Assessment of Economic Impacts of SNPA Proposed Minimum Levels of Pavement Marking Retroreflectivity

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In response to a Congressional directive, the FHWA is working to establish minimum maintained pavement marking retroreflectivity levels that would be incorporated into the Manual on Uniform Traffic Control Devices (MUTCD). This assessment of the economic impacts is part of the rulemaking package being made available for comment along with the Supplemental Notice of Proposed Amendment (SNPA) to the MUTCD. The analysis provides updated costs based on the revised proposal being presented in the SNPA for maintenance standards and guidance regarding pavement marking retroreflectivity. This analysis builds on an initial report from 2008 and a 2010 update that analyzed costs per the Notice of Proposed Amendment that was published in the Federal Register in April 2010. New information includes not only revisions per the revised standards and guidance in the SNPA, but also adds estimated costs for the implementation and briefly describes potential benefits.</td></tr>
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INTRODUCTION

On April 22, 2010, the Federal Highway Administration (FHWA) published a Notice of Proposed Amendments (NPA) to the *Manual on Uniform Traffic Control Devices* (MUTCD) to add language that establishes minimum levels of retroreflectivity for pavement markings. That NPA included a finding from an assessment of the economic impacts of maintaining pavement marking retroreflectivity at the indicated levels. The finding indicated that the annual cost of providing markings that meet the minimum levels across the Nation is $64 million per year. The assessment is documented in two previous reports (FHWA-SA-10-016[1] and FHWA-SA-08-010[2]).

The docket comment period for the NPA closed on August 20, 2010, and generated approximately 100 letters to the docket. After reviewing the docket comments, the FHWA is proposing numerous changes in the structure and content of the minimum pavement marking retroreflectivity language (see Appendix A) in a supplemental notice of proposed amendment (SNPA). These proposed changes necessitate a revision in the expected economic impacts. As they relate to the economic impacts, these proposed MUTCD changes include:

- A requirement ("shall" condition) that agencies use a method to maintain longitudinal pavement markings at a minimum level of 50 mcd/m^2/lx on all roadways with statutory or posted speed limits of 35 mph and higher;
- A recommendation ("should" condition) that agencies use a method to maintain longitudinal pavement markings at a minimum level of 100 mcd/m^2/lx on all roadways with statutory or posted speed limits of 70 mph and higher; and
- Options to exclude pavement markings from the method used to maintain minimum pavement marking retroreflectivity where average daily traffic (ADT) is less than 6,000 vehicles per day (vpd) or where ambient illumination assures the markings are adequately visible.

[1] Federal Highway Administration, *Revised Assessment of Economic Impacts of Implementing Minimum Levels of Pavement Marking Retroreflectivity*, FHWA-SA-10-016 (Washington, DC: FHWA, 2010). Available at: http://safety.fhwa.dot.gov/roadway_dept/night_visib/fhwasa10016/fhwasa10016.pdf (Accessed September 2014).
[2] Federal Highway Administration, *Preliminary Economic Impacts of Implementing Minimum Levels of Pavement Marking Retroreflectivity*, FHWA-SA-08-010 (Washington, DC: FHWA, 2008). Available at: http://safety.fhwa.dot.gov/roadway_dept/night_visib/pavement_visib/fhwasa08010/fhwasa08010.pdf (Accessed September 2014).

ANALYSIS APPROACH

The proposed standard requires the use of a method that is designed to maintain retroreflectivity at certain levels. This will result in agencies incurring costs to implement a method and costs to replace longitudinal pavement markings as they near the minimum levels. The analysis documented here estimates the implementation costs, including start-up costs to develop a method and purchase equipment as well as annual costs to assess or manage pavement markings using the selected method. This analysis also considers potential benefits of the proposed standard. Neither the preliminary impacts analysis nor the analysis prepared for the NPA included these implementation costs.

In estimating costs to replace pavement markings to meet the proposed minimum retroreflectivity levels, this economic assessment uses an approach that estimates the nationwide annual costs of maintaining longitudinal pavement markings at a level compliant with the minimum levels of retroreflectivity proposed in the SNPA. The costs have been estimated only for those miles of markings to which this proposed rulemaking applies. This assessment compares these costs to an estimate of the current cost of maintaining those same markings. This basic analysis procedure is described in detail in *Preliminary Economic Impacts of Implementing Minimum Levels of Pavement Marking Retroreflectivity*.[3] The reader is referred to that report for the basic assumptions used in the analysis that are not discussed in detail here. This document is a national assessment of the expected costs and does not address costs to any specific agency. The analysis discusses potential economic benefits resulting from the proposed MUTCD changes and computes a range of potential economic benefits to compare to costs. It also discusses intangible benefits such as increased driver comfort.

This analysis uses the *Highway Statistics 2012* report[4] for highway mileage and ownership data, compared to the analysis for the NPA which used data from the 2003 Highway Statistics report. The structure of the analysis was also modified to be consistent with the proposed retroreflectivity criteria. The FHWA Office of Policy provided additional mileage information by functional class and ownership based on volume and speed limit by using 2012 sample data available in the Highway Performance Monitoring System (HPMS) database. The analysis procedure consisted of the following steps:

1. Estimate the national start-up costs for agencies that would be required to implement a method to maintain the proposed minimum retroreflectivity levels to comply with the MUTCD. This estimate includes:

[3] Federal Highway Administration, *Preliminary Economic Impacts*.

[4] Federal Highway Administration, *Highway Statistics 2012* (Washington, DC: FHWA, n.d.). Available at: http://www.fhwa.dot.gov/policyinformation/statistics/2012/ (Accessed September 2014).

   a. Staff time to develop minimum retroreflectivity maintenance methods for State and local agencies.
   b. Costs of purchasing equipment to maintain the minimum retroreflectivity levels.
2. Develop an estimate of the annual costs associated with measuring and/or managing retroreflectivity levels for State and local agencies on applicable roadways.
3. Estimate the cost for all agencies to replace pavement markings at a frequency to with those that meet the newly established minimum retroreflectivity levels for the longitudinal pavement markings to which the standards apply. This estimate is based on these steps for each functional classification:
   a. Estimate the miles of U.S. roadway by lane configuration.
   b. Determine the miles of roadway that are expected to be subject to the proposed standard statement and the proposed guidance statement.
   c. Calculate the yellow and white marking mileage for the subject roadway mileage.
   d. Adjust the line miles markings to reduce mileage where adequate illumination allows an exemption.
   e. Separate the subject pavement markings into three categories of pavement marking material types.
   f. Calculate the difference between the current estimated costs for maintaining the subject pavement markings and the estimated costs associated with maintaining the SNPA proposed minimum levels of retroreflectivity.
      i. Apply assumed typical practice of replacing markings based on material type and functional class to determine current estimated costs.
      ii. Apply expected service life of each marking color and material type to calculate the cost of replacing pavement markings to maintain markings per the proposed standard.

Costs for each of the above steps are computed in example problems in Appendix B.

SUPPORTING DATA, ASSUMPTIONS AND CALCULATIONS FOR COST ANALYSIS

The following narrative explains the data sources, formulas and assumptions used in conjunction with each of the steps described in the analysis approach above. Implementation costs are discussed first, because they will occur prior to replacement costs. However, because some of these costs are based on the number of miles of pavement markings that fall under the proposed rule, some steps used in calculating implementation costs are based on data or computations that are calculated during later steps, which are described under the section on marking replacement costs.

Implementation Costs

This analysis developed implementation costs for State and local agencies based on assumed methods that may be used by agencies of various types and sizes. This is based on the flexibility allowed in the proposed SNPA that requires compliance by implementing a method that is designed to maintain retroreflectivity of longitudinal pavement markings. In reality, each agency will choose the best fit for its individual conditions, but this analysis assumed three different methods would be used. Agencies with a larger number of pavement markings to which the proposed rulemaking applies were assumed to contract mobile measurement services. Agencies with smaller, but still substantial quantities of applicable markings were also assumed to use a measurement method, but due to the smaller quantities, the method was based on purchasing handheld retroreflectometers and using in-house services to take measurements. Those agencies with very small quantities of applicable markings were assumed to use a blanket replacement method in which they would simply replace the applicable markings on regular basis to avoid allowing the markings on these few miles of roadway to reach the minimum retroreflectivity levels.

The assessment split implementation costs into two categories: start-up costs and annual costs. Start-up costs (Analysis Approach step 1) include staff time for each type of agency to develop a method and equipment costs for those agencies that were assumed to use handheld retroreflectometers. Each of these agencies was assumed to purchase one handheld retroreflectometer estimated to cost $19,000. This cost is based on the average cost of currently available models. Agencies using contract measurement services incur no equipment costs.

Annual costs (Analysis Approach step 2) were further split into measurement costs and management costs. The contract costs for measuring marking retroreflectivity with a mobile unit is approximately $15/mile/line. The value is based on discussions with contractors that provide such services. For those agencies using this method, the analysis assumed that the agencies would measure one-third of their subject mileage each year, which is a very conservative sample size. Measurement costs for agencies that were assumed to use handheld retroreflectometers were based on a two-person crew measuring 6 miles of marking per hour and measuring all miles of marking each year. This measurement rate is based on sampling procedures outlined in ASTM Test Method D7585[5] and experience.

Staff costs were calculated based on anticipated hours using an average full-time equivalent (FTE) salary. For a person associated with developing or managing a method, salary is assumed to be $82,200 per year based on the 2013 median pay for Civil Engineers[6] adjusted to the current year (2014) with an equivalent increase as that seen between the 2012 and 2013 median salary. For agencies that were assumed to measure their pavement markings with handheld retroreflectometers, a two-person crew was assumed with a salary assumed to be $48,000 per year based on median pay for Civil Engineer Technicians[7] adjusted to the current year in the same manner described above. A 40 percent overhead cost was added to these salary costs.

State Highway Agency Implementation Costs

This analysis assumed that all 50 State highway agencies own some portion of the roadway mileage to which this rule applies, and therefore will need to expend staff time to develop a method. There was no need to assign mileage to individual agencies, because the estimate was computed for all agencies.

The average staff time for a State to develop a method was estimated to include 10 months of an FTE. This is based on an average State DOT having 8 districts that each spend 1 month developing the method and 2 months by staff in the central office. Therefore the cost for all States to develop their methods is $4.8 million, based on the following formula:

$$\text{Cost to develop methods} = \text{FTE} \times (\text{salary} + \text{overhead}) \times \text{number of DOTs}$$

The analysis calculated annual measurement costs for all State highway agencies using the line miles of pavement markings subject to the proposed standard and the cost per mile for the contract service. The first parameter is developed in the process of calculating marking replacement costs, shown in detail later in this report. It requires determining the roadway mileage in the United States subject to the proposed standard based on volume, speed limit, and illumination criteria. The volume and speed limit data were based on HPMS data provided by

[5] ASTM International, *ASTM D7585 / D7585M-10, Standard Practice for Evaluating Retroreflective Pavement Markings Using Portable Hand-Operated Instruments*, (West Conshohocken, PA: ASTM 2010). Available at: www.astm.org (Accessed September 2014).
[6] Bureau of Labor Statistics, "Occupational Outlook Handbook," published January 8, 2014 (online only) at http://www.bls.gov/ooh/
[7] "Occupational Outlook Handbook," http://www.bls.gov/ooh/.

the Office of Policy and data in Table HM-50 of the 2012 Highway Statistics report. The analysis also makes assumptions for various types of roadway and correction factors where sample data is used.

To determine the miles of markings subject to the proposed minimum retroreflectivity levels, several additional steps were needed to estimate percentages of the roadways with various numbers of lanes and associated assumptions about marking patterns for those lane configurations. A sample calculation showing these details is included in Appendix B. The basic formula is:

$$\text{Miles of applicable markings} = \text{roadway mileage} \times \text{percent unlit} \times \text{marking pattern factor}$$

The result for all State-owned roadways is 579,315 line miles of applicable markings. Applying the assumptions previously discussed for mobile measurement, the annual cost to measure these markings is estimated at $2.9 million, using the following formula:

$$\text{Measurement cost} = \text{number of line miles} \times \text{percent measured annually} \times \text{cost per line mile}$$

This analysis also estimated annual costs to manage the effort for the applicable roadways. The average State DOT will manage 11,590 line miles of applicable markings, which is approximately 2,500 roadway miles. These agencies already have programs in place to manage pavement markings, so this analysis assumes that on average each agency will require one additional month of an FTE each year to address the specifics of this proposed rulemaking for their applicable markings. Therefore, the annual increased management costs resulting from the proposed rulemaking are estimated at $479,500 for all State DOTs.

$$\text{Annual management cost} = \text{FTE} \times (\text{salary} + \text{overhead}) \times \text{number of DOTs}$$

In summary, implementation costs for all State highway agencies include both an estimated $4.8 million to develop maintenance methods in accordance with the proposed standards and annual costs of $3.4 million—$2.9 million to measure applicable markings each year and a $0.5 million increase to manage those markings in accordance with the proposed standards.

Local Agency Implementation Costs

Unlike State highway agencies, for local agency implementation, the analysis required several steps to estimate the number of agencies that would be involved and the associated mileage that would be assigned to those agencies in order to make a reasonable estimate of their implementation costs. Based on HPMS data provided by the Office of Policy and data in Table HM-50 of the 2012 Highway Statistics report, the quantity of pavement markings to which the proposed rulemaking applies could be estimated for counties, cities, and other jurisdictions that were included under local agencies for the purposes of this analysis. This analysis assumed that the ownership proportions for markings to which this proposed rulemaking applies are similar to the ownership proportions for all roadway mileage. Appendix B includes a sample calculation. The results indicate that counties own 77,615 miles of applicable markings, cities own 131,821 miles, and other jurisdictions own 7,752 miles. The formula is:

$$\text{Miles for agency type} = \text{Percent miles owned} \times \text{line miles of markings subject to proposed rule}$$

No information is available to determine how many counties or cities own roadways with traffic volumes of 6,000 AADT and speed limits of 35 mph or greater. However, based on the amount of miles in each functional class, we know that more than 80 percent of the applicable markings are in urban areas. Based on engineering judgment, it is unlikely that counties with population of less than 100,000 will have many qualifying roads. However, to avoid underestimating potential costs, it was assumed that smaller counties with as populations as small as 25,000 would have a portion of these roadways. Since there is no information to determine how to distribute the applicable mileage among these counties, it was further assumed that one-third of the mileage would be attributed to each of three categories based on population size. Table 1 indicates the categories and distribution of qualifying pavement markings. Similar assumptions were made for cities, but the analysis used four population groupings deemed more appropriate to this type of entity. Table 2 shows the categories and distributions for cities. The U.S. Census Bureau provided population estimates for local agencies, and these reflect 2012 estimates for all incorporated places.[8,9]

Table 1. Assumed county-owned distribution of applicable pavement markings

County Size	Number of Counties	*Average Miles per Agency	Maintenance Method
Populations over 500,000	131	201	Handheld measure
100,000 to 500,000	450	57	Blanket replacement
25,000 to 100,000	1,006	25	Blanket replacement

*Refers to line miles of pavement markings, which is 3 to 5 times higher than the associated roadway mileage.

Table 2. Assumed city-owned distribution of applicable pavement markings

City Size	Number of Cities	*Average Miles per Agency	Maintenance Method
Populations over 500,000	34	969	Mobile measure
150,000 to 500,000	127	259	Handheld measure
50,000 to 150,000	565	58	Blanket replacement
15,000 to 50,000	1,491	22	Blanket replacement

*Refers to line miles of pavement markings, which is 3 to 5 times higher than the associated roadway mileage.

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[8] U.S. Census Bureau, "Population Estimates – County Totals: Vintage 2012," http://www.census.gov/popest/data/counties/totals/2012/index.html

[9] U.S. Census Bureau, "Population Estimates – City and Town Totals: Vintage 2012," http://www.census.gov/popest/data/cities/totals/2012/index.html

The 8,752 miles of pavement markings on roads owned by "other" entities that are subject to the minimum retroreflectivity levels were assumed to be on major toll facilities operated by the 10 major toll authorities. This assumption is based on information from an FHWA publication[10] indicating that approximately 5,500 miles of roadways in the United States are toll facilities, and each mile of a major toll road (assumed to be 4-lane) would account for 4.5 miles of pavement markings.

Because of the large differences in the quantity of applicable markings that these agencies oversee, this analysis assumed three different methods. The first assumption was that cities with populations greater than 500,000 and the major toll authorities that manage sufficient mileage use mobile measurement vie external (consultant or vendor) services. The second assumption was that counties with populations greater than 500,000 and cities with populations between 150,000 and 500,000 would likely use hand-held retroreflectometers to measure their applicable pavement markings. The final assumption was that counties with populations between 25,000 and 500,000 and cities with populations between 15,000 and 150,000 would likely use the blanket replacement method to manage the small average applicable pavement marking mileage.

The analysis also assumed the average staff time for local agencies to develop a method would be 1 month of an FTE for those that used either mobile or handheld measurement methods and one half of a month for those using blanket replacement methods. There were no sources available to validate these assumptions, so engineering judgment was used. Using the following formula, the total estimated cost for all local agencies to develop a method is $19.7 million:

$$\text{Cost to develop methods} = \text{FTE} \times (\text{salary} + \text{overhead}) \times \text{number of local agencies}$$

The other startup cost in this case is for those agencies assumed to use hand-held retroreflectometers to purchase equipment. A cost of $4.9 million was calculated by multiplying the equipment cost by the number of agencies using this method.

For the large cities and major toll authorities that were assumed to use mobile measurement through contract services, both measurement and management costs were derived in the same manner as explained above for State highway agencies. Appendix B shows each step involved in the calculations. The total estimated cost for all these agencies to measure one-third of their applicable markings annually is approximately $208,500, and associated management costs are estimated at $422,000 annually.

For those agencies assumed to use hand-held retroreflectometers, measurement costs for the two-person crew mentioned above to measure all applicable markings each year is estimated at

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[10] Federal Highway Administration, *Toll Facilities in the United States: Bridges – Roads – Tunnels – Ferries*, FHWA-PL-13-00 (Washington, DC: FHWA, 2013). Available at: https://www.fhwa.dot.gov/policyinformation/tollpage/ (Accessed September 2014).

$639,500. This is based on the total applicable mileage for these agencies from Tables 1 and 2 using the following formula:

$$\text{Handheld measurement cost} = \frac{\text{number of line miles} \times \text{number of staff} \times (\text{salary} + \text{overhead})}{\text{measurement rate}}$$

Annual management for these agencies is based on an assumption that each agency spends approximately 1 month of an FTE managing the applicable markings per the standards. Tables 1 and 2 give the number of agencies to which this method applies, and the average number of line miles of markings per agency is approximately 225, or about 50 to 70 roadway miles. The time estimate is based on engineering judgment regarding the average time it would take each of the agencies using this method to review the results of the measurements, decide on which markings to replace, and assign the work. Applying the formula below, these costs total $2.5 million.

$$\text{Annual management cost} = \text{FTE} \times (\text{salary} + \text{overhead}) \times \text{number of local agencies}$$

Finally, for agencies assumed to use the blanket replacement method, there are no measurement costs. Annual management costs are assumed to be minimal since it simply requires determining to which of the agency's roads the standard applies and ensuring they are remarked regularly. One week per year was assumed for each of these agencies as the decision to replace markings is simply based on the expected service life for the few miles of applicable roadways that the agency is managing. Using the same formula as shown above, the cost is estimated at $7.8 million.

In summary, implementation costs for all local agencies includes estimated startup costs of $19.7 million to develop maintenance methods in accordance with the proposed standards and $4.9 million to purchase equipment. In addition, this analysis estimates annual increases in measurement costs of $0.8 million and a $10.7 million increase to manage those markings in accordance with the proposed standards.

Marking Replacement Costs

To estimate the increased cost for agencies to replace pavement markings such that they are maintained at the minimum levels in the SNPA (Analysis Approach step 3) requires determining the quantity of pavement markings that are subject to the proposed minimum levels of retroreflectivity, estimating the current costs incurred to maintain those markings, and then comparing that to the expected costs of re-marking more frequently to maintain the minimum retroreflectivity levels.

Most of the steps used to make these calculations use the same assumptions for State and local agencies. Therefore, the descriptions that follow do not break out State from local calculations until the final steps, where there are different assumptions for the current maintenance practices.

Assumptions do vary by roadway type, so descriptions and formulas listed provide general information, and specific assumptions are provided based on functional classification. Each of the steps described below have sample calculations shown in Appendix B.

Step 3a. The first step was to distribute the road mileage into categories by number of lanes. This was necessary because pavement marking configuration is inherently tied to the number of lanes, discussed further in step 3c. Based on data available from Table HM-55 in *Highway Statistics 2012*, mileage was distributed into three categories, six-lane, four-lane, and two-lane roads.[11] Interstate mileage provides the most detailed information in Table HM-55, showing data by four-lane, more than four-lane (which were assumed to have six lanes), and other roadways (which were assumed to have two lanes). All other functional classes only show mileage by two lanes, four or more lanes (further broken down by access control), and other.

Based on engineering judgment, rural functional classes with four or more lanes were assumed to be four lanes if they had no access control or partial access control, or to have six lanes if there was full access control. Urban functional classes with four or more lanes were assumed to have four lanes if they had no access control and six lanes if they had partial or full access control. Sections categorized as "other" were assumed to have two lanes. Since HM-55 is based on sample data, Table HM-50 was applied proportionally for each functional class to adjust the mileage. Additionally, some of the lower functional classes have many miles that are unpaved. Since this mileage would not be subject to pavement markings, these miles were removed from the data set for those classes. The formulas are:

$$\text{Percent mileage by number of lanes} = \text{number of miles in category} / \text{total miles} \times 100\%$$

$$\text{Mileage} = \text{percent mileage for number of lanes} \times (\text{HM-50 mileage} - \text{HM-51 unpaved mileage})$$

Table HM-55 does not contain information for roads classified as Rural Minor Collectors, Rural Local Roads, or Urban Local Roads. For Rural Minor Collectors, the percentage of mileage in each category of lane configuration was assumed to be the same as that for Rural Major Collectors. Rural Local Roads were all assumed to be two lanes, and Urban Local Roads used the same percentages for each category as Urban Minor Collectors.

Step 3b. To determine the number of miles of roadway subject to the proposed standard statement and the proposed guidance statement, it was necessary to filter out roadways with AADT less than 6,000 vpd and speed limits less than 35 mph and then determine which of the remaining miles of roadway have speed limits of 70 mph or greater. Tables 3 and 4 contain Highway Performance Monitoring System (HPMS) data provided by the Office of Policy showing this information for most types of roadways. Table 3 was used to determine the total

[11] FHWA, *Highway Statistics 2012*, "Table HM-55. Functional System Length – 2012: Miles by Traffic Lanes and Access Control – Rural," http://www.fhwa.dot.gov/policyinformation/statistics/2012/hm55.cfm

mileage in each functional class that should be removed from paved mileage determined in the previous step. Roadways that have these lower volumes, lower speeds, or both were assumed to be those with the least number of lanes. The formula for each lane configuration category and functional class is:

Applicable mileage = Paved mileage – Table 3 State miles – Table 3 local miles

Since data were not available for Rural Minor Collectors, Rural Local Roads, or Urban Local Roads, the applicable mileage for the two remaining rural classes was based on a percentage of the next higher rural classification. This analysis assumed the applicable percentage of Rural Minor Collector mileage was assumed to be half that of the Rural Major Collector class and that the applicable Rural Local Roads mileage was one-quarter of the Rural Major Collector class. Engineering judgment was used to determine the percentage of mileage to apply in each of these cases. For Urban Local Roads, no assumptions were needed, as all these roadways were excluded from the analysis for other reasons described in step 3d.

Table 3. HPMS ownership data for applicable* roadways

Functional Classification		Ownership	
		State	**Local**
Rural	Interstate	25,608	1,555
	Other Freeways/Expressways	3,266	44
	Other Principal Arterial	28,865	531
	Minor Arterial	14,849	1,540
	Major Collector	4,998	3,183
	**Minor Collector	-	-
	**Local	-	-
Urban	Interstate	15,367	1,201
	Other Freeways/Expressways	10,041	804
	Other Principal Arterial	36,895	14,484
	Minor Arterial	20,352	30,314
	Major Collector	5,017	11,760
	Minor Collector	96	261
	**Local	-	-

* Applicable roadways in this table are those that have AADT of 6,000 vpd or greater and speed limits of 35 mph or greater
** Estimates not available from HPMS

The proposed guidance statement has a higher minimum retroreflectivity level for those roadways with speed limits of 70 mph or higher. The HPMS was the source for all speed distribution data for all functional classes except local roads and rural minor collectors (see Table 4). Based on engineering judgment, all roads functionally classified as local were assumed to have speed limits less than 70 mph and Rural Minor Collectors were assumed to have the same proportions of speed limits as Rural Major Collectors. Speed limits were only categorized by "less than 70 mph" and "70 mph and greater," since mileage with speeds less than 35 mph was already excluded from the data in Table 3.

Table 4. Speeds for functional classifications

Functional Classification		Percent of Functional Class Mileage for Speed Category	
		<70 mph	**≥ 70 mph**
Rural	Interstate	30%	70%
	Other Freeway/Expressway	65%	35%
	Other Principal Arterial	88%	12%
	Minor Arterial	93%	7%
	Major Collector	95%	5%
	*Minor Collector	-	-
	*Local	-	-
Urban	Interstate	74%	26%
	Other Freeway/Expressway	91%	9%
	Other Principal Arterial	99%	1%
	Minor Arterial	100%	0%
	Major Collector	100%	0%
	Minor Collector	100%	0%
	*Local	-	-

** Estimates not available from HPMS

Step 3c. Pavement marking patterns for various cross sections assumed fully marked roadways. For six-lane roads this assumed two solid white edge lines, four broken white lane lines, and two solid yellow center or edge lines. In the case of divided roadways, the yellow marking is an edge line, if undivided it is a center line. Broken lines were assumed to have a 10 foot stripe followed by a 30 foot gap. This resulted in a total of 5 line miles of marking for each mile of six-lane road. See Example 3c in Appendix D for further details. Four-lane roads were assumed to have the same configuration, except they only have two lane lines, which resulted in 4.5 line miles of marking for each mile of four-lane road. There are several potential options for markings on two-lane roadways, based on whether or not passing it allowed in one or both directions. The assumptions used in this analysis were the same as those from both previous analyses – that is, 25 percent of the mileage had two solid center line markings, 50 percent had one solid center line and one broken center line, and 25 percent had one broken center line. Two-lane roads were also assumed to have two solid white edge lines. The result was that two-lane roads had 3.2 line miles of marking per mile of roadway. During this step, the line miles of applicable markings were separated by the color because the service life of white markings is frequently longer than the service life for yellow markings. The factors are derived in Appendix B.

Step 3d. The proposed SNPA has an option to allow pavement markings to be excluded where ambient illumination assures that the markings are adequately visible. No data sources were available to quantify adequate visibility from ambient illumination, so assumptions were made by consensus of a group of FHWA safety engineers from various parts of the United States. It was assumed that any roadway with a rural functional classification would not have adequate ambient illumination to exempt the need for minimum retroreflectivity. The percentage of urban roadway mileage with ambient illumination that would assure adequate visibility of pavement markings was assumed to be 50 percent of the Urban Interstate and Urban Other Freeways and Expressways classifications and 25 percent of the Urban Other Principal Arterial classification. All other urban classes were assumed to have adequate illumination on only 25 percent of the sections with four or more lanes.

Line miles of subject markings = roadway miles (3b) × lane marking configuration factors (3c) × percent unlit roadways for functional class

Step 3e. It was necessary to estimate the type of pavement marking materials used to address the differences in service life. Percentages used for this analysis were gained through discussions with professionals in the pavement marking industry. This analysis assumed that that 75 percent of markings are paint, 20 percent are thermoplastic, and 5 percent are made of other materials. The other materials are represented by epoxy in the analysis. These are the same assumptions used in the analysis for the NPA. As with other assumptions in this analysis, these percentages may not represent any particular agency's usage, but rather typical percentages throughout the United States.

Miles of painted markings = 75% × line miles of subject markings

Miles of thermoplastic markings = 20% × line miles of subject markings

Miles of other marking materials = 5% × line miles of subject markings

Step 3f. The final step in the analysis calculated the current estimated annual cost, based on an assumed average typical current practice, to re-apply paint or other marking materials to the mileage of pavement markings subject to the proposed rule. It also calculated the estimated annual costs to re-apply material to those same markings based on an average service life that was estimated to meet the proposed minimum retroreflectivity levels per the SNPA. The difference between the two calculated costs is the estimated annual cost increase for replacing pavement markings as a result of the proposed rule.

The costs ($/ft) for the pavement marking materials used in this step were initially based on NCHRP Synthesis 306.[12] However, a 2005 unpublished FHWA report,[13] a 2007 TxDOT report,[14] and discussions at the 2007 FHWA workshops on minimum pavement marking retroreflectivity[15] were used to adjust each of the costs slightly. Table 5 shows the cost values used in the analysis. In 2013, FHWA reviewed average unit bid prices in a number of States and contacted a few agencies to verify that the costs used were still appropriate.

Table 5. Marking material costs

Material-	**Material Costs ($/LF)**	
	Federal/State Agencies	**City/County Agencies**
Paint	0.06	0.15
Thermoplastic	0.35	0.50
Epoxy	0.30	0.60

The typical practice for current marking maintenance was assumed based on knowledge of common agency practices across the country. The numbers used represent an average of all agencies in the United States. Service life data for various marking materials used within each roadway functional classification were obtained from an unpublished FHWA report.[16] This is the same marking material service life data used in the analysis for the NPA; however, in this analysis service life was rounded to the nearest 6 months. Also, where the research-based service life was longer than typical practice for replacing pavement markings, a service life equal to the typical practice was used. This is based on the assumption that agencies currently maintaining pavement markings at a standard higher than those in the proposed minimum retroreflectivity levels will continue to maintain pavement markings at that higher level. Table 6 presents both the typical current practice assumptions and service life data used in this analysis.

[12] Migletz, J., and J. Graham, *NCHRP Synthesis 306: Long-Term Pavement Marking Practices.* (Washington, D.C.: Transportation Research Board, National Research Council, 2002).
[13] Donnell, E.T., P.M. Garvey, D. Lee, S. Sathyanarayanan, and M.L. Patten, *Methods to Maintain Pavement Marking Retroreflectivity: Volume 1: Literature Review and Current State-of-the-Practice*, December 2005). (unpublished) Report is available from the FHWA Office of Safety Technology.
[14] Carlson, P.J., J.D. Miles, A.M. Pike, and E.S. Park, *Evaluation of Wet-Weather and Contrast Pavement Marking Applications: Final Report,* FHWA/TX-07/0-5008-2, (College Station, TX: Texas Transportation Institute, 2007).
[15] Falk, K.W. and P.J. Carlson, *Pavement Marking Retroreflectivity Workshops Summary Report,* FHWA-SA-08-003 (Washington, D.C.: FHWA, 2008).
[16] Migletz, J., J.L. Graham, D.W. Harwood, K.M. Bauer, and P.L. Sterner, *Evaluation of All-Weather Pavement Markings,* 2000. (unpublished) Report is available from the FHWA Office of Safety Technology.

Table 6. Pavement marking service life data

Type of Road	Marking Material	Current Practice	Expected Service Life (months) for a Given Color and Retroreflectivity Level (R_L)			
			White		Yellow	
			R_L=50	R_L=100	R_L=50	R_L=100
Freeway	paint	12	12	12	12	12
	thermo	36	36	36	36	24
	epoxy	36	36	24	36	24
Arterial* and Other Roads	paint	24	24	24	12	12
	thermo	48	48	36	42	24
	epoxy	48	48	36	48	30

*Values for arterial with speed of 45 mph and greater used for service life data.

To calculate the current estimated annual costs expended to maintain pavement markings, the cost for each type of material must be calculated separately. The formula for calculating the current annual cost to maintain the painted markings is:

$$\text{Current annual cost} = \text{Miles paint} \times (\text{percent state} \times \text{state paint cost} + \text{percent local} \times \text{local paint cost}) \times \text{current practice}$$

The estimated cost to maintain the subject pavement markings at the proposed minimum retroreflectivity levels substitutes the current practice in the above equation with service life. Since service life is often shorter for those markings that are recommended to have a higher retroreflectivity due to higher speeds, those costs must be calculated separately from the costs calculated for markings on the lower speed roads.

LIMITATIONS OF SNPA COST ANALYSIS

The approach used for this analysis had the following associated limitations:

1. The estimates for implementation costs included both start-up costs and annual costs.
    a. Since no data was available to determine the number of local agencies that maintain roadways over 30 mph and with ADT of 6,000 or more, population and engineering judgment was used to assign the estimated miles of pavement markings subject to the proposed minimum retroreflectivity levels to cities and counties.
    b. The percentages of agencies that would choose the various methods for maintaining pavement marking retroreflectivity is unknown, so the estimates for large and medium-sized agencies was based on measured retroreflectivity, while the small agencies that will only be required to manage a small number of miles subject to the proposed standards were assumed to use visual inspection. This is a conservative estimate since measurement is one of the most costly methods.
    c. The manpower estimates for each agency were made conservatively, but with little data to support the assumptions.
2. The retroreflectivity team could not find data that indicated the total amount of marking mileage associated with any specific functional classification. This led to the need to assume a typical marking pattern for each functional classification.
3. There are some discrepancies in the service life data used for this analysis. The data used for the analysis is from an unpublished FHWA report and represents data collection prior to 2000.[17] While this is the most comprehensive such study, including 19 participating States, like other, smaller studies of this type, there were discrepancies. In one case, yellow markings were found to have longer service lives than white markings. In other cases, the relative service lives for the different materials are not consistent. Due to the inconsistency and lack of precision, the service life values from research were rounded to the nearest 6 months.
4. The service life data used for all roads other than interstates and those classified as Other Urban Freeways and Expressways are based on data for non-freeways with a speed of 45 mph or more. The analysis did not use the service life data for non-freeways with a speed of 40 mph or less.
5. There has been no national evaluation to identify the percentage of markings at the State and local levels that currently comply with the proposed retroreflectivity values. There is also

[17] Migletz, J., J.L. Graham, D.W. Harwood, K.M. Bauer, and P.L. Sterner. *Evaluation of All-Weather Pavement Markings*. McLean, VA: FHWA, U.S. Department of Transportation, 2000. (unpublished) Report is available from the FHWA Office of Safety Technology.

no data available on the current typical practice for replacing markings. The team made assumptions that were fairly conservative to avoid underestimating the cost of the proposed rulemaking.

6. There is no information available to quantify the safety or operational benefits of improved retroreflective pavement markings. Although not quantifiable, several studies have indicated some benefits exist, and they are discussed later in this report. This analysis was limited to determining the nighttime fatal crash reduction factor (CRF) at which the estimated benefits would equal the estimated increase in costs due to this rulemaking.

FINDINGS OF THE SNPA COST ANALYSIS

It is expected that the agencies that maintain the roadways to which the proposed minimum retroreflectivity levels apply will incur some start-up costs to implement a method as well as costs associated with annually managing the pavement markings in accordance with that method. Table 7 summarizes the findings of the analysis of these economic impacts. As can be seen in this table, the total national costs for the first year are estimated to be $44.3 million. This includes the one-time costs for agencies developing their methods, estimated at $24.5 million, and equipment costs, estimated at $4.9 million. Also included in the first year is the cost to measure or otherwise manage the pavement markings subject to the proposed minimum retroreflectivity levels, which is estimated at $14.9 million.

The annual management costs do not include the cost of replacing pavement markings that do not meet the minimum retroreflectivity levels. Although the proposed SNPA does not include a compliance date for replacing pavement markings, the analysis assumed that agencies would replace markings that are near or below the proposed minimum retroreflectivity levels. The annual estimated national increase in this cost as a result of the proposed SNPA is estimated at $52.5 million. Marking replacements are assumed to begin the year following development and initial use of an agency's method due to the need to schedule the work. In the second and following years, annual management costs, which include measuring or otherwise managing the retroreflectivity, would continue to be incurred. Therefore, total national annual costs for the second and subsequent years are estimated at $67.4 million ($14.9 million in management and measurement costs plus $52.5 million in replacement costs). It is worth noting that this analysis is intended to represent an aggregate representation of all agencies in the Nation and is not representative of the costs to any specific agency.

Table 7. National estimated costs of compliance ($ million)

Cost Category	**Local Agencies**	**State Agencies**	**Total**
Cost to develop a method (first year only)	$19.7	$4.8	$24.5
Start-up equipment costs (first year only)	$4.9	$0	$4.9
Annual management/measurement costs (first and subsequent years)	$11.5	$3.4	$14.9
Annual increased replacement costs (second and subsequent years)	$26.7	$25.8	$52.5
Total first year costs	***$36.1***	***$8.2***	***$44.3***
Total second and subsequent years cost	***$38.2***	***$29.2***	***$67.4***

Over 20 years, the discounted costs are approximately $693 million (at 7 percent). Table 8 shows the 20-year discounted costs at both 3 and 7 percent, respectively, as well as the discounted annualized costs.

Table 8. Discounted costs over 20 years ($ million)

Cost Category	Discount Rate of 3%		Discount Rate of 7%	
	20-year Total	Annualized	20-year Total	Annualized
Costs	$981	$66	$693	$65

In the analysis for the NPA, only the cost for replacing pavement markings was included. Those costs were estimated at $64 million per year, which is somewhat higher than similar costs associated with the SNPA, $52.5 million. The major reasons for this difference are:

- In the SNPA, there is no impact for roads with ADT less than 6,000 vpd. This represents a slightly smaller portion of the total roadway mileage than those meeting the required or recommended levels in the MUTCD warrants criteria that were used in the NPA.
- The SNPA requires or recommends lower minimum retroreflectivity levels than the NPA for many miles of roadways. This is tempered with the fact that the SNPA does not allow an exemption for roadways with RRPMs as was include in the NPA.

POTENTIAL BENEFITS OF THE PROPOSED RULEMAKING

Due to the lack of quantifiable safety benefits tied specifically to retroreflectivity of pavement markings, the minimum values used in the proposed rulemaking are based on research indicating visibility needs of the driver to safely guide the vehicle at appropriate speeds. This information is documented in the FHWA report entitled *Updates to Research on Recommended Minimum Levels for Pavement Marking Retroreflectivity to Meet Driver Night Visibility Needs*.[18]

Despite the lack of quantifiable safety benefits, the FHWA expects this proposed standard will result in a reduction of fatalities, injuries, and property-damage-only crashes based on many years of research indicating that adding longitudinal pavement markings reduces crashes. The proposed minimum pavement marking retroreflectivity standards in the SNPA are likely to cause the affected pavement markings to be regularly maintained. This will enable the markings to continually meet at least the minimum visual nighttime needs of a broad range of drivers with only occasional exceptions during short time spans or over short distances. By establishing minimum maintained pavement marking retroreflectivity levels, FHWA expects that the nighttime presence of these markings will be maintained. For roadways where markings are currently allowed to fall below these minimum levels for months or years prior to re-marking, maintaining the markings at the newly established minimum levels is essentially the same as adding markings to the roadway for the nighttime driver during for those additional months or years.

While the safety benefits of pavement marking retroreflectivity cannot currently be quantified, substantial evidence indicates that such benefits exist, and nighttime benefits have been quantified for the addition of longitudinal pavement markings to various roadways. A report summarizing available information on the benefits of pavement marking retroreflectivity is *The Benefits of Pavement Markings: A Renewed Perspective Based on Recent and Ongoing Research* by Carlson et al.[19] One robust study summarized in this report was conceived from the Highway Safety Act of 1973 and showed an overall statistically significant 12 percent decrease in nighttime crashes on two-lane highways from the addition of center-line or edge-line markings or a combination of the two. The report also discusses more recent studies indicating various ranges of reductions that all indicate safety benefits of longitudinal pavement markings. In addition, this report discusses research showing operational benefits of longitudinal pavement markings, including a study indicating that adding edge lines decreases the mental workload rate

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[18] Federal Highway Administration, *Updates to Research on Recommended Minimum Levels for Pavement Marking Retroreflectivity to Meet Driver Night Visibility Needs*, FHWA-HRT-07-059 (McLean, VA: FHWA, 2007). Available at: http://www.fhwa.dot.gov/publications/research/safety/07059/07059.pdf

[19] Carlson, Paul J., Eun Sug Park, and Carl K. Andersen, "The Benefits of Pavement Markings: A Renewed Perspective Based on Recent and Ongoing Research," *Transportation Research Record*, 2107 (2009): 59–68.

of drivers at night. It also addresses the results of several subjective evaluations of drivers indicating that highly visible pavement markings is a high-ranking desire among the public. Lastly, by improving pavement marking maintenance, it is anticipated that this rulemaking will assist safety systems in vehicles, such as lane departure warning devices.

A key reason safety benefits have not yet been quantified is that shortly after retroreflective pavement markings are installed, the retroreflectivity levels of the markings begin to degrade at a rate that is difficult to predict because a large number of factors cause or contribute to this degradation. Very few agencies currently monitor the retroreflectivity of the pavement markings over the life of the markings, although this has begun to increase in recent years as reliable mobile equipment that can take measurements at highway speeds have recently become available. To quantify the relationship between pavement marking retroreflectivity levels and safety would require sampling retroreflectivity levels on a representative number of roadways repeatedly and over many years so that this relationship could be better understood for specific roadway types, traffic volumes, crash types, etc.

Currently, considering all available research, there is no comprehensive understanding of the relationship between pavement marking retroreflectivity levels and all of the variables affecting driver performance during darkness. However, a recent study[20] indicates that maintenance of pavement marking retroreflectivity may have a positive effect on safety by comparing a limited sample of retroreflectivity data available from Michigan DOT with State crash data. Despite this research, there still is insufficient retroreflectivity data available that can be correlated to crashes in order to develop crash reduction factors.

Break-Even Benefit-Cost Estimate

Since a CRF is not available to estimate safety benefits, this analysis calculated the number of fatalities that would need to be reduced annually to result in benefits equal to the calculated costs. Based on this information, a break-even CRF was calculated to be compared against the literature, to test whether that level of benefit seems reasonable to achieve.

The analysis was limited to fatalities because detailed national crash data and cost information related to fatalities is readily available. Detailed information regarding every fatal crash in the U.S. is available in the Fatal Analysis Reporting System (FARS). This includes information about the type of road on which the crash occurred, specifically the functional classification, which allows the analysis to include crashes only on those roads where the rulemaking is

[20] Carlson, Paul J., Eun Sug Park, and Dong Hun Kang. "An Investigation of Longitudinal Pavement Marking Retroreflectivity and Safety," *Transportation Research Record*, 2337 (2013): 59–66.

expected to apply. In regard to cost information, the value of a statistical life that is to be used in this type of analysis is currently estimated at $9.2 million.[21]

There were an average of 9,172 fatalities in the U.S. between 2008 and 2012 in dark, unlighted conditions on all roads other than those functionally classified as urban local. This classification was excluded because the assumptions of the cost analysis did not include these roads, as explained previously. Using this information, the value of a statistical life, and the annualized discounted cost (7 percent), it was determined that seven fatalities ($65 million/$9.2 million per fatality) would need to be eliminated due to the proposed standards to result in benefits approximately equivalent to the estimated cost. This would be representative of a crash reduction factor (CRF) of 0.076 percent. Based on the qualitative information presented in this section, FHWA believes this is attainable and, as such, the potential benefits of the rule justify the costs. Obviously, a higher CRF would result in positive net benefits.

The fatality data described above was used with various potential crash reductions to compute potential benefit-cost ratios. Along with the break-even CRF rounded to the nearest tenth, benefits are calculated using crash reduction factors of 1% and 5%, which is a reasonable range expected by implementation of this rule. Over 20 years, the discounted benefits are approximately $815 million (at 7 percent). Table 9 shows the 20-year discounted benefits at both 3 and 7 percent, respectively, as well as the discounted annualized benefits. By dividing the costs in Table 8 by the potential benefits in Table 9, the benefit-cost ratio would range from approximately 1 to 60, as shown in Table 10.

Table 9. Discounted benefits over 20 years ($ million)

Cost Category	**Discount Rate of 3%**		**Discount Rate of 7%**	
	20-year Total	Annualized	20-year Total	Annualized
Benefits with CRF = 0.1%	$1,173	$79	$815	$77
Benefits with CRF = 1%	$11,734	$789	$8,151	$769
Benefits with CRF = 5%	$58,671	$3,944	$40,753	$3,847

[21] Rogoff, Peter, Under Secretary for Policy, and Kathryn Thomson, General Counsel, Memorandum re: Guidance on Treatment of the Economic Value of a Statistical Life (VSL) in U.S. Department of Transportation Analyses – 2014 Adjustment, June 13, 2014.

Table 10. Potential Benefit-Cost Ratios

CRF	Discount Rate of 3%	Discount Rate of 7%
0.1%	1.2	1.2
1%	12.0	11.8
5%	59.8	58.8

CONCLUSIONS

Establishment of a uniform minimum level of nighttime pavement marking performance based on the visibility needs of drivers is expected to promote safety, enhance operations, and facilitate comfort and convenience for all drivers, especially older drivers. Unfortunately, these benefits are not quantifiable at this time. The national annualized costs estimated to implement this rule are approximately $65 million. A break-even analysis would indicate that the rule would be cost-effective if it saved seven lives annually. Based on the qualitative information presented, FHWA believes this is attainable and therefore, the potential benefits of the rule justify the costs. This cost is well below the current level of $151 million that would qualify this SNPA as an unfunded mandate.

APPENDIX A: 2014 SNPA – PROPOSED PAVEMENT MARKING RETROREFLECTIVITY MUTCD TEXT

Add a row to Table I-2 Target Compliance Dates Established by the FHWA:

2009 MUTCD Section Number(s)	2009 MUTCD Section Title	Specific Provision	Compliance Date
3A.03	Maintaining Minimum Retroreflectivity	Implementation and continued use of a method that is designed to maintain retroreflectivity of longitudinal pavement markings (see Paragraph 1)	4 years from the effective date of this revision of the MUTCD

Add new reference document to Section 1A.11 Relation to Other Publications:

Section 1A.11

"Methods for Maintaining Pavement Marking Retroreflectivity," Report No. FHWA-SA-14-017 (FHWA)

Revise Section 3A.03 as follows:

Section 3A.03 Maintaining Minimum ~~Pavement Marking~~ Retroreflectivity

~~(This Section is reserved for fugure text based on FHWA rulemaking.)~~

STANDARD:

01 **Except as provided in Paragraph 5, a method designed to maintain retroreflectivity at or above 50 mcd/m^2/lx shall be used for longitudinal markings on roadways with statutory or posted speed limits of 35 mph or greater.**

Guidance:

02 Except as provided in Paragraph 5, a method designed to maintain retroreflectivity at or above 100 mcd/m^2/lx should be used for longitudinal markings on roadways with statutory or posted speed limits of 70 mph or greater.

03 The method used to maintain retroreflectivity should be one or more of those described in "Methods for Maintaining Pavement Marking Retroreflectivity" (see Section 1A.11) or developed from an engineering study based on the values in Paragraphs 1 and 2.

Support:

04 Retroreflectivity levels for pavement markings are measured with an entrance angle of 88.76 degrees and an observation angle of 1.05 degrees. This geometry is also referred to as 30-meter geometry. The units of pavement marking retroreflectivity are reported in mcd/m^2/lx, which means millicandelas per square meter per lux.

Option:

05 The following markings may be excluded from the provisions established in Paragraphs 1 and 2:

A. Markings where ambient illumination assures that the markings are adequately visible;

B. Markings on roadways that have an ADT of less than 6,000 vehicles per day;

C. Dotted extension lines that extend a longitudinal line through an intersection, major driveway, or interchange area (see Section 3B.08);

D. Curb markings;

E. Parking space markings; and

F. Shared-use path markings.

Support:

06 The provisions of this Section do not apply to non-longitudinal pavement markings including, but not limited to, the following:

A. Transverse markings;

B. Word, symbol, and arrow markings;

C. Crosswalk markings; and

D. Chevron, diagonal, and crosshatch markings.

07 Special circumstances will periodically cause pavement marking retroreflectivity to be below the minimum levels. These circumstances include, but are not limited to, the following:

A. Isolated locations of abnormal degradation;
B. Periods preceding imminent resurfacing or reconstruction;
C. Unanticipated events such as equipment breakdowns, material shortages, contracting problems, and other similar conditions; and
D. Loss of retroreflectivity resulting from snow maintenance operations.

When such circumstances occur, compliance with Paragraphs 1 and 2 is still considered to be achieved if a reasonable course of action is taken to restore such markings in a timely manner.

APPENDIX B: SAMPLE CALCULATIONS FOR ECONOMIC IMPACTS

Example 1a: Calculate cost for agencies to develop methods to comply with the proposed rule.

STATE DOT CALCULATION:

$$\text{Cost to develop methods} = \text{FTE} \times (\text{salary} + \text{overhead}) \times \text{number of DOTs}$$
$$10 \text{ months} \times 1 \text{ year}/12 \text{ months} \times \$82{,}200/\text{year} \times 1.4 \times 50 \text{ DOTs} = \$4{,}795{,}000$$

LOCAL AGENCY CALCULATIONS:

Assumptions stated in this report indicate counties, cities, and toll authorities that use one of the measurement methods would take 1 month to develop a method and that the other counties and cities (those with small mileage and using blanket replacement) would require one-half a month to develop their method. Tables 1 and 2 provide the number of counties and cities in each category, and there are 10 major toll authorities.

$$\text{Cost to develop measurement methods} = \text{FTE} \times (\text{salary} + \text{overhead}) \times \text{number of local agencies}$$
$$1 \text{ month} \times 1 \text{ year}/12 \text{ months} \times \$82{,}200/\text{year} \times 1.4 \times (131+34+127+10) = \$2{,}896{,}180$$

$$\text{Cost to develop blanket methods} = \text{FTE} \times (\text{salary} + \text{overhead}) \times \text{number of local agencies}$$
$$0.5 \text{ month} \times 1 \text{ year}/12 \text{ months} \times \$82{,}200/\text{year} \times 1.4 \times (450+1{,}006+565+1{,}491) = \$16{,}840{,}040$$

Therefore the total cost for local agencies to develop methods is \$2,896,180 + \$16,840,040 = \$19,736,220.

Example 1b: Calculate cost for agencies to purchase equipment.

Per assumptions in the report, only agencies using handheld retroreflectometers (131 counties with populations over 500,000 and 127 cities with populations between 150,000 and 500,000) need to purchase equipment. The cost per retroreflectometer is \$19,000.

$$(131 + 127) \times \$19{,}000 = \$4{,}902{,}000$$

Example 2a: Estimate annual measurement costs for agencies to comply with the proposed rule.

The general equation is:

$$\text{Miles of applicable markings} = \text{roadway mileage} \times \text{percent unlit} \times \text{marking pattern factor}$$

The miles of applicable markings are also calculated to determine replacement costs. Examples 3a through 3d show detailed explanations of this process. Using the results of Example 3d for *Urban Minor Arterials*, the totals are:

$$76{,}830 + 20{,}520 + 2{,}941 + 45{,}618 + 16{,}416 + 1{,}961 = 164{,}286 \text{ line miles}$$

The split of the applicable roadway miles between State and local was estimated from HPMS data shown in Table 3. For this functional classification, there are 20,352 miles owned by State highway agencies and 30,314 miles owned by local agencies. Therefore, the State proportion is approximately 40 percent.

$$\text{State proportion of Urban Minor Arterials} = 20{,}352 / (20{,}352 + 30{,}314) \times 100\% = 40.17\%$$

$$\text{Local proportion of Urban Minor Arterials} = 30{,}314 / (20{,}352 + 30{,}314) \times 100\% = 59.83\%$$

Applying these percentages to the total line miles of markings to which the proposed rule applies:

$$\text{State Urban Minor Arterial line miles} = 164{,}286 \times 40.17\% = 65{,}994 \text{ line miles}$$

$$\text{Local Urban Minor Arterial line miles} = 164{,}286 \times 59.83\% = 98{,}292 \text{ line miles}$$

After adding these results for all functional classes, there are a total of 579,315 line miles of applicable markings on state-owned roads and 223,633 lines miles of applicable markings on locally owned roads. At this point the calculations need to be broken out by the type of method used.

STATE DOT CALCULATION:

For State DOTs, the assumptions were all lines were measured with mobile equipment under contract for $15/mile/line. States were assumed to measure one-third of their total mileage each year.

$$\text{Measurement cost} = \text{number of line miles} \times \text{percent measured annually} \times \text{cost per line mile}$$

$$\text{State measurement cost} = 579{,}315 \text{ line miles} \times 1/3 \times \$15/\text{line mile} = \$2{,}896{,}575$$

LOCAL AGENCY CALCULATIONS:

For local agencies, three different methods were assumed, depending on the size of the agency. The applicable line miles under each function class was distributed based on percentage of the total mileage in that class per Table HM-50 in *Highway Statistics 2012*.

The first step is to calculate the percentage of local roadway mileage that should be attributed to counties, cities and other jurisdictions. Table HM-50 shows the following U.S. total county mileage in the urban minor arterial category is 24,066 miles. The 52,609 miles assigned to cities is from the column labeled "town/township/municipality," and 421 miles is assigned to other jurisdictions. To calculate the percentage of roadway miles in each category:

County mileage: 24,066 / (24,066+52,609+421) × 100% = 31.22%

City mileage: 52,609 / (24,066+52,609+421) × 100% = 68.24%

Other jurisdictions: 421 / (24,066+52,609+421) × 100% = 0.55%

Next, estimate the mileage of applicable pavement markings in this functional classification attributed to counties, cities and other jurisdictions. Using the percentages calculated above and assuming those same percentages apply to the miles of applicable local markings for this functional class, results in the following estimates:

County mileage: 31.22% × 98,290 = 30,686 miles of applicable markings

City mileage: 68.24% × 98,290 = 67,073 miles of applicable markings

Other jurisdictions: 0.55% × 98,290 = 541 miles of applicable markings

After applying the same assumptions and equations to the other functional classes, the total miles of applicable markings for all roadways are:

County: 77,615 miles of applicable markings

City mileage: 131,821 miles of applicable markings

Other jurisdictions: 8,752 miles of applicable markings

Before calculating the measurement costs, the miles of markings are allocated by size of agency per the report assumptions, which results in the specific mileage for each type and size agency per Tables 1 and 2.

Cities with population over 500,000 and toll authorities were assumed to use the mobile measurement method for their share of the applicable markings. Therefore, the calculations are similar to that used by State DOTs.

Mobile measurement cost = # of line miles × % measured annually × cost per line mile

City (>500K) measurement cost = (34 × 969) line miles × 1/3 × $15/line mile = $164,730

Toll Authority measurement cost = 8752 line miles × 1/3 × $15/line mile = $43,760

A measurement method using handheld retroreflectometers was used for counties with a population over 500,000 and cities with populations between 150,000 and 500,000. They are assumed to measure all their mileage every year. The cost in this case is determined by staff hours to make the measurements. Based on assumptions from the report, the salary to use is \$48,000 with a 40 percent overhead, which is \$67,200. Assume a two-person crew taking measurements at a rate of 6 miles per hour. Assuming a 40 hour work week, there are 2080 hours per year.

$$\text{Handheld measurement cost} = \text{\# of line miles} \times \text{\# staff} \times (\text{salary} + \text{overhead}) / \text{measurement rate}$$

$$\text{County handheld cost} = (131 \times 201)\ \text{miles} \times 2 \times \$67{,}200 / (6 \times 2080)\ \text{miles/yr} = \$283{,}565$$

$$\text{City handheld cost} = (127 \times 259)\ \text{miles} \times 2 \times \$67{,}200 / (6 \times 2080)\ \text{miles/yr} = \$354{,}232$$

There is no measurement cost for the agencies using the blanket replacement method, so the total cost of measurement for local agencies is:

$$\$164{,}730 + \$43{,}760 + \$283{,}565 + \$354{,}232 = \$846{,}287$$

Example 2b: Estimate annual management costs for agencies to comply with the proposed rule.

Annual costs to manage the roadways with the applicable markings from example 2a requires assumptions about the number of staff hours and salaries that are given in the report. Agencies contracting for mobile measurement services were assumed to average 1 additional month of an FTE each year due to of the proposed rulemaking. Agencies using handheld measurement were also assumed to spend 1 month a year on average managing their method, while those using the blanket replacement method were estimated to average only one week on average. Salary for management is assumed at \$82,200 plus 40 percent overhead, which is \$115,080. Tables 1 and 2 are used to obtain the number of local agencies using each method, and there are 10 toll authorities included as well.

STATE DOT CALCULATION:

$$\text{Annual management cost} = \text{FTE} \times (\text{salary} + \text{overhead}) \times \text{number of DOTs}$$

$$\text{Annual State DOT management cost} = 1/12\ \text{FTE} \times \$115{,}080 \times 50 = \$479{,}500$$

LOCAL AGENCY CALCULATIONS:

$$\text{Annual management cost} = \text{FTE} \times (\text{salary} + \text{overhead}) \times \text{number of agencies}$$

$$\text{Annual local mobile management cost} = 1/12\ \text{FTE} \times \$115{,}080 \times (34 + 10) = \$421{,}960$$

Annual local handheld management cost = 1/12 FTE × \$115,080 × (131 + 127) = \$2,474,220

Annual local blanket management cost = 1/52 FTE × \$115,080 × (450 + 1,006 + 565 + 1,491) = \$7,772,326

Therefore, for all local agencies, the total annual management costs = \$421,960 + \$2,474,220 + \$7,772,326 = \$10,668,506.

Example 3a: Estimate roadway mileage by lane configuration.

The example below shows the process for the Urban Minor Arterial classification. Similar calculations are applied in a spreadsheet for each functional classification based on assumptions that vary by functional class as stated in the report.

The *Highway Statistics 2012*[22] Table HM-50 shows the total U.S. mileage in the urban minor arterial classification is 108,328. Before distributing the miles by number of lanes, a correction factor is applied to remove unpaved mileage based on information in Table HM-51. For this class of roadway 717 miles are unpaved. While this may seem insignificant, this method was used for all functional classifications with unpaved mileage and there are significant percentages of unpaved mileage in some categories. Therefore, the total paved mileage in this category for all jurisdictions is 108,328 – 717 = 107,611 miles.

Next we use Table HM-55, which breaks down a sample of the mileage by number of lane. Using some assumptions, it is possible to distribute the mileage into three categories for number of lanes. For this class of roadway Table HM-55 shows 12,133 miles in the United States are divided highways with four or more lanes. Furthermore, 10,839 of those miles have no access control. These are assumed to be four-lane sections. The 1,128 miles with partial access control and 167 miles with full access control that are assumed to be 6-lane sections. The other 94,447 miles of urban minor arterial shown in Table HM-55 (under the categories of two-lanes and other) are assumed to be two-lane roads. Because HM-55 is sample data, the percentages in each "number of lane" categories are then multiplied by the total mileage in this functional class shown in Table HM-50, to correct for the sampling error.

2-lanes: 94,447 / (94,447 + 10,839 + 1,128 + 167) × 107,611 miles = 95,360 miles

4-lanes: 10,839 / (94,447 + 10,839 + 1,128 + 167) × 107,611 miles = 10,944 miles

6-lanes: (1,128 + 167) / (94,447 + 10,839 + 1,128 + 167) × 107,611 miles = 1,307 miles

Example 3b: Estimate roadway mileage subject to the proposed standard (≥ 35 mph) and the proposed guidance (≥ 70 mph).

[22] FHWA, *Highway Statistics 2012*, "Table HM-50. Functional System Length – 2012: Miles by Ownership – Rural," http://www.fhwa.dot.gov/policyinformation/statistics/2012/hm50.cfm

This example shows the process using the Urban Interstate classification. The first several steps are similar to Example a.

From HM-50: 16,910 miles From HM-51: no unpaved miles

From HM-55: Other (2-lanes): 396 mi 4-lanes: 7,339 mi > 4 lanes (6-lanes): 8,679 mi

2-lanes: 396 / (396 + 7,339 + 8,679) × 16,910 miles = 408 miles

4-lanes: 7,339 / (396 + 7,339 + 8,679) × 16,910 miles = 7,561 miles

6-lanes: 8,679 / (396 + 7,339 + 8,679) × 16,910 miles = 8,941 miles

Although there are 16,910 paved miles in this functional class, HPMS estimates (per Table 3 of this report) indicate that only 15,367 + 1,201 = 16,568 miles of roadways owned by all jurisdictions in this functional class that have volumes 6,000 or greater and speed limits of 35 mph or greater. Therefore, 16,910 – 16,568 = 342 miles of roadway in this functional class are exempted from this proposed rulemaking. An assumption was made that all exempt mileage is in the two-lane category. This results in the following revised mileage for this category:

2-lanes: 408 – 342 = 66 miles

Therefore, we have estimated that the proposed standard statement applies to 66 miles of 2-lane roads, 7,561 miles of 4-lane roads, and 8,941 miles of 6-lane roads. To determine how much of that mileage the guidance statement also applies to, we use the percentages provided in Table 4, which indicate 26 percent of urban interstate highway mileage has speed limits of 70 mph or higher.

2-lanes: 66 miles × 26% = 17 miles

4-lanes: 7,561 miles × 26% = 1,966 miles

6-lanes: 8,941 miles × 26% = 2,325 miles

Example 3c. Determine the miles of yellow pavement markings and the miles of white pavement markings per mile of applicable roadway.

The assumptions for marking configurations for each lane configuration is described in step 3c of this report. Edge lines account for 2 line miles of white marking per mile in each category (edge line on each side). Each lane line accounts for 0.25 line miles of white marking per mile or roadway (number of lane lines varies by number of lanes). Similarly, the broken pattern center line in passing zones accounts for 0.25 line miles of yellow marking per mile of roadway. However, where passing is not allowed in either direction (all six-lane and four-lane sections and 25 percent of two-lane sections, the center line accounts for 2 line miles of yellow marking per mile of roadway. On the 50 percent of two-lane roadways where passing is assumed in only one direction, the center line accounts for 1.25 miles of yellow marking per mile of roadway (1 mile for the solid line plus 0.25 miles for the broken line). Therefore, the factors to apply to determine the line miles of marking per mile of roadway for each category are:

For white markings

2-lane: 2 line miles per mile

4-lane: 2.5 line miles per mile (2 + 2 × 0.25)

6-lane: 3 line miles per mile (2 + 4 × 0.25)

For yellow markings

2-lane: 1.1875 line mile per mile (25% × 0.25 + 50% × 1.25 + 25% + 2)

4-lane: 2 line miles per mile

6-lane: 2 line miles per mile

Example 3d. Determine the miles of marking that does not have adequate illumination, and is therefore subject to the proposed minimum retroreflectivity levels.

The example below shows the process for the Urban Minor Arterial classification.

The roadway mileage by lane configuration for this classification was computed in Example 3a. Per Example 3b, an adjustment to the 2-lane category is needed to subtract out the miles of roadway with AADT less than 6,000 and/or speeds less than 35 mph (see Table 3).

107,611 – 20,352 – 30,314 = 56,945 miles below volume/speed threshold

2-lanes white markings: 95,360 miles – 56,945 miles = 38,415 miles

Since this classification has approximately 0 percent of the roadways with speed limits of 70 mph or greater, the guidance statement does not apply to any of these markings. To determine the number of line miles of yellow and white markings on these roadways, the factors derived in Example 3d are applied to the roadway mileage from Example 3a.

2-lanes white markings: 38,415 miles × 2 line miles per mile = 76,830 line miles

4-lanes white markings: 10,944 miles × 2.5 line miles per mile = 27,360 line miles

6-lanes white markings: 1,307 miles × 3 line miles per mile = 3,921 line miles

2-lanes yellow markings: 38,415 miles × 1.1875 line miles per mile = 45,618 line miles

4-lanes yellow markings: 10,944 miles × 2 line miles per mile = 21,888 line miles

6-lanes yellow markings: 1,307 miles × 2 line miles per mile = 2,614 line miles

For urban minor arterials, it was assumed that 25 percent of the roadways with 4 or more lanes had adequate lighting. Therefore, all the markings on the 2-lane roads are subject to the standard, as are 75 percent of the markings on the 4-lane and 6-lane roads.

2-lanes white markings: 76,830 line miles × 100% = 76,830 line miles

4-lanes white markings: 27,360 line miles × 75% = 20,520 line miles

6-lanes white markings: 3,921 line miles × 75% = 2,941 line miles

2-lanes yellow markings: 45,618 line miles × 100% = 45,618 line miles

4-lanes yellow markings: 21,888 line miles × 75% = 16,416 line miles

6-lanes yellow markings: 2,614 line miles × 75% = 1,961 line miles

Example 3e. Distribute the markings from Example 3d into categories by type of material.

White paint markings: 75% × (76,830 + 20,520 + 2,941) = 75,218 line miles

White thermoplastic markings: 20% × (76,830 + 20,520 + 2,941) = 20,058 line miles

White in epoxy markings: 5% × (76,830 + 20,520 + 2,941) = 5,015 line miles

Yellow paint markings: 75% × (45,618 + 16,416 + 1,961) = 47,996 line miles

Yellow thermoplastic markings: 20% × (45,618 + 16,416 + 1,961) = 12,799 line miles

Yellow in epoxy markings: 5% × (45,618 + 16,416 + 1,961) = 3,200 line miles

Example 3f. Calculate the increased cost for the markings in Example 3b (Urban Interstate) under the proposed minimum retroreflectivity levels.

From Example 3b, we know the following:

2-lanes ($\geq$ 70 mph): 17 roadway miles

4-lanes ($\geq$ 70 mph): 1,966 roadway miles

6-lanes ($\geq$ 70 mph: 2,325 roadway miles

2-lanes (< 70 mph): 66 – 17 = 49 roadway miles

4-lanes (< 70 mph): 7,561 – 1,966 = 5,595 roadway miles

6-lanes (< 70 mph): 8,941 – 2,325 = 6,616 roadway miles

In this classification, 50 percent of all roadways are assumed to be lit. To calculate the line miles of white and yellow markings subject to the proposed guidance and standard, use this and the factors developed in example 3c:

2-lanes ($\geq$ 70 mph): 17 × 50% × 2 = 17 white line miles

4-lanes ($\geq$ 70 mph): 1,966 × 50% × 2.5 = 2,458 white line miles

6-lanes ($\geq$ 70 mph: 2,325 × 50% × 3 = 3,488 white line miles

2-lanes ($\geq$ 70 mph): 17 × 50% × 1.1875 = 10 yellow line miles

4-lanes ($\geq$ 70 mph): 1,966 × 50% × 2 = 1,966 yellow line miles

6-lanes ($\geq$ 70 mph: 2,325 x50% × 2 = 2,325 yellow line miles

2-lanes (< 70 mph): 49 × 50% × 2 = 49 white line miles

4-lanes (< 70 mph): 5,595 × 50% × 2.5 = 6,994 white line miles

6-lanes (< 70 mph): 6,616 × 50% × 3 = 9,924 white line miles

2-lanes (< 70 mph): 49 × 50% × 1.1875 = 29 yellow line miles

4-lanes (< 70 mph): 5,595 × 50% × 2 = 5,595 yellow line miles

6-lanes (< 70 mph): 6,616 × 50% × 2 = 6,616 yellow line miles

Applying the percentages of each material type for the two different retroreflectivity levels:

White paint markings ($\geq$ 70 mph): 75% × (17 + 2,458 + 3,488) = 4,472 line miles

White thermoplastic markings ($\geq$ 70 mph): 20% × (17 + 2,458 + 3,488) = 1,193 line miles

White in epoxy markings ($\geq$ 70 mph): 5% × (17 + 2,458 + 3,488) = 298 line miles

Yellow paint markings ($\geq$ 70 mph): 75% × (10 + 1,966 + 2,325) = 3,226 line miles

Yellow thermoplastic markings ($\geq$ 70 mph): 20% × (10 + 1,966 + 2,325) = 860 line miles

Yellow in epoxy markings ($\geq$ 70 mph): 5% × (10 + 1,966 + 2,325) = 215 line miles

White paint markings (< 70 mph): 75% × (49 + 6,994 + 9,924) = 12,725 line miles

White thermoplastic markings (< 70 mph): 20% × (49 + 6,994 + 9,924) = 3,393 line miles

White in epoxy markings (< 70 mph): 5% × (49 + 6,994 + 9,924) = 848 line miles

Yellow paint markings (< 70 mph): 75% × (29 + 5,595 + 6,616) = 9,180 line miles

Yellow thermoplastic markings (< 70 mph): 20% × (29 + 5,595 + 6,616) = 2,448 line miles

Yellow in epoxy markings (< 70 mph): 5% × (29 + 5,595 + 6,616) = 612 line miles

With data from Table 3 we determine the proportion of mileage that is owned by State agencies and local agencies:

State: 15,367 / (15,367 + 1,201) = 92.75%

Local: 1,201 / (15,367 + 1,201) = 7.25%

Using the applicable line miles by color and marking type, apply these percentages for State and local along with the material cost for State or local agency from Table 5. Since we are using linear miles of marking material, multiply the costs by 5,280 feet per mile to convert material costs from per linear foot to per linear mile, Also, to convert the service life from month to year, multiply by 12 months per year then divide by the current practice from Table 6 to obtain annual costs.

Current annual costs:

state white paint = (4,472 + 12,725) × 92.75% × \$0.06 × 5280 x12 / 12 = \$5,053,029

state white thermo = (1,193 + 3,393) × 92.75% × \$0.35 × 5280 x12 / 36 = \$2,620,165

state white epoxy = (298 + 848) × 92.75% × \$0.30 × 5280 x12 / 36 = \$561,219

local white paint = (4,472 + 12,725) × 7.25% × \$0.15 × 5280 x12 / 12 = \$987,452

local white thermo = (1,193 + 3,393) × 7.25% × \$0.50 × 5280 x12 / 36 = \$292,587 local white epoxy = (298 + 848) × 7.25% × $0.60 × 5280 x12 / 36 = $87,738

Similar calculations for yellow markings yield current annual costs of:

state yellow paint = $3,645,280

state yellow thermo = $1,889,993

state yellow epoxy = $404,998

local yellow paint = $712,353

local yellow thermo = $211,050

local yellow epoxy = $63,315

The expected costs are calculated in a fairly similar manner. The main difference is that the expected life from Table 6 is used rather than the current practice. Since these are often shorter for the higher speed condition where the guidance statement applies and sometimes differ between yellow and white, each of these is calculated separately. Note that these differences are more pronounced under other functional classifications.

Expected annual costs (speed $\geq$ 70 mph):

state white paint = 4,472 × 92.75% × $0.06 × 5280 x12 / 12 = $1,314,017

state white thermo = 1,193 × 92.75% × $0.35 × 5280 x12 / 36 = $681,609

state white epoxy = 298 × 92.75% × $0.30 × 5280 x12 / 24 = $218,905

local white paint = 4,472 × 7.25% × $0.15 × 5280 x12 / 12 = $256,782

local white thermo = 1,193 × 7.25% × $0.50 × 5280 x12 / 36 = $76,113

local white epoxy = 298 × 7.25% × $0.60 × 5280 x12 / 24 = $34,222

Expected annual costs (speed < 70 mph):

state white paint = 12,725 × 92.75% × $0.06 × 5280 x12 / 12 = $3,739,012

state white thermo = 3,393 × 92.75% × $0.35 × 5280 x12 / 36 = $1,938,557

state white epoxy = 848 × 92.75% × $0.30 × 5280 x12 / 36 = $415,283

local white paint = 12,725 × 7.25% × $0.15 × 5280 x12 / 12 = $730,670 local white thermo = 3,393 × 7.25% × $0.50 × 5280 x12 / 36 = $216,473

local white epoxy = 848 × 7.25% × $0.60 × 5280 x12 / 36 = $64,923

Adding the two costs for each material type yields:

state white paint = $1,314,017 + $3,739,012 = $5,053,029

state white thermo = $681,609 + $1,938,557 = $2,620,165

state white epoxy = $218,905 + $415,283 = $634,187

local white paint = $256,782 + $730,670 = $987,452

local white thermo = $76,113 + $216,473 = $292,587

local white epoxy = $34,222 + $64,923 = $99,145

Similar calculations for yellow markings yield expected annual costs of:

state yellow paint = $2,697,378 + 947,902 = $3,645,280

state yellow thermo = $1,398,640 + $737,029 = $2,135,669

state yellow epoxy = $299,709 + $157,935 = $457,643

local yellow paint = $527,116 + $185,237 = $712,353

local yellow thermo = $156,182 + $82,302 = $238,484

local yellow epoxy = $46,855 + $24,691 = $71,545

Therefore, for the Urban Interstate classification, the increased cost to replace markings in accordance with the proposed minimum retroreflectivity levels will be:

State Increased Cost = $5,053,029 + $2,620,165 + $634,187 + $3,645,280 + $2,135,669 + $457,643 - $5,053,029 - $2,620,165 - $561,219 - $3,645,280 - $1,889,993 - $404,998 = $371,289

Local Increased Cost = $987,452 + $292,587 + $99,145 + $712,353 + $238,484 + $71,545 - $987,452 - $292,587 - $87,738 - $712,353 - $211,050 - $63,315 = $47,072