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PRELIMINARY ECONOMIC IMPACTS OF IMPLEMENTING MINIMUM LEVELS OF PAVEMENT MARKING RETROREFLECTIVITY

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16. Abstract

The implementation of minimum levels of pavement marking retroreflectivity may lead some agencies to change the types of pavement marking materials used on roads and/or may result in a changed service life for the marking materials they currently used. To assess the economic impacts, researchers developed a spreadsheet-based analysis tool that calculates the costs associated with implementing minimum retroreflectivity levels. The spreadsheet considers the impacts of retroreflectivity levels, choice of materials, cost of materials, roadway types, and roadway mileage. The researchers used the analysis tool to assess several different scenarios that considered retroreflectivity level (low, base, and high), marking cost (low, base, and high), and material selection (water-based and selected durable materials). Using the mid-range of assumed pavement marking costs, the analyses described in this report show that the economic impacts of implementing minimum levels of pavement marking retroreflectivity range from $0 to almost $150 million per year, depending on the assumptions used in the analysis. In some cases, the analyses show that potential cost savings can be realized when status quo practices are compared to alternative practices that include the use of more durable pavement marking materials.

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CHAPTER 1: INTRODUCTION

Pavement markings are a critical component of a safe and efficient transportation network. Markings that have deteriorated, lack clarity, or have been improperly placed create the potential to confuse drivers and pedestrians and may also create a safety concern. Proper design of roadway delineation is a vital element of a safe and efficient transportation system, and markings must be capable of providing guidance during both daytime and nighttime conditions. Furthermore, they must be durable and perform for an extended period of time. It is for these reasons that research continually focuses upon methods of improving pavement markings.

The retroreflective properties of pavement markings provide the ability to see the markings at night. However, the actual visibility of the markings is a function of many different factors including, among others: the amount of illumination provided by the vehicle headlamps, the retroreflective efficiency of the marking, the viewing geometry, the environmental conditions, and the visual capabilities of the driver.

The importance of pavement marking retroreflectivity is recognized in the current *Manual on Uniform Traffic Control Devices* (MUTCD), which includes the following statement regarding marking retroreflectivity (*1*):

> *"Markings that must be visible at night shall be retroreflective unless ambient illumination assures that the markings are adequately visible. All markings on Interstate highways shall be retroreflective."*

However, there are no specific performance requirements in the MUTCD regarding initial or maintained pavement marking retroreflectivity levels. To address this, the United States Congress, as part of the 1993 Department of Transportation Appropriations Act, directed the Secretary of Transportation to revise the MUTCD to address minimum retroreflectivity standards for signs and pavement markings. The Congressional directive stated that:

> *"The Secretary of Transportation shall revise the MUTCD to include a standard for a minimum level of retroreflectivity that must be maintained for traffic signs and pavement markings which apply to all roads open to public travel."*

This report describes potential economic impacts of minimum levels of pavement marking retroreflectivity. The impacts are based on currently available information regarding the quantities of pavement markings, the generalized conditions of these pavement markings, the costs of maintaining pavement markings, and the assumed minimum retroreflectivity levels that FHWA will develop. The research effort described in this report included the development of a spreadsheet-based analysis tool that provides the ability to change assumptions and analyze a wide variety of analysis cases.

CHAPTER 2:
BASIC INPUT DATA

The first step in conducting an economic analysis of minimum pavement marking retroreflectivity guidelines is to identify key input data that serve as the basis for the initial analysis, and which have the potential to be adjusted at a later time as more specific information becomes available. The input data gathered for the analysis include:

- Quantities of pavement markings subject to the minimum retroreflectivity guidelines, including the quantities of each type of material. This information includes:
  - An inventory of roadway mileage, stratified by area type (rural or urban), functional classification (interstate, freeway, expressway, principal arterial, minor arterial, collector, and local road), and jurisdictional ownership (federal, state, county, and city),
  - A count of average laneage for all relevant roadway categories, and
  - Estimates on striping configurations for two- and three-lane undivided highways (related to passing zone policies);
- Service life data for both white and yellow marking materials based on the amount of time that the materials can maintain a specified retroreflectivity level;
- Typical replacement costs for pavement marking materials, stratified by jurisdiction (federal, state, county, and city); and
- Potential retroreflectivity levels that would define the replacement thresholds.

PAVEMENT MARKING QUANTITIES

The total quantity of pavement marking subject to the minimum retroreflectivity guidelines is determined through a multi-step effort which includes estimating the total mileage by functional class, developing typical pavement marking configurations for each functional class, and calculating the total miles of pavement markings by material using information on material type usage.

Roadway Mileage

The total miles of rural and urban roadway by functional classification were obtained from FHWA's Highway Statistics 2003 Table HM-20 (for the total system) and Table HM-50 (broken down by jurisdiction) (*2*). For each functional class, the data were further divided into mileage by the number of lanes (using Highway Statistics Table HM-55). The use of the roadway mileage in the analysis procedure is described in more detail in the next chapter.

Pavement Marking Configurations

There are no national databases containing the quantities of pavement markings used in the United States. To get an estimate of the pavement markings impacted by potential pavement marking retroreflectivity guidelines, the researchers made some basic assumptions about the types of long-line markings used for rural and urban roadways in each functional classification.

It should be noted that the researchers also assumed that the minimum retroreflectivity guidelines would apply only to long lines, not any other types of pavement markings such as stop/yield lines, crosswalks, words, or arrows. Furthermore, the only long lines included in the analysis are those that are required by the MUTCD. As an example, low-volume roads (less than 6,000 vpd) do not require edge line markings. Therefore, this analysis does not include edge line markings for low-volume roads.

Typical striping configurations for each functional classification are shown in Appendix A. These configurations are based on MUTCD guidance and the assumptions listed below.

- All longitudinal markings are 4 inches wide.
- All lane line patterns consist of a 10 ft stripe followed by a 30 ft gap.
- Rural minor arterials, rural major collectors, and urban collectors have sufficiently low average daily traffic (ADT) (less than 6,000 vpd) that they do not require edge lines.
- Rural major collectors and urban collectors have sufficiently low ADT (less than 6,000 vpd) that they do not require center lines unless they have three or more lanes. The center lines on segments with ADT greater than 6,000 vpd consist of double-solid yellow lines.
- Rural minor collectors, rural local roads, and urban local roads have sufficiently low ADT (less than 6,000 vpd) that they do not require any pavement markings.

These striping configurations were then combined with the mileage estimates to obtain an estimate of the total miles of pavement markings. The next chapter provides more details about how this information was used in the actual analysis.

Pavement Marking Material Quantities

There are several types of pavement marking materials in use around the United States. Each type of material has cost and service life implications which are an important part of an economic analysis. Unfortunately, the researchers are not aware of any databases of significance that provide a useful estimate of the quantities of each type of material by class of roadway. However, there have been some surveys of practices that give some indications of the use of various materials (*3*, *4*). The authors used the information from these surveys to select typical distributions of material types for analysis. Several different material type scenarios were analyzed. These scenarios are described in the analysis chapter of this report.

PAVEMENT MARKING SERVICE LIFE AND MATERIAL COST

As with the other quantities, there are no national databases of pavement marking material use and costs. Therefore, the researchers relied upon the most recently available information to populate the cost information. The researchers only included material types in the analysis where recent and sufficient data were available to generate representative cost estimates. The material types used in the analyses total approximately 95 percent of the pavement markings installed in the United States (by mileage) (*3*). The costs represent contractor-installed costs. In many cases, agency-installed costs can be much lower. However, there is substantial variation in costs around the country. Furthermore, factors such as rising energy costs, new environmental restrictions, and raw material availability will have a significant impact on pavement marking costs in the future. The analysis tool provides a function that allows users to enter their own pavement marking material costs.

The costs ($/ft) for the pavement marking materials used in this report were obtained from a variety of sources, including a 2002 NCHRP synthesis (*3*), a 2005 unpublished FHWA report (*4*), a 2007 TxDOT report (*5*), and the 2007 FHWA workshops on minimum pavement marking retroreflectivity (held in Denver and Pittsburgh during the summer of 2007) (*6*). For the economic analysis, representative cost estimates were generated as base costs and then increased and decreased by 25 percent to provide a range of cost data to use in the analysis. These costs are based on figures representing contractor-installed markings. They include the total costs for installation (e.g., materials, labor, overhead, lane closures, etc.). Table 1 summarizes the cost data used in the economic analysis.

Table 1. Marking Material Installation Costs Used in Analysis

Material	Cost ($/linear ft) for jurisdiction (Low/Base/High)	
	Federal / State	City / County
Epoxy	$0.23/0.30/0.38	$0.45/0.60/0.75
Methyl Methacrylate	$0.94/1.25/1.56	Insufficient data
Tape (profiled)	$2.06/2.75/3.44	$3.00/3.00/4.00
Thermoplastic	$0.26/0.35/0.44	$0.38/0.50/0.63
Waterborne Paint	$0.05/0.06/0.08	$0.11/0.15/0.19

The service life estimates for each material type was generated from an FHWA-sponsored research effort (*7*). Although the report was not published, it represents one of the most detailed field efforts that investigated the service life of pavement markings applied in their natural orientation (i.e., longitudinally as opposed to a transverse application, which is a common way to test markings but provides only indirect service life information) and as a function of retroreflectivity levels (*7*). Only service lives for the FHWA research recommended minimum retroreflectivity levels were provided explicitly in the source document (*7*). The regression model parameters used to determine these service life values were used to determine service life values for a range of minimum retroreflectivity levels. The regression models provide service lives in terms of cumulative traffic passes (CTPs). This information was used to develop service life values in months for use in the spreadsheet as a function of the marking retroreflectivity level. The service life values used in the economic analysis are contained in one of the worksheets (marking specifications) of the analysis tool. The individual sheets of the analysis tool, which is described in detail in the next chapter, are presented in Appendix B, where the service life values used in the analysis can be observed.

POTENTIAL RETROREFLECTIVITY VALUES

As one would expect, the results of an economic assessment of minimum pavement marking retroreflectivity levels will depend upon the threshold criteria that are used to define the end of service. However, the threshold criteria have not yet been set. Therefore, the researchers have reviewed recent proposals for minimum pavement marking retroreflectivity and conducted the analysis for a range of minimum retroreflectivity levels.

Over the last 15 or 20 years, numerous research efforts have evaluated pavement marking retroreflectivity. Using the results from these research efforts, there have been a few specific proposals for minimum levels of pavement marking retroreflectivity. This chapter describes these minimum retroreflectivity proposals and the process used to develop each proposal. It is important to note that none of the minimum retroreflectivity proposals has been published in the technical literature in a manner that would make it accessible to the profession.

Internal FHWA Initial Research Recommendations

In 1999, an internal FHWA report presented the initial research recommendations for minimum levels of retroreflectivity (*8*). These levels are shown in Table 2. In this report, the authors compiled information from nine previous studies heavily focused on pavement retroreflectivity. However, to account for deficiencies present in the available information, two new investigations were also devised. Taken together, the research presented in the report provides a comprehensive view of previous research, as well as a foundation on which FHWA research recommendations for minimum retroreflectivity are based.

Table 2. 1999 FHWA Research Recommendations for Minimum Retroreflectivity

Option 1		Non-Freeway, ≤ 40 mph	Non-Freeway, ≥ 45 mph	Freeway, ≥ 55 mph
Option 2		≤ 40 mph	≥ 45 mph	≥ 60 mph, > 10K ADT
Option 3		≤ 40 mph	45-55 mph	≥ 60 mph
With RRPMs	White	30	35	70
	Yellow	30	35	70
Without RRPMs	White	85	100	150
	Yellow	55	65	100

Source: Reference (*8*).
Note: Retroreflectivity values are mcd/m^2/lux and measured at 30 meter geometry.
RRPMs – Retroreflective Raised Pavement Markers.

The research retroreflectivity recommendations in the internal FHWA report were based on an FHWA-sponsored research study focused on pavement marking retroreflectivity (*9*). This report, also unpublished, proposed the minimum retroreflectivity levels shown in Table 3. Although the report was not published by the FHWA, Zwahlen did publish the research results in a peer-reviewed journal paper (*10*).

Table 3. Zwahlen's Recommended Required R_L for Pavement Markings

Speed (mph)	Minimum Required R_L ($mcd/m^2/lx$)	
	Without RRPMs Preview = 3.65 sec	**With RRPMs Preview = 2 sec**
0-25	30	30
26-35	50	30
36-45	85	30
46-55	170	35
56-65	340	50
66-75	620	70

FHWA Pavement Marking Workshop Recommendations

In the fall of 1999, the FHWA sponsored a series of three public agency workshops on minimum pavement marking retroreflectivity. These workshops presented the research and recommendations summarized in the internal FHWA report and solicited input from the 67 public agency participants. An unpublished report describes the workshops and the minimum retroreflectivity recommendations that are based on the input received during the workshops (*11*). The report presented two alternatives for the format of the retroreflectivity guidelines – one based on road speed and one based on road classification. These recommendations are presented in Tables 4 and 5. These recommendations are not based on the specific results of any single research effort, but represent a general consensus of opinion from the local and state public agency personnel that participated in the workshops.

Table 4. Workshop Recommended Speed-Based Minimum Values for Pavement Marking Retroreflectivity

Marking Color	Minimum R_L [a] ($mcd/m^2/lux$) for Indicated Speed [b]		
	≤ 30 mph	**35-50 mph**	**≥ 55 mph**
White	Presence [c]	80	100
Yellow	Presence	65	80

Notes:
[a] R_L measured at 30 meter geometry.
[b] Speed is the posted or statutory speed.
[c] Presence is a visible pavement marking at night, but having no numerical retroreflectivity value.

Table 5. Workshop Recommended Classification-Based Minimum Values for Pavement Marking Retroreflectivity

Marking Color	Minimum R_L [a] ($mcd/m^2/lux$) for Class of Roadway		
	Local and Minor Collector	**Major Collector and Arterial**	**Highways, Freeways, and all roads ≥ 55 mph**
White	Presence [b]	80	100
Yellow	Presence	65	80

Notes:
[a] R_L measured at 30 meter geometry.
[b] Presence is a visible pavement marking at night, but having no numerical retroreflectivity value.

ATSSA Recommendations

In the summer of 2004, the American Traffic Safety Services Association (ATSSA) undertook an internal effort to develop recommendations for minimum levels of pavement marking retroreflectivity. The recommended minimum levels are shown in Table 6. These recommendations were developed through the ATSSA Pavement Marking Committee and approved by the ATSSA Board of Directors. As with the FHWA pavement marking workshop recommendations, the ATSSA recommendations are not based on any specific research effort. Rather, they represent a consensus of those involved in providing traffic safety services. As with the other minimum retroreflectivity recommendations, the ATSSA recommended levels have not been published.

Table 6. ATSSA Minimum Retroreflectivity Levels

Posted Speed (mph)	**≤ 50**	**≥ 55**
Retroreflectivity ($mcd/m^2/lux$)	100	125

Notes: Retroreflectivity levels are based on 30 meter geometry.
Retroreflectivity levels apply to both white and yellow markings.

An interesting aspect of the ATSSA recommendations is that they suggest that the same numerical minimum value be applied to both white and yellow markings. This recommendation is based on the factors listed below.

1. Yellow longitudinal markings receive less light from headlamps than white longitudinal markings because they are on the left side of a vehicle and headlamp beam patterns focus more light toward the right side of the vehicle.
2. The measure of retroreflectivity is a metric that can be used to quantify visibility. As such, a minimum retroreflectivity level defines a minimum visibility level. Assuming that the visibility of white and yellow markings should be the same, then their retroreflectivity level should be the same, despite the lower retroreflectivity levels typically associated with yellow markings.
3. The retroreflectivity level should not be reduced based simply on the fact that a yellow marking fabricated from the same basic material as a white marking has a lower

retroreflectivity value than the white marking of the same material – it is possible to utilize yellow marking materials that will achieve the same retroreflectivity as a given white material.

Summary of Minimum Retroreflectivity Guidelines

Table 7 presents a summary of the retroreflectivity recommendations from the efforts described above. The summary shows that most of the research recommendations are based on minimum levels for white and yellow markings that are near a value of 100 mcd/m^2/lx. The summary also shows that speed is a popular classification metric to distinguish between different levels of minimum pavement marking retroreflectivity.

Table 7. Summary of Retroreflectivity Recommendations

Effort	**Speed (mph)**	**Recommended Retroreflectivity (mcd/m^2/lx)**	
		White	**Yellow**
FHWA Initial Research	≥ 60	150	100
	45-55	100	65
	≤ 40	85	55
FHWA Workshops	≥55	100	80
	35-50	80	55
	≤ 30	Presence	Presence
ATSSA	≥ 55	125	125
	≤ 50	100	100
Average	Higher Speed	125	102
	Moderate Speed	93	73
	Lower Speed	85	55

The researchers used the summarized research recommendations to define minimum pavement marking retroreflectivity levels to use in the economic impacts analysis. Three sets of minimum pavement marking retroreflectivity levels were developed for the economic analysis. A base case was developed using values that best represent the summarized research recommendations. Two additional cases were also developed using values approximately 20 percent lower than the base case and values approximately 20 percent higher than the base case. For each case, there are low-, moderate-, and high-speed groups, each of which are associated with specific roadway functional classifications. Table 8 shows the specific values used in the economic analysis.

Table 8. Retroreflectivity Levels Used in Economic Analysis

Case	Speed	Retroreflectivity (mcd/m^2/lx)	
		White	**Yellow**
Low Values	High Speed	100	85
	Moderate Speed	85	55
	Low Speed	70	45
Base Values	High Speed	125	100
	Moderate Speed	100	70
	Low Speed	85	55
High Values	High Speed	150	125
	Moderate Speed	125	85
	Low Speed	100	65

CHAPTER 3:
DEVELOPMENT OF ECONOMIC IMPACTS MODEL

The development of a spreadsheet-based analysis tool was one of the requirements for the economic analysis. The Microsoft Excel®-based economic impact calculation spreadsheet estimates the national cost of implementing a minimum retroreflectivity standard for pavement markings. The cost calculation is broken down for four different levels of governmental jurisdictions: federal, state, county, and city. The default values in the spreadsheet are for a nationwide analysis of costs. The spreadsheet includes three default cost analysis scenarios: status quo (no minimum retroreflectivity standard) and two alternative scenarios that include different techniques to meet potential minimum retroreflectivity standards.

Only longitudinal markings (lane lines, edge lines, and center lines) required by the MUTCD are included in this analysis; all other pavement markings (stop lines, yield lines, guidance arrows and chevrons, crosswalks, route indications, raised pavement markings, and optional long-lines) are excluded.

SPREADSHEET PROTOCOL

The final spreadsheet analysis tool consists of a single Microsoft Excel® workbook that contains five worksheets. The worksheet titles are: Mileage, Laneage, Marking Specifications, Intermediate Calculations, and Summary. Within these five worksheets are 17 separate tables that define the various input and output values. Appendix B presents images of key tables of the Microsoft Excel® workbook.

Overview of Worksheets

The spreadsheet program contains five worksheets. It is advisable for the user to review and manipulate the spreadsheets in the order in which they are presented. Note that the table numbers in the spreadsheet are prefixed with an S (spreadsheet) to distinguish them from tables in the body of this report.

Mileage Worksheet

Table S-1 on the mileage worksheet stratifies the nation's rural and urban roadways by functional system classifications. Table S-2, the ownership matrix, summarizes roadway ownership by jurisdiction.

Laneage Worksheet

The laneage worksheet calculates the average number of lanes for each roadway functional classification and the percentage of roadway miles with passing zones. Table S-3 and S-6 require the user to enter average lane counts for subsets of certain classifications. For example, rural interstate highways are broken down into the categories of four lanes, greater than four lanes, and other. The user must enter an average lane count for the category of greater than four lanes.

In Tables S-4, S-5, S-7, and S-8, the user is required to enter average values for the percentage of passing-permitted sections on two- and three-lane roads. These numbers, in turn, are used to determine the required length of pavement marking material for each roadway class.

Marking Specifications Worksheet

The marking specifications worksheet contains cost data for the various pavement marking materials (Table S-9) and their service lives based on various possible minimum retroreflectivity levels (Tables S-10 and S-11). The user must assume service lives for the materials for the case of no minimum standard and enter these assumed values into the cells in Tables S-10 and S-11. These assumed values should be based on the agency's typical practice (in other words, how often the agency would replace the markings in the absence of a retroreflectivity standard).

Intermediate Calculations Worksheet

The intermediate calculations worksheet produces the results of the economic impact calculations, which are presented in the summary worksheet. The intermediate calculations worksheet requires user inputs for the pavement marking materials and the minimum retroreflectivity level.

Summary Worksheet

The summary worksheet provides the overall pavement marking replacement costs for each government jurisdiction level and the sum of all costs nationwide. Costs are provided for three default scenarios, and the impacts (cost changes) and percentage changes with respect to the status quo scenario are provided for the two alternative scenarios.

SPREADSHEET CALCULATION METHODOLOGY

The following section provides a detailed description of the calculation steps employed in the worksheets. Brief explanations are also provided for the default data entered into the spreadsheets' tables.

Figure 1 shows a flow chart of the economic impact spreadsheet's calculation methodology. The italicized items at the top of the chart are the characteristics of each roadway analysis group, which are inputted in the intermediate calculations worksheets. Each box represents one of the five worksheets in the spreadsheet program. As shown in the flow chart, the total pavement marking replacement cost is calculated by determining the center line mileage of roadway in each analysis group, the striping mileage on those roadways, the service life of the marking materials used on those roadways, and the cost of replacing the chosen material.

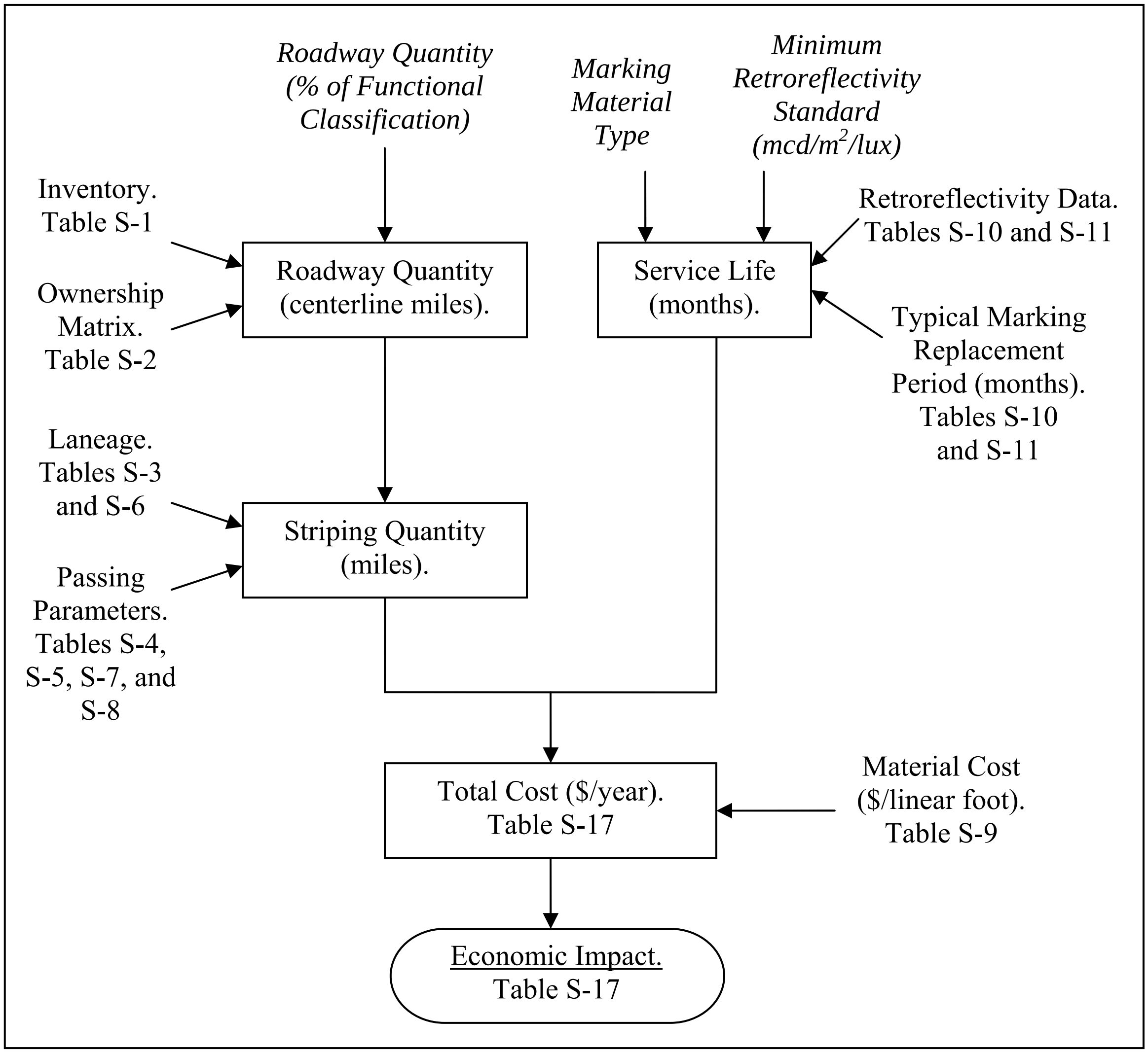

Figure 1. Economic Impact Analysis Methodology.

Default Data Sources

When the spreadsheet program is opened, a default set of data are entered in the various tables. On the mileage worksheet, Tables S-1 and S-2 are populated with values from FHWA's Highway Statistics 2003 Table HM-20 and Table HM-50, respectively (*2*). On the laneage worksheet, Tables S-3 and S-6 contain values from Highway Statistics Table HM-55. The accompanying documentation for Highway Statistics states the following (*12*):

> *"In the past, rounding and expansion related differences were spread across table cells so that all table-to-table length totals on related tables matched precisely. While these steps made all functional system table totals match, an unintended result is that the tables are not reproducible from the data set by any other users. As a result, FHWA decided to discontinue the adjustment and spreading process, and users may note minor differences in table-to-table length totals. For record purposes, FHWA considers the length totals from Table HM-20, Public Road Length, Miles by Functional System, to be the controlling totals should a single value be required."*

To be consistent with this guidance, any equations in this spreadsheet program that require center line mileage totals for a given functional classification are written to reference Table S-1, which is where the data from the Highway Statistics Table HM-20 are contained. Data from other Highway Statistics tables are used to calculate proportions among the functional classifications (for example, the proportions in Tables S-2, S-3, and S-6), and these proportions are then multiplied by the total center line lengths in Table S-1. The actual marking costs are based on the laneage parameters in Tables S-3 to S-8.

On the marking specifications worksheet, pavement marking costs are used from Table 1 of this report and service life data are from the unpublished October 2000 report by Migletz, Graham, et al. (*7*). These default values are relevant for an impact analysis of national scope. Any agency can tailor the scope of the analysis to analyze only the agency's roads by entering the required type of data in each table.

It is worth noting that the analysis of aggregate data compiled from multiple states and other jurisdictions creates inconsistencies in the quality of the aggregate data because of varying policies and practices that affect the accuracy of the estimates. However, using such aggregate data, even with the potential inconsistencies, provides the most appropriate means of evaluating the economic impacts on a national scale.

Roadway Center Line Mileage Inventory

The first step in the economic impact analysis is to categorize and quantify the nation's existing roadway system. Roadway mileage is separated between urban and rural area types in Table S-1 to allow the user to analyze the costs associated with each area type, and to treat the area types with different marking practices if desired. Roadway mileage is stratified by functional classification because each classification has its own requirements for pavement marking practices, based on typical configurations, traffic volumes, and applicable standards from the MUTCD and other documents (*1*, *12*).

Column 3 of Table S-1 shows the percentage of total rural or urban system length for each functional classification. The cells for the "total" rows should display 100 percent; a different value would suggest that one or more of the values entered into column 2 of Table S-1 are incorrect, and the sum of mileage in each functional classification does not add up to the total system mileage. A good inventory data set should categorize and account for all roadway mileage.

Tables 9 and 10 provide a comparison of the percentages in Table S-1 and the functional classification percentages provided in AASHTO's *A Policy on Geometric Design of Highways and Streets* (*Green Book*) for rural and urban roadways, respectively (*13*). The tables show good agreement between the *Green Book* and the Highway Statistics data. These percentages are expected, as the general trend is for roads of higher functional classification to be less abundant but have higher traffic volumes than their lower-classified counterparts. A general rule of thumb, for example, is for freeways to constitute no more than 5 percent of the total roadway capacity in the typical American city, though those freeways carry about half of the total traffic volume. Table S-2 breaks the functional classification mileages down by jurisdictional ownership. This allows the economic impacts among jurisdictions to be identified and separated.

Table 9. Rural Functional Classification Percentages

Functional Classification	Percentage of Total	
	Highway Statistics	Green Book
Interstate	1.1%	2-4%
Principal Arterial	3.2%	
Minor Arterial	4.5%	4-8%
Major Collector	14.0%	20-25%
Minor Collector	8.8%	
Local	68.5%	65-75%
Total	100.0%	100%

Table 10. Urban Functional Classification Percentages

Functional Classification	Percentage of Total	
	Highway Statistics	Green Book
Interstate	1.5%	5-10%
Other Freeway and Expressway	1.0%	
Principal Arterial	6.0%	
Minor Arterial	10.0%	10-15%
Collector	10.3%	5-10%
Local	71.1%	65-80%
Total	100.0%	100%

Laneage Calculations and Counts of Pavement Marking Quantities

The second step in the economic impact analysis is to determine the average lane count in each functional classification, which in turn affects the required number of pavement lines per mile. Laneage data are entered into columns 3 and 4 of Tables S-3 and S-6 for rural and urban roadways, respectively. The lengths entered into column 4 are center line miles. The width groups in column 2 of these tables are based on the stratifications provided in Highway Statistics Table HM-55. The same functional classifications must be used for Tables S-1, S-2, S-3, and S-6. The width groups are coarsely defined; the roadways are split into the groups of "two lanes" and "four or more lanes" for all functional classifications except interstates, which are split into "four lanes" and "more than four lanes."

The laneage values in column 2 of Tables S-3 and S-6 are rough averages, based on engineering judgment. These values and their explanations are provided in Tables 11 and 12. The cells in column 5 of Tables S-3 and S-6 will indicate a value not equal to 100 percent if inaccurate numbers are entered into column 4, resulting in over- or under-counting of center line mileage within a functional classification.

Table 11. Width Groups for Rural Roadways

Functional Classification	Width	Average Lane Count	Reason
Interstate	4 lanes	4	Defined in Highway Stats 2003 Table HM-55
	> 4 lanes	6	Rural interstates seldom exceed six lanes
	Other	2	Defined in Highway Stats 2003 Table HM-55
Principal Arterial	2 lanes	2	Defined in Highway Stats 2003 Table HM-55
	≥ 4 lanes	4	Rural highways seldom exceed four lanes
	Other	3	Rural highways seldom exceed four lanes
Minor Arterial	2 lanes	2	Defined in Highway Stats 2003 Table HM-55
	≥ 4 lanes	4	Rural highways seldom exceed four lanes
	Other	3	Rural highways seldom exceed four lanes
Major Collector	2 lanes	2	Defined in Highway Stats 2003 Table HM-55
	≥ 4 lanes	4	Rural highways seldom exceed four lanes
	Other	3	Rural highways seldom exceed four lanes
Minor Collector	2 lanes	2	Assumed (*2*)
Local	2 lanes	2	Assumed (*2*)

Table 12. Width Groups for Urban Roadways

Functional Classification	Width	Average Lane Count	Reason
Interstate	4 lanes	4	Defined in Highway Stats 2003 Table HM-55
	> 4 lanes	7	Assumed equal amount of 6- and 8-lane roads
	Other	2	Defined in Highway Stats 2003 Table HM-55
Other Freeway and Expressway	2 lanes	2	Defined in Highway Stats 2003 Table HM-55
	≥ 4 lanes	7	Assumed equal amount of 6- and 8-lane roads
	Other	3	Rare; probably atypical configurations
Principal Arterial	2 lanes	2	Defined in Highway Stats 2003 Table HM-55
	≥ 4 lanes	5	Assumed equal amount of 4- and 6-lane roads
	Other	3	Includes 3-lane 2-way roads and 1-way roads
Minor Arterial	2 lanes	2	Defined in Highway Stats 2003 Table HM-55
	≥ 4 lanes	4	Most 6-lane roads would be principal arterials
	Other	3	Includes 3-lane 2-way roads and 1-way roads
Collector	2 lanes	2	Defined in Highway Stats 2003 Table HM-55
	≥ 4 lanes	4	Urban collectors seldom exceed four lanes
	Other	3	Urban collectors seldom exceed four lanes
Local	2 lanes	2	Assumed (*2*)

The user must enter assumptions about passing configurations for two- and three-lane undivided highways in the cells in Tables S-4, S-5, S-7, and S-8. These assumed values require engineering judgment, as data on passing configurations might be difficult to acquire and passing zone policies might vary considerably between jurisdictions. The default assumptions entered into these tables are as follows:

- Two-lane undivided highways
  - 25 percent no passing (double solid yellow line)
  - 50 percent passing in one direction (single solid + single skip yellow line)
  - 25 percent passing in both directions (single skip yellow line)
- Three-lane undivided highways
  - 25 percent no passing (double solid yellow line)
  - 75 percent passing in one direction (single solid + single skip yellow line)

Intermediate calculations on striping mileage quantities are also shown on the laneage worksheet. These calculations determine how many miles of yellow and white pavement marking material are required per center line roadway mile for each functional classification.

The quantities labeled as “mi-%” on the laneage worksheet are used in the total cost calculations. The “mi-%” quantities yield the total length of the relevant color pavement marking for a given functional classification when multiplied by the center line mileage of that classification. The final calculation for total cost (which occurs on the calculations worksheet) references the length values in Table S-1, again because FHWA considers the data from Highway Statistics Table HM-20 to be most accurate (*2*).

Material Cost and Service Life Considerations

Table S-9 on the marking specifications worksheet contains pavement marking material cost data, broken down by governmental jurisdiction. The values in Table S-9 can be altered by an agency wishing to make an analysis of its own costs incurred by a minimum retroreflectivity standard.

Tables S-10 and S-11 contain service life data for white and yellow marking materials, respectively. The data from Migletz, Graham, et al., show that marking service life varies by roadway type and speed (*7*). The three speed groups used in their study are freeway, non-freeway ≥ 45 mph, and non-freeway ≤ 40 mph. These groups are consistent with the first of three speed groups suggested in the FHWA research (*8*), but not with the functional classifications used in Highway Statistics. Thus, it is necessary to place roadways from the functional classifications into the speed groups by assuming typical speed values for roads in each functional classification. In the spreadsheet program, the functional classifications are matched with the speed groups as shown in Table 13. For instance, the functional classification of rural interstate was associated with the road/class and speed group of freeway/highway, which has assumed speeds of 60 mph or greater.

Table 13. Functional Classification Matching with Speed Groups

	Functional classification (for roadway inventory data)	Road Class and Speed Groups (for service life data)		
		Freeway/Highway	Non-freeway	Non-freeway
		≥ 60 mph (high speed)	45-55 mph (moderate speed)	≤ 40 mph (low speed)
Rural	Interstate	X		
	Other principal arterial	X		
	Minor arterial		X	
	Major collector			X
Urban	Interstate	X		
	Other freeway & expressway	X		
	Other principal arterial		X	
	Minor arterial			X
	Collector			X

The third column in Tables S-10 and S-11 is populated with cells where the user enters "typical practice" service lives for each marking material. These values are the typical time periods for which agencies will use pavement markings before replacing them, in the absence of a minimum retroreflectivity standard. These values will likely vary significantly between agencies, so the user is encouraged to adjust the numbers based on his agency's typical practice.

Migletz, Graham, et al., did not provide service life data for some material/speed group combinations due to a lack of suitable study sites for those combinations. In these cases, the service life values for the next-highest speed group for which data are available are substituted. Pavement markings will likely retain their retroreflectivity the same amount of time, if not longer, on roads with lower operating speeds. Since no data were available for the service life of yellow waterborne paint markings, a service life of 12 months was assumed, based on the typical agency practice of replacing waterborne paint markings annually (*3*).

Total Cost and Economic Impact of Retroreflectivity Standard

The intermediate calculations worksheet contains three tables. The first one shows the calculations for pavement marking costs if no minimum retroreflectivity standard is adopted (status quo). The other two show alternative scenarios with minimum retroreflectivity standards adopted. The alternative scenarios assume pavement marking management techniques that use the same materials as in the status quo scenario, but replacing them more often as required to maintain the minimum standard (alternative 1); and using more expensive, longer-lasting materials than those selected in the status quo scenario (alternative 2). In this manner, it is possible to do a single analysis that compares two analysis scenarios to the status quo. The intermediate calculations tables are not included in Appendix B.

Two more assumptions are made in the calculation methodology. First, the same replacement costs are used in all three scenarios. Theoretically, increased rates of pavement marking replacement could impose strains in the supply of marking materials and/or labor, thereby temporarily driving costs up. It is uncertain whether the increased rate of pavement marking replacement under the alternative scenarios would be sufficient to cause such cost increases. It is also possible that an increase in replacement rates would cause pavement marking costs to eventually decrease due to improved efficiencies in production and delivery. Second, the roadways classified as being under “other” jurisdictions are excluded from the analysis. These roadways constitute a small portion of the nation’s total mileage (1.8 percent of rural mileage and 1.4 percent of urban mileage) and their actual jurisdiction is unclear. The footnotes for Highway Statistics Table HM-50 state that jurisdictions for the roadways in the “other” category can include state parks, state toll agencies, other state agencies, other local agencies, and unidentified (probably unknown) jurisdictions.

Summary of Costs and Impacts

Tables S-12, S-13, and S-14 output the pavement marking replacement costs for rural roadways, urban roadways, and all roadways, respectively. Costs are shown for each level of governmental agency, for all levels, and for state/local agencies (federal agencies are excluded from this category). In each table, column 2 provides costs for the status quo scenario, columns 3-5 provide costs and impacts (cost changes) for alternative 1, and columns 6-8 provide costs and impacts for alternative 2. The cost of implementing minimum levels of marking retroreflective is simply the difference between the alternative and status quo scenarios.

CHAPTER 4:
IMPACTS ASSESSMENT

After developing the spreadsheet analysis tool, the researchers developed a series of scenarios to assess the potential economic impacts of minimum retroreflectivity levels. The scenarios were developed by changing three variables in the analysis: the type of marking material(s), the cost of the marking material(s), and the assumed minimum retroreflectivity level. Each scenario included a status quo cost (impacts without the minimum retroreflectivity level) and the resulting cost associated with implementing minimum retroreflectivity levels.

There were two basic groups of scenarios: those that used only one material and those that included a combination of materials. The scenarios characterized with only one material included waterborne paint, thermoplastic, epoxy, and tape. The tool includes the capability to analyze other materials as well. The scenarios that analyzed a combination of materials were based on a high percentage of a durable material (80 or 90 percent, depending upon the roadway type), 10 percent waterborne paint, and 10 percent tape on high-speed urban roads. The combination of materials scenarios are intended to represent the situations where state transportation agencies primarily use a durable material on the rural high-speed roadways on the state system and primarily use a durable material and some tape products on urban freeways and expressways. The lower speed rural and urban roadways are considered to be primarily under the jurisdiction of local agencies where there is a greater use of waterborne paint for markings. Table 14 summarizes the distribution of materials in these scenarios. Separate scenarios were analyzed using thermoplastic and epoxy as the durable materials. Table 15 shows the results of the economic analyses.

Table 14. Material Percentages for Combination of Materials Scenarios

Rural Roads		**Urban Roads**	
Material Usage	**Road Types**	**Material Usage**	**Road Types**
90% Durable 10% Waterborne Paint	Interstate Other principal arterial	80% Durable 10% Waterborne Paint 10% Tape	Interstate Other freeway and expressway
50% Durable 50% Waterborne Paint	Minor arterial Major collector	50% Durable 50% Waterborne Paint	Other principal arterial Minor arterial Collector

Table 15. Economic Analysis Results

Material Scenario	Retro Level	Cost Level	Annual Cost: Status Quo (× 1,000,000)	Annual Cost: with Minimum R_L Levels (× 1,000,000)	Annual Impact (× 1,000,000)
100% Epoxy	Low	Low	$677	$615	($62)
100% Epoxy	Base	Low	$677	$730	$53
100% Epoxy	High	Low	$677	$974	$297
100% Epoxy	Low	Base	$903	$821	($82)
100% Epoxy	Base	Base	$903	$974	$71
100% Epoxy	High	Base	$903	$1,298	$395
100% Epoxy	Low	High	$1,128	$1,026	($103)
100% Epoxy	Base	High	$1,128	$1,217	$89
100% Epoxy	High	High	$1,128	$1,623	$494
100% Thermoplastic	Low	Low	$699	$670	($29)
100% Thermoplastic	Base	Low	$699	$798	$98
100% Thermoplastic	High	Low	$699	$995	$295
100% Thermoplastic	Low	Base	$932	$894	($39)
100% Thermoplastic	Base	Base	$932	$1,063	$131
100% Thermoplastic	High	Base	$932	$1,326	$394
100% Thermoplastic	Low	High	$1,165	$1,117	($48)
100% Thermoplastic	Base	High	$1,165	$1,329	$164
100% Thermoplastic	High	High	$1,165	$1,658	$492
100% Waterborne	Low	Low	$447	$447	$0
100% Waterborne	Base	Low	$447	$447	$0
100% Waterborne	High	Low	$447	$460	$13
100% Waterborne	Low	Base	$596	$596	$0
100% Waterborne	Base	Base	$596	$596	$0
100% Waterborne	High	Base	$596	$613	$17
100% Waterborne	Low	High	$745	$745	$0
100% Waterborne	Base	High	$745	$745	$0
100% Waterborne	High	High	$745	$767	$22
Epoxy Combination	Low	Low	$634	$631	($3)
Epoxy Combination	Base	Low	$634	$726	$92
Epoxy Combination	High	Low	$634	$925	$291
Epoxy Combination	Low	Base	$845	$841	($5)
Epoxy Combination	Base	Base	$845	$967	$122
Epoxy Combination	High	Base	$845	$1,233	$388
Epoxy Combination	Low	High	$1,057	$1,051	($6)
Epoxy Combination	Base	High	$1,057	$1,209	$152
Epoxy Combination	High	High	$1,057	$1,541	$485
Thermoplastic Combination	Low	Low	$661	$667	$5
Thermoplastic Combination	Base	Low	$661	$772	$111
Thermoplastic Combination	High	Low	$661	$934	$273
Thermoplastic Combination	Low	Base	$881	$888	$7
Thermoplastic Combination	Base	Base	$881	$1,028	$147
Thermoplastic Combination	High	Base	$881	$1,244	$363
Thermoplastic Combination	Low	High	$1,102	$1,110	$9
Thermoplastic Combination	Base	High	$1,102	$1,286	$184
Thermoplastic Combination	High	High	$1,102	$1,556	$454

The economic analysis results indicated in Table 15 should be interpreted with caution. There are assumptions associated with the calculations that could have an impact on the results. For instance:

- It is difficult to know what percentage of existing pavement markings at any time would have retroreflectivity levels at or below hypothetical minimum levels. Therefore, the analysis in this report is based on the comparison of calculated annual pavement marking expenditures using assumptions regarding the status quo of pavement marking maintenance practices and then changing the assumptions so that assumed minimum pavement marking retroreflectivity levels could be maintained.
- The results do not include costs associated with the development of pavement marking management systems, the costs associated with assessing the current condition of an agency's markings, the costs to measure markings, or additional indirect costs above and beyond the costs considered in this report.
- For analyses purposes, the calculations described in this report are based on required longitudinal pavement markings as defined by the MUTCD warrants.
- All pavement markings were assumed to be 4 inches wide and lane line patterns were assumed to be 10 ft stripe with a 30 ft gap.
- Pavement marking costs are based on several sources ranging from published research to agency supplied annual pavement marking expenditure estimates. The costs represent contractor-installed costs. The costs used in this report are assumed to representative of costs from 2005 to 2007. There is a wide range of factors that lead to variability in pavement marking costs.
- Pavement marking degradation was based on a model developed in earlier FHWA-sponsored research. For this report, the model was assumed representative of national conditions. There is a wide range of factors that contribute to variability in pavement marking degradation rates. For instance, weather conditions and winter maintenance activities in the northern states can have a significant impact on the pavement marking materials used and their durability.
- The FHWA has not yet established minimum pavement marking retroreflectivity levels. The assumed minimum values used in this report are based on a meta-analysis of the currently available recommendations.

In addition, there are several important elements of the analysis that should be considered when determining the impacts of implementation of minimum pavement marking retroreflectivity guidelines. For example, some of these factors include:

- There are several highly variable elements associated with pavement markings that will influence the economic costs of implementing marking retroreflectivity, and many of these elements cannot be addressed in an aggregate analysis of national pavement marking implementation costs. Some of these elements include:
    - The service life of a given marking material can vary significantly from one part of the country to another. There are many different factors that can account for the difference in service life, including:

    - The quality of installation and the associated inspection affect both service life and marking cost. Agencies that closely inspect markings tend to obtain greater life from those markings, but typically pay more for them.
    - An agency's specifications can impact the service life of pavement markings. Unlike traffic sign retroreflective sheeting, which is manufactured in only a few grades with little variability between grades, pavement markings are a product that are manufactured on-site as they are applied. For instance, specifications that define the raw materials used in the binder and the application procedures can create the potential for a wide range of retroreflective performance.
- There are an unlimited number of potential scenarios that could be analyzed to evaluate the economic impact of minimum retroreflectivity guidelines. The analysis is limited to a limited number of representative scenarios that are intended to represent costs on a national basis.
- The economic analysis results are based on a defined set of material usage. The selection of materials is not intended to represent the material use at any one agency. Furthermore, there is not sufficient information available on a national basis to define overall material use by agency and road type to provide material use that is representative of the entire country. The material usage scenarios selected for analysis provide insight into how implementation costs might vary by material combinations. As with the service life and cost information, any one agency may use materials and/or material combinations that are different from those used in the analysis. The scenarios that assume 100 percent of a given material are obviously not applicable to the country as a whole, but have value in that they represent the impacts that would be associated if such materials were used across the country.
- The scenarios based on the lower retroreflectivity levels for the 100 percent durable materials show a cost savings associated with implementation of minimum retroreflectivity. These results indicate that the minimum retroreflectivity levels are below those associated with the current replacement of these markings, even though replacement may not be based on actual retroreflectivity measurements. These scenarios imply that the current materials could remain in place longer than the current practice.
- The annual impacts shown in the table provide a direct comparison of the costs associated with implementing the minimum retroreflectivity guidelines for a defined set of materials. One of the possibilities is that agencies may change material selection because of the minimum retroreflectivity guidelines. It is possible to assess the economic impacts of such factors by using the status quo costs for one material combination and comparing the implementation costs for a different combination. For example, assuming base minimum retroreflectivity levels and base costs, an agency that uses 100 percent thermoplastic now could save $35 million by going to a thermoplastic combination instead of maintaining a 100 percent thermoplastic policy.
- The analysis procedure assumes a maximum service life of 12 months for waterborne pavement markings. As a result, the annual impacts for the low and base retroreflectivity levels are zero, as the retroreflectivity replacement levels are below the levels that would be expected at the end of 12 months. However, the higher retroreflectivity levels would shorten the life of waterborne markings to less than 12 months, resulting in a small annual increase in costs.

- The analysis does not consider the impacts of the striping season in areas with winter weather. In some of these areas, agencies stripe twice a year (as soon as possible in the spring and as late as possible in the fall) because their winter maintenance activities and operations are so severe that maintaining pavement marking presence, let alone retroreflectivity, through the winter months is difficult (with surface applied pavement marking materials). This report does not attempt to address the costs associated with in-laid pavement markings materials.
- The analysis procedure does not consider the costs associated with the administrative aspects of implementing minimum retroreflectivity levels. It would be expected that agencies would incur some costs associated with putting a pavement marking management system in place. These costs would include factors such as the retroreflectivity measurement, record-keeping, and contract administration. There are no data that would indicate what this cost would be on a national basis.
- The annual impact of implementing minimum retroreflectivity levels is assumed to be the same each year of the seven year analysis period because pavement markings have a life of less than seven years.
- The FHWA research recommendations for minimum retroreflectivity provide for lower minimum levels if RRPMs or lighting are used (*8*). However, the analysis does not consider the impacts of retroreflective raised pavement markers (RRPMs) or roadway lighting on the implementation of minimum retroreflectivity levels due to a lack of data that indicate the percentage of roads that the lower retroreflectivity levels would apply to.

CHAPTER 5: CONCLUSIONS

The analysis described in this report provides an estimate for the national impact of the proposed rule for minimum maintained pavement marking retroreflectivity. The analysis is based on the comparison of calculated annual pavement marking expenditures using assumptions regarding the status quo of pavement marking maintenance practices and then changing the assumptions so that assumed minimum pavement marking retroreflectivity levels could be maintained. There were a total of 45 different scenarios considered in the analyses. The analyses were not intended to cover all possible conditions or future pavement marking management practices that may be implemented as a result of minimum pavement marking retroreflectivity levels. Rather, the analyses show the broad range of economic impacts depending on various assumptions regarding the factors considered in the spreadsheet analysis.

Using the mid-range of assumed pavement marking costs and minimum retroreflectivity levels, the analyses described in this report show that the impacts range from $0 to almost $150 million per year, depending on the assumed type or combination of pavement marking materials used in the analysis. Using the high end of the range of assumed pavement marking cost and minimum retroreflectivity levels, the impacts could range from $21 million to almost $500 million per year. Using the low end of the range of assumed pavement marking cost and minimum retroreflectivity levels, the impacts could range from $5,000,000 to an actual savings of approximately $64 million per year.

The single direct impact of the proposed rule is the increased cost to agencies of using more durable pavement marking materials. Indirect costs of establishing and operating a pavement marking management system were not included in the calculations.

In the future, it would be beneficial to conduct a national assessment of the condition of pavement markings so that a more powerful economic impacts analysis can be completed. The effort should cover all functional classes of roadways under varying degrees of jurisdiction. It should also include condition assessments of pavement markings in northern climates where winter maintenance activities exist for several months of the year. Having such data would provide an opportunity to recompute the economic impacts of pavement markings, thus providing estimates of the costs with fewer assumptions.

CHAPTER 6:
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APPENDIX A:
ROADWAY STRIPING CONFIGURATIONS

Figure 2. Rural Interstate, Urban Interstate, Urban Other Freeway and Expressway Striping Configuration.

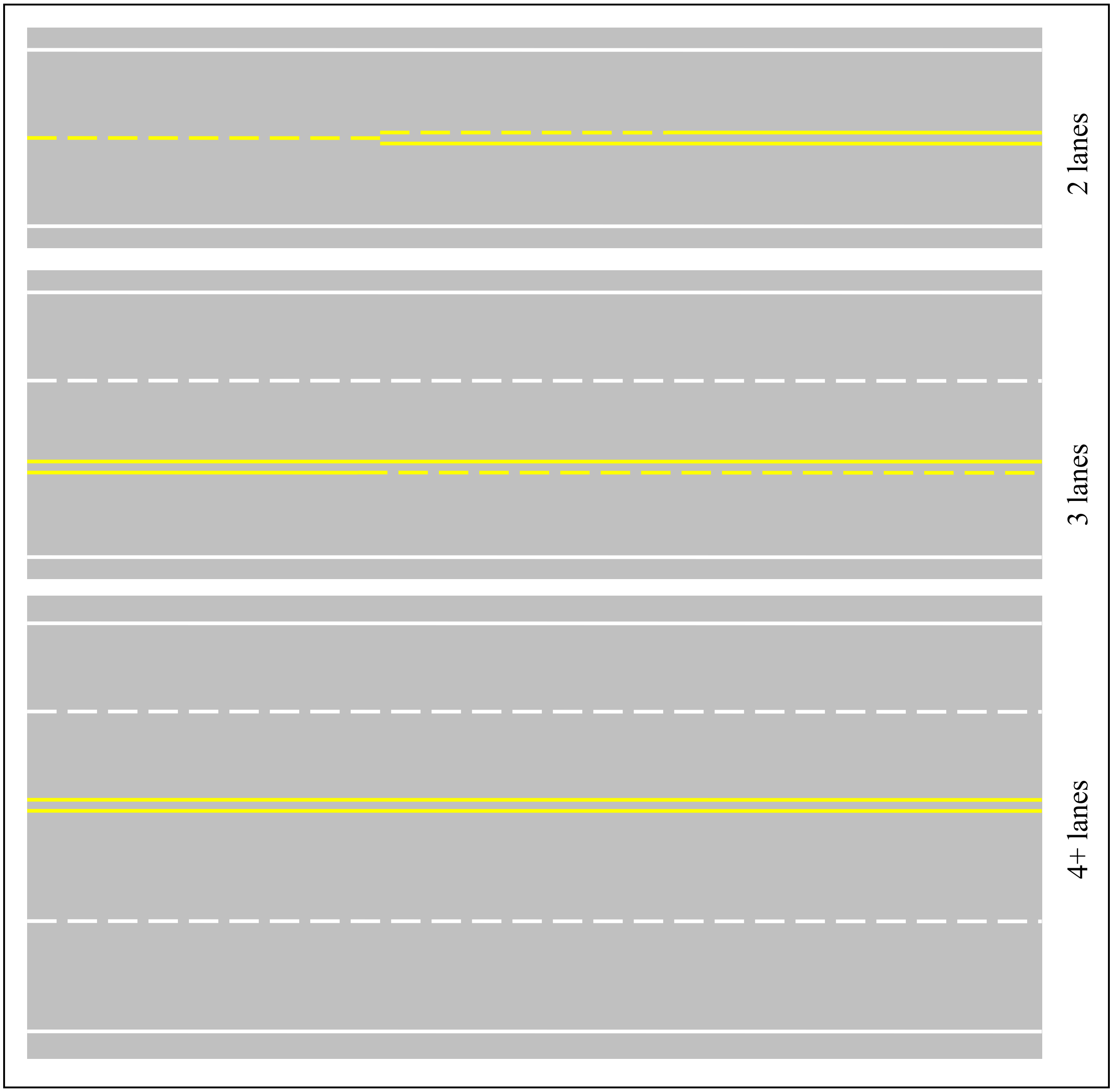

Figure 3. Rural Principal Arterial Striping Configuration.

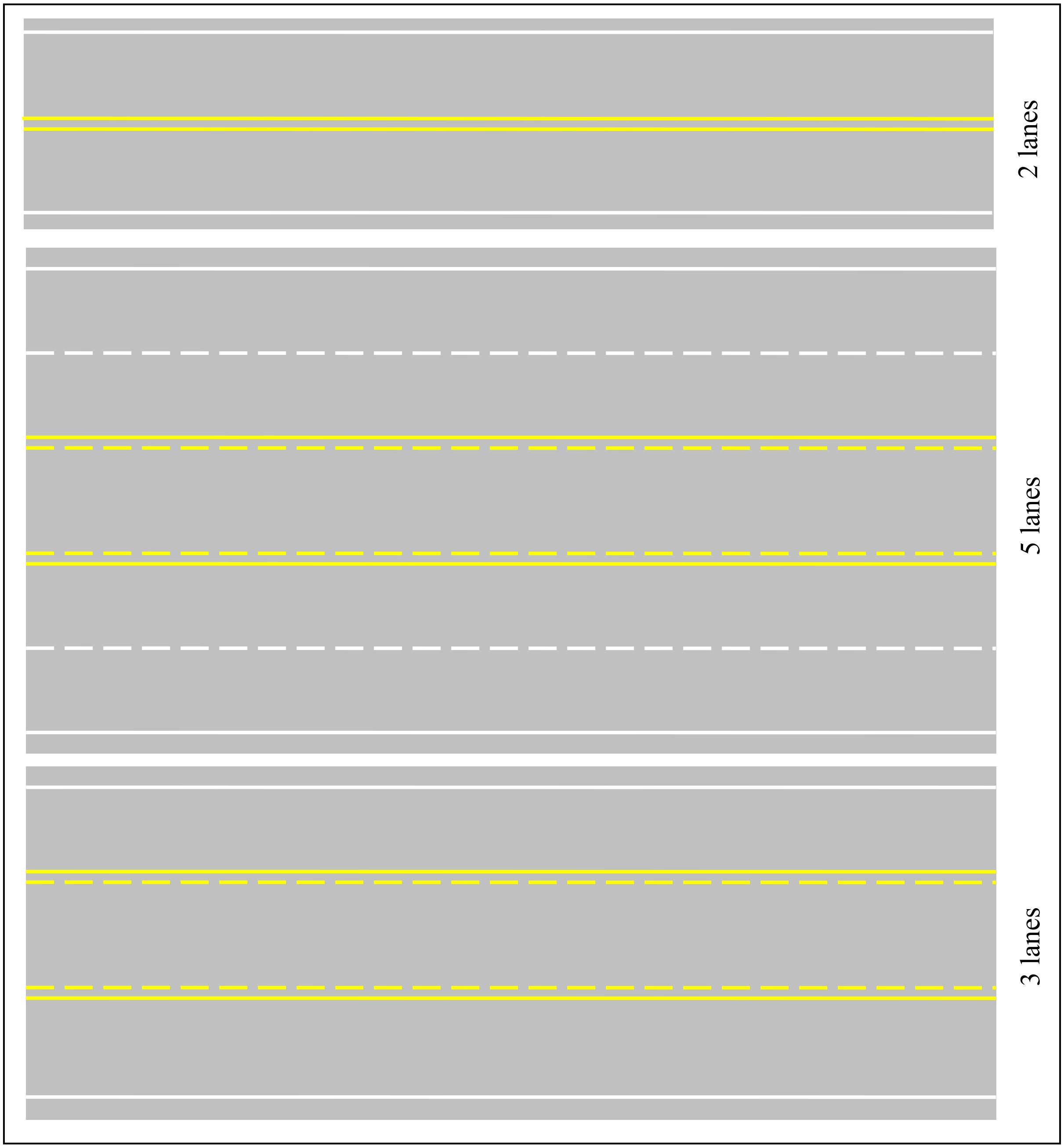

Figure 4. Urban Principal Arterial Striping Configuration.

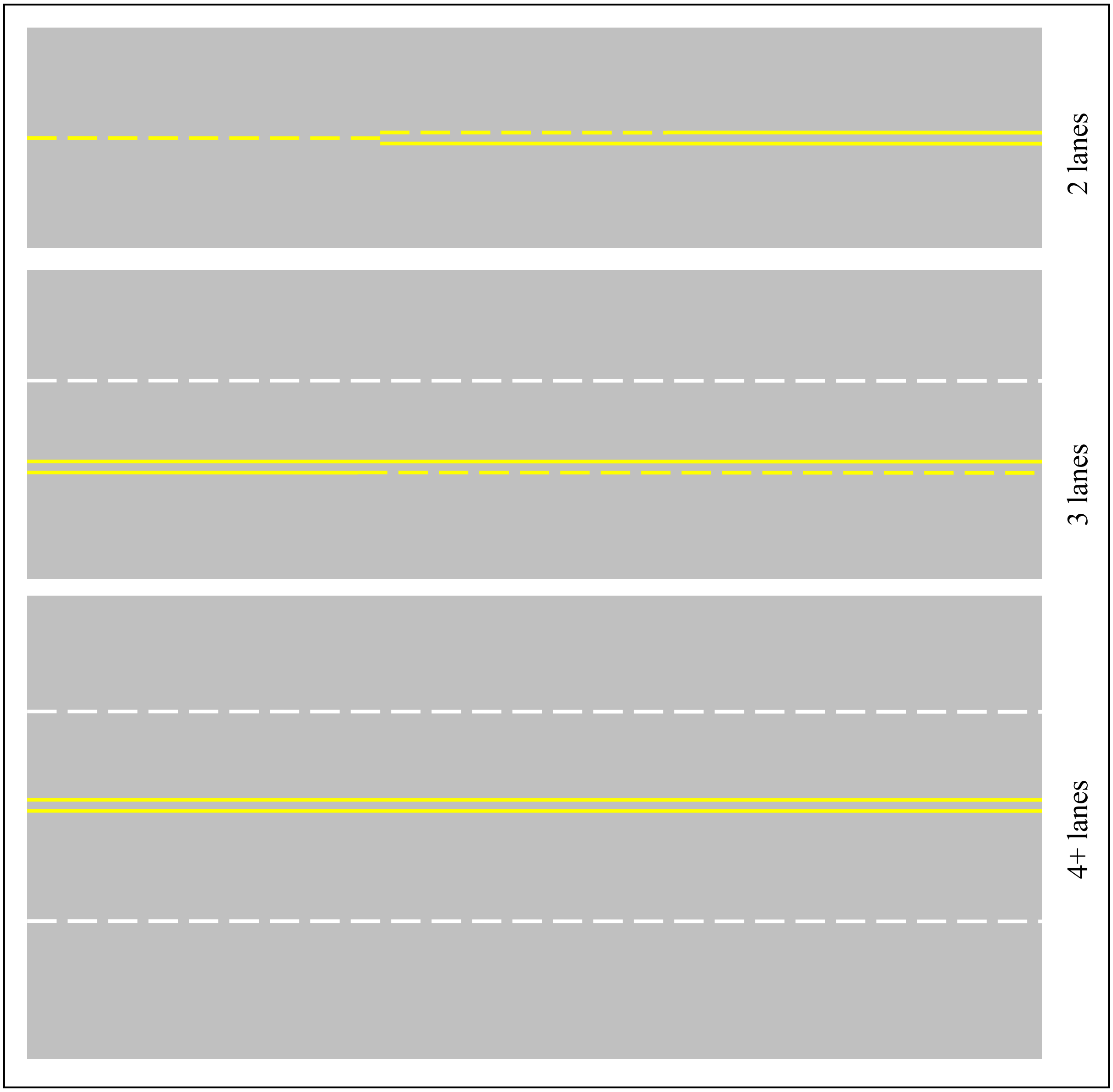

Figure 5. Rural Minor Arterial Striping Configuration.

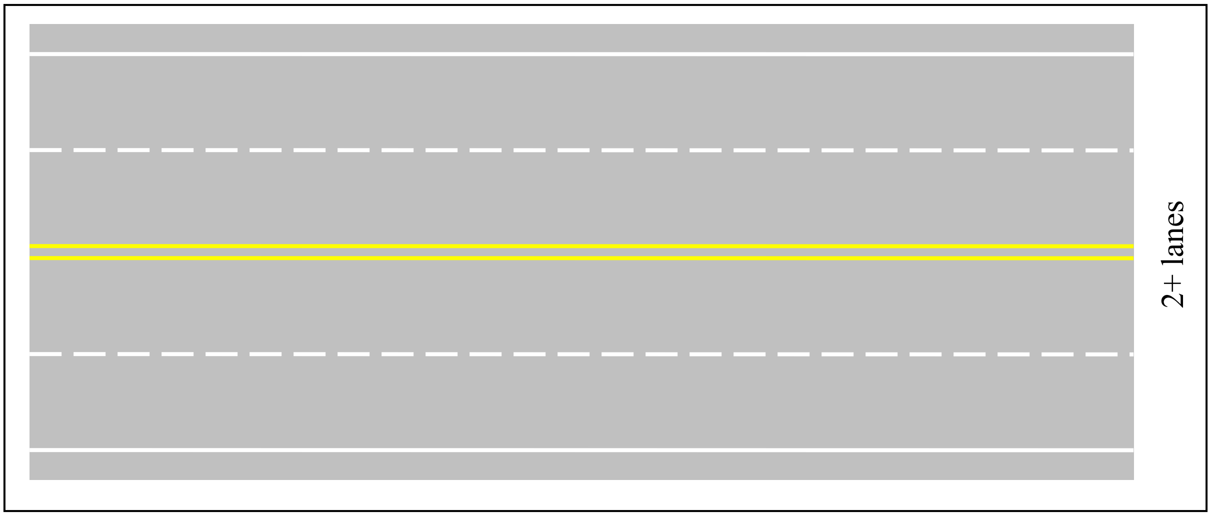

Figure 6. Urban Minor Arterial Striping Configuration.

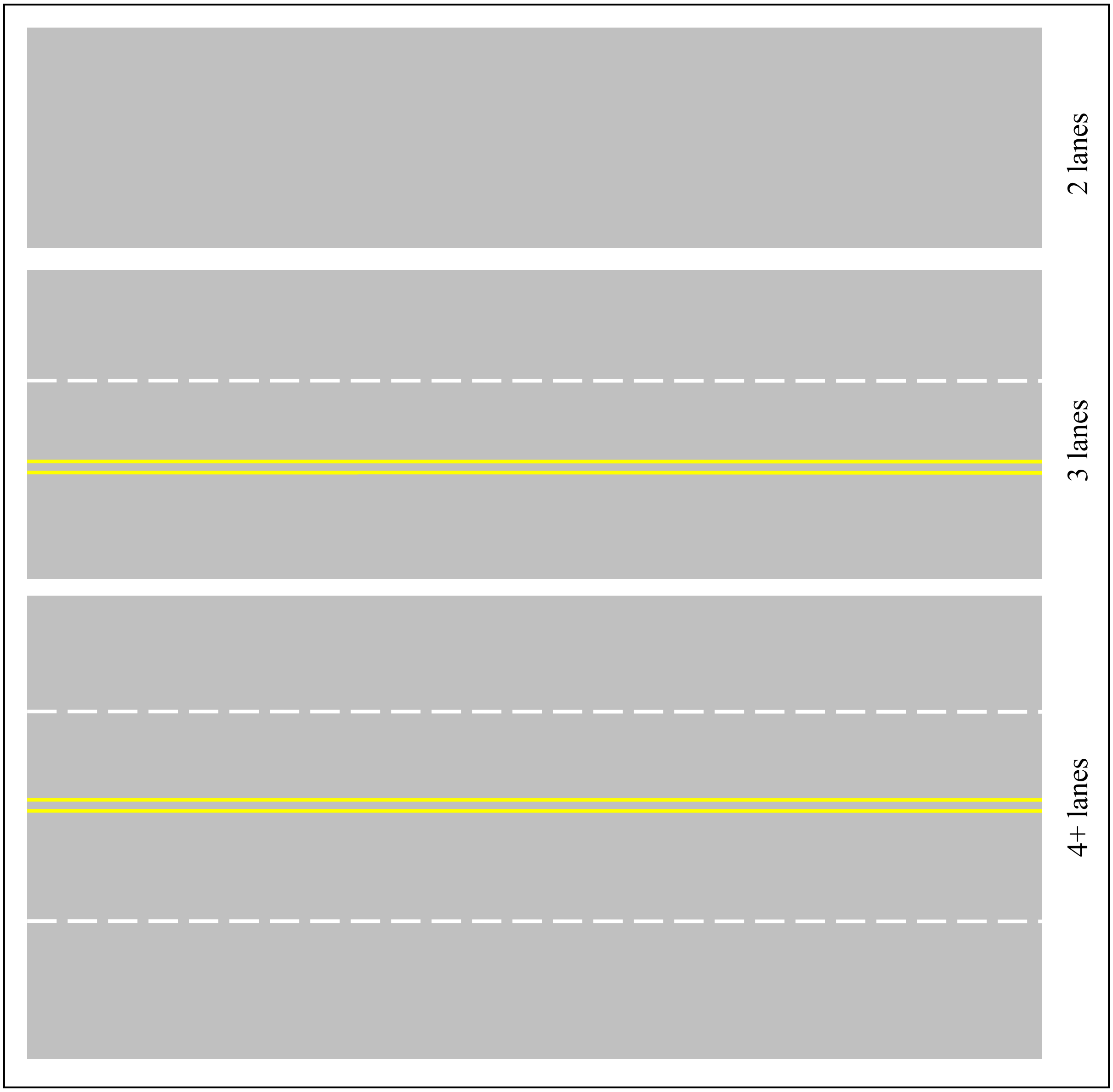

Figure 7. Rural Major Collector and Urban Collector Striping Configuration.

APPENDIX B:
ECONOMIC ANALYSIS SPREADSHEET

The following pages present the individual worksheets of the analysis spreadsheet tool. The worksheets shown are those for the base retroreflectivity and base cost associated with the thermoplastic combination scenario.

Table S-1. Functional System Inventory.

Rural (US totals)	Length (mi)	% of total
Interstate	32,048	1.1%
Principal arterial	97,038	3.2%
Minor arterial	135,596	4.5%
Major collector	424,288	14.0%
Minor collector	267,524	8.8%
Local	2,076,644	68.5%
Total	3,033,138	100%
Urban (US totals)	Length (mi)	% of total
Interstate	14,460	1.5%
Other fwy & expwy	9,870	1.0%
Principal arterial	56,870	6.0%
Minor arterial	93,888	10.0%
Collector	97,114	10.3%
Local	668,767	71.1%
Total	940,969	100%

Source:
Highway Statistics 2003, Table HM-20

Table S-2. Functional System Ownership Matrix.

Rural (US totals, mi)	Federal	State	County	City	Other	Total	% of class
Interstate		30,608			1,439	32,047	100%
Principal arterial	135	96,095	323	84	397	97,034	100%
Minor arterial	1,376	128,416	5,239	480	87	135,598	100%
Major collector	4,647	192,078	216,137	9,526	1,906	424,294	100%
Minor collector	8,088	65,528	179,608	12,177	2,120	267,521	100%
Local	105,966	139,802	1,222,477	558,564	49,843	2,076,652	100%
Total	120,212	652,527	1,623,784	580,831	55,792	3,033,146	100%
Rural (US, % of row total)	Federal	State	County	City	Other	Total	
Interstate	0.0%	95.5%	0.0%	0.0%	4.5%	100.0%	
Principal arterial	0.1%	99.0%	0.3%	0.1%	0.4%	100.0%	
Minor arterial	1.0%	94.7%	3.9%	0.4%	0.1%	100.0%	
Major collector	1.1%	45.3%	50.9%	2.2%	0.4%	100.0%	
Minor collector	3.0%	24.5%	67.1%	4.6%	0.8%	100.0%	
Local	5.1%	6.7%	58.9%	26.9%	2.4%	100.0%	
Urban (US totals, mi)	Federal	State	County	City	Other	Total	% of class
Interstate		13,387			1,075	14,462	100%
Other fwy & expwy	58	8,951	100	261	498	9,868	100%
Principal arterial	93	38,612	3,817	14,100	252	56,874	100%
Minor arterial	206	26,171	19,269	47,794	451	93,891	100%
Collector	102	14,083	21,094	61,460	377	97,116	100%
Local	3,101	18,832	112,314	523,832	10,690	668,769	100%
Total	3,560	120,036	156,594	647,447	13,343	940,980	100%
Urban (US, % of row total)	Federal	State	County	City	Other	Total	
Interstate	0.0%	92.6%	0.0%	0.0%	7.4%	100.0%	
Other fwy & expwy	0.6%	90.7%	1.0%	2.6%	5.0%	100.0%	
Principal arterial	0.2%	67.9%	6.7%	24.8%	0.4%	100.0%	
Minor arterial	0.2%	27.9%	20.5%	50.9%	0.5%	100.0%	
Collector	0.1%	14.5%	21.7%	63.3%	0.4%	100.0%	
Local	0.5%	2.8%	16.8%	78.3%	1.6%	100.0%	

Source:
Highway Statistics 2003, Table HM-50

Table S-3. Rural Highway Laneage Parameters.

Rural (US totals)	Width	Avg. lane count	Length (mi)	% of class
Interstate	4 lanes	4	29,142	91.2%
	> 4 lanes	6	1,768	5.5%
	Other	2	1,035	3.2%
	Total		31,945	100%
Principal arterial	2 lanes	2	68,199	70.3%
	≥ 4 lanes	4	23,801	24.5%
	Other	3	4,984	5.1%
	Total		96,984	100%
Minor arterial	2 lanes	2	128,314	94.6%
	≥ 4 lanes	4	4,159	3.1%
	Other	3	3,117	2.3%
	Total		135,590	100%
Major collector	2 lanes	2	420,685	99.2%
	≥ 4 lanes	4	1,651	0.4%
	Other	3	1,919	0.5%
	Total		424,255	100%
Minor collector*	2 lanes	2	267,524	100%
Local*	2 lanes	2	2,076,644	100%

Source:
Highway Statistics 2003, Table HM-55

*: Width of 2 lanes is assumed for all roads in this class

Table S-4. Rural Two-Lane Highway Passing Parameters.

Roadway class	Passing on 2-lane section			
	None	1 direction	2 directions	Total
Principal arterial	25%	50%	25%	100%
Minor arterial	25%	50%	25%	100%

Table S-5. Rural Three-Lane Highway Passing Parameters.

Roadway class	Passing on 3-lane section		
	None	1 direction	Total
Principal arterial	25%	75%	100%
Minor arterial	25%	75%	100%

Table S-6. Urban Highway Laneage Parameters.

Urban (US totals)	Width	Avg. lane count	Length (mi)	% of class
Interstate	4 lanes	4	6,766	47.4%
	> 4 lanes	7	7,465	52.3%
	Other	2	56	0.4%
	Total		14,287	99%
Other fwy & expwy	2 lanes	2	376	3.8%
	≥ 4 lanes	7	9,193	93.8%
	Other	3	236	2.4%
	Total		9,805	99%
Principal arterial	2 lanes	2	19,165	33.8%
	≥ 4 lanes	5	21,564	38.1%
	Other	3	15,903	28.1%
	Total		56,632	100%
Minor arterial	2 lanes	2	65,717	70.2%
	≥ 4 lanes	4	11,403	12.2%
	Other	3	16,460	17.6%
	Total		93,580	100%
Collector	2 lanes	2	88,175	91.3%
	≥ 4 lanes	4	2,607	2.7%
	Other	3	5,790	6.0%
	Total		96,572	99%
Local*	2 lanes	2	668,767	100%

Source:
Highway Statistics 2003, Table HM-55

*: Width of 2 lanes is assumed for all roads in this class

Table S-7. Urban Two-Lane Highway Passing Parameters.

Roadway class	Passing on 2-lane section			
	None	1 direction	2 directions	Total
Minor arterial	25%	50%	25%	100%

Table S-8. Urban Three-Lane Highway Passing Parameters.

Roadway class	Passing on 3-lane section		
	None	1 direction	Total
Minor arterial	25%	75%	100%

Intermediate calculations

	stripe mi/road mi		mi-%	
Rural	Yellow	White	Yellow	White
	2.00	2.50	1.8245	2.2806
	2.00	3.00	0.1107	0.1660
	2.00	2.00	0.0648	0.0648
Interstate			2.0000	2.5115
	1.19	2.00	0.8350	1.4064
	2.00	2.50	0.4908	0.6135
	1.44	2.25	0.0739	0.1156
Principal arterial			1.3997	2.1356
	1.19	0.00	1.1238	0.0000
	2.00	0.50	0.0613	0.0153
	1.44	0.25	0.0330	0.0057
Minor arterial			1.2182	0.0211
	0.00	0.00	0.0000	0.0000
	2.00	0.50	0.0078	0.0019
	2.00	0.25	0.0090	0.0011
Major collector			0.0168	0.0031

	stripe mi/road mi		mi-%	
Urban	Yellow	White	Yellow	White
	2.00	2.50	0.9472	1.1839
	2.00	3.25	1.0450	1.6981
	2.00	2.00	0.0078	0.0078
Interstate			2.0000	2.8899
	2.00	2.00	0.0767	0.0767
	2.00	3.25	1.8752	3.0471
	2.00	2.25	0.0481	0.0542
Other fwy & expwy			2.0000	3.1780
	2.00	2.00	0.6768	0.6768
	2.50	2.50	0.9519	0.9519
	2.50	2.00	0.7020	0.5616
Principal arterial			2.3308	2.1904
	1.19	2.00	0.8339	1.4045
	2.00	2.50	0.2437	0.3046
	1.44	2.25	0.2528	0.3958
Minor arterial			1.3305	2.1049
	0.00	0.00	0.0000	0.0000
	2.00	0.50	0.0540	0.0135
	2.00	0.25	0.1199	0.0150
Collector			0.1739	0.0285

Table S-9. Pavement Marking Material Costs.

Material	Code	Cost ($/linear ft) for jurisdiction *			
		Federal	State	County	City
Epoxy	EPX	$0.30	$0.30	$0.60	$0.60
Methyl Methacrylate	MMA	$1.25	$1.25		
Methyl Methacrylate (profiled)	MMP				
Polyester	PLY				
Tape (profiled)	TPP	$2.75	$2.75	$3.00	$3.00
Thermoplastic	THM	$0.35	$0.35	$0.50	$0.50
Thermoplastic (profiled)	THP				
Waterborne Paint	WBP	$0.06	$0.06	$0.15	$0.15

Source:
NCHRP Synthesis 306, Table 39

*: Federal costs assumed to be same as state costs

Table S-10. White Pavement Marking Material Service Life.

Freeway		Typical	Service Life (mo) for RL_{min}							
Material	Code	practice	30	35	70	85	100	125	150	
Epoxy	EPX	36	51.9	47.8	27.5	23.7	23.2	18.3	12.8	
Methyl Methacrylate	MMA	36	50.2	47.8	33.5	28.1	22.9	17.7	11.9	
Methyl Methacrylate (profiled)	MMP	36	155.3	148.1	103.4	85.9	68.8	40.8	14	
Polyester	PLY	36	101	97.6	74.3	64.2	54.2	37.5	20.8	
Tape (profiled)	TPP	36	68.2	63.3	40.9	34.5	29	21.3	19.6	
Thermoplastic	THM	36	60.7	58.3	44.8	39.9	35.2	27.6	22.6	
Thermoplastic (profiled)	THP	36	52.6	50.7	39.8	35.5	31.5	24.8	18.4	
Waterborne Paint	WBP	12	12	12	12	12	12	12	10.4	
Non-freeway ≥ 45 mph		Typical	Service Life (mo) for RL_{min}							
Material	Code	practice	30	35	70	85	100	125	150	
Epoxy	EPX	36	71	68	51	44.7	38.8	29.3	20.3	
Methyl Methacrylate	MMA	36	68.1	63.1	40.8	34.5	29.3	21.9	16.2	
Methyl Methacrylate (profiled)	MMP	36	48.4	47.4	40.6	37.7	34.8	30	25	
Polyester	PLY	36	60.8	57.1	38.5	32.6	27.4	17.2	12.6	
Tape (profiled)	TPP	36	62.2	59.2	45.1	40.9	37.3	32.4	27.7	
Thermoplastic	THM	36	58.9	56.4	43.9	40	36.6	32	26.9	
Thermoplastic (profiled)	THP	36	41.7	39.8	30.5	27.5	24.9	20.8	17.3	
Waterborne Paint	WBP	12	12	12	12	12	12	12	10.4	*
Non-freeway ≤ 40 mph		Typical	Service Life (mo) for RL_{min}							
Material	Code	practice	30	35	70	85	100	125	150	
Epoxy	EPX	36	69.1	65.3	45.9	39.4	33.6	24.6	16.5	
Methyl Methacrylate	MMA	36	68.1	63.1	40.8	34.5	29.3	21.9	16.2	**
Methyl Methacrylate (profiled)	MMP	36	48.4	47.4	40.6	37.7	34.8	30	25	**
Polyester	PLY	36	60.8	57.1	38.5	32.6	27.4	17.2	12.6	**
Tape (profiled)	TPP	36	32	31.6	28.3	26.9	25.5	23.2	20.9	
Thermoplastic	THM	36	58.9	56.4	43.9	40	36.6	32	26.9	**
Thermoplastic (profiled)	THP	36	67.2	66.1	58.8	55.7	52.5	47.2	42	
Waterborne Paint	WBP	12	12	12	12	12	12	12	10.4	*

Source:
Migletz, *Evaluation of All-Weather Pavement Markings*, October 2000

*: Assumed to be same as *freeway* values

**: Assumed to be same as *non-freeway ≥ 45 mph* values

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Table S-11. Yellow Pavement Marking Material Service Life.

Freeway		Typical	Service Life (mo) for RL_{min}								
Material	Code	practice	30	45	55	65	70	85	100	125	
Epoxy	EPX	36	63.6	50.3	41.7	33.7	33.9	24.5	23.2	12.8	
Methyl Methacrylate	MMA	36	34.4	30.2	27.4	24.5	22.9	20	15.6	8.3	
Methyl Methacrylate (profiled)	MMP	36	47.3	40.5	36.2	32.5	30.7	25.8	21.1	13.7	
Polyester	PLY	36	68.1	62	57.9	53.9	51.9	45.9	39.7	29.6	
Tape (profiled)	TPP	36	59.7	49.7	43.6	38.9	36.7	30.6	25.8	18.2	
Thermoplastic	THM	36	82.3	68	58.6	49.4	44.8	35.5	24.7	15	
Thermoplastic (profiled)	THP	36	52.6	45.8	41.3	37.2	35.2	29.1	23.5	14.1	
Waterborne Paint	WBP	12	12	12	12	12	12	12	12	12	*
Non-freeway ≥ 45 mph		Typical	Service Life (mo) for RL_{min}								
Material	Code	practice	30	45	55	65	70	85	100	125	
Epoxy	EPX	36	60.6	53.1	48.4	44.1	42.1	36.6	30.6	21.9	
Methyl Methacrylate	MMA	36	45.6	33.3	25.9	20.5	18.1	12	6.5	4.6	
Methyl Methacrylate (profiled)	MMP	36	41.4	36.9	33.9	31	29.5	25.1	20.5	13.1	
Polyester	PLY	36	61	55.4	51.7	47.9	46.1	40.3	34.9	25.4	
Tape (profiled)	TPP	36	43	41.3	40.1	38.9	38.4	36.6	34.9	32	
Thermoplastic	THM	36	52.7	43.7	38.2	33.8	31.8	26.3	21.5	15	***
Thermoplastic (profiled)	THP	36	30.7	27.2	25	23	22.1	19.2	16	14.4	
Waterborne Paint	WBP	12	12	12	12	12	12	12	12	12	*
Non-freeway ≤ 40 mph		Typical	Service Life (mo) for RL_{min}								
Material	Code	practice	30	45	55	65	70	85	100	125	
Epoxy	EPX	36	61.7	50.7	43.9	38.4	35.9	28.9	22.4	12.8	
Methyl Methacrylate	MMA	36	45.6	33.3	25.9	20.5	18.1	12	6.5		**
Methyl Methacrylate (profiled)	MMP	36	41.4	36.9	33.9	31	29.5	25.1	20.5	13.1	**
Polyester	PLY	36	61	55.4	51.7	47.9	46.1	40.3	34.9	25.4	**
Tape (profiled)	TPP	36	21.5	20.4	19.6	18.9	18.5	17.4	16.2	14.4	
Thermoplastic	THM	36	52.7	43.7	38.2	33.8	31.8	26.3	21.5	15	**
Thermoplastic (profiled)	THP	36	64.7	56.3	50.7	45.2	42.4	34	25.7	11.7	
Waterborne Paint	WBP	12	12	12	12	12	12	12	12	12	*

Source:
Migletz, *Evaluation of All-Weather Pavement Markings*, October 2000

*: Assumed to be "typical practice" life of 12 mo
**: Assumed to be same as *non-freeway ≥ 45 mph* values
***: Value for RL_{min}=125 assumed to be same as for *freeway*

Table S-12. Rural Summary.

	Status Quo	Alternative 1			Alternative 2		
Jurisdiction	Cost ($/yr)	Cost ($/yr)	Impact ($/yr)	% Change	Cost ($/yr)	Impact ($/yr)	% Change
Federal	$1,104,331	$1,263,007	$158,676	14%	$1,448,578	$344,247	31%
State	$355,479,585	$454,843,648	$99,364,063	28%	$672,192,929	$316,713,344	89%
County	$9,829,953	$10,509,824	$679,871	7%	$10,981,382	$1,151,429	12%
City	$906,188	$1,020,660	$114,472	13%	$1,143,294	$237,107	26%
Total	$367,320,057	$467,637,139	$100,317,082	27%	$685,766,184	$318,446,126	87%
State/Local	$366,215,726	$466,374,133	$100,158,406	27%	$684,317,606	$318,101,880	87%

Table S-13. Urban Summary.

	Status Quo	Alternative 1			Alternative 2		
Jurisdiction	Cost ($/yr)	Cost ($/yr)	Impact ($/yr)	% Change	Cost ($/yr)	Impact ($/yr)	% Change
Federal	$835,620	$962,784	$127,164	15%	$1,320,729	$485,109	58%
State	$237,006,978	$289,040,938	$52,033,960	22%	$434,377,824	$197,370,846	83%
County	$73,824,656	$72,137,266	-$1,687,389	-2%	$79,808,100	$5,983,444	8%
City	$202,172,645	$198,579,167	-$3,593,477	-2%	$226,654,358	$24,481,713	12%
Total	$513,839,898	$560,720,155	$46,880,257	9%	$742,161,011	$228,321,113	44%
State/Local	$513,004,278	$559,757,372	$46,753,094	9%	$740,840,282	$227,836,004	44%

Table S-14. Rural and Urban Summary.

	Status Quo	Alternative 1			Alternative 2		
Jurisdiction	Cost ($/yr)	Cost ($/yr)	Impact ($/yr)	% Change	Cost ($/yr)	Impact ($/yr)	% Change
Federal	$1,939,951	$2,225,791	$285,840	15%	$2,769,306	$829,355	43%
State	$592,486,563	$743,884,586	$151,398,023	26%	$1,106,570,753	$514,084,190	87%
County	$83,654,609	$82,647,091	-$1,007,519	-1%	$90,789,483	$7,134,873	9%
City	$203,078,832	$199,599,827	-$3,479,005	-2%	$227,797,652	$24,718,820	12%
Total	$881,159,955	$1,028,357,295	$147,197,339	17%	$1,427,927,194	$546,767,239	62%
State/Local	$879,220,004	$1,026,131,504	$146,911,500	17%	$1,425,157,888	$545,937,883	62%