WEEKEND CLOSURE FOR CONSTRUCTION OF ASPHALT OVERLAY ON URBAN HIGHWAY

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ABSTRACT: Construction of asphalt overlays for urban highways is generally restricted to off-peak hours, often exclusively nighttime hours, and to partial closures to minimize public inconvenience. Such constraints are thought to adversely affect production and quality. In August 1997, the Washington State Department of Transportation implemented a pilot project to evaluate the option of a full weekend closure—closure of all lanes in a single direction throughout designated weekend hours—as an alternative to nighttime closures. Two concerns were consistent construction quality between nighttime and daytime paving and general comparison of the full weekend closure with other closure strategies. Surface smoothness (rideability) and in-place density were compared between nighttime and daytime mainline paving for this project, and gradation and asphalt cement content variabilities were compared with published average values. Production rates were compared to those from a comparably sized nighttime project. The investigation revealed that consistent quality, exceeding reported average values, may be achieved. High paving production rates resulted from close proximity of the hot mix plant to the work zone.

INTRODUCTION

Construction of asphalt overlays on highways in congested urban areas is typically performed via partial closures of the highway, and often the work is conducted during nighttime hours to minimize impact to users and the local community. The potential downside to nighttime closures is that they may extend the overall period of inconvenience to users and local residents. In addition, and especially true for large projects, the necessarily frequent mobilizations and shutdowns inhibit productivity and may even affect construction quality. Finally, there are safety concerns for both the traveling public and the construction crews.

A potentially attractive alternative to frequent night closures is the complete weekend shutdown of a single direction of traffic. Presently, however, no data exist to use as a guide in deciding between the weekend closure and nighttime closure options. In an attempt to provide initial answers to questions concerning the weekend closure strategy, the Washington State Department of Transportation (WSDOT), Olympia, Washington, adopted a unique weekend closure strategy to complete overlay operations on a section of I-405 in the Seattle area. The overlay construction was a part of ''Contract C4756 Tukwila to Factoria SC&DI Stage 1.'' All traffic lanes (three) were closed in a single direction for two consecutive weekends in August 1997. A team of investigators from the University of Washington at Seattle conducted a study focusing on the major issues of quality, user impacts, and construction costs to assess the benefits of the weekend closure approach. This project provided the first set of data available for assessing benefits of the weekend closure option.

Although several benefits were expected from the weekend closure, the major question with regard to construction performance was whether consistent quality for mainline paving could be achieved through the night and day cycles of the weekend closure. A secondary question was how the construction quality would compare to benchmark levels of quality for flexible pavements. This paper presents the results of the examination of construction quality from the I-405 weekend closure. Primary quality parameters of surface smoothness (rideability), in-place density, and gradation were quantitatively analyzed. Qualitative observations were made for other construction problems or defects. Another important concern addressed by the investigators was the impact of the weekend closure upon users (motorists and businesses). The reader is referred to Nam et al. (1999) for a discussion of the user impacts.

FACTORS AFFECTING CONSTRUCTION PERFORMANCE

The longer period of uninterrupted work afforded by weekend closures raised the question of whether consistent quality could be achieved through the day-night cycles. Changes in temperature and lighting conditions might have negative impacts upon the levels of quality in smoothness of ride, density, longitudinal joint construction, etc. On the other hand, the contractor has a closed work site, a factor that generally facilitates a consistent level of quality throughout the project. High paving production rates, however, may counteract attention to details surrounding rolling (compaction) operations and construction of longitudinal joints. In drawing conclusions along these lines concerning weekend closures, production rates must be kept in mind.

PROJECT DESCRIPTION

Construction of the asphalt overlay on the pilot project constituted only a portion of the larger project to install traffic monitoring equipment. The project specifications called for a 46-mm (0.15-ft) asphalt concrete pavement (ACP) Class A overlay and a minimum 18-mm (0.06-ft) ACP Class G prelevel, both standard state of Washington mixes. The project was bounded by bridges to the south and to the north, a distance of about 8.85 km (5.5 miles). Projected tonnage for the mainline paving was 15,410 Mg (16,990 tons) for the southbound lanes and 16,123 Mg (17,776 tons) for the northbound lanes. The southbound overlay was constructed during the first weekend, the northbound overlay during the following weekend. Hours allotted for paving each weekend were from 8 p.m. on Friday to 5 a.m. on Monday. For the purposes of this study,

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the paving subcontractor is hereafter referred to as the ''contractor.''

The contractor provided asphalt concrete (AC) mix from a mobile rotary drum plant erected in the parking lot of a large local manufacturing business, located 0.4 km (0.25 mi) from the pair of ramps that were used for access near the southern end of the project. This particular feature of the project was expected to provide a tremendous benefit to the delivery operation and to support a sustained high rate of production. Mainline paving was executed with a single paver, and the windrowed AC mix was transferred to the paver with a pickup device. Two roller compactors were employed during each weekend (two additional rollers broke down during the second weekend). The contractor's crews worked 12-h shifts, starting at either 8 p.m. or 8 a.m.

LITERATURE REVIEW

The body of information addressing differences between daytime and nighttime paving is the most useful for identifying potential key issues in the day-night cycles of weekend paving. Hinze and Carlisle (1990) outlined many of the factors related to nighttime paving productivity and evaluated their relevance. They held that traffic volume, type of work, material delivery, lighting, supervision, communication, and worker morale were among the factors that affect nighttime versus daytime paving productivity. Price (1986) compared the quality and cost of daytime and nighttime projects in Colorado and postulated that the material delivery rate increases because of less traffic, which normally contributes to idle time. He also stated that temperature extremes could have an adverse effect on crew and equipment performance. Ellis and Kumar (1993) examined differences in cost and productivity between nighttime and daytime paving in Florida and found that nighttime paving production rates for the projects that they examined were no better than those for daytime paving.

With regard to quality, researchers have acknowledged that nighttime paving introduces the potential for effects from numerous factors related to supervision, material quality, and worker effectiveness (Price 1986; Hinze and Carlisle 1990; Read 1996). Temperature changes may have an impact on the quality levels achieved with compaction, longitudinal joints, and some forms of cyclic segregation. Read (1996) suggested that cyclic segregation is a function of temperature gradients within the AC mix that could be addressed with attention to material handling, especially the use of transfer devices. Although rationalizations of the impacts on construction quality are generally accepted, quantification of these impacts has been elusive (Ellis and Kumar 1993). A National Cooperative Highway Research Program synthesis report by Hughes (1996) presented a compilation of standard levels of quality measures for pavement construction reported by various agencies across the United States. Such information is useful for benchmarking quality measures for any closure strategy.

METHODOLOGY

To assess the level of quality achieved in the construction of the overlay, the investigators analyzed measurements of surface smoothness, in-place densities, and mix gradation. Qualitative observations of longitudinal joints and the pavement surface were also considered. Production rates were also examined to provide perspective on the levels of quality achieved.

Measurements of surface smoothness were obtained using a California profilograph, model CS 8200 Version 1.0 manufactured by James Cox and Sons Inc., Colfax, Calif., which was made available by WSDOT. This particular model has been noted for smoothing the data, producing readings that are less sensitive than earlier manual approaches and models using higher order filters (Huft 1992; Scofield et al. 1992). For the purposes of this study, however, consistency in the smoothness of the riding surface was of primary importance; therefore, measurement technique sensitivity was of less significance. Measured sections were separated by lane and wheel path, by nighttime versus daytime paving, and by bridges. Both prelevel and overlay data were collected to isolate the benefit of the overlay. This approach prevented the collection of data from the entire work zone, because each measured section had to be traveled twice without obstructing construction operations. Statistically based comparisons for differences in surface smoothness between weekends and between nighttime and daytime paving were performed using the *t*-statistic because sample sizes were quite small.

In-place densities were analyzed statistically for differences between nighttime and daytime paving and between weekends. Density readings were correlated with the sequence of paving operations and plotted against time to facilitate this analysis. The variance ratio or *F*-statistic was utilized to determine whether differences existed with respect to variability.

Gradation analysis, which included asphalt cement content, was performed by comparison to the specified job mix formula and to published historical standard deviations. Longitudinal joints were visually inspected and considered in light of construction practice. Production rates were derived from truck tickets and inspector daily reports.

Finally, a brief survey of several state highway agencies (SHAs) was conducted to determine which closure strategies receive the highest priority and the type of construction quality experienced with these primary strategies. The survey was limited to states noted to have large urban areas where managing the public impact of reconstruction or rehabilitation projects would be most critical. Survey respondents were also queried on which innovative strategies they were considering for the future.

PRODUCTION RATES

The actual total tonnage for the two weekends was 35,746.7 Mg (39,412.05 tons)—18,496.7 Mg (20,393.30 tons) on the southbound section and 17,250 Mg (19,018.75 tons) on the northbound section. These totals included the mainline, shoulders, and ramps. Table 1 shows the production totals and average production rates for each shift (8 a.m. to 8 p.m.) for the respective weekends (directions). Actual paving hours were used to arrive at more accurate hourly rates. Mainline paving

TABLE 1. Production by Shift from I-405 Project

	Southbound Paving		Northbound Paving	
Shift (1)	Production [Mg (tons)] (2)	Hourly production [Mg/h (tons/h)] (3)	Production [Mg (tons)] (4)	Hourly production [Mg/h (tons/h)] (5)
Friday night	3,370.9 (3,716.5)	337 (372)	3,723.6 (4,105.45)	331 (365)
Saturday day	4,495.0 (4,955.85)	375 (413)	3,792.8 (4,181.65)	361 (398)
Saturday night	2,889.3 (3,185.58)	251 (277)	3,173.0 (3,498.35)	289 (318)
Sunday day	770.4 (849.45)	308 (340)	151.5 (167.1)	303 (334)

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TABLE 2. Production Rates for I-405 in Comparison with Nighttime Project on I-5

Project (1)	Transfer method (2)	Average shift duration (h) (3)	Maximum production rate [Mg/h (tons/h)] (4)	Minimum production rate [Mg/h (tons/h)] (5)	Average production rate [Mg/h (tons/h)] (6)
I-5 Northbound, 1993	Conventional	6.4	254 (280)	122 (135)	200 (220)
I-5 Northbound, 1994	Mass transfer	7.1	300 (331)	261 (288)	284 (313)
I-5 Southbound, 1994	Mass transfer	6.0	293 (323)	135 (149)	242 (267)
I-405 Southbound, 1997	Pickup	9.1	375 (413)	251 (277)	314 (346)
I-405 Northbound, 1997	Pickup	10.9	361 (398)	288 (318)	320 (354)

operations were complete at about 10:30 a.m. on Sunday for both weekends.

A maximum shift paving production rate of 375 Mg/h (413 tons/h) was achieved during the southbound paving and a maximum of 361 Mg/h (398 tons/h) during the northbound paving. Average production rates were 314 Mg/h (346 tons/h) and 320 Mg/h (354 tons/h), respectively. The close proximity of the production plant to the construction site was key to achieving such high production rates. Knowledge of the high paving production rates (recall that only one paver was used) provides a valuable backdrop for understanding any difficulties encountered in maintaining consistent quality.

Comparison with unpublished hourly paving rates for nighttime paving from WSDOT data demonstrate that the paving production levels for the weekend closure were quite high, even in light of the use of a pickup device. Production rates from the I-405 project are compared to rates from project C4250 on I-5 from the Nisqually River to the Gravelly Lake Interchange in Table 2. The I-5 project was a nighttime project that was comparable in paving quantity to the I-405 project. The total tonnage for the I-5 project was 34,364.6 Mg (37,888.2 tons), with 20,261.2 Mg (22,338.7 tons) in the northbound direction and 14,103.4 Mg (15,549.5 tons) in the southbound direction. Longer project limits in the northbound direction explain the large difference in paving quantities between the two directions. The northbound overlay was constructed during 14 nights in 1993 and three nights in 1994. The southbound overlay was constructed during 11 nights in 1994. The 1993 northbound overlay was characterized by numerous instances of cyclic segregation. In 1994 a mass transfer device (remixer) was used to complete the northbound lanes and to construct all of the southbound lanes. The strategy was successful in eliminating the cyclic segregation problem.

Table 2 compares the range of production rates from the I-405 weekend closure to those of the I-5 nighttime only paving. On the surface, the effect of the full closure condition seems to yield greater paving quantities. The minimum production rate for I-405 southbound resulted from necessary rework when the specified course thickness was exceeded. An unexplained and less dramatic slowdown was noted for the northbound Saturday night paving, but no explanations were indicated in the inspector daily reports. It appears that average paving rates of about 317 Mg/h (350 tons/h) or more may be achieved with the full weekend closure strategy when a single paver is used, the asphalt plant is in close proximity to the construction site, and traffic-free access is ensured. By comparison, it may be more appropriately stated that the results indicated that the continuous, unobstructed paving operation resulted in an approximate 21% increase in production rates over paving executed without the same protected material delivery conditions.

QUALITY CHARACTERISTICS OF OVERLAY

As noted above, the evaluation of the quality of the AC overlay included both quantitative and qualitative assessments. The evaluation addressed two broad questions about (1) whether differences existed between nighttime and daytime paving quality; and (2) whether the overall characterization of the project compared well to other paving jobs. Results of the analysis between night and day cycles are presented below.

Surface Smoothness

Table 3 summarizes the smoothness measurements that were taken during the two weekend closures. For each lane, the profile index (PRI) represents a continuous segment of the lane. Measurements were first taken from the prelevel surface to isolate the improvement of the overlay course, and they are also listed in the tables.

The profilograph measurements are put into perspective by considering the smoothness specification for AC pavements that is currently utilized by the Southwest Region Office of WSDOT. The supplement specification requires the contractor to produce a riding surface with a profile index of 80 mm/km (5 in./mi), as measured with a California-type computerized profilograph. This specification was based upon examples from other states and is representative of a customarily acceptable surface smoothness for flexible pavements. Reference to this specification indicates that the contractor for the I-405 project produced smoothness appropriate to a high quality pavement. Only the PRI for the last section listed for the southbound direction came close to the threshold value.

Statistical analysis of the PRIs revealed no differences between nighttime and daytime paving shifts, nor between southbound and northbound lanes. Note, however, that the number of samples obtainable on this project was small and included mostly daytime shifts. A larger database from several projects is desirable for drawing firm, statistically supported conclusions.

In-Place Densities

The results obtained from measurements of in-place density were compared for differences between daytime and nighttime paving and between weekend closures.

TABLE 3. Profilograph Summary

Lane (1)	Wheel path (2)	Prelevel PRI [mm/km (in./mi)] (3)	Overlay PRI [mm/km (in./mi)] (4)	Improvement in PRI [mm/km (in./mi)] (5)	When paved (6)
(a) Southbound Paving					
1	Inside	68 (4.3)	47 (3.4)	+14 (0.9)	Night
2	Outside	106 (6.7)	28 (1.8)	+77 (4.9)	Day
2	Inside	28 (1.8)	27 (1.7)	+2 (0.1)	Day
2	Outside	79 (5.0)	22 (1.4)	+57 (3.6)	Day
1	Inside	66 (4.2)	79 (5.0)	−13 (0.8)	Day
(b) Northbound Paving					
1	Inside	182 (11.5)	20 (1.3)	+161 (10.2)	Night
3	Outside	123 (7.8)	38 (2.4)	+85 (5.4)	Day
2	Inside	98 (6.2)	20 (1.3)	+77 (4.9)	Day

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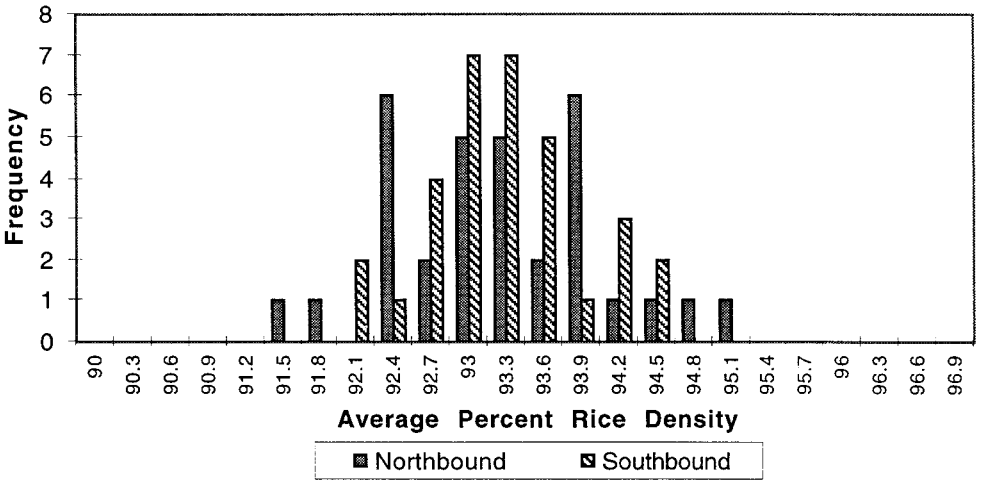

FIG. 1. Frequency Histogram of Average Rice Density Percentages for Each Direction

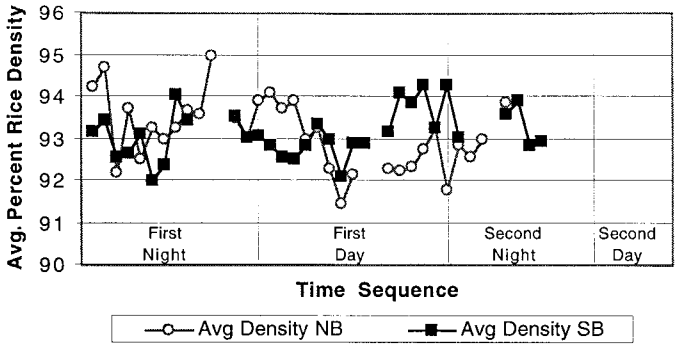

FIG. 2. Average Rice Density throughout Paving Operations

Overview of Density Results

Mat density measurements were taken in sequence with the paving operations along the length of both the southbound and northbound lanes with a calibrated nuclear densometer. In accordance with WSDOT Test Method No. 716, five measurements were taken from sublots of each 363-Mg (400-ton) lot and an average density was calculated for each lot. Average Rice density percentages were found to be normally distributed (Fig. 1). Average densities over the entire worksite ranged from 91.46 to 94.98%, with an average density of 93.14% and a standard deviation of 0.73%. The range for all individual sublots was from 90.1 to 96.4%.

Statistical tests indicated that there were no significant differences in the average (mean) densities between the two weekends (directions). The mean density in the northbound direction was 93.13% and that in the southbound direction was 93.14%, virtually the same. However, the statistical variation about the mean densities was significantly different. The range of densities for the northbound direction (91.46–94.98%) was slightly greater than the range for the southbound direction (92.0–94.28%).

Fig. 2 shows a plot of densities measured as paving operations progressed through each respective weekend. The time is expressed in terms of the day and night intervals, which coincided with shift changes. *F*-tests for statistical differences in variation revealed that the difference in variation between the two weekends of paving could be isolated to the first day of paving. That is, the variation in average in-place densities was shown to be different between the Saturday daytime shifts. No other source of variation difference was statistically supported.

It was noted that a trend line (not shown) through the data from the southbound direction indicated a slight general increase in average densities as paving operations progressed, implying more effective paving operations as the first weekend proceeded. On the other hand, a slight decrease in average densities was apparent for the northbound direction, indicating a general loss of effectiveness. Such an apparent trend may be attributed to growing human fatigue after the first weekend or to the slightly faster paving rate of the second weekend and thus more pressure on the roller compaction to keep pace with the paving. However, explanations for the apparent trends cannot be guaranteed because of limited data and questionable assumptions. For example, the validity of connecting the shifts in sequence is questionable.

Statistical analysis revealed no significant differences in pavement densities between lots paved in the daytime and those paved in the nighttime. This was true for both northbound and southbound directions, individually and considered together.

Densities in Perspective

Comparison with historical data helps to put the average Rice densities into perspective. When Markey et al. (1994) studied the initial impact of the WSDOT quality assurance (QA) specification, they included three QA projects. In Table 4, the statistical parameters for density from those jobs are compared to those from the mainline paving for the I-405 project. The I-405 project compares quite well. Its mean average density is exceeded by only one of the other three projects (Contract No. 3522), as is its variability (Contract No. 3587).

Further examination of construction quality included comparison of the air voids in the compacted ACP with values quoted in the literature. Notwithstanding differences between measurement methods, the I-405 project variability was found to be distinctly less than those reported from the several sources quoted by Hughes (1996) and included in Table 5.

The effect that air voids in the compacted mix have upon pavement quality is worth noting. Linden et al. (1989) conducted a study wherein they confirmed a basic rule of thumb

TABLE 4. Comparison of I-405 Average Rice Density Percentage Parameters to Early QA Projects

Job (1)	Number of lots (2)	Mean (3)	Maximum (4)	Minimum (5)	Range (6)	Standard deviation (7)	Variance (8)
I-405	64	93.14	94.98	91.46	3.52	0.716	0.513
3522	46	93.34	95.52	91.24	4.28	1.035	1.070
3587	24	92.87	94.82	91.66	3.16	0.694	0.482
3636	131	92.49	94.42	88.64	5.78	0.867	0.756

Note: From Markey et al. (1994).

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TABLE 5. Comparison with Reported Standard Deviation of Asphalt Concrete Air Voids for Roadway Compacted Mixtures

Source (1)	Year (2)	Method (3)	Average (%) (4)
I-405	1997	Nuclear	0.73
California	1995	Cores	1.9
New Jersey	1995	Cores	1.5
Ontario	1995	Cores	1.6
Colorado	1993	Cores	1.0
Washington	1993	Nuclear	0.9
Virginia	1984	Cores	1.3

Note: Adapted from Hughes (1996).

that for every 1% above 7% of air voids in the compacted roadway mix, pavement life decreases by 10%. The average percentage of air voids for the project was 6.8, suggesting a satisfactory period of service from the overlay.

Gradation

Areas of quality performance that were explicitly specified in addition to density were the gradation of aggregates and the asphalt cement. The mix of aggregate and asphalt cement fractions for this job compared quite favorably to the job mix formula. For each aggregate size and for the asphalt cement content, job gradation fell well within the specified range limits. Even a band of 2 standard deviations (95% of cases) from the job average still fell within specified range limits in all instances except for the 6.33-mm (1/4-in.) size.

Table 6 helps to put the gradation variability from the I-405 project into perspective. Aggregate gradation variability data published by Hughes (1996) is shown here for direct comparison to the I-405 gradation results. Note that the variabilities from the I-405 project were consistently less than those reported from the four most recent sources presented from Hughes's synthesis study. The Washington State data from 1993 were obtained from a project that was executed under the then newly developed statistical QA specification.

The asphalt cement content variability can also be compared with some typical standard deviations. Table 7 shows how the variability from the I-405 project compares to data previously published from several sources and condensed by Hughes (1996). Only data since 1988 are presented here. The I-405 project compares favorably with the other data, although it is acknowledged that variations may exist between measurement procedures.

Longitudinal Joints

Longitudinal joints were expected to be of good quality because the unfinished mat had not been exposed to normal traffic before the joints were constructed (normally the case with partial closures). However, there were noted difficulties as indicated by both waviness in the joint line and deep cracks or tears near and parallel to the joint. Several instances of poor longitudinal joints were noted during both weekends. However, the remedial measure of applying a fog seal to the joints was only deemed necessary during the first weekend (southbound direction).

Without direct observation, causes for flaws in the longitudinal joints are speculative. However, consultation with the contractor's supervisors, reference to inspection reports, and reference to the literature (*Hot*; *Asphalt* 1992) revealed three potential explanations for the problems with the longitudinal joints. The first possibility is that the wide drums of the large rollers may have extended too far beyond the free edge of the mat, thus creating an improper edge on the cold mat side of the joint. The second possibility is excessive rolling of the joint, especially during the cooler nighttime hours when the AC mat temperature may have been too low. A final possibility is that too much of the width of the vibratory roller extended onto the cold mat.

A final point to recognize is that certain general conditions of the closure strategy also contributed to problems with the longitudinal joints. Flaws in the longitudinal joints were more extensive because nighttime visibility inhibited recognition of the problem. In addition, the relatively high speed of the paving operation often meant that the compaction operations fell too far behind, thus giving the AC mat more time to cool before compaction. The writers note that the contractor did begin the second weekend with four rollers, only to lose two due to breakdowns.

Cyclic Segregation

Experiences with other projects initially raised the issue of cyclic segregation on the I-405 project. As expected, however, the continuous paving with a pickup device, combined with no expectation of prolonged nighttime cooling of the hot mix asphalt in the truck, apparently precluded any problem with cyclic segregation. Visual inspection of the pavement by both the investigators and WSDOT personnel revealed no evidence of cyclic segregation.

Surface Defects

There were numerous tears in the ACP mat throughout the outside lane (No. 1) in the northbound direction. One speculation was that the tack coat might have been inadequate, perhaps through removal by heavy truck traffic. The resulting lack of adhesion between the prelevel surface and the overlay would allow the mat, which was unrestrained on the shoulder side, to slide and therefore to tear easily during the rolling operations. Later inspection after 3 months of traffic indicated that fog seal applications to these tears were sufficient to promote the healing of these tears. This problem, along with the assessment of the longitudinal joints, indicates a need to pay

TABLE 6. Comparison with Typical Asphalt Concrete Aggregate Gradation Variability from Extraction Tests

	Percent Passing Standard Deviation				
Size (1)	I-405 (2)	Washington, 1993 (3)	Arkansas,[a] 1993 (4)	Pennsylvania, 1982 (5)	Virginia, 1968 (6)
19 or 12.5 mm (3/4 or 1/2 in.)	0.83	1.6	1.7	2.3	—
9.5 mm (3/8 in.)	1.64	2.5	2.6	4.4	1.9
6.33 or 4.75 mm (1/4 in. or No. 4)	2.19	3.0	2.8	3.4	3.3
2.3 or 2.00 mm (Nos. 8 or 10)	1.43	2.4	1.7	2.5	3.2
425 or 300 μm (Nos. 40 or 50)	0.92	1.6	1.3	1.5	1.6
75 μm (No. 200)	0.41	0.5	0.6	1.0	0.9

Note: Adapted from Hughes (1996).
[a]Data from questionnaire responses.

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TABLE 7. Comparison with Typical Asphalt Cement Content Variability

Source (1)	Year (2)	Test (3)	Standard deviation (%) (4)
I-405	1997	Nuclear	0.18
Arkansas[a]	1994	Extraction	0.21
Virginia	1994	Extraction	0.18
Virginia	1994	Nuclear	0.21
NCAT	1994	Nuclear	0.19
NCAT	1994	Centrifuge	0.44
NCAT	1994	Ignition	0.30
Washington	1993	Extraction	0.24
Colorado	1993	Extraction	0.15
Kansas	1988	Nuclear	0.27
Virginia	1988	Extraction	0.19

Note: Adapted from Hughes (1996).
[a]Data from questionnaire responses.

closer attention to the interaction between temperature, the speed of paving, and the paving plan lane sequence.

EXPERIENCES OF OTHER SHAs

Although it was known at the outset of this study that the full weekend closure strategy was unique, learning what other selected states were planning for or had experienced with various closure strategies was deemed valuable for assessing the place of weekend closures within the spectrum of closure options. Nine SHAs were contacted, and six provided responses to a brief survey. The surveyed states were among those considered to have heavily populated areas that would require innovative approaches for accomplishing large highway reconstruction or rehabilitation projects. The responding states were Illinois, California, Georgia, Massachusetts, Texas, and Florida. An abbreviated discussion of survey responses is provided here. A more complete tabulation and discussion is found elsewhere (Dunston and Mannering 1998).

Preferred Lane Closure Strategies

Choices for lane closure strategies were characterized by number of lanes and time of day. Table 8 shows that single lane closures were used most often by five of the six states. As expected, the majority also employed night closures most frequently, with no consensus on the second or third choices. However, single lane closure was the overall leading choice for number of closure lanes, whereas the choice between night and day was roughly even. The notion of multilane closures did not appear significant until the fourth level of frequency was reached. In addition, each state preferred to use the multilane strategy first during night hours before selecting it as a daytime option.

Quality from Preferred Strategies

Each state respondent was asked to indicate any quality trends associated with the most frequently used closure strategy. None of the respondents noted any differences in gradation. The survey did not inquire whether the difference in ride quality was judged by measurement or by inspection.

Because each of the states responding to this question with noted differences utilized the nighttime option most frequently, their responses may be expected to provide a picture of the type of quality that is often achieved through nighttime paving. The responses indicated that nighttime paving tends to result in greater variability in densities, a rougher ride, more instances of cyclic segregation, and lower quality longitudinal joints. It is encouraging that this study found that the three former difficulties can be overcome.

TABLE 8. Survey Responses—Preferred Closure Strategies

State (1)	Alternatives Ranked by Frequency of Use: First (2)	Second (3)	Third (4)	Fourth (5)
Illinois	Single day	Complete day	Single night	Complete continuous
Georgia	Single night	Single day	Multilane night	Multilane day
Florida	Single night	Single day	Single continuous	—
California	Multilane night	Single night	Single day	Multilane day
Massachusetts	Single night	Multilane night	Single day	Multilane day
Texas	Single night	Single day	Multilane night	Multilane day

Respondents were queried on other performance parameters that are not directly related to the overlay condition. Two states, Massachusetts and Texas, reported lower safety incident rates for both workers and the public. The respondents were almost equally divided on whether pay factors were the same or higher for nighttime paving.

Hourly production rates were noted to be different in the form of either greater variability or higher rates. Only one respondent, Massachusetts, cited lower production rates. Although Florida noted higher production rates, an earlier Florida study by Ellis and Kumar (1993) concluded that nighttime paving productivity (tons/h) may be as high as for daytime paving, although the total shift production may not be as high. In fact, no statistical difference in paving production rates could be confirmed in their study.

Public Response and Feedback

Public response to closure strategies motivates the search for more innovative strategies. Respondents said that the public is generally pleased with the approach of partial closures at night. This public response would be expected because conventional views are that the partial night closure is the least disruptive alternative available. As more SHAs consider the full weekend closure strategy, more data will become available to gauge user responses and preferences between the full weekend closure and the partial night closure.

Approaches Under Consideration

The survey queried respondents on new or innovative closure strategies that would be a departure from current practice for reconstruction projects. Table 9 shows the responses and indicates a general trend (four of the six) toward contractual arrangements such as A+B (cost-plus-time) contracting and lane rental. The A+B contracting requires bidders to submit a two-component bid—component A as the traditional unit price bid for all contract items and component B as the bid for the total number of calendar days. The formula for bid evaluation

TABLE 9. Closure Strategies under Consideration

State (1)	Strategy considered (2)
Illinois	A+B; nighttime closures
Georgia	Lane rental with restrictions
Florida	Lane rental
California	Weekend closures (55 h)
Massachusetts	More night work in high average daily traffic areas
Texas	Lane rental

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is A + (B × road user cost/day), the user cost specified by the contracting agency (Rohlf 1994). Herbsman (1995) showed that a significant number of states have taken this approach, namely A+B bidding. He listed 15 states (including California and Georgia) that had used the method at least once, and five of the states—California, Maryland, North Carolina, Missouri, and New York—>10 times. Beyond the motivation to minimize the total project duration, this contracting method does not direct the contractor toward any specific construction method. Lane rental calls for the contractor to pay a contractually specified fee, based on user costs, for occupying or obstructing any part of the roadway during construction. This approach specifically encourages the contractor to consider the sequence and timing of work, as fees can vary with the number of lanes, type of lanes, and the time of day (Rohlf 1994). In both of these approaches the responsibility for innovations to minimize impacts to the public rests primarily with the contractor.

The SHAs appear to be at various points along the spectrum of innovative highway reconstruction strategies. Out of the six respondents to this study, only California is actively considering the weekend closure option. The picture presented by these responses underscores the uniqueness of this approach and the need to gather more comparative data. Responses from Illinois and Massachusetts imply that some SHAs have yet to make extensive use of the nighttime paving option.

SUMMARY AND CONCLUSIONS

The overall level of quality for the weekend closure overlay was good with respect to smoothness, density, gradation, and cyclic segregation. Comparisons with historical data for in-place density and gradation from WSDOT, as well as a few other agencies, were quite favorable, indicating that the quality of the I-405 project with respect to these parameters was decidedly better than average. Not only were commendable mean values achieved, but variabilities were notably minimized. Although there were no contractually specified requirements for smoothness, most of the surface smoothness measurements well exceeded the limit specified in a particular supplement specification for flexible pavements.

For the measured quality parameters, no statistically substantiated differences appeared between night and day paving. However, more samples between night and day shifts would be desirable to draw solid conclusions on surface smoothness. Smoothness data from future weekend closures should be combined with the data from the I-405 project to allow a more comprehensive evaluation of the quality achieved with the weekend closure option.

Perhaps mostly due to the speed of the laydown operation, rolling operations seem to be the major area of difficulty during the weekend closure. This was evident in problems with the longitudinal joints and in surface tears in one lane of the northbound direction. The high speed of the laydown operation demands substantial effort by rakers and the roller operators to keep up with the paver. Close attention to these important construction tasks is recommended for future weekend closure projects.

Average shift production rates for the weekend closure were higher than those documented for a similar nighttime paving project that employed similar equipment. These facts support a general impression of success for the weekend closure strategy. One caveat offered by the investigators is to carefully consider the impact of a remote production facility on projects that utilize the weekend closure option. The proximity of the mobile plant is believed to have been a major factor in achieving the production rates and consistency observed on this project.

It appears from the survey of selected SHAs that the partial nighttime closure strategy is still the most popular strategy for minimizing highway reconstruction impacts to the public. Although night closures create problems related to the quality of the overlay and other performance parameters, the public is generally pleased with the relative minimal impact of this closure strategy. One conclusion might be that the desirability of the full weekend closure alternative will develop only as more states find specific motivations to utilize the option and are successful in minimizing user impacts. The general direction of SHAs, however, appears to be toward A+B bidding and lane rental options that make the contractor responsible for initiating innovations within the confines of the more traditional closure strategies.

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