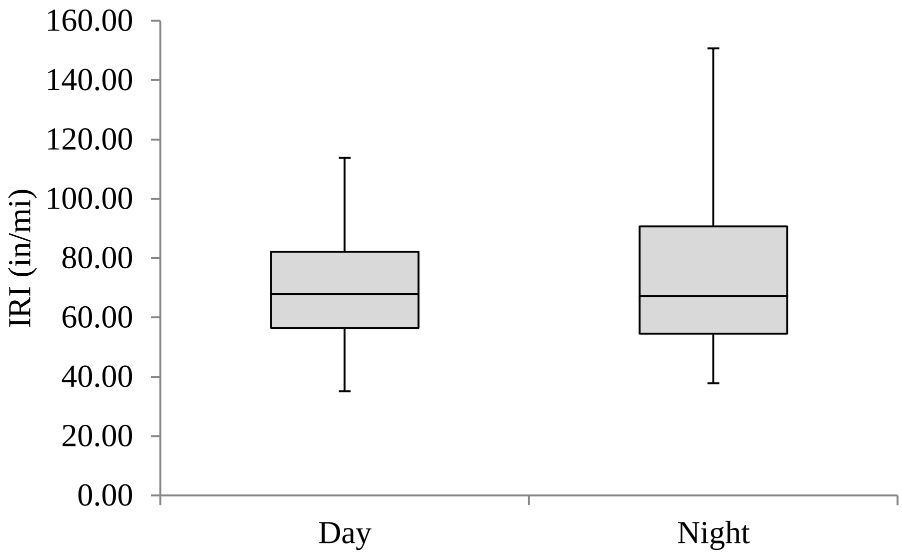


Figure 4. Box Plot: All Day and Night Project IRI Values

Table 6. Descriptive Statistics for Figure 4.

Description	IRI Values		
	n (collections)	μ (in/mi)	σ (in/mi)
All Day IRI Values	121	68.67	18.51
All Night IRI Values	110	73.84	25.75

5.3.5 Exponential Regression Attempt for Entire Data Sets

The easiest method to investigate relative to time is regression. Using the collection age and IRI value pairs, exponential regression was attempted for both the day and night data sets.

Exponential regression was utilized to comply with literature claiming exponential regression in the following form (Eq. 5) was the best fit for IRI-related data (Al-Suleiman & Shiyab, 2003):

$$y = ae^{bx} \qquad \text{(Eq. 5)}$$

Where:

$$y = Projected\ IRI\ (\frac{in}{mi})$$

$$a = IRI\ \left(\frac{in}{mi}\right),\ 0\ months\ after\ project\ completion$$

$$b = IRI\ growth\ constant\ (\frac{1}{month})$$

For the two data sets in this study, however, no regressions yielded favorable least-squares values. The IRI values over time are shown in Figures 5 and 6.

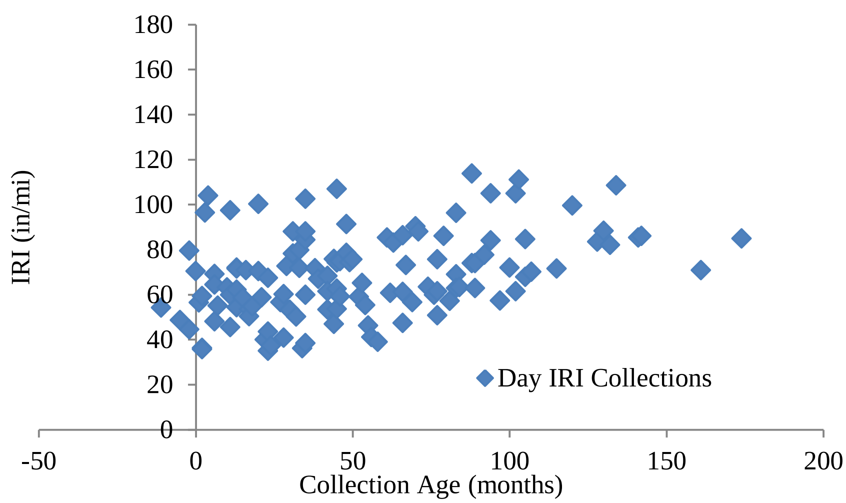


Figure 5. All Daytime IRI Values Over Time.

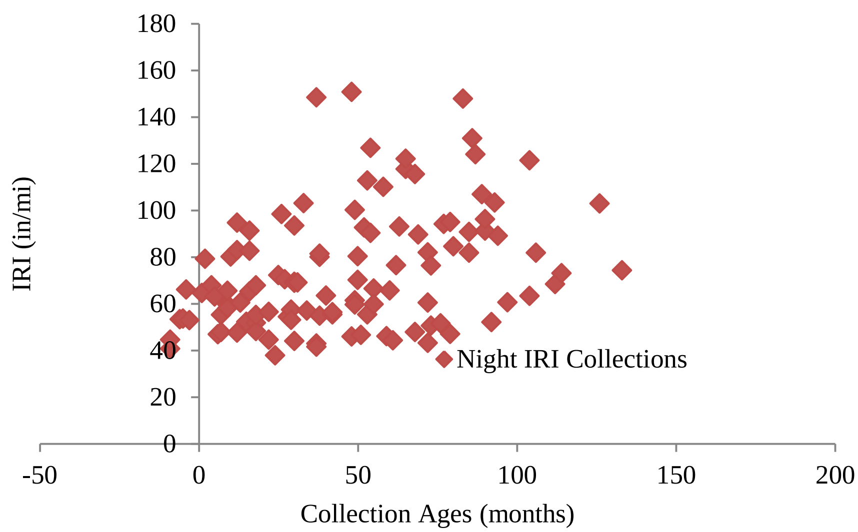


Figure 6. All Nighttime IRI Values Over Time.

The exponential regressions yielded the following equations:

$$y_D = 57.044e^{.0028x}, R^2 = .1654 \qquad \text{(Eq. 6)}$$

$$y_N = 58.374e^{.0039x}, R^2 = .1524 \qquad \text{(Eq. 7)}$$

Where:

$$y_i = Projected\ IRI\ Value\ (\frac{in}{mi})$$

$$x = Age\ of\ project\ (months)$$

Ideally, the data sets would have acceptably applicable regression lines; however, the weak R^2 values reflect the wide variances of the two sets and the inability to compare them accurately as they are organized. What the graphs in Figures 5 and 6 do show is a relatively streamlined increase in IRI over time for the day projects, as opposed to the wider range of IRI values over time for night values. This visual discrepancy lead researchers to believe that there was a difference in the data sets, but looking at them in their entirety was too wide of a range of values to get an accurate depiction. Not only that, but these data sets are extremely front-heavy, with 28 of 49 day projects and 17 or 39 night projects having 2 or fewer IRI collections. Because of the variances in ESAL ranges, having the data so front-loaded seemed to skew the data terribly. Therefore, two separate analyses were performed with different arrangements of the data to create more comparable samples. The first arrangement consisted of all IRI values organized in 30 month groups, and the second arrangement consisted of the same 30 month groups, but IRI values from projects with less than 3 IRI values. The first comparison will reduce the skew of the data by only comparing small time spans, and the second will show better show trends in linked data points. In the end, the second arrangement had very small sample sizes, but the results can be found in Appendix J. Therefore, in this section only the first comparison is discussed.

5.4 Comparison of Entire Day and Night Data Sets in 30-Month Groups

Arranging the entire Day and Night IRI values by collection ages allowed an incremental comparison of roughness along the lives of the pavements. Inasmuch as the data began to become sporadic in higher categories due to small sample sizes, only IRI values collected at within the first 90 months of the project lives were considered. Also, the day IRI value set had 2 extreme outliers within the 90 month intervals, which are discussed in detail in their respective interval section. These two data points were removed to ensure that only normal cases were investigated in the intervals, and special problem cases, whatever they may have been, did not skew the data. Application of this criterion left exactly 100 day project IRI Values and 100 night project IRI values. Table 7 shows the sample size, mean and standard deviation of collection ages and ESAL range ranks for each day and night interval.

Table 7. Collection Ages and ESAL Range Ranks: 30-Month Intervals. The sample sizes, means, and standard deviations of Collection Ages and ESAL Range Ranks for the Day and Night 30 Month Intervals.

Interval	Description	Collection Ages			ESAL Range Ranks		
		n (collections)	μ (months)	σ (months)	n (values)	μ (rank)	σ (rank)
1	≤30 Months, Day	41	12.56	10.40	41	3.94	1.15
	≤30 Months, Night	43	13.65	11.56	39	4.36	.74
2	31-60 Months, Day	34	42.79	7.91	33	3.86	1.26
	31-60 Months, Night	30	46.47	8.43	28	4.25	.76
3	61-90 Months Day	25	75.56	9.02	24	4.08	.97
	61-90 Months, Night	27	75.44	9.11	25	4.26	.74

Table 8. Collection Ages and ESAL Range Ranks: 30-Month Intervals P-Values. Differences in means and variance tests for Collection Ages and ESAL Range Ranks for Day and Night 30-month Intervals. 2-sided tests. P≤.05 is significant.

Interval	Collection Age Comparison		ESAL Range Comparison	
	Diff. Means	Diff. in Variances	Diff. in Means	Diff. in Variances
≤30 Months	.650	.505	.056	.008
31-60 Months	.078	.720	.148	.009
61-90 Months	.964	.957	.480	.183

Table 8 shows that the collection ages are comparable for each interval, since no P-values are above the .05 threshold. However, it is apparent that in the first and second intervals, the day ESAL range variance is greater than the night ESAL range variance with confidence intervals of (1.03, 5.56) and (1.01,7.16) at the 99% confidence level. These differences should not actually influence the roughness in the early parts of the project as literature suggests (Shane, Kandil, & Schexnayder, 2012; Dunston et al., 2000). It is also crucial to point out that the only interval in which both the collection ages and ESAL Ranges are statistically equal is the third interval, 61 to

90 months. Therefore, in the interval where differences in quality would most likely be evident, the data sets are comparable.

5.4.1 Interval 1: IRI Collections ≤30 Months after Project Completion

The first interval investigated IRI values calculated within the first 30 months of the project lifecycle. One extreme outlier, 134.71 in/mi at 28 months, was removed from the day project interval, inasmuch as it was 4.3 deviations from the mean; still, it did not change the non-significance of the results. There was no difference in means (P=.295) or variances (P=.201) between the day project IRI values (n = 41 IRI Values, μ = 60.29 in/mi, σ = 17.32 in/mi) and the night project IRI values (n = 43 IRI Values, μ = 62.22 in/mi, σ = 15.18 in/mi), The lack of differences in means and variances corroborates with current literature, as previously mentioned, and also fits in with general design specs, which go unchanged in terms of roughness for night and day projects (Shane, Kandil, & Schexnayder, 2012; Dunston et al., 2000). Figure 7 shows that while the edges of the 1st and 4th quartiles for the day project IRI reach further, the middle 50% of the data is relatively similar to the middle 50% of the night project IRI values. Therefore, there is no initial difference in roughness between night and day projects.

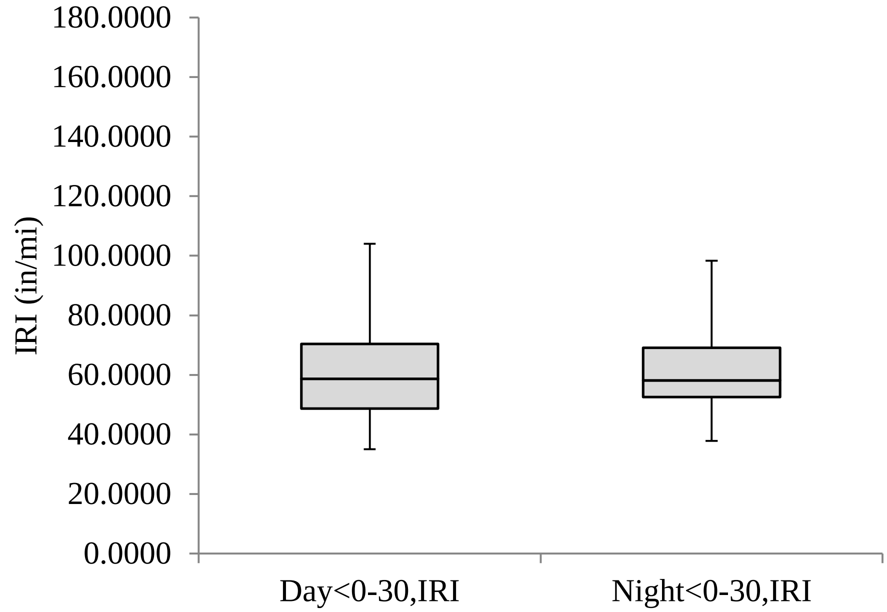


Figure 7. Boxplot: Day and Night IRI Values—Interval 1.

Table 9. Descriptive Statistics for Figure 7.

Description	Interval 1 IRI Values		
	n (Values)	μ (in/mi)	σ (in/mi)
≤30 Months, Day	41	60.29	17.32
≤30 Months, Night	43	62.22	15.18

5.4.2 Interval 2: IRI Collections 31-60 Months after Project Completion

In this interval, IRI values collected between ages 31 months and 60 months, inclusively, were analyzed. With 90% confidence, there was a difference in means (P=.069) between the day project IRI values (n = 34 IRI Values, μ = 67.03 in/mi, σ = 17.84 in/mi) and the night project IRI values (n = 30 IRI Values, μ = 76.49 in/mi, σ = 29.90 in/mi). Although this does not meet the 95% significance level, this difference does show that the IRI means are increasing at different rates, since there was no difference whatsoever in the first interval. In this interval, the night variance was much wider than the day variance (P=.002, CI=1.53, 5.09) with 99% significance. Essentially, the day and night IRI means begin to be statistically distinguishable in months 31 to 60, and there is already much more uncertainty in the night roughness values. Figure 8 graphically shows that the IRI values associated with nighttime values cover a greater range than their daytime counterparts.

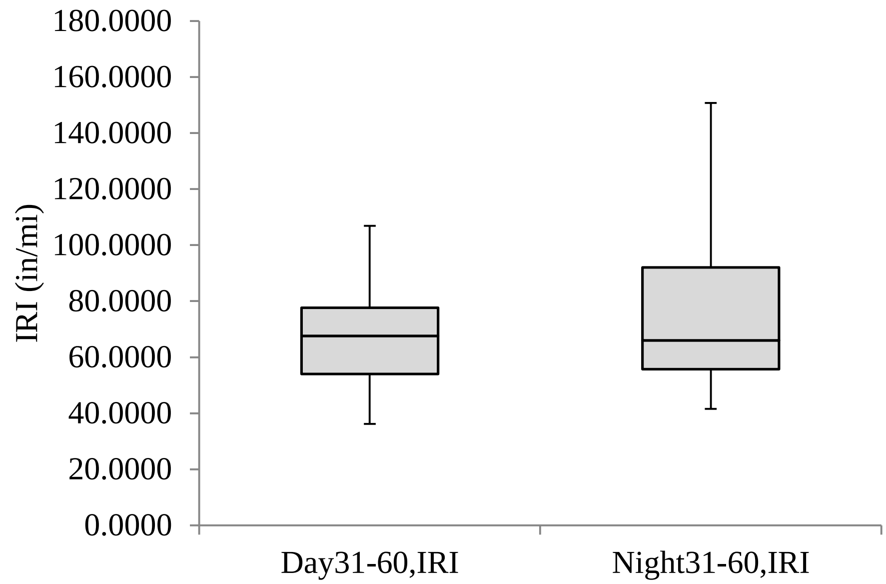


Figure 8. Boxplot: Day and Night IRI Values—Interval 2.

Table 10. Descriptive Statistics for Figure 8.

Description	Interval 2 IRI Values		
	n (Values)	μ (in/mi)	σ (in/mi)
31-60 Months, Day	34	67.03	17.84
31-60 Months, Night	30	76.49	29.90

5.4.3 Interval 3: IRI Collections 61-90 Months after Project Completion

This final interval is the most important to this phase of research, because differences in later phases of the pavement life would prove that a difference in the rate of increase in roughness exists. According to NYDOT's "Surgical Spending," the optimal service life before substantial maintenance is around 7 years; therefore, these projects are nearing or just at the age where some level of maintenance might be performed (Bennett, 2007). One day IRI value was discarded for being 3.8 standard deviations from the mean, but even with this value included there was the night mean was still greater with 95% confidence (P=.039), but the night variance was greater with only 90% confidence (P=.086). After discarding this value to ensure normality, the IRI values from night projects (n = 27 IRI Values, μ = 89.87 in/mi, σ = 32.19 in/mi), had a greater mean (P=.007, CI=6.05, 29.51) and a greater variance (P=.0004, CI=2.13, 8.15) at the 99% confidence level than the day IRI values (n = 25 IRI Values, μ = 72.09 in/mi, σ = 15.81 in/mi). The significance for the greater night mean and variance has substantially increased since the last interval. In other words, not only has the average night IRI value increase faster than the day mean IRI value over time, but the variance and uncertainty in roughness has expanded faster, as well. Figure 9 displays the 61-90 month day and night intervals: it is clear that the night data set is different than the day set. The results of this interval are legitimized by the statistically similar ESAL ranges and collection ages.

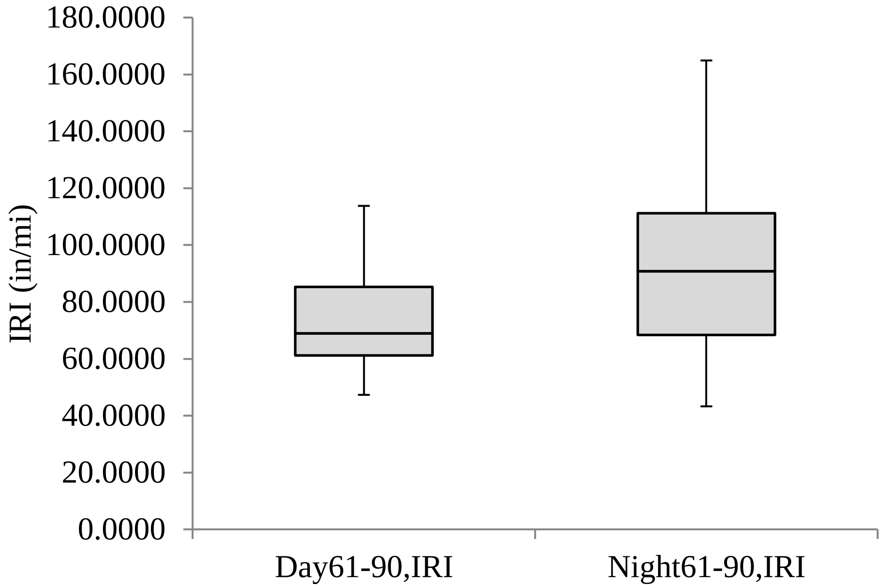


Figure 9. Boxplot: Day and Night IRI Values—Interval 3.

Table 11. Descriptive Statistics for Figure 9.

Description	Interval 3L IRI Values Ages		
	n (Values)	μ (in/mi)	σ (in/mi)
All Day Collections	25	72.09	15.81
All Night Collections	27	89.87	32.19

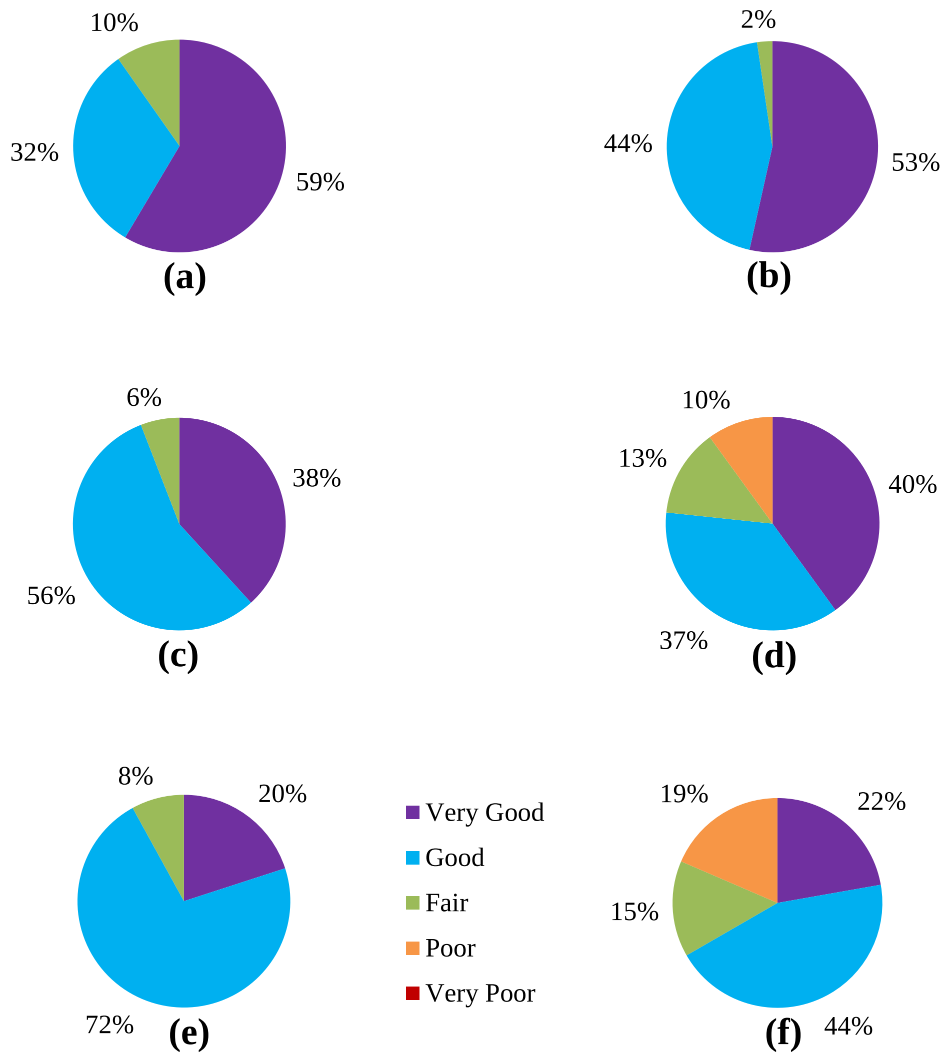
5.4.4 IRI Values and FHWA Quality Designations

As supplementary evidence, each interval's IRI values were organized into the five roughness condition categories as designated by the Federal Highway Administration: Very Good (IRI≤60), Good (60<IRI≤95), Fair (95<IRI≤120), Poor (120<IRI≤170), and Very Poor (IRI>170) (WSDOT, 2012). In Table 12, the designations, associated IRI ranges, and frequency of values in those ranges per interval are listed. In the first interval, there are actually more night IRI values, 97.7% of the values, than day IRI values, 90.2%, that would have been considered

“Very Good” or “Good.” This was no trend, inasmuch as the second and third intervals, as the statistical analysis showed favored the day values. In fact, the night IRI data set posted 10% of the second interval’s sample set and 18.5% of the third interval’s set in the group designated as “Poor” pavement condition. Figures 10(a)-(f) provides a visual aid of the deterioration of the pavement based on the data in Table 12. This faster progression of night IRI values from Very Good to worse condition ratings supports the findings of the statistical analysis. At each interval, although the “Very Good” section remains similar between night and day IRI values, the “Good,” Fair,” and “Poor” groups become increasingly different over time with night IRI values being skewed towards the poorer end.

Table 12. Pavement Condition Frequencies: Day versus Night over Time.

Quality	IRI Range	$Day_{\leq 30}$	Day_{31-60}	Day_{61-90}	$Night_{\leq 30}$	$Night_{31-60}$	$Night_{61-90}$
Very Good	≤60	58.5%	38.2%	20.0%	53.5%	40.0%	22.2%
Good	61-95	31.7%	55.9%	72.0%	44.2%	36.7%	44.4%
Fair	96-120	9.8%	5.9%	8.0%	2.3%	13.3%	14.8%
Poor	121-170	0.0%	0.0%	0.0%	0.0%	10.0%	18.5%
Very Poor	>170	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%



Figures 10(a)-(f). Pie Charts: Pavement Condition Frequencies for (a) Day IRI Values <30 months, (b) Night IRI Values <30 Months, (c) Day IRI Values 31-60 Months (d) Night IRI Values 31-60 Months, (e) Day IRI Values 61-90 Months (f) Night IRI Values 61-90 Months. Based on Table 10.

Shown in both Table 12 and Figures 10(a)-(f), The IRI values from the day projects never reached the "Poor" category, and only reached a maximum of 8% in the "Fair" category, while

10% of the IRI values from nighttime construction reach the that category by months 31 through 60—under 5 years into the pavement lifecycle. Nearly one fifth of the night IRI values collected between 61 and 90 months belong to projects that are in need of substantial repairs, whereas none of the day projects from this same time frame are in need of such rehabilitative action at all.

CHAPTER 6

DICUSSION OF RESULTS

The statistical findings from the IRI serve to prove that the paving industry should take into account the expanding differences in means and variances in IRI over time between day- and night-paved roads. The differences are reflections of the uncertainty inherent in nighttime paving, which is a seemingly streamline project. This idea, along with a greater regard for road quality should hold more weight in discussion of paving alternatives.

Though results from IRI analysis serve as the fundamental findings of this research, the interviews (Appendix H), on-site observations (Appendix I), and collected field data brought to light several recurring themes that could have an effect on the quality of nighttime paving. These themes include lighting and visibility issues, difficulty remaining alert and attentive, and a lack of inspection. In this chapter, these themes are explored, as well as a brief discussion on lifecycle cost differences between day and night paving. At the end of this chapter, the limitations of the research are briefly discussed, as well.

There was a general consensus among interviewees and field data that day paving led to better quality. Dooley B., a contractor, claimed that he has noticed “differences in the surface of the road” between day and night projects. Likewise, Jody L., a superintendent felt that “day-work leads to a better finish.” These sentiments were mirrored among all interviewees except for Adam S. an asphalt foreman, who felt that was “no difference in daytime and nighttime project quality.” The fact is that neither of these opinions is incorrect, in as much as initially there is no difference, but, over time there is a clear separation in quality with regard to roughness as shown in the IRI data. The remaining themes include the interviewees' examples to support their preferences, along with relevant observations and field data.

6.1 Illumination and Resulting Visibility Issues

Issues regarding illumination and visibility proved to not only affect the laborers at the point of paving, but also vehicle operators, and indirect personnel such as engineers and inspectors. To be clear, illumination is the amount of light, or luminous flux over a given area measured in lux (lumens per square meter), while visibility is the level of ability to see clearly as a result of luminance, illuminance, and glare. Adam S. claimed that "visibility is low, but it is still good enough to get the job done;" however the goal is not just to get the job done, but to do so with high quality. Dooley explained that "sweepers miss debris that cannot be seen at night" and that there were "more roller marks on the pavement after night work." Ronnie P., a state agency engineer, concurred mentioning the inability to "tell the difference between layers and levels." Perhaps Randy D., a project supervisor explained it best: You can use all the lights you want, but it's still not the same as working in the day.

Problems due to lack of visibility occurred on an on-site observations on Culver Road in Tuscaloosa, Alabama, and on I-20/59 in Bessemer, Alabama. On Culver Road, a manhole was milled over instead of around because the operator on the bobcat (with a mounted milling tool) could not see directly in front of him due to inadequate illumination. Even worse, for two nights on Culver Road, the street lights were all turned off along the jobsite, and management became very upset because the lack of visibility caused problems both nights. When attempting to rework the area, the operator milled too deeply, most likely due to inadequate lighting again. On I-20/59, utilization of a single bubble light, made it difficult to inspect anything not directly adjacent to the pavement spreader and eventually led to a foreman having to rework labor mistakes.

These issues with visibility were not unfounded, as the checklists and surveys explained the opinions and issues faced in the paving operation. Over the 11 night POPQC assessments, 76 incident light values were collected using the light meter. An average illuminance of 94.04 lux was found around the pavement spreader at night. Even though the spreaders had supplemental lighting around them and balloon lamps above them, that 94 lux is still less than the 108 lux illumination level suggested by literature and implemented by many states (Ellis, 2001; Hyari & El-Rayes, 2006). Likewise, the average uniformity ratio, a comparison of average to minimum visibility measured around the spreaders, was 6.23. This is quite poor considering that the 94.04 lux average is both lower than the suggested paving illuminance but still 6 times as bright as the minimum of 15 lux, which is extremely dark for paving purposes. It is easy to conclude that paving in these conditions could easily result in less than adequate work quality, which would then lead to higher roughness over time.

6.2 Difficulty Remaining Alert and Attentive

The lack of alertness and attentiveness on the jobsite at night was mentioned in most of the interviews as well as backed up by onsite observations and field data. The fatigue induced by night scheduling affects not only the laborers, but also drivers, inspectors, and engineers. Dooley admitted that during night projects “crews usually have to rework parts of the project” and “inspectors are more lenient” due to their own fatigue. Randy D. confirmed that “fatigue and apathy set in at night” and “affects everyone.” This sentiment was realized on the Culver Road site when the project manager exclaimed “By Thursday Night, the entire crew is like zombies, we’re supposed to be asleep at night, and it can’t be healthy to be out here so much.” Generally, one would hope that due to lower visibility and increased worker fatigue, inspection would be strict to ensure quality matching that of daytime paving. Poor inspection early in the paving procedures, such as throughout the milling process and post-milling debris clean-up could easily affect the initial quality and the quality over time as the pavement takes on more loading over time with traffic and congestion increasing.

This lack of alertness and attentiveness caused problems on all projects observed. On Culver Road, spreaders and hoppers were not lining up correctly and caused several asphalt spills. On the US 43 project, a fast starting pace wore off completely by the end of the night and everyone on the project site was dragging to complete tasks, much to management’s chagrin. On the I-20/59 project, inspectors were consistently inactive.

Field data showed that this lack of alertness and attentiveness proved detrimental for both inspector and worker productivity. 4 of 6 night DNGC’s showed that inspectors were not actively checking milled areas for debris, and only half of the night SC’s showed that employees were paying attention to the work area and surroundings. 6 of 13 WPC’s showed at least 1 asphalt worker showing signs of exhaustion or fatigue. The worst night was on State Route 69/US 43 when 4 workers showed a loss of concentration, 7 showed the need to work at a reduced pace, and 7 showed signs of exhaustion. On this same night, the crew had to spend at least 15 minutes searching for a Tracker Rebound which is crucial from a quality standpoint for checking the grade at which the paving is being performed. The piece was directly next to the spreader where it had fallen. In the opinion of researchers, the inability to find this important piece was directly correlated to the exhaustion of those searching for it. The worker fatigue data from the WPC is shown in Table 13.

Table 13. Worker Fatigue Data from WPC

Date	Day or Night	Location	How many workers exhibit:				
			Loss of Concentration	The Need to Repeat a Job	The Need to Work at a Reduced Pace	Lack of Energy or Exhaustion	Horseplay
9/13/2011	Night	US 43/SR-69	0	0	0	0	0
9/15/2011	Night	US 43/SR-82	0	0	0	0	0
9/15/2011	Night	US 43/SR-82	3	0	0	3	0
9/16/2011	Night	US 43/SR-82	2	0	0	0	2
9/28/2011	Night	US 43/SR-82	0	0	0	0	0
9/29/2011	Night	US 43/SR-69	4	0	7	7	0
10/6/2011	Night	US 43/SR-69	0	0	0	0	0
10/6/2011	Night	US-43/SR-69	1	0	0	0	0
10/19/2011	Night	I-59	0	0	0	0	0
10/19/2011	Night	I-59	0	0	0	0	0
10/20/2011	Night	I-59	0	0	0	0	0
11/15/2011	Night	I-59	3	3	0	0	0
11/15/2011	Night	I-59	1	0	1	1	0
9/24/2012	Day	SR-80	0	0	0	0	0
9/25/2012	Day	SR-80	0	0	0	0	0
9/25/2012	Day	SR-80	0	0	0	0	0

Additionally, the WPC showed a 44.6% increase of workers designated with and "idle" work status from day to night. Although the night sample was much larger, this is a cause for concern, because tired, idle workers not only hurt the bottom line, but also are a safety hazard on a project site. Also, 24% of nighttime inspectors were designated "idle" at WPC data collection times compared to 0% of daytime inspectors. If at any given time, one-fourth of inspectors are idle, that is also a cause for concern. Lack of active workers and inspectors clearly can have a large impact on the level of work quality on any construction project.

6.3 Lack of Inspection

On any project, proper and consistent inspection serves to ensure the quality of the construction meets certain standards. Regardless of how fatigued everyone on the site may be, it is crucial that inspectors be present both physically and mentally at all times to keep the project on track from a quality perspective. This was not the case on the projects observed in this study. In fact, inspection was lax and essentially uninvolved most of the time.

Dooley, the subcontractor, claimed that "inspectors are more lenient at night." This statement held true throughout the study, inasmuch as inspectors found in difficult to consistently inspect the milled or paved areas. Inspector involvement was spotty at best for the night projects. In fact only twice in the 6 night DNGC inspector sections did the inspectors receive a favorable mark for involvement in all five observed areas. For day projects, both site visits results in perfect marks for involvement. In terms of actively checking is milled areas were debris-free, 4 of 6 checklists had "N" for No during night observances. The figures were identical for actively checking if milled areas were defect-free. Since defects in the sub-base and lower levels of asphalt result in construction related roughness and poor quality, the inactiveness of inspectors on night projects could a culprit in a difference in road quality between day and night projects.

Inspector designations (direct, indirect, and idle) from the WPC, followed a similar trend. Of the 34 inspectors counted over 3 day WPC's and 13 night WPC's, 6 were from day observations and 28 were from night observations. All 6 of the daytime inspectors earned indirect status because they were actively checking for distresses and debris, clean joints, and temperature control in asphalt trucks. On the other hand, 24% (n=8 inspectors) of night inspectors were idle at the time of observation, and only 76% (n=20 inspectors) were working indirectly.

If these discrepancies held true in larger and more evenly collected sample sizes, one could determine that lack of worker and inspector involvement is a major factor that nighttime paving quality might be worse than daytime paving quality. Lack of inspection would allow low quality work from uninterested workers to be accepted, which would then turn into distresses and roughness much sooner in the pavement lifecycle.

6.4 Cost Effectiveness of Nighttime Construction

From a state agency's perspective, the cost analysis of a nighttime project is not simply compared to the day of scheduling the project during the day, but also to the amount of money saved by reducing the congestion impact of daytime construction. According to a nationwide state agency survey provided by AASHTO, Alabama estimates life-cycle costs by including resurfacing or needed maintenance at 12 and 20 years into the 28 year estimated pavement life at an inflation rate of 4% (MDOT, n.d.). No matter the scenario, one thing is certain, letting a roadway reach "Very Poor" in terms of FHWA condition ratings is poor practice, and a standardized plan should be put into place to resurface roads before they reach their worst condition (Bennett, 2007). Resurfacing a highway can cost an estimated $300,000 per lane mile in Alabama (McInnes, 2010), and complete reconstruction of a road can easily reach more than $1.5 million (King, 2012). However, minor thin-layer resurfacing alternatives, used when the pavement condition merits some maintenance but not a full resurfacing, can cost as little as $23,000 to per lane mile (Lamptey, Ahmad, Labi, & Sinha 2005). Also, on must consider nighttime construction contracts are generally 9% more than daytime construction contracts (Hinze & Carlisle, 1990). With these costs in mind, using the approach allowed to run a simple cost comparison between night and day projects.

For the sake of analysis, we utilized Arkansas's 2012 estimates for roadway construction and rehabilitation costs and Alabama's estimations used in the American Reinvestment and Recovery Act (ARRA) (King, 2012; McInnes, 2010). We assumed two identical, 1 mile, 4 lane, undivided asphalt road construction projects begin on the same calendar day—one using only a day schedule, and the other using a night schedule. The expected cost of the day project is roughly $5.675 million (King, 2012). Therefore, the night project, roughly 10% higher, would be $6.2425 million. By using the following equations, researchers in this study performed a very simple life-cycle cost comparison including only original construction and future resurfacing for the described project scenarios.

$$Day\ Project\ IRI = 58.592e^{.0028x}\text{ , } R^2 = .9833 \qquad \text{(Eq. 8)}$$

$$Night\ Project\ IRI = 57.562e^{.006x}\text{ , } R^2 = .9988 \qquad \text{(Eq. 9)}$$

Where:

x = age of project since completion, months

According to the exponential regressions performed with the respective day and night IRI averages from the 30-month intervals (Eq. 8 and 9), the day project would have an IRI of 87.60 in/mi at 12 years—still well below the “Fair” category. Maintenance for this project would be minimal preservation activities, such as thin overlays costing around $23,000 per lane mile, or $92,000 total for this project (Lamptey et al., 2005). The regression for night IRI averages gave a 12-year age IRI of 136.57 in/mi, which puts the road in the “Poor” FHWA category. Therefore, the night project at this same age would require full resurfacing or “structural overlays, mill and overlays, pothole repair, patching, and crack repair” (Johnson, 2000). Depending on the severity of the corrective action, the maintenance costs here could be anywhere between $50000 and $400000 (NDOR, 2002). Staying true to the $300,000 per lane mile estimate from the ARRA, plus 10% for night project construction, a cost of $1.32 million was attributed to this project at the 12 year mark.

Conservatively assuming that maintenance efforts return both projects to their initial roughness values and that the roughness will increase at the same rate as the first 12 years—instead of much more quickly—the day and night project IRI values at the 20 year mark will be 76.58 in/mi and 102.4 in/mi, respectively. Therefore, the “Good” day project may only cost $92,000 total to perform minor repairs, once again. The night project, however, would receive the same heavier repairs but to a lesser degree. Most likely, the night repairs would cost around $100,000 per lane mile plus the 10% night project increase for a total of $440,000. Figure 11 shows the projected IRI values over the 20 year period, while Figure 12 shows the cash flow diagram for both the day and night projects' construction and maintenance at the 12- and 20-year mark.

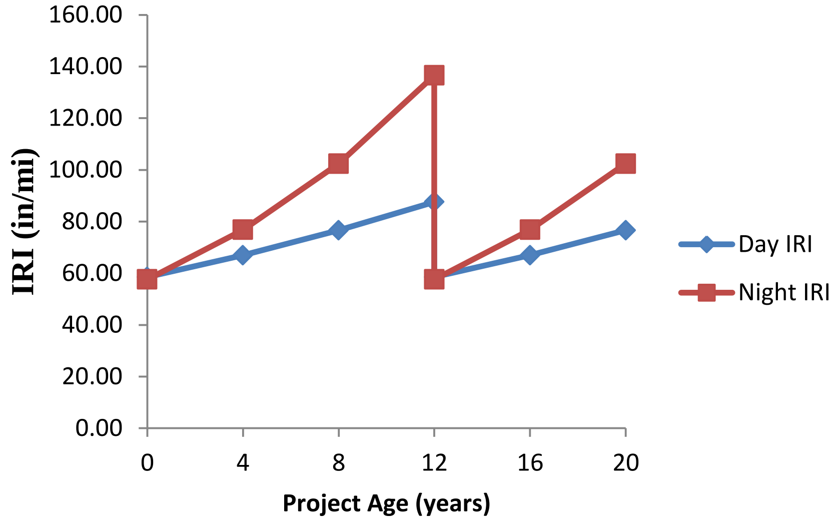


Figure 11. IRI Progression for LCCA.

Table 14. IRI Progression for LCCA. Coincides with Figure 11.
*Maintenance performed.

Project Age (yrs)	Day IRI (in/mi)	Night IRI (in/mi)
0	58.53	57.56
4	66.95	76.77
8	76.58	102.40
12	87.60	136.57
12*	58.53	57.56
16	66.95	76.77
20	76.58	102.40

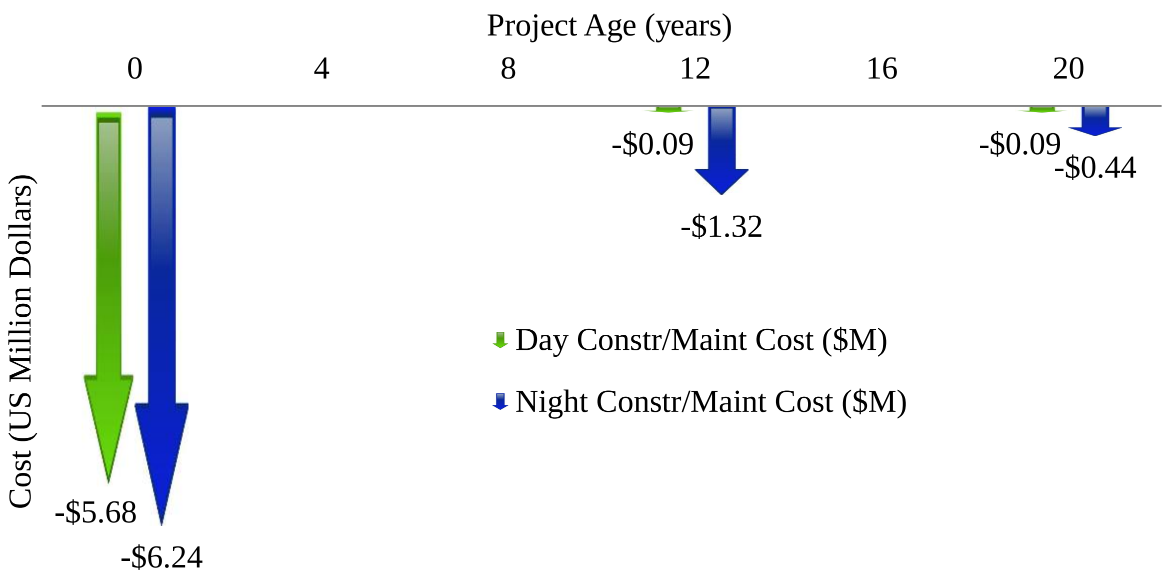


Figure 12. Cash Flow Diagram for Day and Night LCCA

Using these estimates, the Alabama resurfacing schedule, the 4% rate of return, and the single payment present worth formula for each construction/maintenance cost, the net present value of the day project cost is $5,774,450.53, as opposed to the much higher $7,267,778.36 night project net present worth. This amounts to a 26% increase in costs in terms of present worth. Although these numbers are based on a very simple method, the central message is clear. Night projects cost much more over time from the agency perspective when they are maintained according to day maintenance timing standards, and, due to the difference in condition deterioration, they cannot be subjected to the same life-cycle cost schedule as day projects.

Considering the vast number of nighttime projects across the United States, it is conceivable that the penalty in lifecycle costs due to poorer roughness resulting nighttime paving may outweigh the dollar-value of congestion relief. However, the data sets in this research were not geared for cost analysis, it is difficult to determine if the poorer quality of nighttime paving over time is enough to make a cost-effective versus congestion argument. It is clear however, that more money is spent in both the short term and long term on increased contracts and earlier significant maintenance, respectively, for a worse product in terms of roughness relative to daytime paving projects.

6.5 Limitations of Research and Results

With any study, there are some limitations to research, methodology, and results. This study is no different. In this thesis, three limitations are worth noting: differences due to mix types, potential geographical differences, and a need for corroborative research.

First, and foremost, it should be noted that significant differences in mix types may have an effect on road roughness over time. Due to the potentially small sample sizes, this research did not take into account mix design properties, other than our request to ALDOT included a preference for Hot Mix Asphalt (HMA) pavement projects. While all the projects did meet this criteria, preferences regarding actual types of HMA pavements such as superpave (SP),open grade friction course (OGFC), stone mix asphalt (SMA), or others were not made explicit. One study found that SMA mixes have higher initial IRI values (Wen, 2011), but the percentage of SMA mixes in this study was very low. Future research should investigate the effects of the different mixes on IRI over time.

Another limitation on this research is that all the data came from the Alabama Department of Transportation, and thus is not necessarily indicative of all paving projects outside of the state. Weather and traffic differences may change the outcomes of this research. Different locations have different practices and designs to fight pavement deterioration, so this difference in geography is a limitation worth noting.

Furthermore, this research should be repeated and expounded upon within 3 to 5 years. This will allow more IRI data to be collected for the projects involved, and for more observational and field data to be collected. With more data points and site-visits, a more concrete judgment could be made. In these subsequent studies, researchers could include IRI differences relative to mix types, maximum aggregate size, ESAL ranges, urban and rural locations, and roadway lengths. This will give a more expansive view of the problem at hand.

CHAPTER 7

CONCLUSION

Night construction has become an integral part of the paving industry due to the increasing congestion in urban areas of the United States. Contractors and government agencies alike seemingly agreed that the lack of congestion was worth working at night and the extra costs that that incurred. Time after time the issue of quality arose, but research either failed to provide substantial proof or the proof lacked a sample size large enough to matter. This study, however, proved that paving strictly on a nighttime schedule coincides significantly with a faster increase in roughness over time. Not only were the mean IRI-values significantly different and grow more significantly different over time, but the variances followed the same rule and to a higher degree. Night construction leads to both higher and less predictable roughness indices over time.

In the first 30 months of the pavement life, there was no difference in means or variances of IRI values. Therefore, new roads, whether paved on a day schedule or night schedule, will have statistically indistinguishable roughness indices. This coincides with current literature. As time goes on however, specifically in the second 30 months, the night project IRI-value mean is greater than the day mean (P=.069, CI=1.33 in/mi, 17.60 in/mi) with 90% significance. In this same interval, the night IRI variance was wider than the day variance (P=.002, CI=1.53,5.09) at the 99% significance level. Furthermore, in the final 30 month interval analyzed, both the night IRI mean (P=.007, CI=6.05, 29.51) and the night IRI variance (P=.0004, CI=2.13, 8.15) were greater than their day IRI counterparts with 99% confidence. The gap between both nighttime and daytime IRI means and variances widens as the pavement age increases, meaning there is significant evidence of a difference in roughness over time.

From interviews, onsite observations, and field data collection, researchers determined that the main underlying causes for differences in roughness, and potentially, overall quality of work, lie in the lack of adequate lighting on jobsites and the difficulty of remaining alert and attentive during the night hours.

Lastly, a simple hypothetical construction-maintenance cost comparison showed that night projects can cost much more to state agencies over their life-cycle due to higher bid prices and poorer quality leading to more expensive maintenance procedures, however, this study did not have the resources to perform an in-depth cost analysis of real projects.

These findings are extremely important on several counts. First, contractors and agencies alike should take note that the difference in variance of IRI values between day and night projects is essentially a difference in variability, or uncertainty. Quality, or roughness to be exact, should be taken into account with greater weight when making the decision to implement day or night paving schedules. It should also be noted that greater measures should be taken to ensure that visibility and worker/inspector fatigue and apathy do not affect the finished work.

Secondly, although this research dealt with a larger sample size than several other studies, furtherance of this research should involve even larger sample sizes, separated by ESAL Range, so that, hopefully, the variance will shrink for each data set, and a successful regression analysis could be performed for each level of service. With larger sample sizes, average resurfacing ages for night and day projects, and estimates for average cost of resurfacing at those ages, future research could potentially determine the cost-effectiveness of nighttime construction versus saved money from congestion alleviation in life-cycle terms, based on the roughness of the roads. Also, a state-by-state comparison of nighttime construction quality in terms of life-cycle roughness could be performed, which would allow states to collaborate and share ideas to increase the quality of their roadways in the future.

Although congestion continues to plague our highway system, there are many measures taken by government agencies to alleviate the problem. One major mitigation tactic is the utilization of nighttime scheduling for paving projects. Although there is definitely short term gain in congestion relief relative to performing projects during the day, the long term costs due to poor quality and higher roughness indices on the night-paved roads could put a major dent in those savings. One thing is for certain, though: in the state of Alabama nighttime paving projects increase in roughness and decrease in quality at a faster rate than comparable daytime projects.

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APPENDIX A

DAYWORK/NIGHTWORK GENERAL CHECKLIST

Location:____
Date:___________
Time:___________
Temperature:________
Description of Work:

Tonight's Project Stations: _________________ to ___________________
Shift Time: __________ to ___________
Planned Distance of Overlay:__________

Tonight:
Milling Work: Planned Distance_________ Actual__________
Depth___________

Paving: Planned Distance_________ Actual__________

- Layer_________ Mix __________ Depth__________
- Layer_________ Mix __________ Depth__________
- Layer_________ Mix __________ Depth__________

- ○ How many lanes are to be paved? ________
- ○ How much asphalt will be poured? _______
- ○ How many lanes are closed?_______

Head Count:

Title	Amount
Engineers	
Inspectors	
Foremen	
Asphalt Workers	
Traffic Control Workers	
Drivers	

Equipment Count:

Type of Equipment	Amount

Inspectors:
Are/have the inspectors actively checking/checked the following:

Inspection	Y/N/NA	Method of Inspection
Clean Joints at Ends		
Asphalt Truck Temperatures		
Milled Areas are Debris-Free		
Milled Areas are Defect-Free		
Vehicle Operation Safety		

Notes:

APPENDIX B

SAFETY CHECKLIST

Location:
Date:
Description of Work:

Public Traffic:
Are proper measures taken to keep motorists obeying posted rules to assure safe conditions for workers and themselves?
- Adequate Signs: ______
- Proper Signs: ______
- Highway Patrol:______
- Wrecker Service (to rapidly remove disabled vehicles): ______
- Emergency Radio Stations in Work Zone: ______

Comments:

Signage:
Are all signs in good and readable condition? ______
Are all signs placed at correct angle to be seen from oncoming traffic's headlights? ______
Do any signs contradict each other? ______
Are damaged signs replaced in a timely manner? ______
Are non-applicable signs covered in a proper and timely manner? ______
Are signs positioned properly for adequate warning of work zone conditions? ______
Are traffic signals withing the work zone functioning properly? ______
Are signal heads positioned and adjusted to match active lanes in the work zone? ______
Comments:

Illumination and Reflectors:
Are paint lines clearly visible at night?______
Are paint lines correct width? ______
Are all lollipop reflectors in place and visible? ______
Are all reflectors on side of barrier wall in place and visible? ______
Is barrier wall too dull at night? ______
Are all raised pavement markings in place and visible? ______
Have all unnecessary raised pavement markings been removed? ______
Are message boards flashing properly? ______
Are message boards clear and concise? ______
Are all channeling devices properly illuminated? ______
Comments:

Lane Closures:
Are lane closures properly set up and taken down? ______
Do lane closures exceed maximum length? ______
If more than one lane closure, are they the minimum length apart? ______
Are all arrow boards in correct place and working properly? ______
Is crash truck in place? ______
Is crash truck attenuator in working order? ______
Is crash Truck attenuator properly illuminated? ______
Comments:

Lighting:
Do floodlights cause a glare problem for motorists? ______
Is work area adequately lit for safe work? ______

Are proper warning lights being used? ______
Are screens used if appropriate? ______
Comments:

<u>Shoulder Conditions:</u>
Are disturbed shoulders properly identified by placement of barrels? ______
Are any drop-offs greater than 2"? ______
Are stored material and parked equipment 30' or more from unprotected roadway? ______
Comments:

<u>Channeling Devices:</u>
Are all cones, barricades, and barrels properly spaced? ______
Are all cones, barricades, and barrels standing? ______
Are all cones, barricades, and barrels properly managed? ______
Do all channeling devices represent a clear traveling path? ______
Are cones, barricades, and barrels interrupting the flow of traffic? ______
Comments:

<u>Attenuators:</u>
Are attenuators in properly working order? ______
Are attenuators properly illuminated? ______
Comments:

<u>Traveling Equipment (Dump Trucks, Loaders, Rollers, etc.):</u>
Are all signals, illumination, and backup alarms working properly? ______
Are vehicles driving safely and obeying traffic rules? ______
Are employees driving company trucks safely and obeying traffic rules? ______
Comments:

<u>Employees:</u>
Are employees paying attention to work area and surroundings? ______
Are employees equipped with proper communication devices (radios, phones)? ______
Are employees horse playing? ______
Are employees operating equipment correctly? ______
Are all employees wearing proper safety equipment and illumination?
- Hardhats ______
- Safety Glasses ______
- Vests ______
- Steel Toe Shoes ______
- Gloves ______
- Other Safety Equipment and Illumination Needed ______

Are all flaggers properly dressed?
- Orange Shirt ______
- Vest ______

Are flaggers obeying correct procedures?
- Correct Motions ______
- Correct Signs ______
- Proper Radio Communication ______

Are flaggers standing in correct positions? ______
Are flaggers trained and briefed on correct procedures? ______
Do flaggers adequately speak the same language? ______
Comments:

APPENDIX C

WORKER PRODUCTIVITY CHECKLIST

Location:____
Date:_______________
Temperature:________
Description of Work:

Behavior and Fatigue of Workers:
Time:__________
Number of Workers:____________
Activity:_____________
Are workers equipped with proper communication devices (radios, flashlights, etc)?_______
How many exhibit--

- A loss of concentration?______
- The need to repeat a job?______
- The need to work at a reduced pace?______
- A lack of energy or exhaustion?______
- Horseplay? ______

Productivity Check (Visual Inspection, One Walk along Jobsite):
Direct Work = Laying down primecoat or tackcoat, asphalt placement, asphalt compaction, etc
Indirect Work = Dust removal (sweepers), asphalt hauling (trucks), inspection, meetings, etc
Idle = Anything that does not constitute work of aid in completion of construction.

Worker Title	Direct	Indirect	Idle

Notes:

APPENDIX D

PAVING OPERATIONS PRODUCTIVITY AND QUALITY CHECKLIST

Location:____
Date:____________
Time:____________
Temperature:_________
Description of Work:

Equipment Behavior:
Do all worksite vehicles have their headlights turned on?________
If not:

Which Vehicles?	How Many?

Are any vehicles idle on freshly-poured asphalt?________
If so:

Which Vehicles?	How Many?

If there are idle rollers, how many are stopped at 45 degree angles off the new asphalt? _________

Visibility Check (Night Only):
Are all vehicle controls well lit? __________
If not:

Which Vehicles?	How Many?

Are there streetlights along the worksite?_________
Are they on?_____

Is there an overhead light on the Asphalt Truck?_____
Is there supplemental lighting on the sides of the Asphalt Truck?_____
Are the asphalt pours clearly visible to the workers?_____
Is it possible to detect imperfections in newly-paved asphalt at all points with the given lighting conditions?_____
Is it possible to diligently inspect the milled areas for debris?________
Is it possible to identify defects in the milled area (i.e. alligator cracking)?__________

Surface Preparation (Based on Visual Inspection):
Are there failed pavement areas that have not been removed and replaced prior to paving?________
Are there potholes that have not been properly patched?_________
Are there cracks that have not been cleaned and sealed?_________
Are there rutted layers that have not been filled or removed?__________
Are there uneven layers that have not been leveled by milling or placement of asphalt level course?________
Is there debris in the milled areas? ________
Are there defects (rutting, alligator cracking, transversal cracking) in the milled area? ________

Placement Techniques (Based on Visual Assessment):
Do the hoppers/dump trucks stop short of the spreader and let the spreader approach them?________
If not, how many? ________
Do the dump trucks leave tailgate up when angling the bed for pour into the hopper/spreader?_______
If not how many? ________
Once the mix is delivered to the hopper, is the spreader brought up to paving speed as quickly as feasible? _______
Is it operated at a constant speed? ________
Does the paver come to a complete stop during truck exchanges? ________
Are the flow gates on the back of the hopper set at a height which allows for nearly constant 100% operation of the paver augers?_________

Illumination around Direct Work -Related Vehicles (Paver) (Night Only):

Sekonic L-308S Flashmate Flash and Ambient, Incident and Reflective Light Meter

Vehicle	Position of Lightmeter (2.5 ft horz back, 5.5' vert)	Incident/Ambient Light (EV)	Reflective Light (ISO 100)
Spreader 1st Check	Behind Asphalt		
	Left of Asphalt		
	Right of Asphalt		
Spreader 2nd Check	Behind Asphalt		
	Left of Asphalt		
	Right of Asphalt		
Spreader 3rd Check	Behind Asphalt		
	Left of Asphalt		
	Right of Asphalt		

Asphalt Cooling and Compaction Over Time:
Flir i7 Thermal Camera

Mix	
Mix Design Pour Temperature	
Minimum Compaction Temperature	

Beginning Station: ______________________

Observed Pour # and Time	Roller Pass #	Time of Pass Execution	Minimum Temperature (°F) After Pass	Picture Designation File Name	Are Workers Still Shoveling?

Notes:

APPENDIX E

EQUIPMENT AND INSTRUCTIONS FOR

POPQC "Illumination around Direct Work-Related Vehicles"

Equipment Sekonic L-308S Flashmate, Flash and Ambient, Incident & Reflected Exposure Meter ISO 100, 1s shutter speed,
1. As the pavement truck spreads asphalt, take one incident light reading at five feet five inches vertically , close to eye level, angled down toward the fresh pavement. a. Be sure that the asphalt truck is just ahead of you in the lane. Gather light meter readings within five to ten feet of the truck. This will simulate being part of the asphalt crew shoveling directly under the lights. b. Record one reading from the left side of the lane being paved, from the right side of the lane, and from directly behind the spreader. c. Repeat this two more times to get a total of nine incident readings if possible.

Appendix F

EQUIPMENT AND INSTRUCTIONS FOR

POPQC "Asphalt Cooling and Compacting Over Time"

Equipment
Flir i7 Compact Infrared Camera

1. At the top right of the page, write the mix being used, the optimum pouring temperature, and the minimum compaction temperature, if the information is readily available.
2. Turn on infrared camera. Ensure that the time and date are both correct on the screen.
3. Standing 3 feet away from the edge of the paving area on the side safest from on-coming traffic, take a single picture of the freshly laid asphalt as soon as the spreader moves far enough away.
4. For the initial infrared picture, record the following data for the pour.
    a. Column 1 – Number and Time of observed pour
    b. Column 2 – 0 for Roller Pass #, since the Roller has not executed a pass yet
    c. Column 3 – For the 0-Pass, this will be the time at which the initial picture was taken. This is saved to the picture in the camera's memory and can be seen in picture view mode.
    d. Column 4 – The bottom left corner of the picture shows the minimum temperature found in the entire image. That temperature will go here.
    e. Column 5 – The file name associated with the picture is inputted here, and can be found at the bottom of the screen when in picture view mode.
    f. Column 6 – Simply observe and record whether or not workers are shoveling.
5. Once the first row is finished, the remaining rows will be completed after every compaction cycle over the original spot, until the crew stops compacting.
    a. Column 1 will remain empty until the crew is finished compacting.
    b. Column 2 will increase by one for every Roller pass executed.
        i. If there is a delay in passes, take an infrared photo of the chosen area to keep a quasi-continuous flow of data.
        ii. If this is the case, do not increase the Roller Pass # in column 2. Keep it constant.
    c. Column 3 –Write the time associated with the picture taken for the row
    d. Column 4 – See Section 3.d of this procedure.
    e. Column 5 – See Section 3.e of this procedure.
    f. Column 6 – See Section 3.f of this procedure.

Repeat this process for 1 or 2 pours per hourly checklist, whichever time permits.

APPENDIX G

LONGITUDINAL VISIBILITY SURVEY

Project:____________________ Page____/_____

Sekonic L-308S Flashmate Flash and Ambient, Incident and Reflective Light Meter

Date:__________Time:_______

Measured 5'5" (Approximately eye level) from the ground, looking down onto the paving area from right side, walking with traffic

Area Column Input>> NA=Non-Activity A=Activity

STA	RL	IL	Side Light Source	Area	Obstacles	Comments

APPENDIX H

EXAMPLE SPREADSHEET

SENT TO ALDOT DIVISIONS

	Project Number	Daywork or Nightwork	Project Dates (MM/DD/YY - MM/DD/YY)	Project Type	State Route	Project Beginning Milepost	Project End Mileposts	Mix	Mix Beginning Milepost	Mix End Milepost	Mix Type	Layer Type	Maximum Aggregate Size (in.)	ESAL or ESAL Range	Rate (lb/yd^2)
EXAMPLE 1	99-305-632-069-901	Nightwork	5/3/10 - 1/21/11	Resurfacing	SR-69	138.2	141.596	424A-281	138.956	141.596	SP	Wearing Surface	3/4	E	200
EXAMPLE 2	99-305-632-069-001	Daywork	5/10/10 - 11/22/10	Resurfacing	SR-69	148.4	152.4	424A-356	148.4	152.4	SP	Wearing Surface	3/8	C/D	90
								424B-650	148.4	149.8	SP	Upper Binder	3/4	C/D	165
								424B-651	149.8	152.4	SP	Upper Binder	1	C/D	300

APPENDIX I

DIRECTIONS FOR SPREADSHEET

SENT TO ALDOT DIVISIONS

To whom it may concern:

ALDOT requests you to participate in a data collection effort that aims at determining the differences in the quality of the finished surfaces between nighttime and daytime resurfacing projects. To this end, we ask you to kindly fill and return the attached spreadsheet with data for:

- Divisions 1st, 3rd, 5th, 6th, and 9th: 10 resurfacing projects executed *exclusively during daytime* and 10 resurfacing projects executed *exclusively during nighttime,* and all of them executed over a range of years. Thus, please make sure that the age of the 20 projects is approximately distributed *between 1 and 15 years old (Completion dates between 1996-2010)*. (**)
- Divisions 2nd, 4th, 7th, and 8th: 5 resurfacing projects executed *exclusively during daytime* and 5 resurfacing projects executed *exclusively during nighttime*, and all of them executed over a range of years. Thus, please make sure that the age of the 10 projects is approximately distributed *between 1 and 15 years old (Completion dates between 1996-2010)*. (**)

The attached spreadsheet comes with examples on how to be filled. Place the cursor on top of each column to find its definition. Once completed, please save the spreadsheet with your division's number in the file name −for example, "3rdDiv.xls" . Please send the file back or make any question you may have to Joey McElvy at [redacted], or by phone at [redacted]. We would like to have your project data file by **October 16**.

Sincerely,
Joey McElvy
Graduate Student – Civil Engineering
University of Alabama
[redacted]

(**) An indicative list of the sources of information required to fill each column in the spreadsheet follows:

- Project Number: Project Plans
- Daywork or Nightwork: Construction Department Database
- Project Dates: Construction Department Database
- Project Type: Project Plans
- State Route: Project Plans
- Project Beginning Milepost: Project Plans
- Project End Milepost: Project Plans
- Mix: Project Plans
- Mix Beginning Milepost: BMT-4 Asphalt Placement Reports
- Mix End Milepost: BMT-4 Asphalt Placement Reports
- Mix Type: Project Plans
- Layer Type: Project Plans
- Maximum Aggregate Size: Project Plans
- ESAL or ESAL Range: Project Plans
- Rate: Project Plans

APPENDIX J

INTERVIEWS

5-12-11
ST Bunn III Interview Notes

ST Bunn III "Dooley"

Highway 11, perfect project for this, ½ Day, ½ Night
Culver Rd Project – Josh Norris or Benji Cantrell overseeing the work
- 100 work days, delayed at first
- D – 8-3:30pm M-F
- N – 7pm-5am Su-Th
- Safety Day – Class 2 vest
- Safety Night – Class 3 Vest (more strips and sleeves w/ strips)
- Plans are available, Mill and Fill 1-2 inches
- "Match Existing" project
- Hwy 11 (Greensboro) West to Fosters (out of city limit)
- ALDOT owns the project (5^{th} Division)

Daytime – Spreading is better (bumps go unseen at night)
Use a 16 ft straightedge to ensure a good joint
Problems on some jobs:
- sometimes sweepers misses debris (reflector, tire) cant notice this at night
- usually have to rework
- McFarland – resurfaced a cone weight
- I-359 paved over a turtle

Quality of Asphalt:
- Day – Hotter asphalt leads to better quality
- Night – Not as much heat, more roller marks
- roller parks at 45 deg. To have easy roll out
- theory says to move off road, but sometimes theory is too impractical

Mistakes in Mill Depth:
- 3:00am milled 8 in., supposed to be 2 in. >> .3 Miles
- Profilograph read 35, supposed to mill out at 10 (calibration problem)
- with poor grades in smoothness and surface condition, paycuts increase in 5% increments

Density of Asphalt:
- perfect density = 102% pay
- 10 lb/yd^2 allowance
- check spread, slope, density, thickness
- with todays equipment, 10 lb/yd^2 allowance is easy to achieve

ALDOT – 3/8 mix

- lasts about a year on old roads
- use on new roads simply for aesthetics
- highway 171 0.0-4.5 mile marker, all 3/8 mix

More specific thoughts on night practices

- more lights on spreader
- reflector tape on everything (equipment, tools, units)
- caution drivers on backing up
- change logos to reflective type, ball caps too
- all workers have flashlights (hand and head)
- Airstar lights for night workers
- Paver goes slower at night, 110 lb = 2 miles of paving/night
- Skyland Project – Chip Sealing was difficult
- pink ribbons around powerlines phone poles, to see them when backing up
- orange line in front of them
- generally use the same crew for each night job
- less traffic, but drivers are more dangerous (drunk, tired)
- inspectors are more lenient at night, stay all night
- street lights cause multiple shadows
- more incidents at night
- spreader must turn off headlights, crew has hit nuclear gauge w/o headlights

Difference in Quality

- More bumps at night, roller marks, wrecking equipment (more of a safety issue)
- same mix, the most difference is in the surface of the road
- Manhole Risers put in after paving (for night jobs)
- Have not seen a difference in the life of the asphalt
- bigger mess at night (broom trucks)
- clean up during the next day (usually the same crew cleans their mess)

Safety (N vs. D)

- safety meeting once per week
- had a wreck in almost every night job
- mostly DUI's wrecking into equipment
- items thrown at workers from passersby
- workers
- required trooper or cop to direct traffic while implementing lane closure and signage
- stands all the way in front
- MUTCD (manual uniform traffic control devices)
- Specs (light on first barrel)
- D – some workers have fallen out from the heat

Costs (Night v. Day)

- Night > Day

- Night – lights, generators, reworking, and reflective materials
- 10% extra for night bid
- There is more paving time in the day, so shorter project theoretically
- Must pay shift differential to night workers
- Night – Productivity slows over time in the night (fatigue, apathy)
- always pay “show-up time” if work is cancelled
- when equipment goes down at night, construction is haulted until the next day
- repair dealerships are not open at night
- much more down-time at night, coupled with less time to pave

Other projects currently or once involved with:

- Univ, Greensboro (hwy 215) night
- I-359 (2008)
- I-59 exit 73-71
- I-59 exit 73-86
- Hwy 69 – Hargrove road/skyland
- City contract – 2 roads at night (2003) 7th street between Greensboro and 22nd avenue
- Univ. Blvd (capitol building – Lurleen South)
- Lurleen N & S (359 Bridge to River Bridge

5-19-11

<u>Ronnie Pugh</u>

At night, hard to inspect for alligator cracking

Hard to tell the difference between layers and levels

- Leads to bad binding, failure in the future

Milling is done to create a flush profile with the curb

The clay content in the subgrade fails, that starts the alligator cracking

- Fix this by tearing up all of failure asphalt, then patching or refilling

State will allow up to 20% Milling material in final wearing layer

- You can use more in under-layers
- Aggregate in milling material has been polished and has less surface friction

Temperature- day time allows more time to compact and pave

- Night – must compact and pave before cooling

Lighting – as equipment moves, need continuous lighting

- Vertical lighting is used, many dead spots on project

Life of pavement – 20 yrs on subdivision

- 10 yrs on heavy traffic

Asphalt compacts differently based on depth/amount of mix

Alligator cracking – failure below (subgrade, base), moves, reflects on top

“it’s worth working at night to not put up with the traffic”

Measuring Tack Rate – gal/yd^2 – read amount on meter to make sure it meets specifications

Jody Lindsay
Night part of project will last about a month
Night- less traffic
- Bleed spots in mix (can't see them)
- Glare of cars

Believes from experience that day-work leads to better finish.**
Night – takes longer, costs more
- Always working in a shadow, miss more problems
- Fatigue of workers plays substantial role, 3-5 AM especially
    - Want to just go home, often can't sleep during day

Benji Cantrell
Lack of visibility
2 night jobs – no operational problems (interstate and skyland)
Safety issues – milling 5-6 inches, woman walked in hole, shattered elbow
Never had to do any rework
Opinion: Limitation on lane closure causes day to last longer

6-8-11
Randy Davis
Laborers – 16 Workers – ST BUNN
- 1 Pilot Car
- 4 Flaggers – rented, DOT, not BUNN employees
- 8 Dump Trucks – Milling Material, asphalt
- 1 Tack Truck
- 1 Paving Truck
- 1 Roller
- 2 Sweepers, cleanup
- 1 Back-hoe clean-up

8 inch deep mill, 1300 ft
Currently waiting for milling to advance before paving
"day is better for resurfacing projects because of obvious conditions. The light and fatigue factors really affect everyone"
At night, drunk drivers veer into project site and bust cars in the 8-inch milling depth.
- did not happen on this project only an example

Workers are happier and work harder, faster during the day. (fatigue and apathy set in at night)
Believes more paving can be done in the day (hours, light)

Biggest setback at night, traffic control on such a short/tight area, (one lane) is more difficult to accomplish at night because of lack of worker and driver visibility

- "you can use all the lights you want, but it's still not the same as working during the day."
- This project is using a "warm mix," less workable but can be worked at a lower temperature.
    - This helps cancel the effects of working at night with a lower temperature.

1300 of 1300 ft to be paved were paved.

<u>Ashley McCall and Byron Tubbs</u>
Inspectors
Looking for
- clean joints
- 8 in milling depth
- asphalt temperature in trucks (laying temp) remains constant and at spec (every 3rd truck is sufficient)
- Rate of asphalt being laid, making sure that too little or too much isn't being used

6-9-11
<u>Adam Simpson</u>
Supervises paving crew
In summer, nighttime is better
- Daytime heat is simply overwhelming
- Interesting that the worker's view differes from the engineer, the workers who actually perform the direct labor hate day time.)

"visibility is low, but it is still good enough to get the job done"
Sees no difference in Daytime and Nighttime Project quality (immediately speaking, not a valid source for over-time differences)

<u>William Holloway</u>
Traffic control
Claims that nothing changes in how they control traffic between Day and Night practice-wise;
- The only change is the volume of cars, and the amount of work the traffic workers do.
- Says set-up is still the same.

APPENDIX K

ON-SITE OBSERVATIONS

On-Site Observations

The following observations were made on-site at projects in the following Alabama cities: Tuscaloosa, Northport, Bessemer, and Bellamy.

Culver Road Project

6-9-11

Worker using a small mounted milling tool on a bobcat to mill around a manhole. Only light is that from the bobcat, which projects too far out to see the manhole directly in front of the machine. Has to rework and eventually mills too deep. That's a small waste of asphalt that could have been avoided during the day.

6-14-11

Milling Machine broke down early into project work tonight. Milling Machine must be repaired by on-site mechanic, who has been idle up until tonight in the project. Had this been a day project, the project mngr claims a new milling machine would have been brought on-site, and an off-site mechanic would have fixed the truck. This would have saved valuable work time. They decide to go ahead and pave what they have already milled, which is a very short stint of road. Eventually late in the night, a small 7-ft wide milling machine comes in from another project in the county. Mngr spends entire night away from supervising the crew to deal with the broken profiler (front axle). Eventually a trailor comes to take it away when the onsite mechanic cannot fix it. Steering mechanism breaks on milling machine as it is loaded. Requires 2 bobcats to pull the machine onto the trailer, instead of working elsewhere on the jobsite. These are all normal occurrences when machines break down, but because it was nighttime, extended time was spent trying to initially fix the machine.

6-23-11

Crew is working, albeit very slowly. Much slower than the past few nights.

"By Thursday Night, the entire crew is like zombies, we're supposed to be asleep at night, and it can't be healthy to be out here so much" – Project Manager

6-28-11

Tonight, work is being done under the I-359/US-43/AL-69 overpass at 15th Street. All the traffic lights are out, and no additional lighting other than that one large bulb on the Pavement Truck and the headlights of bobcats, sweepers, and rollers. Workers upset because they can't see to do their job. Managers upset because Job is not getting well. Second Night in a row that street lights are out. Underestimated amount of mix needed, thanks to reworks and inaccurate measurements up front. Nighttime weariness and low visibility definitely played a large role in the reworking.

6-29-11

Workers are keeping a very slow pace, and the hopper and spreader are not lining up with precision. This has caused one or two spills. This is likely due to low visibility. No trucks on the jobsite put their headlights on. This is to save the drivers ahead of them from the potential glare. This means that when trucks are backing up, there is little to no visibility other than the bulb atop the back of the spreader.

US 43N&S from University Blvd to US 82 (Northport)

9-13-11

No Engineers Present. 2 foremen. All intersection work. Foremen, Inspectors, and Traffic Control are well-engaged due to high traffic area.

9-15-11

Almost 800 feet between stations being paved. 1 Engineer present.

SMA used tonight leading up to the intersection. The SMA is laced with polymer. This strengthens the asphalt, but decreases the workability. This contractor steers clear of shoveling the SMA because of this, and the fact that it segregates the mix too much and leads to a less than stellar pavement rating. Basically the rollers do all the compacting, and low night visibility leads to poor recognition of the markings and asphalt lines. This also leads to poor pavement quality.

9-28-11

2 Engineers present, and superintendent. This project team is much more organized and efficient. This is expected with the additional leaders on-site.

By the end of the night, the fast pace up front has worn off, and workers are dragging miserably. Of the 14 workers, 4 are showing severe lack of concentration, 7 show a need to work a reduced pace, and 7 show lack of energy and exhaustion.

10-6-11

This is the last night of direct work for this project. The remainder will be signage and cleanup. The inspectors are not active. Laborers are working quickly, overpaced, and sloppy. It seems like everyone is just ready to get finished, and they are not worried about the quality of their work or aesthetics at all.

I-20/59 Milepost 111-115

10-19-11

The crew is putting down a leveling layer tonight. According to the contractor, this is not as intensive as putting in layers with consistent depth. He claims that there is a wider margin of error for this layer. It is 48 degrees Fahrenheit, but the level layer can be installed at temperatures as low as 35 degrees Fahrenheit. There is barely enough light out here to see anything beyond the spreader. The bubble light attached to the spreader really is not helping beyond a 20 foot radius or so. Even if the inspectors were active, which they are not, they would not be able to see the defects and debris in the milled areas. A foreman had to rework a laborer’s mistake in the pavement. Did not take long, but clearly wasted valuable time.

APPENDIX L

ARRANGEMENT 2: IRI VALUES FROM PROJECTS

WITH 3 OR MORE IRI COLLECTIONS

Comparisons of Day and Night Projects with at least 3 IRI Collections

This section of research focused on the 21 day projects and 22 night projects with at least 3 IRI collections on their record. As shown by earlier analyses in this study, comparing longitudinal data directly is fruitless, if not futile. Collection ages, ESAL ranges, and IRI values were compared on the 30-month interval level, and project ages were compared on the entire set level. Two-sided null hypotheses of equality of means and variances between the day project ages (n = 21 projects, $\mu = 9.14$ years, $\sigma^2 = 11.53$) and night project ages (n = 22, $\mu = 7.36$ years, $\sigma^2 = 5.19$) could not be rejected with P-values of .053 and .077, respectively—although it was close. This is not alarming though, inasmuch as this research focuses on the collection age and IRI aspects of the data, regardless of the project age.

Studying the IRI values in different phases of the service lives of the roadways helped to reduce the variance in collection ages and, surprisingly, the variance in the ESAL ranges as well. This interval approach provided a better comparison of the day and night data sets. All of the collection ages and corresponding IRI values in the interval analysis come from projects with at least 3 IRI collections.

To ensure that the results from IRI-value comparisons among the 3 intervals were valid, the same precautionary analysis regarding collection ages and ESAL ranges was performed. The general statistics from the 3 sets of preliminary analysis are shown in Table L-1, while the P-values for the 2-tailed analyses are shown in Table L-2.

Table L-1.Sample sizes, means, and standard deviations for Collection ages (months) and ESAL Range Ranks.

Interval	Description	Collection Ages			ESAL Range Ranks		
		n	μ	σ	n	μ	σ
1	≤30 Months, Day	20	12.45	10.16	20	4.35	1.10
	≤30 Months, Night	26	15.15	11.81	24	4.52	.70
2	31-60 Months, Day	21	43.62	8.24	20	4.43	1.03
	31-60 Months, Night	27	46.67	8.68	26	4.31	.76
3	61-90 Months Day	19	74.42	9.35	18	4.28	1.06
	61-90 Months, Night	24	75.25	9.38	22	4.34	.75

Table L-2. Comparison of collection ages and ESAL Ranges. P<.05 marks a significant difference in means or variances.

Interval	Collection Age Comparison		ESAL Range Comparison	
	Diff. Means	Diff. in Variances	Diff. in Means	Diff. in Variances
≤30 Months	.409	.476	.553	.040
31-60 Months	.221	.790	.672	.159
61-90 Months	.775	.975	.933	.128

As one can see in Table 2, the only P-value lower than α=.05 is that of the first interval's difference in variances for ESAL ranges with the day variance being wider than the night variance (P=.020). Even with a significant difference in ESAL ranges between day and night collections, it is still acceptable to compare them, because initial values for IRI should be similar for all highways, night or day, regardless of background data according to current literature (NCHRP 726; Dunston et al., 2000). With all other preliminary data showing comparability between the day and night intervals, the IRI values can be investigated with confidence.

Interval 1: IRI Collections ≤30 Months after Project Completion

The first interval analyzed included IRI calculations performed within the first 30 months after project completion. A boxplot of the values is shown in Figure L-1. The results of this interval comparison give a good indication of the initial state of road roughness through the first 2.5 years. The day IRI values (n = 20 Values, μ = 59.50 in/mi, σ^2 = 311.47) and the night IRI values (n = 26 Values, μ = 57.52 in/mi, σ^2 = 167.03) have neither a difference in means (P=.662), nor a difference in variances (P=.144). As previously stated, current literature claims that there is little difference in the initial pavement quality for day and night projects. This interval is corroborative with that notion, which provides credibility to results to come.

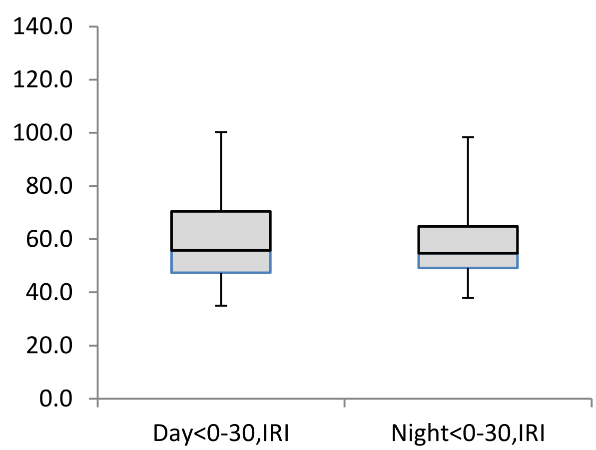

Figure L-1. ≥3 IRI Projects' Day and Night IRI values from collections within the first 30 months after project completion.

Interval 2: IRI Collections 31-60 Months after Project Completion

The second interval looked a IRI values calculated between years 2.5 and 5 of each project's records. This is where difference might begin to be noticeable, since the initial stage of the pavement life is all but over, and traffic will have had time to take its toll on any construction issues that may have been present.

The night IRI values in this interval (n=27 Values, μ = 70.20 in/mi, σ^2 = 523.68) and day IRI values (n = 21, μ = 58.30 in/mi, σ^2 = 170.90) are show in Figure L-2. The night mean is significantly greater than the day mean (P=.014) with a 95% confidence interval of (3.07, 20.73). The night variance is greater than the day variance (P=.006) by a factor in the 99% interval of (1.08, 8.16). The difference in both categories show that not only did the average IRI for night projects increase significantly faster than the day average, but the day values had much less variability, which is synonymous with uncertainty. The continuing of this trend into the third interval would show that there is a statistically significant difference in roughness between roads paved during the day and roads paved at night.

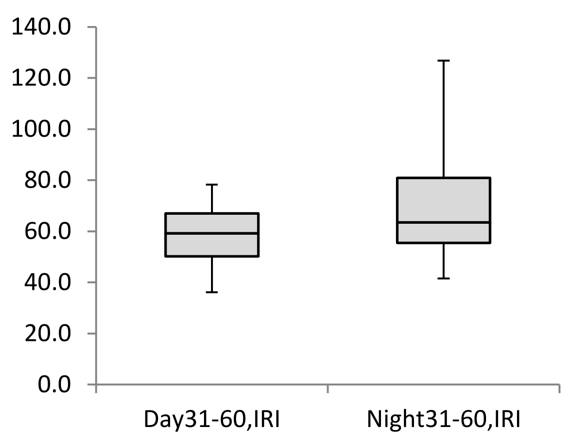

Figure L-2. ≥3 IRI Projects' Day and Night IRI values calculated between 31 and 60 months after project completion

Interval 3: IRI Collections 61-90 Months after Project Completion

This interval, the values of which are shown in Figure 3 includes the projects in which IRI calculations were performed between year 5 and year 7.5 of the pavement lives.. The mean of the night IRI values in this interval (n = 24 Values, $\mu = 84.55$ in/mi, $\sigma^2 = 749.58$) are significantly greater than that of the day IRI values (n = 19, $\mu = 68.35$ in/mi, $\sigma^2 = 241.84$) with a P-value value of .009 and a 99% confidence interval of (.07, 32.32). The difference in variances yields the same P =.009 and a confidence interval of (1.03, 8.78) showing that the night variance is greater than the day variance. This proves that the differences found in Interval 2 were no statistical fluke, and the fact that the mean difference and variance difference was even greater in Interval 3 further supports this.

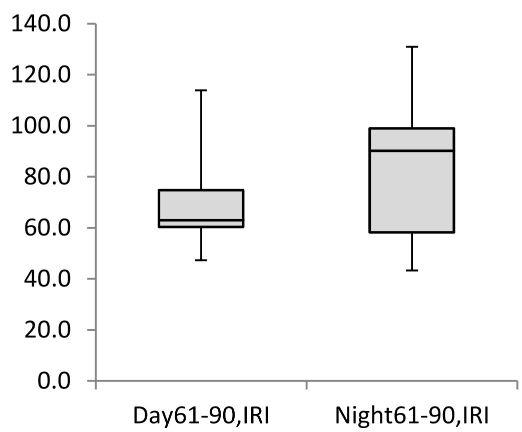

Figure L-3. ≥3 IRI Projects' Day and Night IRI value collected between 61 and 90 months after project completion.

According to these interval analyses, paving at night can not only result in a faster rate of increasing roughness, but also it could lead to significantly higher uncertainty in the rideability of the road over time.   This further supports the analysis of the full day and night data sets, however, the sample sizes were too small to consider the results as significant as those included in the body of this thesis..

APPENDIX M

FULL ANALYSIS OF PHASE 2 RESEARCH

Interviews

Each interviewee had something interesting to say, and each brought a different set of skills and knowledge to the discussion. The following notes were taken from the interviews; the full sets of interview notes can be found in Appendix J. Last names have been abbreviated, and company names have been redacted since the views expressed do not necessarily reflect management or the organizations.

The first interview was with a subcontractor, Dooley B. After discussing some current projects on which his company was working, he began to discuss several advantages and disadvantages of both daytime and nighttime paving. The contractor claimed that for daytime paving, in general, “spreading is better [because] bumps go unseen at night” and that the “hotter asphalt [during the day] leads to better quality.” Dooley also claimed that there are many recurring issues with on-site quality control when working at night. In no particular order, here are these claims:

- Sweepers miss debris that cannot be noticed at night
- The crews usually have to rework parts of the project
- One crew once resurfaced a cone weight; another over a turtle
- He noticed more roller marks on the pavement after night work
- Inspectors are more lenient at night [and] stay all night.

Here, the last claim sums up the previous four. Generally, one would hope that due to lower visibility and increased worker fatigue, inspection would be strict to ensure quality matching that of daytime paving. Poor inspection early in the paving procedures, such as throughout the milling process and post-milling debris clean-up could easily affect the initial quality and the quality over time as the pavement takes on more loading with traffic and congestion increasing exponentially. Even though he has noticed “differences in the surface of the road” between day and night projects, he also claimed that he has not noticed “a difference in the life of the asphalt.”

In terms of costs, the first interviewee mentioned that the costs of night paving projects generally are greater than those of day projects. His company increases the bid by 10% for night work to cover costs for “lights, generators, reworking, and reflective materials.” This also covers the cost of paying “shift differential to night workers.” Not only does he have a shift differential for night workers, the contractor also pays them “show-up time,” which amounts to two hours’ pay, if work is cancelled soon after workers arrive.

On the subject of day versus night paving productivity, Dooley claimed to have noticed a slowing in productivity in nighttime paving. When asked for examples or reasoning, he said that for his crews, but not necessarily all contractors, “the paver goes slower at night” for safety reasons, which directly affects productivity rates. Also, the he felt that productivity “slows over time” due to “fatigue and apathy.”

Dooley was not the only interviewee with strong opinions on the matter at hand. Ronnie P., a state transportation agency engineer, believes that day paving is better in all aspects. His disdain for night projects is mostly related to the general difficulty in inspection. He specifically mentioned the inability to "tell the difference between layers and levels" which he said "leads to bad binding" and "failure in the future." His reasoning, as expected, was the effect of "vertical lighting [leading to] many dead spots on the project." Ronnie also believed that the higher temperatures generally associated with daytime paving allow "more time to compact and pave," whereas during night projects crews must hastily "compact and pave before cooling." These views were generally mirrored in the other interviews.

One such mirroring view was that of Randy D., a project supervisor, who also observed that "the [lack of] light and fatigue factors really affect everyone." "Fatigue and apathy set in at night," Randy explained, "workers are happier and work harder—faster—during the day." Randy claimed that the biggest problem he seemed to encounter at night was "traffic control on such a tight area," referring to the one-lane closures that are generally set up for his projects. The lack of visibility not only affects the workers, but also the truck drivers and the travelling public, which clearly can lead to major safety issues. When asked if better lighting conditions would help match the quality of daytime, he replied, "You can use all the lights you want, but it's still not the same as working during the day." The next interviewee would agree with Randy and Dooley as well.

Jody L., a superintendent, also harped on how a lack of visibility wreaks havoc on night jobs. Because of the inhibited sight of workers and inspectors, "bleed spots" often go undetected. These mistakes can lead to the development of potholes and increased rutting (Brown, Cross, & Gehler, 1991). Jody attributed the missed problems in night work to "always working in a shadow," which led to the "fatigue of workers playing a substantial role" in poorer quality over time. From experience working on both day and night paving projects, the superintendent felt that “day-work leads to a better finish.” Like the other leaders on the projects, Jody believed that the quality of the nighttime paving was not as high as that of daytime paving. There was one leader who felt differently, though.

Adam S., the foreman in charge of the asphalt laborers, was the only person interviewed with a differing opinion on the subject. To this point in his career, he had seen “no difference in daytime and nighttime project quality.” In fact, not only had he seen no difference, but he preferred to work at night, and claimed that the workers in his crew agreed with his sentiment. When asked to elaborate, Adam cited the heat being “simply overwhelming” between the Alabama sun and the fresh asphalt. When asked if nighttime visibility is ever a problem for himself or his crew, Adam firmly stated that “visibility is low, but it is still good enough to get the job done.” An interesting point can be made about Adam’s interview. As an asphalt foreman, and thus the person closest to laborers and their work, Adam’s opinion differed from those further away from the manual labor aspect of the paving project: the people performing direct work preferred nighttime projects and saw no difference in quality, whereas the people performing indirect work preferred daytime projects and did see a difference.

Although it is important to obtain firsthand accounts regarding night and day projects, personal experience and opinions are not enough to make a firm, decisive claim on the impact of nighttime construction. However, all interviewees covered the same general aspects that could be inhibitive to pavement quality, and only one claimed that there was no difference between day and night project quality. Consistent with the current literature, the prevalent issues were visibility for workers, inspectors, drivers, and also worker fatigue and apathy. Therefore, if there is a statistical difference in roughness between night and day projects, it is most likely due to these issues.

<u>On-Site Observations</u>

The following observations were made on-site at projects in the following Alabama cities: Tuscaloosa, Northport, Bessemer, and Bellamy.

Culver Road Project

6-9-11

Worker using a small mounted milling tool on a bobcat to mill around a manhole. Only light is that from the bobcat, which projects too far out to see the manhole directly in front of the machine. Has to rework and eventually mills too deep. That's a small waste of asphalt that could have been avoided during the day.

6-14-11

Milling Machine broke down early into project work tonight. Milling Machine must be repaired by on-site mechanic, who has been idle up until tonight in the project. Had this been a day project, the project mngr claims a new milling machine would have been brought on-site, and an off-site mechanic would have fixed the truck. This would have saved valuable work time. They decide to go ahead and pave what they have already milled, which is a very short stint of road. Eventually late in the night, a small 7-ft wide milling machine comes in from another project in the county. Mngr spends entire night away from supervising the crew to deal with the broken profiler (front axle). Eventually a trailor comes to take it away when the onsite mechanic cannot fix it. Steering mechanism breaks on milling machine as it is loaded. Requires 2 bobcats to pull the machine onto the trailer, instead of working elsewhere on the jobsite. These are all normal occurrences when machines break down, but because it was nighttime, extended time was spent trying to initially fix the machine.

6-23-11

Crew is working, albeit very slowly. Much slower than the past few nights.

"By Thursday Night, the entire crew is like zombies, we're supposed to be asleep at night, and it can't be healthy to be out here so much" – Project Manager

6-28-11

Tonight, work is being done under the I-359/US-43/AL-69 overpass at 15th Street. All the traffic lights are out, and no additional lighting other than that one large bulb on the Pavement Truck and the headlights of bobcats, sweepers, and rollers. Workers upset because they can't see to do their job. Managers upset because Job is not getting well. Second Night in a row that street lights are out. Underestimated amount of mix needed, thanks to reworks and inaccurate measurements up front. Nighttime weariness and low visibility definitely played a large role in the reworking.

6-29-11

Workers are keeping a very slow pace, and the hopper and spreader are not lining up with precision. This has caused one or two spills. This is likely due to low visibility. No trucks on the jobsite put their headlights on. This is to save the drivers ahead of them from the potential glare. This means that when trucks are backing up, there is little to no visibility other than the bulb atop the back of the spreader.

US 43N&S from University Blvd to US 82 (Northport)

9-13-11

No Engineers Present. 2 foremen. All intersection work. Foremen, Inspectors, and Traffic Control are well-engaged due to high traffic area.

9-15-11

Almost 800 feet between stations being paved. 1 Engineer present.

SMA used tonight leading up to the intersection. The SMA is laced with polymer. This strengthens the asphalt, but decreases the workability. This contractor steers clear of shoveling the SMA because of this, and the fact that it segregates the mix too much and leads to a less than stellar pavement rating. Basically the rollers do all the compacting, and low night visibility leads to poor recognition of the markings and asphalt lines. This also leads to poor pavement quality.

9-28-11

2 Engineers present, and superintendent. This project team is much more organized and efficient. This is expected with the additional leaders on-site.

By the end of the night, the fast pace up front has worn off, and workers are dragging miserably. Of the 14 workers, 4 are showing severe lack of concentration, 7 show a need to work a reduced pace, and 7 show lack of energy and exhaustion.

10-6-11

This is the last night of direct work for this project. The remainder will be signage and cleanup. The inspectors are not active. Laborers are working quickly, overpaced, and sloppy. It seems like everyone is just ready to get finished, and they are not worried about the quality of their work or aesthetics at all.

I-20/59 Milepost 111-115

10-19-11

The crew is putting down a leveling layer tonight. According to the contractor, this is not as intensive as putting in layers with consistent depth. He claims that there is a wider margin of error for this layer. It is 48 degrees Fahrenheit, but the level layer can be installed at temperatures as low as 35 degrees Fahrenheit. There is barely enough light out here to see anything beyond the spreader. The bubble light attached to the spreader really is not helping beyond a 20 foot radius or so. Even if the inspectors were active, which they are not, they would not be able to see the defects and debris in the milled areas. A foreman had to rework a laborer's mistake in the pavement. Did not take long, but clearly wasted valuable time.

Field Data Analysis

Using the five aforementioned on-site data collection sheets— the Daywork/Nightwork General Checklist, Safety Checklist, Worker Productivity Checklist, Paving Operation Productivity and Quality Checklist, and the Longitudinal Visibility Survey —an observable sample of data on several subjects was collected. Like the interviews and on-site observations, this data is not meant to provide conclusive evidence in this thesis, but rather to support analysis of historical records that follow. Projects observed were all located in the following Alabama cities: Tuscaloosa, Northport, Bessemer, and Bellamy. Even though there were several sites, the sample sizes for questions on the checklists and surveys were very small, and, thus, only the most noteworthy differences are discussed. The following sections describe the observations that can be made through individual and collective interpretation of the results from each of the data collection documents.

Daywork/Nightwork General Checklist

The DNGC was completed a total of 8 times over 6 night project observations and 2 day project observations.

Head Counts

In terms of personnel on site, day projects had more foremen present during construction activity; however, night projects had more engineers, superintendents, inspectors, traffic control workers, drivers, and asphalt workers present per shift. There seemed to be more personnel in hopes of ensuring that enough eyes were on-site to obtain a quality product. In fact, in the two days spent onsite during the day project observed, there were absolutely no engineers present.

Equipment Head Counts

Most difference between day and night equipment counts were trivial and simply based on the phase of the project that researchers arrived in such as number of milling machines, and striper trucks—all of which had higher averages at night. It is interesting however, that there were more broom trucks and sweepers present at night, presumably to ensure that debris was kept off of freshly paved surfaces and surfaces yet to be paved, since visibility might have inhibited workers from noticing it as easily. Also the night projects averaged a much higher number of dump trucks per night, nearly 7 per shift, than day projects at 3 per shift. This difference could have been caused by a combination of distance to the asphalt source and availability of materials at night.

Inspector Behavior

Inspector involvement was spotty at best for the night projects. In fact only twice in the 6 night DNGC inspector sections did the inspectors receive a favorable mark for involvement in all five observed areas. For day projects, both site visits results in perfect marks for involvement. In terms of actively checking is milled areas were debris-free, 4 of 6 checklists had “N” for No during night observances. The figures were identical for actively checking if milled areas were defect-free. Since defects in the sub-base and lower levels of asphalt result in construction related roughness and poor quality, the inactiveness of inspectors on night projects could a culprit in a difference in road quality between day and night projects.

Safety Checklist

In all, the SC was completed 8 times over 6 night project observances and 2 day project observances. If the difference in yes or no answers were not more than 50% between day and night observations, then they were not considered significant enough for discussion. Of the 72 yes or no questions on the SC, notable difference only arose in 5 questions. Table M-1 shows the questions and the percentages of both day and night "Yes" records. The first three questions showing differences in safety management involve site management problems, and the last two revolve around employee safety. The day projects were safe in these regards except for the last question regarding wearing hardhats on site, which never happened occurred while onsite during the day. Earlier interviews stressed safety issues at night, but some general precautions were lacking relative to daytime safety management procedures. This is definitely a topic that should be investigated further in the future: theories and procedures can be written, but it is up to contractors to ensure their implementation.

Table M-1. Differences from Safety Checklists. Questions from Safety Checklist resulting in notable differences in "Yes" answers.

Question	Day % Yes	Night % Yes
Stored material & parked equipment are 30' or more from unprotected roadway?	100	0
Are all cones, barricades, and barrels standing?	100	33
Are all cones, barricades, and barrels properly managed?	100	33
Are employees paying attention to work area and surroundings?	100	50
Are employees wearing proper safety equipment and illumination? (Hardhats?)	0	83

Worker Productivity Checklist

The WPC was completed a total of 16 times consisting of 13 nighttime observations and 3 day observations. The fatigue section is based on the researcher's perspective of the workers in the activity area at the time of observation, and thus is subjective and qualitative in nature; however, the Labor Designation section was done strictly based on direct and indirect labor definitions, and could be investigated in more detail.

Worker Fatigue

In the 3 daytime observations, no workers showed any of the signs of fatigue listed on the WPC. However, 6 of the 13 observations at nighttime jobs included at least one worker with signs of exhaustion or fatigue. The worst night was on State Route 69/US 43 when 4 workers showed a loss of concentration, 7 showed the need to work at a reduced pace, and 7 showed signs of exhaustion. On this same night, the crew had to spend at least 15 minutes searching for a Tracker Rebound which is crucial from a quality standpoint for checking the grade at which the paving is being performed. The piece was directly next to the spreader where it had fallen. In the opinion of researchers, the inability to find this important piece was directly correlated to the exhaustion of those searching for it. Table M-2 shows as excerpt from the WPC with all observations of worker fatigue.

Table M-2. Worker Fatigue Data from WPC

Date	**Day or Night**	**Location**	**How many workers exhibit:**				
			Loss of Concentration	**The Need to Repeat a Job**	**The Need to Work at a Reduced Pace**	**Lack of Energy or Exhaustion**	**Horseplay**
9/13/2011	Night	US 43/SR-69	0	0	0	0	0
9/15/2011	Night	US 43/SR-82	0	0	0	0	0
9/15/2011	Night	US 43/SR-82	3	0	0	3	0
9/16/2011	Night	US 43/SR-82	2	0	0	0	2
9/28/2011	Night	US 43/SR-82	0	0	0	0	0
9/29/2011	Night	US 43/SR-69	4	0	7	7	0
10/6/2011	Night	US 43/SR-69	0	0	0	0	0
10/6/2011	Night	US-43/SR-69	1	0	0	0	0
10/19/2011	Night	I-59	0	0	0	0	0
10/19/2011	Night	I-59	0	0	0	0	0
10/20/2011	Night	I-59	0	0	0	0	0
11/15/2011	Night	I-59	3	3	0	0	0
11/15/2011	Night	I-59	1	0	1	1	0
9/24/2012	Day	SR-80	0	0	0	0	0
9/25/2012	Day	SR-80	0	0	0	0	0
9/25/2012	Day	SR-80	0	0	0	0	0

Labor Designation: Direct, Indirect, or Idle

In this section, all personnel around the activity area were designated as direct, indirect, or idle based on their participation in the paving process. Once a member of the project team had been labeled, they were not counted again. Likewise, the labels were not changed, even if the person in question changed their status on the site. This helped with uniformity in data collection.

The only counts that were truly of note in this section were the asphalt workers and inspectors. Indirect and idle behavior for asphalt workers means that productivity is down, and idle behavior for inspectors means that quality is not being ensured. Both of these things are legitimate concerns as discussed in the Interviews section and in aforementioned literature.

With regards to the 3 daytime WPC's, of the 13 asphalt workers counted, none were indirect or idle during the data collections. Therefore, they were all working diligently as the researchers surveyed the activity area. This is vastly different than observations from the nighttime projects.

At night, there were 56 asphalt workers counted over 13 observations. 39.3% of night asphalts workers (n=22 workers) were designated as direct work, 16.1% (n=9 workers) were designated indirect, and 44.6% (n=25 workers) were deemed idle by researchers. Although this is a much larger sample size than the day observations, a 44.6% increase in idle workers from day time to nighttime it cause for concern. These checks were never done during waiting periods or mistakes, but only when direct work should have been being performed, so this observation speaks volumes of potential discrepancies of nighttime and daytime paving.

Inspector designation percentages follow a similar trend. Of the 34 inspectors counted over 3 day WPC's and 13 night WPC's, 6 were from day observations and 28 were from night observations. All 6 of the daytime inspectors earned indirect status because they were actively checking for distresses and debris, clean joints, and temperature control in asphalt trucks. On the other hand, 24% (n=8 inspectors) of night inspectors were idle at the time of observation, and only 76% (n=20 inspectors) were working indirectly.

If these discrepancies held true in larger and more evenly collected sample sizes, lack of worker and inspector involvement would easily be a major reason that nighttime paving quality might be worse than daytime paving quality. Lack of inspection would allow low quality work from uninterested workers to be accepted, which would then turn into distresses and roughness much sooner in the pavement lifecycle.

Paving Operation Productivity and Quality Checklist

The POPQC was completed 14 times consisting of 11 nighttime completions and 3 daytime completions. On this checklist, visibility data was recorded only during the nighttime, since it can be assumed that there was clear visibility during the day on these projects. Like the WPC, the sample sizes were small and thus only substantial differences in answers between night and day checklists are discussed. For the sake of this section, substantial difference in percentages of certain answers was defined as a difference of 25% of the appropriate correct answer, yes or no.

Equipment Behavior

In this section, only the question regarding idle vehicles was answered during both day and night POPQC assessments. While the night projects had no vehicles sitting idly on freshly poured pavement, there was one roller idle on new pavement during the day project checks. This was not necessarily detrimental to quality, though, since the idle equipment was parked at a 45 degree angle, which, according to the earlier interviews, allows grooves created by the parked machine to be worked out more easily.

For the night projects, only 9% (n=1 assessment of 11 assessments) of checks found that all worksite vehicles had headlights on. Earlier interviewees claimed that this helps reduce glare for safety reasons and provides less disrupted worker vision. One interesting thought, however, is that utilizing the headlights could have potentially increased safety for the drivers and workers and helped inspectors find defects and debris in milled areas if such problems exist.

Visibility Check

The first five questions of the visibility check portion of the POPQC deal with night visibility only, asking questions about vehicle control visibility, streetlight presence and functionality, and supplemental lighting on the vehicles paving machinery. In this section, all questions garnered 100% affirmative marks except for a question which asked whether or not there were any streetlights or permanent light fixtures around the site. Only 55% (n=6 assessments of 11) of the night projects were performed in areas with permanent light fixtures, which mean that 45% (n=5 assessments of 11) of the projects relied solely on the self-provided lighting of the contractor’s machinery. Interestingly, the same 45% appeared as negative answers when assessing inspectors’ ability to identify debris and distresses in the milled area. Obviously, there was a major difference favoring the day project assessments (n=3 assessments of 3) on the debris and distress questions. Essentially, this section hints that even with contractor-provided lighting, problems were still more difficulty identified, if identified at all, during night projects.

Surface Preparation

In this section there were no substantial differences in assessment answers. In fact the only difference in answers occurred in the fifth question regarding uneven layers existing in areas to be paved. One of the eleven night assessments resulted in a yes when asked if there were uneven layers being paved. If not diligently paved, this type of mistake could result in construction related distresses. Also, the night answers for this section were much more difficult to come by than the day answers, in that during the day it was very easy to determine if there were any rutted areas, potholes, or other general failed pavement areas being resurfaced without preparation. During the night, this was a difficult task, but it was possible given the right amount of diligence and attention, so positive marks were still given. Therefore, even though the surface preparation section of the POPQC did not provide any substantial numerical differences between night and day practices, the effort needed to match the quality of daytime in these practices was much more demanding. If inspectors were not active, which was the case several times as shown in the previous WPC section, quality in surface preparation could easily slip.

Placement Techniques

In this section, both day and night assessment received answers for all questions. Three questions showed differences in answers between night and day, but only two of those was substantial. Only 2 of 11 nighttime assessments, as opposed to 3 of 3 daytime assessments showed that asphalt hauling dump trucks completely lifted tailgates when angling the bed for pouring into the receiving machinery. Doing this practice would greatly reduce segregation according to the Hot-Mix Asphalt Paving Handbook (1991). The other substantial disparity resulted from checking if the pavement spreader was brought to paving speed as quickly as possible. At night on 73% (n=8 of 11 assessments) showed that the spreader was, indeed, brought up to speed quickly, as opposed to the perfect three positive marks out of three assessments for daytime POPQC completions. Slowly bring the spreader to paving speed results in inconsistent paving, which results in poorer quality, pavement distresses, and eventually higher roughness values (*Hot-mix Asphalt Paving Handbook* 1991). Furthermore, differences in placement techniques could easily affect the overall quality of work, and once again, it should be up to the diligent attention of contractors and inspectors to ensure that proper placement techniques are utilized.

Visibility around Direct Work-Related Vehicles

This section of the POPQC involved the utilization of a light meter to better understand the amount of light asphalt workers and inspectors have available on the job site around asphalt spreaders. Incident light values were measured from up to three points around the new pavement as the spreader was paving layers, which allowed researchers to investigate exactly what level of visibility the workers and inspectors had when they were performing work.

Over the 11 POPQC assessments, 76 incident light values were collected using the light meter. Only one assessment's worth of day values were taken for reference's sake, since visibility was unlikely to change too drastically during the day. By averaging the illuminance measurements from values converted from EV to lux, an average illuminance of 94.04 lux was found around the pavement spreader. Even though the spreaders had supplemental lighting around them and balloon lamps above them, that 94 lux is still less than the 108 lux suggested by literature and implemented by many states (Ellis, 2001; Hyari & El-Rayes, 2006). This clearly shows that generally, the lighting on night projects was not adequate to provide workers or inspectors with an environment conducive to quality paving activities.

On the other hand, the observed day project had an average incident light value of 33982 lux, which is near the low end between non-direct full daylight (10000-25000 lux) and direct overhead sunlight (130000 lux) (Schlyter, 2009).Because the day value was collected in late September, this average makes perfect sense, and adds credibility to the low night values.

The uniformity ratio around the paving machines for night projects was not very good, when coupled with the low illuminance average. The uniformity ratio involves dividing the average work area illuminance by the minimum work area illuminance to quantify consistency or lack thereof in work zone lighting. In this regard, the optimum uniformity ratio is 1, meaning that the average is extremely close to the minimum. The illuminance values around the pavement spreaders had a uniformity ratio of 6.23. This is quite poor considering that the 94.04 lux average is both lower than the suggested paving illuminance but still 6 times as bright as the minimum of 15 lux, which is extremely dark for paving purposes. It is easy to conclude that paving in these conditions could easily result in less than adequate work, which could then lead to higher roughness over time.

Asphalt Cooling Over Time

This section originally aimed to see if there was a difference between night and day paving in terms of the speed at which asphalt cools. Some literature claimed that lower temperatures could actually help with compaction (Price, 1986; Rebholz et al., 2004). However, the when the nights become too cold, the asphalt pavement stiffens sooner, thus providing a much shorter time interval to compact the pavement (US Army Corps of Engineers 1991).

Although the sample size was quite small—9 sets of cooling data for night projects, and 2 sets of cooling data for day projects—the regression lines for night and day asphalt cooling were very similar (Equations # and #). The average outside temperature for night time (n=9 readings, μ= 60.3°F) was roughly 23 Fahrenheit degrees cooler than the daytime outside temperature (n=2 readings, μ=83.5°F).

$$Day\ Cooling: y = 254.18e^{-.0286x} \qquad R^2 = .9547$$

$$Night\ Cooling: y = 256.04e^{-49-.0346x} \qquad R^2 = .5412$$

Where:

y = predicted temperature in °F

x = minutes elapsed since pouring of asphalt

Using the Goalseek Excel function showed that the day projects night projects cooled to the recommended 180°F minimum temperature for compaction in 10 minutes and 11 seconds, approximately 2 minutes faster than the 12 minute 4 second daytime cooling time (US Army Corps of Engineers 1991). This amounts to a difference of about 1 complete compaction run on the vibrating roller relative to the data. If the contractors feel that 10 minutes is still enough time to reach adequate compaction, then there should be no difference in compaction between night and day in this regard; however, it should be noted that if proper oversight and diligence is not given to compacting, that 10 minute window may not be enough to properly compact the asphalt, in which case a difference in quality could easily arise. With a larger sample set, one could investigate different mix types for asphalt cooling differences for more accurate and conclusive results.

Longitudinal Visibility Survey

Using the Sekonic L-308S Flashmate along the outermost side of the paving site, illuminance values in lux were recorded and analysed separately for activity area readings (n=203 readings) and non-activity area readings (n=1312 readings). These readings were taken from all night project sites, and averaged together, inasmuch as all sights should still adhere to the same standards. Night Activity areas averaged 34.62 lux, which is well below the 108 lux recommended for paving, milling, and any active paving operation. In fact that 34.62 lux average is even less than the 54 lux recommendation for excavation, sweeping, and moving areas between tasks. Without these suggested standards met, lack of visibility can easily cause detrimental lapses in quality the pavement condition both in the short term and the long term.

The uniformity ratio for the workzone area had similar poor results. The optimum ratio is 1, meaning that there are very few darks pots relative to the average illuminance value. The night projects in this research, however, had a uniformity ratio of 12.12 in the activity areas; therefore, not only was the average lux was very low, it was also still substantially higher than the minimum illuminance in the work areas (2.86 lux). Such inconsistency could easily, and most likely did, cause problems for asphalt workers and inspectors.