CHAPTER FOUR

# TRAFFIC CRASHES AND PAVEMENT MARKINGS

Pavement markings have the potential to reduce traffic crashes during both daylight and darkness. Although pavement markings provide daytime longitudinal guidance to help keep drivers in the travel lanes, other aspects of the roadway environment, such as the roadside alignment, also provide guidance. Drivers rely more on retroreflective pavement markings to provide guidance information during darkness than daylight.

Pavement markings could potentially reduce many single- and multiple-vehicle crashes that occur during darkness/nighttime, including those on dry and wet pavements, under normal, rain, and fog conditions. Crashes occurring when pavements are covered with snow or ice are less likely to be affected by pavement markings, because such markings may not be visible during these conditions.

This chapter presents traffic crash statistics of the United States and Canada. The types of crashes that can be reduced by pavement markings are discussed. A safety evaluation to determine whether pavement markings reduce traffic crashes is presented. In addition, because pavement marking crews are exposed to traffic crashes while striping at speeds much slower than surrounding traffic, traffic crashes involving marking crews are summarized.

## TRAFFIC CRASHES AND RELATED STATISTICS

This section reviews the traffic crash statistics of the United States and Canada and compares them with those of other countries.

### U.S. Statistics

Traffic crash and related statistics are presented to show trends and the types of traffic crashes that can be reduced by quality pavement markings. The National Highway Traffic Safety Administration (NHTSA) provides these crash statistics [*Traffic Safety Facts 1999* (2000); *Fatality Analysis Reporting* . . . 2001; *Traffic Safety Facts 2000* (2001)]. Data are obtained from police crash reports or by interpreting the information provided through the crash diagram, a police officer's written summary, or combinations of variables on the report, which could result in some data remaining unknown. The NHTSA applies statistical procedures to account for unknown data. Statistics related to fatal crashes are the most reliable, because each one is investigated and more information is collected. Injury and property-damage-only crashes undergo more statistical estimation and are less reliable. Even though there may be errors in the estimates, the NHTSA statistics are the best nationwide data available for describing the types and frequencies of traffic crashes.

Table 11 presents the changes in U.S. traffic crash and related transportation statistics for the years 1990 and 1999 [*Traffic Safety Facts 1999* (2000), Tables 1 and 2]. The table shows that the numbers of all types of crashes decreased, following the general trend for the past 35 years. The population, number of drivers, registered motor vehicles, and vehicle-miles traveled (VMT) increased, resulting in an overall decrease in crash rates. The percentage of fatal crashes per total crashes remained constant at 0.6%, while injury crashes also remained constant at one-third of the total crashes.

TABLE 11
CHANGE IN U.S. CRASH STATISTICS FROM 1990 TO 1999

| Statistic | 1990 | 1999 | Change from 1990 to 1999 (%) |
|---|---|---|---|
| Total crashes | 6,471,000 | 6,279,000 | –3.0 |
| Fatal crashes | 39,836 | 37,043[a] | –7.0 |
| Injury crashes | 2,122,000 | 2,054,000 | –3.2 |
| Fatalities | 44,599 | 41,611 | –6.7 |
| Injuries | 3,231,000 | 3,236,000 | –6.7 |
| Resident population | 249,464,000 | 272,691,000 | 9.3 |
| Licensed drivers | 167,015,000 | 187,170,000 | 12.1 |
| Registered motor vehicles | 184,275,000 | 212,685,000 | 15.4 |
| Vehicle-miles traveled (VMT) (billions) | 2,144 | 2,691 | 25.5 |
| Fatal crashes per 100 million VMT | 1.86 | 1.38 | –25.9 |
| Injury crashes per 100 million VMT | 98.97 | 76.33 | –22.9 |
| Fatalities per 100 million VMT | 2.08 | 1.55 | –25.7 |
| Injuries per 100 million VMT | 150.70 | 120.25 | –20.2 |

[a]Other 1999 NHTSA data show 37,140 fatal crashes (*Fatality Analysis Reporting* . . . 2001).

[*Source*: *Traffic Safety Facts 1999,* Tables 1 and 2 (2000).]

TABLE 12
CRASHES IN 1999 BY WEATHER CONDITION, LIGHT CONDITION, AND CRASH SEVERITY

| Weather Condition | Light Condition | | | | Total |
|---|---|---|---|---|---|
| | Daylight | Dark, but Lighted | Dark | Dawn or Dusk | |
| *Fatal Crashes* | | | | | |
| Normal | 16,873 | 4,944 | 9,732 | 1,371 | **32,961** |
| Rain | 1,376 | 444 | 769 | 123 | **2,714** |
| Snow/sleet | 313 | 61 | 199 | 33 | **606** |
| Other[a] | 175 | 82 | 276 | 49 | **582** |
| Unknown | 53 | 5 | 36 | 3 | **180** |
| **Total[b]** | **18,790** | **5,536** | **11,012** | **1,579** | **37,043*** |
| *Injury Crashes* | | | | | |
| Normal | 1,262,000 | 252,000 | 175,000 | 57,000 | **1,747,000** |
| Rain | 148,000 | 45,000 | 24,000 | 12,000 | **229,000** |
| Snow/sleet | 24,000 | 8,000 | 7,000 | 2,000 | **42,000** |
| Other | 21,000 | 5,000 | 7,000 | 3,000 | **36,000** |
| **Total** | **1,456,000** | **311,000** | **213,000** | **75,000** | **2,054,000** |
| *Property-Damage-Only Crashes* | | | | | |
| Normal | 2,552,000 | 452,000 | 375,000 | 121,000 | **3,501,000** |
| Rain | 294,000 | 80,000 | 51,000 | 22,000 | **447,000** |
| Snow/sleet | 89,000 | 34,000 | 24,000 | 10,000 | **157,000** |
| Other | 51,000 | 13,000 | 14,000 | 5,000 | **83,000** |
| **Total** | **2,985,000** | **579,000** | **465,000** | **158,000** | **4,188,000** |
| *All Crashes* | | | | | |
| Normal | 3,831,000 | 709,000 | 560,000 | 180,000 | **5,281,000** |
| Rain | 443,000 | 126,000 | 76,000 | 35,000 | **679,000** |
| Snow/sleet | 114,000 | 42,000 | 31,000 | 12,000 | **199,000** |
| Other | 72,000 | 19,000 | 22,000 | 8,000 | **120,000** |
| **Total** | **4,460,000** | **895,000** | **689,000** | **235,000** | **6,279,000** |

*Includes 126 fatal crashes that occurred under unknown light conditions.
[a]371 (64%) of the 582 "Other" fatal crashes occurred under darkness during rain and fog or fog conditions (*Fatality Analysis Reporting* . . . 2001).
[b]Other 1999 NHTSA data show the following fatal crashes: Daylight—18,835; Dark, but lighted—5,564; Dark—11,032; Dawn 709 or Dusk 879—1,588; and Total—37,140 (*Fatality Analysis Reporting* . . . 2001).
[*Source*: *Traffic Safety Facts* (2001), Table 25.]

Traffic fatalities in the United States decreased by more than 3,000 (from 44,599 to 41,508) from 1990 to 1991 [*Traffic Safety Facts 2000* (2001), Table 2]. However, over the 10-year period from 1991 through 2000 traffic fatalities have remained fairly constant, averaging 41,256 fatalities per year, with a range from 39,250 to 42,056. The variation in fatalities appears to be random. Traffic safety, as judged by a reduction in traffic fatalities, is not improving, even though crash rates decreased because of increased travel.

Table 12 presents crash statistics for 1999 by weather condition, light condition, and crash severity [*Traffic Safety Facts 1999* (2000), Table 25]. The number of crashes occurring under darkness (dark but lighted, dark, and dawn or dusk) during normal and rainy weather conditions is more likely to be reduced by retroreflective pavement markings. In addition, crashes that occur under darkness during rain and fog or fog conditions are classified as "Other" and can also be reduced by retroreflective pavement markings. Of the fatal crashes that occurred under darkness during rain and fog or fog conditions, 1% (371) were classified as Other (*Fatality Analysis Reporting* . . . 2001). Boxes in the table designate these crashes.

The following section summarizes the crashes shown in Table 12 that occurred under darkness during normal and rainy weather.

#### Crashes Occurring Under Darkness During Normal and Rainy Weather

- Categorized by severity, those crashes occurring under darkness during normal weather consisted of 43% (16,047) fatal, 24% (484,000) injury, and 23% (948,000) property-damage-only (PDO). Fatal crashes occurring under darkness during normal weather are overrepresented. Twenty-three percent (1,448,047) of all crashes (6,279,043) occurred under darkness during normal weather.
- Crashes occurring under darkness during rainy weather were constant at 4% across all crash severities

TABLE 13
FATAL CRASHES IN 1999 BY LIGHT CONDITION AND VARIOUS CLASSIFICATIONS

| | Light Condition | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Classification | Daylight | % | Darkness[a] | % | Unknown | % | Total[b] | % |
| Roadway Surface Condition | | | | | | | | |
| Dry | 16,125 | 86 | 15,272 | 84 | 45 | 37 | 31,442 | 85 |
| Wet | 2,120 | 11 | 2,319 | 13 | 4 | 3 | 4,443 | 12 |
| Other and unknown[c] | 590 | 3 | 593 | 3 | 72 | 60 | 1,255 | 3 |
| Total | 18,835 | 100 | 18,184 | 100 | 121 | 100 | 37,140 | 100 |
| Relation to Junction | | | | | | | | |
| Non-junction | 12,439 | 66 | 14,093 | 78 | 75 | 62 | 26,607 | 72 |
| Junction—intersection | 4,703 | 25 | 2,571 | 14 | 12 | 10 | 7,286 | 20 |
| Junction—intersection related | 612 | 3 | 654 | 4 | 2 | 2 | 1,268 | 3 |
| Other and unknown | 1,081 | 6 | 866 | 5 | 32 | 26 | 1,979 | 5 |
| Total | 18,835 | 100 | 18,184 | 100 | 121 | 100 | 37,140 | 100 |
| Relation to Roadway | | | | | | | | |
| On roadway | 12,401 | 66 | 9,492 | 52 | 26 | 21 | 21,919 | 59 |
| Run-off-road[d] | 6,318 | 34 | 8,549 | 47 | 69 | 57 | 14,936 | 40 |
| Other and unknown[e] | 116 | 1 | 143 | 1 | 26 | 21 | 285 | 1 |
| Total | 18,835 | 100 | 18,184 | 100 | 121 | 100 | 37,140 | 100 |
| Manner of Collision | | | | | | | | |
| Not collision with motor vehicle in transport | 8,847 | 47 | 12,382 | 71 | 101 | 83 | 21,780 | 59 |
| Angle, rear end, and unknown[f] | 6,393 | 34 | 3,168 | 17 | 17 | 14 | 9,578 | 26 |
| Head-on and sideswipe[g] | 3,595 | 19 | 2,184 | 12 | 3 | 2 | 5,782 | 16 |
| Total | 18,835 | 100 | 18,184 | 100 | 121 | 100 | 37,140 | 100 |
| Speed Limit (mph) | | | | | | | | |
| 50 and less | 8,166 | 43 | 8,637 | 47 | 37 | 31 | 16,840 | 45 |
| 55 and greater | 10,204 | 54 | 9,132 | 50 | 37 | 31 | 19,373 | 52 |
| No statutory limit and unknown | 465 | 2 | 415 | 2 | 47 | 39 | 927 | 2 |
| Total | 18,835 | 100 | 18,184 | 100 | 121 | 100 | 37,140 | 100 |
| Roadway Function Class | | | | | | | | |
| Rural | 11,909 | 63 | 10,297 | 57 | 88 | 73 | 22,294 | 60 |
| Urban | 6,870 | 36 | 7,838 | 43 | 32 | 26 | 14,740 | 40 |
| Blank and unknown | 56 | 0 | 49 | 0 | 1 | 1 | 106 | 0 |
| Total | 18,835 | 100 | 18,184 | 100 | 121 | 100 | 37,140 | 100 |
| Atmospheric Condition | | | | | | | | |
| No adverse atmospheric conditions | 16,919 | 90 | 16,103 | 89 | 41 | 34 | 33,063 | 89 |
| Rain and/or fog[h] | 1,516 | 8 | 1,712 | 9 | 2 | 2 | 3,230 | 9 |
| Other and unknown[i] | 400 | 2 | 369 | 2 | 78 | 64 | 847 | 2 |
| Total | 18,835 | 100 | 18,184 | 100 | 121 | 100 | 37,140 | 100 |
| No. of Travel Lanes | | | | | | | | |
| One lane | 102 | 1 | 89 | 0 | 2 | 2 | 193 | 1 |
| Two lanes | 14,929 | 79 | 13,855 | 76 | 78 | 64 | 28,862 | 78 |
| Three lanes | 1,091 | 6 | 1,418 | 8 | 4 | 3 | 2,513 | 7 |
| Four lanes | 2,044 | 11 | 2,002 | 11 | 5 | 4 | 4,051 | 11 |
| Five lanes | 126 | 1 | 197 | 1 | 0 | 0 | 323 | 1 |
| Six lanes | 188 | 1 | 258 | 1 | 2 | 2 | 448 | 1 |
| Seven or more lanes | 43 | 0 | 49 | 0 | 0 | 0 | 92 | 0 |
| Unknown | 312 | 2 | 316 | 2 | 30 | 25 | 658 | 2 |
| Total | 18,835 | 100 | 18,184 | 100 | 121 | 100 | 37,140 | 100 |
| Road Surface Type | | | | | | | | |
| Portland cement concrete[j] | 1,846 | 10 | 1,997 | 11 | 7 | 6 | 3,850 | 10 |
| Asphaltic concrete[k] | 16,130 | 86 | 15,395 | 85 | 76 | 63 | 31,601 | 85 |
| Other and unknown[l] | 859 | 5 | 792 | 4 | 38 | 31 | 1,689 | 5 |
| Total | 18,835 | 100 | 18,184 | 100 | 121 | 100 | 37,140 | 100 |
| Total | 18,835 | 51 | 18,184 | 49 | 121 | 0 | 37,140 | 100 |

Note: 1 mph = 1.6 km/h.
[a]Darkness—Dark, dark but lighted, dawn, and dusk.
[b]Total—Other NHTSA 1999 data show 37,043 fatal crashes [*Traffic Safety Facts 2000* (2001), Tables 1 and 2].
[c]Other and unknown—Snow, slush, ice, sand, dirt, oil, other, and unknown.
[d]Single-vehicle run-off-road—Shoulder, median, roadside, outside right-of-way, and off roadway—location unknown.
[e]Other and unknown—In parking lane, gore, separator, and unknown.
[f]Angle, rear end, and unknown—Angle, rear end, rear-to-rear, and unknown.
[g]Head-on and sideswipe—Head-on, sideswipe same direction, and sideswipe opposite direction.
[h]Rain and/or fog—Rain, fog, and rain and fog.
[i]Other and unknown—Sleet (hail), snow, sleet and fog, other (smog, smoke, blowing sand), and unknown.
[j]Portland cement concrete—Concrete.
[k]Asphaltic concrete—Blacktop, bituminous, or asphalt.
[l]Other and unknown—Brick, block, slag, gravel, stone, dirt, other, unknown.
(*Source*: *Fatality Analysis Reporting* . . . 2001.)

(1,336 fatal, 81,000 injury, and 153,000 PDO for a total of 235,336).

Table 13 presents a further breakdown of fatal crashes in 1999 by light condition (daylight and darkness) and various classifications. The different types and numbers of crashes that can be reduced by retroreflective pavement markings are shown. For example, 84% (15,272) occurred on dry pavements under darkness.

The fatal crash data in the table were obtained through the NHTSA query system. The number of fatal crashes in the query system (37,140) (*Fatality Analysis Reporting* . . . 2001) is greater than those reported earlier in Tables 11 and 12 (37,043) [*Traffic Safety Facts 2000* (2001)].

Other related statistics for 1999 are summarized here (*Fatality Analysis Reporting* . . . 2001).

- Fifty-six percent of fatal crashes involved only one vehicle, compared with 28% of both injury and PDO crashes.
- Fifty-nine percent of single-vehicle fatal crashes occurred at night, whereas 47% of injury and 48% of PDO crashes, respectively, occurred at night. More than one-half of fatal crashes (52%) occurred on roads with posted speed limits of 88.5 km/h (55 mph) or more, whereas only 22% of PDO crashes occurred on these roads.
- Forty-four percent of fatal crashes occurred on two-lane highways with speed limits of 88.5 km/h (55 mph) and greater.
- Collisions with fixed objects and noncollisions accounted for only 17% of all crashes, but did account for 41% of fatal crashes.
- Thirty-eight percent of fatal crashes involved alcohol. Seventy-five percent of fatal crashes occurring from midnight to 3:00 AM involved alcohol. (Alcohol involvement—blood alcohol concentration of 0.01 g/dl or greater.)

### Canadian Statistics

In 1996, Canada started an initiative to make their roads the safest in the world. The initiative has four priorities: raise public awareness of road safety issues; improve communication, coordination, and collaboration among road safety agencies; develop more efficient enforcement to deal with problem areas such as impaired driving and the non-use of seat belts; and improve the collection of safety data (*The State of Road Safety* . . . 2000). Canadian statistics for the year 1998 are shown in Table 14.

TABLE 14
CANADIAN STATISTICS FOR 1998

| Statistic | 1998 |
|---|---|
| Total crashes | 601,153 |
| No. of vehicles involved in crashes | 1,092,103 |
| Fatalities | 2,934 |
| Injuries | 217,754 |
| Resident population | 30,200,000 |
| Licensed drivers | 20,000,000 |
| Registered motor vehicles | 18,000,000 |

(*Source: The State of Road Safety* . . . 2000.)

From 1988 to 1998, traffic fatalities in Canada decreased by more than 29%, whereas the number of licensed drivers increased by 20% and registered motor vehicles by 15% (*The State of Road Safety* . . . 2000). By comparison, traffic fatalities in the United States decreased by 12% over the same period, whereas licensed drivers increased 14% and registered motor vehicles by 17% [*Traffic Safety Facts 2000* (2001), Tables 1 and 2]. In 1998, the number of Canadian fatalities reached the lowest level in 40 years, and persons injured reached the lowest level in 21 years (*The State of Road Safety* . . . 2000). Among driver fatalities, the percentage of those tested for the use of alcohol and found to be above the legal blood alcohol concentration limit of 0.08 g/dl decreased from 40.3% in 1988 to 32.8% in 1998, which was up 1.1% from 1997.

### Comparison of International Statistics

The crash statistics of 10 comparable countries belonging to the Organization for Economic Cooperation and Development (OECD) (United States and Canada plus Australia, Germany, Great Britain, Japan, The Netherlands, Norway, Sweden, and Switzerland) were compared. In 1998, the United States ranked first in vehicle ownership at 76.8 vehicles per 100 population, while Canada ranked sixth at 59.5 vehicles per 100 population (*The State of Road Safety* . . . 2000).

The rates of road-user fatalities per registered vehicles are shown for three countries in Table 15 and the rates of road-user fatalities per population for three countries are shown in Table 16.

TABLE 15
ROAD USER FATALITIES PER 10,000 REGISTERED MOTOR VEHICLES IN 1998

| Rank | Country | Fatality Rate |
|---|---|---|
| 1 | Sweden | 1.18 |
| 9 | Canada | 1.63 |
| 10 | United States | 2.00 |

(*Source: The State of Road Safety* . . . 2000.)

Tables 15 and 16 show that the United States had the highest fatality rates per registered motor vehicle and

TABLE 16
ROAD USER FATALITIES PER 100,000 POPULATION IN 1998

| Rank | Country | Fatality Rate |
|---|---|---|
| 1 | Great Britain | 5.94 |
| 9 | Canada | 9.68 |
| 10 | United States | 15.34 |

(*Source: The State of Road Safety* . . . 2000.)

population of the 10 OECD countries, and Canada the next highest rates. Canada and the United States have the two largest land areas of the 10 countries studied ("Canada in Brief" 2001; "United States in Brief" 2001). In 1998, Canada had a population density of 3.0 persons per square-kilometer (7.8 persons per square-mile). The United States had a much higher population density of 28.9 persons per square-kilometer (74.8 persons per square-mile), which compares more closely with the OECD member country average of 31.0 persons per square-kilometer (80.4 persons per square-mile) (*The State of Road Safety* . . . 2000; "Canada in Brief" 2001; "United States in Brief" 2001). Both the United States and Canada have mobile populations that depend heavily on personal vehicles for travel, which contributes to the higher fatality rates. Because neither the VMT nor the crash rate per VMT for Canada and the other countries is known, that comparison cannot be done. Another consideration could be the differences in recording and reporting traffic crash data among the 10 OECD countries.

## SAFETY EVALUATION

Despite the increase in expenditure for pavement markings, little is known about the safety effects of the use of more durable markings with longer service lives and higher levels of retroreflectivity. A before-and-after safety evaluation was done in an FHWA study to determine whether the longer lasting more retroreflective materials reduced traffic crashes (Migletz et al. 2000 unpublished data). The majority of the 55 sites were located on freeways (65%), with 15% on non-freeways with speeds of 72 km/h (45 mph) or more and 18% on non-freeways with speeds of 64 km/h (40 mph) or less. Marking materials evaluated included epoxy, methyl methacrylate, polyester, tape, and thermoplastic. The markings in the before-installation period consisted of 48 sites with conventional solvent paint and 7 sites with epoxy.

The safety analysis considered all types of crashes except multiple-vehicle collisions at intersections. Although the markings installed did include longitudinal lines at intersections, they did not include intersection-related markings such as stop lines and crosswalk lines. Furthermore, intersection collisions at night are not typically understood to result from a lack of longitudinal guidance information in the same sense that crashes between intersections are.

A total of 10,312 crashes occurred in the before-and-after study periods and included single- and multiple-vehicle crashes occurring between intersections during daytime and nighttime on dry and wet pavements. Multiple-vehicle intersection crashes and crashes on ice- and snow-covered pavements, where markings are covered and therefore not expected to function properly, were excluded.

The five measures of exposure considered in the safety evaluation were: site length, duration of study period (in days), average ADT, proportion of ADT under daytime and nighttime conditions, and proportion of ADT under dry and wet conditions. Estimates of the number of hours of dry and wet pavement conditions were made using the computer program WETTIME, which estimates pavement conditions from available weather data (Harwood et al. 1988).

The results of the analysis are shown in Table 17. Overall, from before to after installation of the durable markings, nighttime dry pavement crash frequencies, adjusted for exposure, decreased by a statistically significant average of 11%. The significant decrease means that it was unlikely to occur by chance. The nighttime wet pavement accident frequency increased by an average of 15%, but was not statistically significant, and could have occurred because of random variation. When nighttime, dry and wet pavement crash data were combined the net change in accident frequency decreased by a statistically insignificant average of 6%.

A subsequent analysis comparing the 48 before-period sites with conventional solvent paint with the same sites striped with durable markings in the after period produced non-significant results as described here.

- The change in wet night crash rate from before to after installation of durable pavement markings for both 29 freeway and 19 non-freeway sites was not statistically significant.
- The change in wet night crash rate from before to after installation of durable pavement markings for both 11 AC pavement and 18 PCC pavement sites on freeways was not statistically significant.
- The change in wet night crash rate from before to after installation of durable pavement markings for both 12 sites with epoxy and 8 sites with profiled thermoplastic was not statistically significant.

In the year 2000 survey, the Washington State DOT reported a reduction in traffic crashes due to pavement markings. A benefit-cost ratio of 1.9 for year-round pavement markings on a rural, two-lane, two-way arterial was achieved. These findings were reported to be statistically significant at the 95th percentile level, but documentation was not provided.

TABLE 17
NIGHTTIME BEFORE-AND-AFTER CRASH ANALYSIS RESULTS ADJUSTED FOR EXPOSURE BY TYPE OF PAVEMENT CONDITION

| Pavement Condition | Sum of Weighted log Odds Ratios | Sum of Weights | Weighted Average Odds Ratio[a] | Percentage Change in Crash Rate[b] | Significantly Different from Zero at 5% Level? *p* level |
|---|---|---|---|---|---|
| Dry | –41.83 | 363.03 | 0.89 | –11% | Yes (0.03) |
| Wet | 15.21 | 106.80 | 1.15 | 15% | No (0.15) |
| Wet + dry | –26.75 | 471.31 | 0.94 | –6% | No (0.22) |

[a]Weighted odds ratio = exp(weighted log odds ratio) = exp(Σweighted log odds ratios/Σweights).
[b]Percentage change (before to after) = 100% × (1 – weighted odds ratio).
(*Source*: Migletz et al. 2000 unpublished data.)

## SAFETY OF MARKING CREWS

Pavement marking operations are done with traffic, except for new road projects that are not yet opened to traffic. The marking convoy consists of the application vehicle (striper) and one or more vehicles providing advance warning and protection. These vehicles can also place and retrieve traffic cones that protect the wet paint.

VDOT conducted a survey to determine the safety of the marking crews (Cottrell and Hanson 2001). VDOT crews are marking pavements an average of 157 days per year. Most districts have two crews available and each crew marks an average of 30.4 km (19 mi) of roadway per day. During 1999, there was one crash involving a marking crew. For the 3-year period from 1997 through 1999, there were nine crashes consisting of two with injury and seven PDO.

The VDOT survey found that a substantial percentage of markings are installed under contract (Cottrell and Hanson 2001). Sixty percent of marking work on Interstate highways, 30% on primary roads, and 50% on secondary roads is by contract. The number of crashes involving marking crews could be even greater when contractor crews are included in the count.

## SUMMARY

The long-term trend in the United States and Canada shows reductions in traffic fatalities, but U.S. traffic fatalities have remained fairly constant since 1991 (through 2000). Increased VMT in the United States has resulted in reduced crash rates.

Pavement markings can reduce traffic crashes occurring under darkness. Fatal crashes in the United States are more likely to occur under darkness than injury or PDO crashes. In 1999, 23% (1,449,000) of all traffic crashes in the United States occurred under darkness during normal weather. An FHWA study of pavement-marking retroreflectivity showed an 11% reduction in nonintersection traffic crashes occurring at night on dry pavements.

In 1999, 4% (270,920) of all crashes occurred under darkness during rain and/or fog conditions. The FHWA study of pavement-marking retroreflectivity did not show a reduction in nonintersection nighttime crashes on wet pavements.

The FHWA before-and-after study analyzed 10,312 crashes at 55 of the 89 test sites where pavement markings were installed. Traffic crash and/or volume data were not available for the other 34 sites. A combination of the 55 test sites and the number of traffic crashes occurring at the sites was not large enough to provide definitive conclusions for crashes occurring at night on wet roads and for the total number of crashes occurring at night on dry and wet roads.

The NHTSA traffic crash data are useful for showing the types of crashes that can be reduced by pavement markings. Any analysis of the crash reduction potential of pavement markings requires detailed data showing VMT so that traffic crash rates can be calculated to perform a reliable analysis. For example, to determine whether a type of pavement-marking material reduces crashes occurring under darkness, VMT during daylight and darkness are required. State transportation agencies are collecting VMT data that are summarized and presented as a nationwide statistic as shown in Table 11. To satisfy traffic crash analysis needs, VMT data would have to be classified in the same manner that much of the NHTSA fatal accident data are classified (*Fatality Analysis Reporting* . . . 2001); that is, by light condition, roadway-surface condition, relation to junction, speed limit, etc.

CHAPTER FIVE

# MATERIAL SELECTION CRITERIA

Transportation agencies have developed criteria for selecting marking materials. The most common factors used in this selection are type of line, pavement surface, type of street and highway, and ADT. Guidelines for selecting materials are presented and summarized in this chapter.

Eight state agencies responding to the survey (Arkansas, Kansas, Maryland, Ohio, North Dakota, Tennessee, Washington, and Wisconsin) have published one-page pavement-marking material selection guidelines, which are presented in Appendix D. These guidelines enable the selection of pavement-marking materials based on a number of factors. Attributes of the material, such as thickness, bead type, application rate, and minimum level of retroreflectivity, are not in the guidelines, but can be found in the specifications and special provisions.

## MATERIAL SELECTION FACTORS

Table 18 summarizes the guidelines presented in Appendix D. Material selection comes down to the use of durable materials versus nondurable materials; that is, paint. Durable materials cost more than paint to obtain and apply. Examples of durable pavement-marking materials include epoxy, thermoplastic, polyester, and profiled tape. Some agencies specify the type of durable marking materials, whereas other agencies provide a list of acceptable durable

TABLE 18
FACTORS USED IN SELECTING PAVEMENT-MARKING MATERIALS

| State Transportation Agency[a] | Type of Line[b] | Pavement Surface[c] | Traffic Volume (ADT)[d] | Type of Street and Highway[e] | Pavement Condition[f] | Remaining Pavement Service Life[g] | Area[h] | Snow Removal Area[i] | Brightness Benefit Factor[j] | Speed[k] | Length of Project[l] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Arkansas | X | X | X | X | | | | | | | |
| Kansas | X | | X | | | X | | | X | | |
| Maryland | X | X | X | X | | | X | | | X | |
| Ohio | X | X | X | | X | | | | | | |
| North Dakota | X | X | X | | X | | | | | | |
| Tennessee | X | X | X | X | | | | | | | |
| Washington | X | | | X | X | X | X | X | | | |
| Wisconsin | X | X | | X | | X | X | | | | X |
| Total | 8 | 6 | 6 | 5 | 3 | 3 | 3 | 1 | 1 | 1 | 1 |

[a]See Appendix D for state guidelines. Pavement marking policies present more information than shown in these guidelines.
[b]Type of line—centerline, lane line, edge line, transverse line, or auxiliary (message, arrow, railroad, etc.).
[c]Pavement surface—Asphaltic concrete (AC), portland cement concrete (PCC), or PCC bridge deck.
[d]Average daily traffic (ADT) volume—
1. >25,000 or <25,000 for National Highway System (NHS) other than Interstate or freeway or expressway.
2. 6,000 or more per lane.
3. >10,000, 4,000–10,000, 2,000–4,000, or <2,000.
4. >2,000 for two-lane, two-way or <2,000 for two-lane, two-way.

[e]Type of street and highway—
1. Interstate or freeway or expressway, multilane, or two-lane, two-way.
2. NHS multilane or divided other than Interstate or freeway or expressway.
3. Interstate urban or rural, major arterial, minor arterial, or collector.

[f]Pavement condition—
1. AC good condition or AC poor condition; PCC new or good condition, rough finish, and no curing compound; or PCC poor condition or smooth finish or containing curing compound.
2. AC new, good, or fair/poor; or PCC new, good, or fair/poor.

[g]Remaining pavement service life—
1. Two years or more than 2 years.
2. At least the service life of the material.
3. At least 3 years.

[h]Area—urban or rural.
[i]Snow removal area—ice chisel, steel blade, or rubber blade used for snow removal.
[j]Brightness benefit factor—Number, expressed in units of millicandela-years per dollar-meter, which combines a product's average useful retroreflectivity, durability, and cost per unit length. Used to compare pavement marking selection alternatives with different lives, retroreflectivities, and cost. Not in Appendix D. ("Pavement Marking Policy" 2000.)
[k]Speed—two-lane, two-way 72 km/h (45 mph) or greater; or two-lane, two-way 64 km/h (40 mph) or less.
[l]Length of project—>5 km (3 mi) or <5 km (3 mi).

materials and give the engineer the option of which to use. The decision may be based on desired performance or marketplace availability and prices ("Recommended Pavement Markings" 2000).

The 11 factors in the table are used by the 8 state agencies to select marking materials. The factors used by the respective agencies are denoted by an "X"; for example, the Arkansas State Highway and Transportation Department selects pavement-marking materials based on four factors: type of line, pavement surface, ADT, and type of street and highway.

The number of times the individual factors appear in the guidelines is summed for each factor. The four most common factors are type of line, pavement surface, traffic volume, and type of street and highway. Examples of the factors are presented below the table as footnotes. The 11 factors in the table are described here.

#### Type of Line

The factors used to select the pavement-marking material by "type of line" are centerlines, lane lines, edge lines, transverse lines, and auxiliary markings. Although it may not be shown in the guidelines presented in Appendix D, the pavement marking policies for all eight agencies include type of line in selecting materials.

#### Pavement Surface

Those states that differentiate marking materials by "pavement surface" include AC, PCC, and PCC bridge decks as the three categories. For example, the Ohio DOT (see Figure D4 in Appendix D) selects or prohibits marking materials by different types of AC pavements and the condition of the pavement—new, good, or poor. Other pavement surfaces, such as seal coat, are not addressed in any of these guidelines.

#### Type of Street and Highway

In the state guidelines, there were three different classifications for selecting the marking material by "type of street and highway." The first classification uses three factors: Interstate or freeway or expressway; multilane highway; and two-lane, two-way highway. The second classification is by the National Highway System. The third classification is "Other High Volume Highways." The decision for which type of material used is decided at the district level. For example, one district uses durable markings on four-lane, divided highways with few changes in lane configuration and two-lane highways in mountainous areas. Otherwise, waterborne paint is used.

#### Traffic Volume

There were four classifications for the "traffic volume" level or ADT used to decide marking material. These levels are related to the type of street and highway factor. After limited access highways, other highways are classified by ADT level. However, the Ohio DOT does not use the type of street and highway factor, but instead uses an ADT value of 6,000 vehicles or more per lane. The other states use roadway ADT counts to select materials.

#### Pavement Condition

Agencies want to ensure that the pavements on which durable marking materials are placed are going to last through the service life of the marking material. The "pavement condition" factor helps ensure that the more expensive durable materials are used in cost-effective applications. The classification of factors ranges from new to poor for AC and PCC pavements. The more durable markings are placed on the best pavements.

#### Remaining Pavement Service Life

The "remaining pavement service life" factor is similar to the pavement condition factor, but instead of only making an "on-the-spot" evaluation of the pavement, the date the pavement was constructed or refurbished is considered. There are two classifications with either 2 or 3 years of remaining service life as the cut-off point for determining the selected material.

KDOT discusses pavement service life in the department's pavement marking policy ("Pavement Marking Policy" 2000). Materials are selected based on the remaining pavement service life (ranging from less than 1 year to more than 7 years), ADT level (<5,000, 5,000–50,000, and >50,000), and brightness benefit factor (discussed later). Table 19 presents the expected pavement service lives in years for highways in Kansas and is divided into major modification categories—new construction for AC and PCC pavements and substantial maintenance categories ("Pavement Marking Policy" 2000). Each of the maintenance treatments has a range of service life associated with it. For example, the cold in-place recycle/20–40 mm (0.8–1.6 in.) overlay has an expected service life from 3 to 7 years.

TABLE 19
KANSAS DOT EXPECTED PAVEMENT SURFACE LIVES

| Categories | Years |
|---|---|
| Major Modification | |
| New concrete | 20–30 |
| New asphalt construction | 10 |
| Substantial Maintenance | |
| Cold-in-place recycle/20–40 mm overlay | 3–7 |
| Modified slurry seal (micro-surfacing) | 3–4 |
| 40-mm Mill and 40-mm overlay | 4–7 |
| Cold in-place recycle/conventional seal | 3–5 |
| 40-mm straight overlay, no milling | 3–7 |
| Conventional seal | 2–4 |
| Milling (for rutting) | 1–2 |

(*Source:* "Pavement Marking Policy" 2000.)

#### Area

The "area" factor consists of selecting materials to be located within either an urban or rural area. It is related to the traffic volume factor in that higher traffic volumes tend to occur in urban areas.

#### Snow Removal Area

The Washington State DOT considers the types of winter snow removal conditions and the type of plow blade used to remove the snow or ice as a factor for selecting materials. In general, areas with the harshest winter weather and most severe snow removal practices receive the least-durable and retroreflective materials. That is, areas of the state where ice chisel snow removal blades are used generally receive the least durable materials, followed by areas using steel snow plow blades, and areas using rubber blade snow plows that receive the most durable and retroreflective RRPMs and materials.

#### Brightness Benefit Factor

KDOT developed the "benefit brightness factor" (BBF), which is used for material selection in conjunction with remaining pavement service life and ADT level ("Pavement Marking Policy" 2000). The BBF is defined as a number, expressed in units of millicandela–years per dollar–meter, which combines a product's average useful retroreflectivity, durability, and cost per unit length. The BBF is used to compare pavement-marking selection alternatives with different lives, retroreflectivity, and cost. In general, the product with the highest BBF should be considered first on any given project.

Road-user costs borne by the driving public are factored into the BBF and are associated with a single pavement marking installation ("Pavement Marking Policy" 2000). These costs consist of increased vehicle operating expenses and lost wages due to extended driving times through work zones.

#### Speed

"Speed" is a factor used by the Maryland State Highway Administration to select materials on two-lane, two-way highways. The two speed levels are 72 km/h (45 mph) and 64 km/h (40 mph) and they are used in conjunction with ADTs of greater than or less than 15,000 to produce four categories of two-lane, two-way highways. The more durable and retroreflective materials are applied on two-lane highways with higher speeds and ADT.

#### Length of Project

The Wisconsin DOT uses two levels of the factor "length of project," greater than 5 km (3 mi) and less than 5 km (3 mi), in selecting materials for each of the pavement surface and roadway type classifications for newly paved or resurfaced highways. It is assumed the new pavement will be free from maintenance for at least 3 years.

### LINE WIDTH AND PATTERNS

Part 3 of the MUTCD defines widths and patterns of longitudinal lines. Transportation agencies have developed standards based on the MUTCD [*MUTCD 2000* (2000)]. MUTCD standards and transportation agency application of the standards are described here.

#### MUTCD Widths and Patterns of Longitudinal Lines

*MUTCD Standard*

- A solid line prohibits or discourages crossing.
- A normal line is 100 to 150 mm (4 to 6 in.) wide.
- A wide line is at least twice the width of a normal line. The width of the line indicates the degree of emphasis.
- A double line consists of two normal lines separated by a discernible space and indicates maximum or special restrictions.
- A broken line consists of normal line segments separated by gaps and indicates a permissive condition.
- A dotted line consists of noticeably shorter line segments separated by shorter gaps than used for a broken line. The width of a dotted line is at least the same as the width of the line it extends. A dotted line provides guidance.
- The value of *N* for a broken or dotted line is equal the length of one line segment plus one gap. The value of

TABLE 20
SPECIFIED WIDTH OF LONGITUDINAL NORMAL LINES

| Transportation Agency | Survey Responses | No. of Agencies Specifying 100 mm (4 in.) | 130 mm (5 in.) | 150 mm (6 in.) |
|---|---|---|---|---|
| State | 36 | 31 | 2 | 3 |
| Canadian | 5 | 5 | 0 | 0 |
| County | 5 | 4 | 1 | 0 |
| City | 4 | 4 | 0 | 0 |
| Total | 50 | 44 | 3 | 3 |

Note: 1 in. = 25.4 mm.

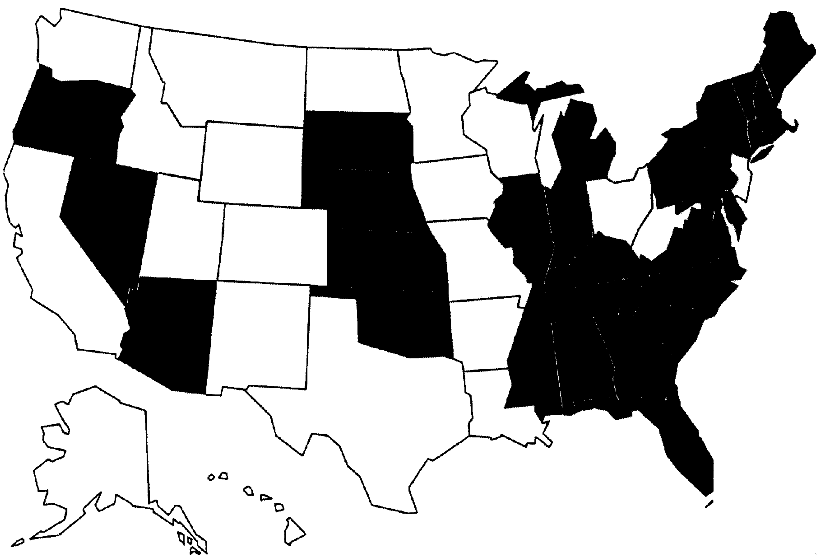


FIGURE 19 State agencies using wider lines [Longitudinal normal lines wider than 100 mm (4 in.)]. (*Source*: Gates and Hawkins 2002.)

*N* referenced for solid lines equals the value of *N* for the broken or dotted lines that might be adjacent to or might extend the solid lines.

*MUTCD Guidance*

On rural highways broken lines should consist of 3-m (10-ft) line segments and 9-m (30-ft) gaps or similar dimensions in a similar ratio of line segments to gaps as appropriate for traffic speeds and need for delineation.

*MUTCD Option*

A dotted line may consist of 0.6-m (2-ft) line segments and 1.2-m (4-ft) or longer gaps with a maximum segment-to-gap ratio of 1:3.

**Widths of Longitudinal Normal Lines**

The widths of longitudinal normal lines specified by transportation agencies are shown in Table 20. The most common line width is 100 mm (4 in.) and is specified by 44 responding agencies (88%). Five state agencies (14%) specify wider lines, but more reported using them. Seven state agencies (19%) use wider normal lines on Interstate and other high-speed or access-controlled highways. A Texas Transportation Institute (TTI) study determined that the 29 state agencies (58%) shown in Figure 19 are using wider longitudinal normal lines (Gates and Hawkins 2002). Table 21 shows how the KDOT uses wider lines ("Pavement Marking Policy" 2000). The standard line width is 100 mm (4 in.). Lane lines are 150 mm (6 in.) wide to provide additional guidance on higher-level highways. Other markings are wider to conform to FHWA standards for providing greater emphasis.

TABLE 21
KANSAS DOT PAVEMENT MARKING LINE STANDARDS

| Line Type | Width (mm) | Color |
|---|---|---|
| Centerline[a] | 100 | Yellow |
| Edge line | 100 | Yellow or White |
| Broken lane line[b] | 150 | White |
| Solid lane line[b] | 150 | White |
| Gore markings | 200 | White |
| Diagonals and chevrons[c] | 300 | Yellow or White |
| STOP line | 600 | White |
| Crosswalk | | |
| Type I | 300 | White |
| Type II | 600 | White |

Notes: 1 in. = 25.4 mm; 4 in. = 100 mm.
[a]Double yellow centerlines will be separated by a 100-mm space.
[b]Lane line markings if applied by KDOT maintenance forces may be applied at a width of 100 mm.
[c]Shall be inclined at 30° and spaced at a distance in meters equal to the speed in km/h divided by 5.
(*Source*: "Pavement Marking Policy" 2000.)

Through a literature review and agency survey, TTI reported that wider lines provide the following benefits (Gates and Hawkins 2002):

- Improved long-range detection under nighttime driving conditions, especially for older drivers;
- Improved stimulation of the peripheral vision;
- Improved lane positioning and other driver performance measures; and
- Improved driver comfort.

The drawback is that lines wider than 100 mm (4 in.) often cost more to apply. Cost is dependent on marking width, contract size, marking material, and striping procedures.

Wider normal longitudinal markings would likely have the greatest benefit when used in the following situations (Gates and Hawkins 2002):

- Locations where a higher degree of lane or roadway definition is perceived as necessary to all drivers, including
  - Horizontal curves,
  - Roadways with narrow shoulders or no shoulders, and
  - Construction work zones.
- Locations where low luminance contrast of markings is common.
- Locations where older drivers are prevalent and thus require added roadway visibility under all conditions.

## SUMMARY

Eight state agencies have summarized guidelines for the selection of materials based on 11 factors, the most common being type of line, pavement surface, traffic volume, and type of street and highway. Material selection comes down to durable materials versus nondurable materials; that is, paint. Centerlines and lane lines are more likely to receive durable markings than edge lines. Interstate highways, freeways, and expressways are more likely to receive durable markings than two-lane, two-way highways. Highways with higher traffic volumes and pavements in new or good condition are more likely to receive durable materials. Most agencies specify the standard normal line width as 100 mm (4 in.), although the majority of state agencies reported using wider lines. Wider lines provide a number of benefits, but tend to cost more than 100 mm (4 in.) lines. Highway locations where wider lines would likely provide the greatest safety benefits are described.

CHAPTER SIX

# SPECIFICATIONS AND CONSTRUCTION PRACTICES

Transportation agency specifications address all aspects of pavement markings, from materials, quantities, and application methods to removal. The types of specifications and construction practices used by agencies to provide quality pavement markings are described.

A specification is a written requirement for performing work (*Standard Specifications* . . . 1996). Specifications approved for general application and repetitive use are published in one document known as standard specifications. Specifications govern the work done by agency personnel and contractors. For contract work, the contract, special provisions, plans, and standard specifications are contract documents and govern in the order listed. Contract documents are defined by the FHWA (*Standard Specifications* . . . 1996), AASHTO (*Transportation Glossary* 1983), and transportation agencies.

## SPECIFICATIONS FOR PAVEMENT MARKINGS

The three basic types of specifications for pavement markings are the prescriptive/material specification, performance-based specification, and warranty provisions specification. Transportation agencies may use one specification or a combination of specifications to provide quality pavement markings.

### Prescriptive/Material Specification

A prescriptive or material specification is the recipe for exactly what is wanted in the marking material. It varies by the type of material. Examples of prescriptive/material specifications are presented in the appendixes. Appendix E presents a special provision for epoxy pavement markings used by the Maryland State Highway Administration. Specifications for glass beads from the FHWA, AASHTO, and the Georgia DOT are presented in Appendix H. The FHWA specification for RPMs and the VDOT approved list of pavement markers are presented in Appendix I.

### Performance-Based Specification

Under a performance-based specification payment depends on the level of retroreflectivity that is achieved, with an incentive or disincentive applied to the contract payment. Materials may be qualified as acceptable for use on an agency's highways under a performance-based specification. For example, materials may be required to undergo a test-deck evaluation for a period of one or more years and maintain a minimum level of retroreflectivity, durability, and color. Some state agencies rely on the results of NTPEP testing to qualify materials. Appendix F presents an example performance-based special provision for waterborne paint used by VDOT. The Georgia DOT special provision for RPMs is presented in Appendix I.

### Warranty Provisions Specification

Under warranty provisions work is guaranteed for a period of time and a minimum level of retroreflectivity, durability, and color should be maintained during the warranty period. The contractor is required to repair or replace the markings that fail the warranty provisions. Appendix G presents an example warranty provisions special provision for durable marking materials used by the Oregon DOT. Four figures (G1–G4) show the qualified products and standard drawings of application methods.

## SPECIFICATIONS USED BY TRANSPORTATION AGENCIES

In the survey, agencies were asked whether they were satisfied that the specifications they use ensure quality pavement markings. Agencies use prescriptive, performance-based, and warranty provisions specifications either individually or in combination. Table 22 shows the number of agencies using the four most-common types of specifications and their level of satisfaction: prescriptive only, a combination of prescriptive and warranty provisions, a combination of prescriptive and performance-based, and warranty provisions only. For example, agencies listed as using only the prescriptive specification did not use any other. All four types rated high in satisfaction. No agency used only performance-based specifications.

Overall, 75% of the responding agencies indicated that they were satisfied with their specifications. By level of satisfaction, agencies were most satisfied with prescriptive and performance-based, followed by warranty provisions only, prescriptive and warranty provisions, and prescriptive only. Some agencies using only prescriptive specifications indicated that they would probably add warranty provisions or performance-based specifications.

TABLE 22
SATISFACTION WITH SPECIFICATIONS USED TO PROVIDE QUALITY PAVEMENT MARKINGS

| Agency | $N^a$ | Only Prescriptive | | | Prescriptive and Warranty Provisions | | | Prescriptive and Performance-Based | | | Only Warranty Provisions | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $N^b$ | Satisfied | % | $N^b$ | Satisfied | % | $N^b$ | Satisfied | % | $N^b$ | Satisfied | % |
| State | 37 | 14 | 10 | 71 | 9 | 7 | 78 | 6 | 6 | 100 | 4 | 3 | 75 |
| Canadian | 5 | 3 | 2 | 67 | 0 | 0 | NA | 0 | 0 | NA | 0 | 0 | NA |
| County | 5 | 4 | 4 | 100 | 0 | 0 | NA | 0 | 0 | NA | 1 | 1 | 100 |
| City | 4 | 3 | 1 | 33 | 0 | 0 | NA | 0 | 0 | NA | 0 | 0 | NA |
| Total | 51 | 24 | 17 | 71 | 9 | 7 | 78 | 6 | 6 | 100 | 5 | 4 | 80 |

Note: NA = not applicable.
[a]Number of agencies responding to the survey.
[b]Number of agencies using the specification and satisfied with it. For example, 14 state agencies use only the prescriptive specification and 10 (71%) of these agencies are satisfied that the specification provides quality pavement markings.

One agency that used warranty provisions was pleased that contractors could be called back if markings did not last over a winter season. Performance-based and warranty provisions specifications were more commonly used for durable marking materials. Specifications for the retroreflectivity of markings are just starting to be used.

## CONSTRUCTION REQUIREMENTS

The FHWA specifications for pavement-marking materials are contained in Sections 634 and 718 of the *Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects* (FP-96) (1996). State and local transportation agencies follow these specifications. A summary of the FHWA construction requirements for 11 types of permanent pavement markings is presented in Table 23. Each type of marking is given a designation; for example, a Type A marking is conventional paint with Type 1 glass beads. Bead specifications are presented in Figures H1–H3 in Appendix H.

Bead types I and II are specified by AASHTO, whereas types 3, 4, and 5 are specified by the FHWA. Type I is known as a standard bead and type II is a uniform grade. Bead types 3, 4, and 5 are respectively larger by gradation. The properties of the beads and gradations of the respective types are shown in the specifications. Each type of material cited in Table 23 has a specified bead type or combination of bead types associated with it.

FP-96 is in metric units, but many agencies use standard units for marking materials. For each material, the specifications address minimum air and pavement temperatures that must be met before materials can be applied, application thickness, bead types and application rates for both single- and double-drop systems, and other information relevant to the materials. FP-96 references AASHTO specifications, ASTM specifications, and the MUTCD. The specification for thermoplastic, for example, states that the material shall also conform to AASHTO specification M 249.

## COLOR SPECIFICATIONS

Four standard colors are used for pavement markings (yellow, white, red, and blue) and are described in chapter 2. Black, which may be used in combination with one of the four standard colors, is not considered a color, but a method of increasing contrast on light-colored pavements.

The FHWA published a notice of proposed rulemaking to revise its color specifications for retroreflective signing and pavement-marking materials ("Color Specifications . . ." 1999). The revision would include daytime and nighttime specifications for both assigned and unassigned colors found in the MUTCD.

The ASTM has a standard specification for the color of pavement-marking materials (*Standard Specification for Color* . . . 2001). It addresses the daytime and nighttime color of retroreflective pavement-marking materials used for longitudinal and word and symbol markings. It is not applicable for quality-control purposes of material without added drop-on beads.

Transportation agencies have specifications addressing the colors yellow and white. Marking materials are to remain opaque and maintain their color under both daylight and artificial light. They are not to discolor under exposure to weather or traffic or show discoloration through the service life on either AC or PCC pavements.

VDOT specifies that white waterborne paint shall be equal to Federal Standard Color No. 595-17886, and yellow shall be equal to Federal Standard Color No. 595-33538 ("Paint Pavement Marking Material" 2000). Color determination is also required to meet chromaticity specifications as described in the special provision for waterborne paint presented in Appendix F. VDOT specifies that color should be measured at least 24 h after application on markings without glass beads using a zero deg/45 deg Hunter Labminiscan Spectro-Colorimeter or equivalent. A separate

TABLE 23
PAVEMENT MARKING CONSTRUCTION REQUIREMENTS

| MATERIAL[a] FHWA Specification FP 96 Sections 634 and 718 | Minimum Pavement and Air Temperature | | Application Thickness | | | First Bead Type[b] | First Bead Application Rate | | Second Bead Type[b] | Second Bead Application Rate | | Total Application Rate | | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (Deg C) | (Deg F) | (mm) | (mils) | Wet/Dry | | Metric | Standard | | Metric | Standard | Metric | Standard | |
| *Conventional Paint* | | | | | | | | | | | | | | |
| Type A | 4 | 40 | 0.38 | 15 | Wet | 1 | 0.7 kg/L | 6 lb/gal | | | | 0.7 kg/L | 6 lb/gal | AC and PCC pavements. |
| *Waterborne Paint* | | | | | | | | | | | | | | |
| Type B | 10 | 50 | 0.38 | 15 | Wet | 1 | 0.7 kg/L | 6 lb/gal | | | | 0.7 kg/L | 6 lb/gal | AC and PCC pavements. |
| Type C | 10 | 50 | 0.38 | 15 | Wet | 3 | 1.4 kg/L | 12 lb/gal | | | | 1.4 kg/L | 12 lb/gal | AC and PCC pavements. |
| *Epoxy* | | | | | | | | | | | | | | |
| Type D | 10 | 50 | 0.38 | 15 | Dry | 1 | 1.8 kg/L | 15 lb/gal | | | | | | Two component, 100% solid system. |
| Type E | 10 | 50 | 0.38 | 15 | Dry | 4 | 1.4 kg/L | 12 lb/gal | 1 | 1.4 kg/L | 12 lb/gal | 2.8 kg/L | 24 lb/gal | Use two bead dispensers |
| *Polyester* | | | | | | | | | | | | | | Two component system. Spray at 53±4°C (128±7°F). Discard all material heated over 66°C (150°F) (gun tip temperature). Do not use fast dry on hot AC pavements less than 1 yr old. |
| Type F | 10 | 50 | 0.38 | 15 | Dry | 1 | 1.8 kg/L | 15 lb/gal | | | | 1.8 kg/L | 15 lb/gal | |
| Type G | 10 | 50 | 0.38 | 15 | Dry | 4 | 1.4 kg/L | 12 lb/gal | 1 | 1.4 kg/L | 12 lb/gal | 2.8 kg/L | 24 lb/gal | Use two bead dispensers. |
| *Thermoplastic* | | | | | | | | | | | | | | Conform to AASHTO M 249. On PCC and old AC pavements, apply an epoxy resin primer/sealer according to manufacturer recommendations. Allow primer/sealer to dry. Spray or extrude at 220±3°C (430±5°F). The minimum bond strength on PCC pavements shall be 1.2 MPa (175 lb/in.$^2$). |

TABLE 23 (*Continued*)

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Type H | 10 | 50 | 2.3 | 90 | Dry | 1 | 0.59 kg/m² | 12 lb/100 ft² | | | | 0.59 kg/m² | 12 lb/100 ft² | Centerlines and lane lines. Or apply at a rate of 0.437 m²/L (17.8 ft²/gal). |
| Type H | 10 | 50 | 1.5 | 60 | Dry | 1 | 0.59 kg/m² | 12 lb/100 ft² | | | | 0.59 kg/m² | 12 lb100 ft² | Edge lines. Or apply at a rate of 0.655 m²/L (26.7 ft²/gal). |
| Type I | 10 | 50 | 2.3 | 90 | Dry | 5 | 0.59 kg/m² | 12 lb/100 ft² | 1 | 0.59 kg/m² | 12 lb/100 ft² | 1.18 kg/m² | 24 lb/100 ft² | Use two bead dispensers. Centerlines and lane lines. |
| Type I | 10 | 50 | 1.5 | 60 | Dry | 5 | 0.59 kg/m² | 12 lb/100 ft² | 1 | 0.59 kg/m² | 12 lb/100 ft² | 1.18 kg/m² | 24 lb/100 ft² | Use two bead dispensers. Edge lines. |
| | | | | | | | | *Preformed Plastic* | | | | | | Conform to ASTM D 4505 type I, V, VI, or VII, grade A, B, C, D, or E. Apply according to manufacturer recommendations. |
| Type J | | | | | | | | | | | | | | When applied during final compaction of AC pavement, apply when pavement temperature is 60°C (140°F). Roll into the surface with a steel wheel roller. The finished marking may extend approximately 0.25 mm (10 mil) above the final surface. |
| Type K | | | | | | | | *Nonreflectorized* | | | | | | Apply any of the above, except preformed plastic (Type J), as described above, but with no glass beads added. |
| | | | | | | | | *Raised Pavement Marker* | | | | | | Conform to AASHTO M 237. Use epoxy resin or asphalt adhesive. The minimum bond strength shall be 12 kPa (1.75 lb/in.²) or a total tensile strength of 110 N (25 lb). |

TABLE 23 (*Continued*)

| | | | |
|---|---|---|---|
| Epoxy adhesive | 10 | 50 | Heat A and B components separately with indirect heat mix, and apply at 21±6°C (70±10°F). Discard all material heated over 49°C (120°F) or stiffened by polymerization. Space and align to within 13 mm (0.5 in.) of the required location. Do not place over pavement joints. |
| Asphalt adhesive | 10 | 50 | Heat and apply adhesive at 211±7°C (450°F). Discard all material heated over 232°C (450°F). |

Conversion:
1 mil = 0.254 mm. 1 lb = 0.454 kg. 1 gal = 3.785 L.
Notes: Remove loose particles, dirt, tar, grease, and other deleterious material from the surface to be marked. Where markings are placed on PCC pavement less than 1 yr old, clean the pavement of all residue and curing compounds. Remove temporary pavement markings the same day permanent pavement markings are applied. Apply markings to a clean, dry surface according to the MUTCD. Make lines 100 mm (4 in.) wide. Make broken lines 3 m (10 ft) long with 9 m (30 ft) gaps. Make dotted lines 0.5 m (2 ft) long with 1 m (4 ft) gaps. Separate double lines with a 100 mm (4 in.) of space.

[a]Material
Type A–Conventional traffic paint with type 1 glass beads
Type B–Waterborne traffic paint with type 1 glass beads
Type C–Waterborne traffic paint with type 3 glass beads
Type D–Epoxy markings with type 1 glass beads
Type E–Epoxy markings with type 1 and type 4 glass beads
Type F–Polyester markings with type 1 glass beads
Type G–Polyester markings with type 1 and type 4 glass beads
Type H–Thermoplastic markings with type 1 glass beads
Type I–Thermoplastic markings with type 1 and type 5 glass beads
Type J–Preformed plastic markings
Type K–Nonrefectorized markings.

[b]Bead types 1 and 2 are AASHTO M 247-81 (1996) specification (See Figure H1). Bead types 3, 4, and 5 are FP 96 specification (See Figure H2).
(*Source*: *Standard Specifications* . . . 1996).

**DURABILITY**

Durability is the material's resistance to wear and loss of adhesion to the pavement surface over time. Wear may be due to traffic volumes, snow-plowing, and weather conditions. The measure of durability is made by the percentage of material remaining from the original marking on a "0" to "10" scale. Potential losses due to pitting, bubbling or cracking may also be considered in the account of lost material. Compare the pavement marking with the durability pictures presented below.

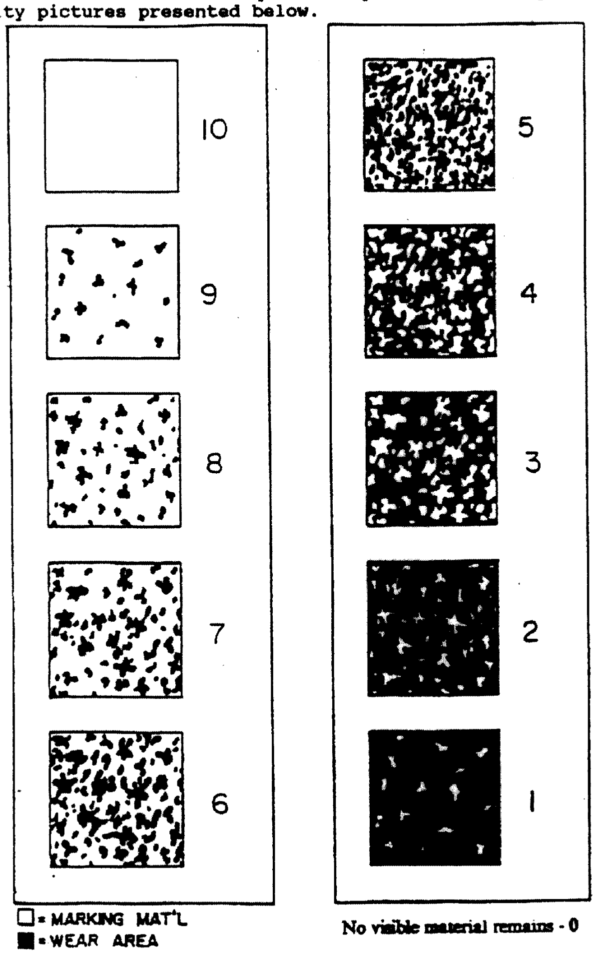


FIGURE 20 Subjective durability rating procedure. (*Source*: Ohio DOT 1983, 1990.)

set of color coordinates is used for measurements on markings with glass beads and covers a period of 1 year for long-term markings.

A spectrophotometer is used to objectively measure the chromaticity. Some agencies specify an instrument to be used, whereas others permit contractors to use an acceptable spectrophotometer. Yellow can also be subjectively evaluated using a yellow color tolerance chart. The chart has seven color chips that cover the range of acceptable limits for yellow. It is placed on the yellow marking whose color must be within the acceptable range in a pass or fail test. Another subjective evaluation can be done using a color visual effectiveness rating on a scale of zero to 10, with 10 representing a new properly applied marking.

## DURABILITY SPECIFICATIONS

Durability is the material's resistance to wear and loss of adhesion to the pavement surface over time. Wear may be due to traffic volume, snowplowing, and weather conditions. Durability of the test pavement markings is usually evaluated on overall appearance with the unaided eye, which includes an estimated percentage of marking material remaining. The measure of durability is made by the percentage of material remaining from the original marking on a zero to 10 scale, where a zero rating means that no visible material remains and 10 that 100% of the material remains. Potential losses because of pitting, bubbling, or cracking are considered in the account of lost material. The procedure used by the Ohio DOT includes diagrams of the percentage of remaining material at each rating level and is shown in Figure 20.

TABLE 24
DURABILITY RATING SPECIFICATION AS ESTIMATED BY THE FOUR MEMBER RATING PANEL

| Changes or Undesirable Features | % Lost | Desirable Features | % Retained | Rating |
|---|---|---|---|---|
| None | 0 | Perfect | 100 | 10 |
| Slight trace | 1 | Excellent | 99 | 9 |
| Trace | 2–4 | Very good | 96–98 | 8 |
| Slight | 5–7 | Good | 93–95 | 7 |
| Slight to moderate | 8–12 | Fairly good | 88–92 | 6 |
| Moderate | 13–18 | Fair | 82–87 | 5 |
| Moderate to marked | 19–25 | Fairly poor | 75–81 | 4 |
| Marked | 26–34 | Poor | 66–74 | 3 |
| Very marked | 35–47 | Bad | 53–65 | 2 |
| Severe | 48–68 | Very bad | 32–52 | 1 |
| Complete failure | 68–100 | None | 0–31 | 0 |

(*Source: Specification for White* . . . 2000.)

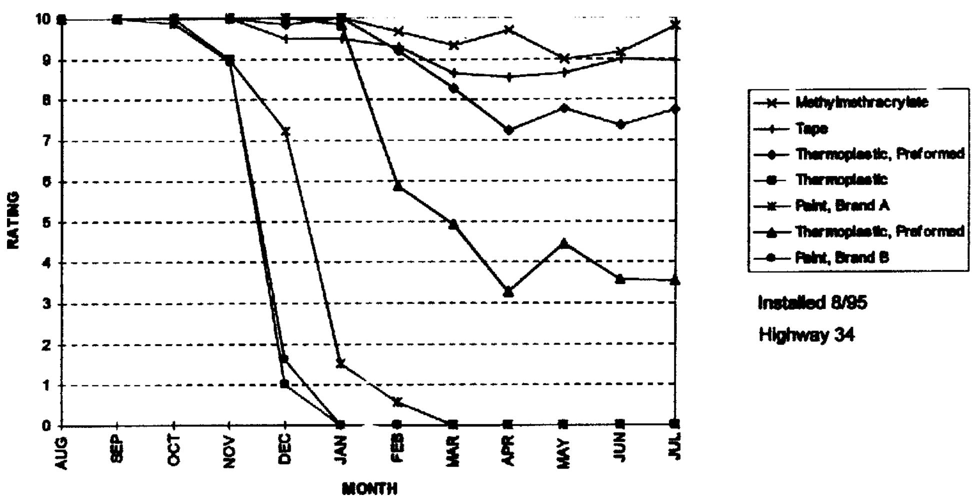


FIGURE 21 Durability data for transverse lines on portland cement concrete pavement. (*Source*: Oregon DOT 1995.)

There are three kinds of durability evaluations that may be conducted on a pavement marking: laboratory, test deck, and field. Laboratory testing is done as part of the initial material evaluation, and the materials are subjected to various bonding and abrasion tests.

Caltrans uses the test-deck method to evaluate the durability of marking materials. Markings are applied transversely across the pavement in accordance with ASTM Method D713 (*Standard Practice* . . . 1998). The markings are evaluated after 180 days and must achieve a rating of six or better on a scale of zero to 10 to be accepted ("Paint, Waterborne Traffic Line . . ." 2000). Table 24 shows the scale of durability rating factors used by the Alberta Infrastructure. Figure 21 shows durability graphs for seven materials. Based on the California rating criteria, only three materials are acceptable after 6 months. Other agencies require the same evaluation to be performed on NTPEP test decks.

Other agencies rely on a field evaluation of a marking's durability during an acceptance period. KDOT considers epoxy unsatisfactory if more than 10% of the material delaminates within the 180-day warranty period, or in the case of profiled preformed tape, the material must be intact with no evidence of lifting, curling, breaking, or displacement (*Durable Pavement Marking* . . . 1990). The Florida DOT requires that thermoplastic material loss must not exceed 5% (*Thermoplastic* . . . 2000). The Oregon DOT only permits a 5% reduction of thermoplastic and methyl methacrylate material during the 180-day acceptance period (*Durable Permanent Pavement Striping* 2000). The Pennsylvania DOT permits a 15% reduction in longitudinal durable materials during the 3-year warranty period and a 10% reduction for word and symbol markings for intersections and mid-block areas during the 6-month warranty period (*Long-Term Pavement Markings* 2000). Most agencies require that unsatisfactory markings be replaced at the contractor's expense.

The North Carolina DOT summarizes the content of other agency durability specifications.

> Provide pavement-marking material, which during the 180-day observation period, shows no signs of failure due to blistering, excessive cracking, chipping, bleeding, staining, discoloration, oil content of the pavement materials, smearing or spreading under heat, deterioration due to contact with grease deposits, oil, diesel fuel, or gasoline drippings, spilling, poor adhesion to the pavement materials, loss of reflectivity, vehicular damage, and normal wear. Replace, at no additional expense to the Department any pavement markings that do not perform satisfactorily under traffic during the 180-day observation ("Pavement Marking General Requirements" 1999).

## RETROREFLECTIVITY SPECIFICATIONS

Specifications published by ASTM and CEN defining retroreflectivity and the procedures for measuring it are presented here.

- E 1710-97—*Standard Test Method for Measurement of Retroreflective Pavement Marking Materials with CEN-Prescribed Geometry Using a Portable Retroreflectometer* (1998).
- D 6359-98—*Standard Specification for Minimum Retroreflectance of Newly Applied Pavement Marking Using Portable Hand-Operated Instruments* (1999).
- EN 1436: 1997—*Road Marking Materials—Road Marking Performance for Road Users* (1997).
- ENV 13459-3: 1999—*Road Marking Materials—Quality Control—Part 3: Performance in Use* (1999).
- E 2177—*Test Method for Measuring the Coefficient of Retroreflected Luminance* ($R_L$) *of Pavement Markings in a Standard Condition of Wetness* (2001).
- E 2176—*Measuring the Coefficient of Retroreflected Luminance* ($R_L$) *of Pavement Markings in a Standard Condition of Continuous Wetting* (2001).

ASTM specification E 1710-97 is a test method for measuring the retroreflective properties of horizontal markings (longitudinal, word, and symbol) using a portable (hand-held) retroreflectometer. The method is intended for field measurements, but may be used to measure the performance of materials on sample panels before placing the marking material in the field. The 30-m (98.4-ft) geometry is specified for measuring retroreflectivity.

The quality of the pavement marking is determined by the coefficient of retroreflected luminance, $R_L$ (mcd/m$^2$/lux), and depends on the materials used, age, and wear pattern. Under the same conditions of illumination and viewing, larger values of $R_L$ correspond to higher levels of visual performance (quality). The hand-held retroreflectometer shall be capable of measuring retroreflectivity in the range from 1 to 1,500 mcd/m$^2$/lux (*Standard Test Method* . . . 1998).

ASTM specification D 6359-98 provides standards for newly applied horizontal pavement markings, which are those that have been applied within 14 days before testing and from which all excess glass beads have been removed. Excess beads contribute to erroneous readings directly after application and are generally not present a few days after application. State agencies will usually require a 14- to 30-day waiting period before retroreflectivity is measured on newly applied pavement markings.

ASTM specifies that the marking material be retroreflecting white or yellow and be readily visible as white or yellow when viewed with automobile headlights at night (*Standard Specification for Minimum* . . . 1999). Retroreflectivity is measured after removal of all excess glass spheres and is required to have a minimum $R_L$ of 250 mcd/m$^2$/lux for white and 175 mcd/m$^2$/lux for yellow.

The specification goes on to describe the procedure used to collect retroreflectivity samples, summarize, and interpret the results of the measurements of markings that appear questionable. The sampling plan is based on the road length containing the markings that appear to be below specification, which is known as a zone of measurement. There are three zones of measurement: 300 m (984 ft), 300 m to 10 km (984 ft to 6.2 mi), and greater than 10 km (6.2 mi). The procedure describes measurement of solid longitudinal lines, broken longitudinal lines, and legends, symbols, pedestrian crossing, etc. An acceptable quality level of 6.3% is specified. The acceptable quality level is the maximum percent defective that, for purposes of sampling inspection, can be considered satisfactory as a process average. Some state agencies reference the specification and present the sampling requirements.

CEN specification EN 1436: 1997 addresses the performance of white and yellow road markings, as expressed by their reflection in daylight and under road lighting, retroreflection in vehicle headlamp illumination, color, and skid resistance. The measuring conditions for the luminance coefficient under diffuse illumination, in daytime visibility, $Q_d$ (mcd/m$^2$/lux), nighttime visibility, $R_L$ (mcd/m$^2$/lux), and measurement for skid resistance, skid resistance tester value, are described. Figure 22 shows an instrument measuring daytime diffuse illumination.

Specifications describe collecting measurements of pavement-marking retroreflectivity when the pavement is wet (condition of wetness) (*Road Marking Materials* . . . 1997; *Test Method for Measuring* . . . 2001). The test condition is created using clean water poured from a 10-L (2.6-gal) bucket from a height of approximately 0.5 m (1.6 ft) above the surface (bucket-of-water technique). The water is poured evenly along the test surface so that the measuring field and its surrounding area is momentarily flooded by a crest of water. The coefficient of retroreflected

FIGURE 22 Measuring daytime diffuse illumination. (*Source*: Flint Trading Company, Inc.)

FIGURE 23 CEN procedure for wetting the marking for wet simulation testing. (*Source*: Flint Trading Company, Inc.)

luminance, $R_{L,}$ in condition of wetness is measured 1 min after the water was poured. Figure 23 shows the CEN procedure for wetting the marking for wet simulation using a hand-held retroreflectometer.

The specifications go on to describe measurements made during rain (condition of rain), either actual or simulated (*Road Marking Materials* . . . 1997; *Measuring the Coefficient* . . . 2001). To fulfill the CEN condition of rain, test conditions shall be created using clean water giving artificial rainfall, without mist or fog, at an average intensity of 20 ± 2 mm (0.8 ± 0.08 in.) per hour of rainfall over an area that is at least twice the width of the sample being tested and of a minimum width of 0.3 m (1 ft), and which is more than 25% longer than the measuring field. The variation in rainfall between the lowest and the greatest intensity shall be no greater than the ratio of 1 to 1.7. Pavement markings that meet retroreflectivity standards under these conditions can be considered all-weather pavement markings. The ASTM has adopted test methods similar to CEN for conditions of wetness and of simulated rain (*Measuring the Coefficient* . . . 2001). ASTM specifications include hand-held and mobile retroreflectometers, whereas the CEN specifications only include hand-held retroreflectometers (*Test Method for Measuring* . . . 2001).

In 1993, the FHWA defined an all-weather pavement marking as a marking that is visible under dry conditions and also under rainy conditions at rainfall rates of up to 0.635 cm (0.25 in.) per hour (Migletz et al. 2000 unpublished data). The CEN rainfall intensity is more than three times the rainfall intensity of the FHWA definition. As a general estimate, a rainfall intensity of 0.635 cm (0.25 in.) per hour is equivalent to driving in rainfall that permits the windshield wipers to be operated at a low speed.

CEN specification ENV 13459-3: 1999 describes the methods for the quality control of pavement-marking performance for road users and for the geometry of the markings. It is intended for the quality acceptance of new markings and for the evaluation of existing markings and applies to day and night visibility. Procedures for sampling, evaluating, and interpreting results are presented.

State agencies specify levels of retroreflectivity for newly applied pavement markings and for the acceptance period after the markings are placed. In almost all cases, the levels of retroreflectivity appear in the specification addressing the specific type of marking material. Table 25 presents the KDOT retroreflectivity specifications for durable pavement markings and addresses seven types of materials. Minimum levels of retroreflectivity are specified by type of material and color of line for the initial period (12 h to 14 days) and the acceptance period (180 days) for warranty contracts. The striping contractor provides a 30-m (98.4-ft) retroreflectometer to be used by the agency to measure the retroreflectivity during the initial and acceptance periods. The sampling plan for collecting and summarizing measurements over all lines is described.

Table 26 presents the KDOT warranty period for durable materials and complements Table 25. The warranty period is specified for each material and is based on three levels of ADT. The warranty addresses durability, retroreflectivity,

TABLE 25
KANSAS DOT 30-METER RETROREFLECTIVITY SPECIFICATION FOR DURABLE PAVEMENT MARKINGS

| Type of Material | Color | $mcd/m^2/lux$ (minimum) (Initial) | $mcd/m^2/lux$ (minimum) (Acceptance) |
|---|---|---|---|
| Cold plastic | White | 250 | 200 |
| | Yellow | 175 | 125 |
| Patterned cold plastic | White | 475 | 425 |
| | Yellow | 375 | 325 |
| Epoxy | White | 300 | 250 |
| | Yellow | 225 | 175 |
| High-durability tape | White | 225 | 200 |
| | Yellow | 175 | 150 |
| Thermoplastic | White | 300 | 250 |
| | Yellow | 225 | 175 |
| Preformed thermoplastic | White | 300 | 250 |
| | Yellow | 225 | 175 |
| Spray thermoplastic | White | 300 | 250 |
| | Yellow | 225 | 175 |

Notes: The Contractor will provide the Engineer with an acceptable 30-m retroreflectometer to use on this project. The retroreflectometer will remain the property of the contractor. The Engineer will measure the retroreflectivity a minum of 12 h after, and within 14 days of the application. The Engineer will take a minimum of 10 readings per color line evenly spaced on a 600-m roadway section every 16 km. The Engineer will average all of the readings for each color line within the 600-m section to determine the retroreflectivity. Initial period = 12 h–14 days; acceptance-period = 180 days.

(*Source: Durable Pavement Marking* . . . 1990.)

TABLE 26
KANSAS DOT WARRANTY PERIOD FOR DURABLE PAVEMENT MARKINGS

| | Warranty Period (years) [ADT class (1,000 vpd)] | | |
|---|---|---|---|
| Material | <5 | 5–50 | >50 |
| Cold plastic | 6 | 5 | 5 |
| Patterned cold plastic | 6 | 5 | 5 |
| Epoxy | 4 | 3 | 2 |
| High-durability tape | 3 | 2 | 2 |
| Thermoplastic | 6 | 5 | 4 |
| Preformed thermoplastic | 3 | 2 | 2 |
| Spray thermoplastic | 2 | NA | NA |

Notes: The pavement-marking material will be considered unsatisfactory if more than 10% of the project's markings delaminate from the roadway within the warranty period, if it fails to meet the minimum retroreflectivity (yellow markings—100 $mcd/m^2/lux$, white markings—150 $mcd/m^2/lux$, and if they fail to remain within the chromaticity specified. NA = not available; ADT = average daily traffic; vpd = vehicles per day.

(*Source: Durable Pavement Marking* . . . 1990.)

TABLE 27
KANSAS DOT CHROMATICITY SPECIFICATION FOR YELLOW DURABLE PAVEMENT MARKINGS

| | 1 | | 2 | | 3 | | 4 | |
|---|---|---|---|---|---|---|---|---|
| Color | X | Y | X | Y | X | Y | X | Y |
| Yellow | 0.475 | 0.450 | 0.490 | 0.433 | 0.495 | 0.475 | 0.520 | 0.450 |

Notes: Remove and replace markings that do not meet these minimum chromaticity coordinates. The Contractor will provide the Engineer with an acceptable spectrophotometer to use on this project. The spectrophotometer will remain the property of the contractor. The Engineer will take one reading every 16 km to verify chromaticity of the material. At the end of the acceptance period, the chromaticity readings taken at this time must be within the same limits as the readings taken after the material was applied. A 0.3-m section every 16 km shall be placed without beads to accurately test for chromaticity. The beadless areas shall be referenced by the Contractor for future observation.

(*Source: Durable Pavement Marking* . . . 1990.)

and color. All materials are required to maintain 90% of the material originally applied. The minimum acceptable levels of retroreflectivity are 100 $mcd/m^2/lux$ for yellow and 150 $mcd/m^2/lux$ for white markings. Materials are subject to evaluation at any time during the warranty period.

Yellow materials must also maintain their color according to the chromaticity specification shown in Table 27. The contractor provides the spectrophotometer to be used by the department according to the sampling plan. A 0.3-m (1-ft) section every 16 km (10 mi) should be placed without beads to accurately test for chromaticity.

## CONSTRUCTION PRACTICES

The effort to obtain and place quality materials is done in the laboratory through quality assurance testing when materials are purchased and in the field through quality-control evaluation when markings are placed. Preparation of the pavement surface before markings are placed is important to the life of the marking. The maintenance of a pavement marking system includes removal, repair, and replacement. Quality-control evaluation, pavement surface preparation, and pavement-marking removal practices are described here.

### Quality Control

Most agencies are confident that they are receiving good materials, but less sure that the application of the markings is adequate. Others expressed frustration with being able to monitor the application of markings.

Quality-control evaluation is done when markings are applied and is important to achieving a durable, retroreflective marking. Quality control is the system of collection, analysis, and interpretation of measurements and other data concerning prescribed characteristics of a material, process, or product for determining the degree of conformance with specified requirements (*Transportation Glossary* 1983). For example, the thickness of a newly applied stripe is measured and compared with the specified thickness to determine whether the application is acceptable.

Agencies were asked how they control the quality of long-term pavement markings at the time of application. Several agencies reported having procedures that are used for field inspection. VDOT test method for quality control, presented in Appendix J, describes five procedures for evaluating pavement markings (*Virginia Test Method* . . . 1994).

- Checking for moisture in the pavement,
- Determining the wet mil thickness of liquid markings,
- Determining the mil thickness for thermoplastic markings,
- Determining the application rate of glass beads applied by pressurized spray or drop-on methods, and
- Visual inspection.

Taping a plastic or tarpaper sheet to the pavement and observing whether moisture forms on the sheet after a given time, usually 20 min, checks for moisture in the pavement.

The thickness of a marking is determined by placing a plate on the road surface and striping over it. The plate is then removed from the road surface and the thickness is measured.

Bead application rates are checked by putting a bag or bucket under the application nozzle and running the striper a known distance. The beads are then weighed or measured to verify that they are being applied at the proper rate.

Visual inspection is made of both the marking and glass beads to check for uniformity. Markings must be in the correct location and of the correct width and thickness. Beads must be distributed across the marking and should be embedded into the marking material without being completely buried. Application of beads should be uniform across and longitudinally down the pavement marking.

Several other agencies mentioned that application rates were checked by calculating the amount of material used for a certain mileage of marking and comparing this to the quantities used by the marking contractor. Quality control using retroreflectivity measurement is discussed in chapter 9.

### Pavement Surface Preparation

Transportation agencies were asked about preparing the pavement surface for application of long-term pavement markings. Pavement surface preparation can be as simple as brooming off loose material, but becomes more complicated when using durable materials and on PCC pavement. In some cases, surface preparation may involve application of primers or adhesives, removal of old markings, and grinding or blasting of surfaces to be marked.

The FHWA specifies, "Remove loose particles, dirt, tar, grease, and other deleterious material from the surface to be marked. Where markings are placed on PCC pavement less than one year old, clean the pavement of all residue and curing compounds" (*Standard Specifications* . . . 1996).

Many agencies reported that the pavement surface must be clean and dry prior to marking application. Other surface preparation methods include sweeping; air, sand, shot, or water blasting; the use of solvents; grinding; and scraping. Several agencies specified that the surface be air cleaned immediately prior to marking application. A nozzle on the striper immediately ahead of nozzles that spray the marking material often accomplishes this task. Two agencies reported no surface preparation.

Additional surface preparation is usually specified on PCC surfaces to remove curing compounds and laitance. This preparation was specified as a wire brush or abrasive blast by the Georgia DOT. The Georgia DOT also specified a two-part, epoxy binder–sealer on all PCC pavements for either sprayed or extruded thermoplastic material.

TABLE 28
PAVEMENT-MARKING MATERIAL APPLICATION RESTRICTIONS

| Material | Restriction |
|---|---|
| Conventional solvent paint | The EPA volatile organic compound (VOC) limit of 150 g/L will eliminate their general use. |
| Waterborne paint | Waterborne material can be applied over any type of pavement or any previous pavement-marking material. |
| High-solid epoxy resin | Epoxy formulations can be applied over themselves. New portland cement concrete (PCC) pavement or bridge decks shall be sandblasted or shot blasted prior to placement. Paint on asphaltic concrete (AC) or PCC pavements is to be removed prior to placement. |
| Thermoplastic | Thermoplastic can be applied directly to new PCC pavement and over itself. Recoating of old AC and PCC pavement requires an application of a high VOC content primer sealer. Applications of the materials over existing paint without eradication is not recommended. It cannot be applied over epoxy, polyester, or preformed tape. |
| Two-component polyester resin | Polyester cannot be applied to new AC pavements or over old paint markings. It may be applied over thermoplastic markings and themselves. |
| Preformed tape | Preformed tapes cannot be applied over any existing markings. Old tape should be removed before applying new tape. It requires prior application of a primer/sealer for all installations except on new AC (less than 3 days old). |

(*Source*: Cirillo et al. 1994.)

Thermoplastic and epoxy materials can be applied over old materials of the same type, but if applied over paint or a different material, the old material must be removed. One agency specified that thermoplastic shall not be installed on paint where more than 50% of the line is present. However, thermoplastic may be applied on paint for seal coats. Table 28 presents marking material application restrictions.

Agencies specify what percentage of lines to be removed, ranging from a low of 75% of the area free of material to a Georgia DOT specification that the existing traffic stripe be 100% removed. Removal of lines is also specified if the line is found to be unacceptable.

The Arkansas State Highway and Transportation Department specifies that AC surfaces shall have a minimum cure period of 30 days prior to installing inverted profile thermoplastic markings.

Temporary markings are needed if the existing markings were removed or covered, as in a paving operation, including markings to define all lanes and passing/no-passing zones. Temporary markings shall comply with Part 3 of the MUTCD and should not be in place for more than 2 weeks unless justified by an engineering study [*MUTCD 2000*, 6F.66 (2000)].

### Pavement-Marking Removal

The MUTCD states that markings that are no longer applicable for roadway conditions or restrictions and that might cause confusion for the road user shall be removed or obliterated so as to be unidentifiable as a marking as soon as practical [*MUTCD 2000* (2000)]. When surveyed on methods of removing pavement markings, more than one-half of the responding agencies mentioned grinding. Blasting with an abrasive such as sand, water, or shot was cited by one-third of the responding agencies. Other methods mentioned included scraping, seal coating, and burning.

Despite the frequency that grinding is used, it is prohibited in at least one agency because of damage done to the pavement. Other agencies specifically prohibited painting or seal coating over markings. A few agencies reported that they never removed markings or tried to avoid the problem.

The policies of several agencies noted that markings containing hazardous materials, such as lead or chromium, must be taken away when removed from the pavement.

## SUMMARY

The three types of pavement-marking specifications are prescriptive/material, performance-based, and warranty provisions. Agencies may use one specification or a combination of specifications. The four most common types of specifications used are prescriptive/material, prescriptive/material and warranty provisions, prescriptive/material and performance-based, and warranty provisions. Performance-based and warranty provisions specifications are more commonly used for durable materials. Of the surveyed agencies, 75% indicated satisfaction with their specifications. Agencies have begun to use more performance-based and warranty provisions contracts to place more responsibility for quality markings on contractors.

The FHWA published construction requirements for 11 marking materials to aid other agencies in the selection and application of markings. Air and pavement temperature, application thickness, bead type, and application rates are addressed.

Agencies require that markings meet color, durability, and retroreflectivity specifications. The use of color must meet chromaticity specifications. Durability is the resistance to wear and loss of adhesion and is usually evaluated subjectively on a scale of zero to 10, with a rating of six being the minimum acceptable limit. ASTM specifies that a new marking is required to a minimum $R_L$ of 250 mcd/m$^2$/lux for white markings and 175 mcd/m$^2$/lux for yellow markings. Some state agencies require higher initial $R_L$ depending on the material.

Most agencies are confident that they are receiving good materials, but less sure that the application of the markings is adequate. Quality-control evaluation is important to achieving a durable retroreflective marking and is done when markings are applied. Quality control includes checking for moisture in the pavement, determination of the wet mil thickness of liquid markings, determination of the mil thickness for thermoplastic markings, determination of the application rate of glass beads applied by pressurized spray or drop-on methods, and visual inspection. Agencies use a number of methods for preparing the pavement surface for material application including sweeping; air, sand, shot, or water blasting; use of solvents; grinding; and scraping. Surface preparation becomes more complicated when using durable materials and on PCC pavement. Temporary markings will be needed if the existing markings were removed or covered. Temporary markings shall comply with Part 3 of the MUTCD and should not be in place for more than 2 weeks unless justified by an engineering study.

The MUTCD requires that markings that are no longer applicable for roadway conditions or restrictions and that might cause confusion for the road user be removed or obliterated as a marking as soon as practical. Grinding is the most common method of removing markings. Several agencies require that markings containing hazardous materials, such as lead or chromium, be taken away when removed from the pavement.