Developing Pavement Marking Management Plans for Accommodating Advanced Vehicle Technologies in Wyoming

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1 Introduction

Pavement markings are fundamental elements of roadway networks. Hence, their maintenance is critical. Currently, the Wyoming Department of Transportation (WYDOT) periodically resurfaces its road pavement markings. Yet, their maintenance procedure is not conducted under a fully-fledged rigorous management program. Furthermore, with the advent of new vehicle technologies such as advanced driver assistance systems (ADAS) and connected/autonomous vehicles (CAVs), pavement marking standards are required to be updated. Such state-of-the-art technologies use machine vision systems, which are algorithms employed to process images from the vehicles' video cameras in order to analyze the surroundings particularly the pavement markings. It is believed that updating pavement marking standards will enhance the ability of machine vision systems when it comes to detecting and identifying the markings. Besides, the National Committee on Uniform Traffic Control Devices (NCUTCD), which suggests amendments to the Manual on Uniform Traffic Control Devices MUTCD (Federal Highway Administration, 2009), American Association of State Highway and Transportation Officials (AASHTO), Society of Automotive Engineers (SAE), Texas Transportation Institute (TTI), Alliance of Automobile Manufacturers (Auto Alliance), which represents the majority of car manufacturers in the nation, and American Traffic Safety Services Association (ATSSA) among other entities provided their input regarding recommended changes to the current pavement marking standards. This is to improve the markings' ability to be recognized by machine vision systems (National Committee on Uniform Traffic Control Devices, 2020; Road Readiness Criteria for Automated Vehicle Technologies, 2020). Remarkably, states, such as California, are implementing the suggested pavement marking specifications even though the upcoming edition of the MUTCD, with the suggestions provided, is yet to be published (Falsetti, 2017; Missouri Department of Transportation, 2019; Principe, 2019). WYDOT is planning to implement the suggested marking specifications and a comprehensive pavement marking management program in the near future. The following subsection comprises a discussion of the objectives of this study while the following sections comprise discussions of NCUTCD's recommended amendments to the current MUTCD, pavement marking practices of other states, especially the ones implementing the suggested marking specifications to accommodate machine vision systems, this study's tasks, timeline for this study and the budget required for this study.

1.1 Objectives

The objectives of this study are to develop strategic long-term pavement marking management plans for Wyoming. Specifically, five- and ten-year plans will be developed considering multiple scenarios having various budget levels. The plans will be developed considering road functional classifications, land uses and traffic volumes, which are all factors that influence the frequency of pavement marking maintenance activities. WYDOT will be implementing a pavement marking retroreflectivity measuring tool to aid in their pavement marking management program. For instance, freeways linking industrial areas are often used by tractor-trailers and thus would require frequent maintenance or durable marking material. On the other hand, two-lane highways characterized by low recreational traffic volumes and heavy vehicle percentages would require less frequent maintenance. Recommendations pertaining to a comprehensive pavement marking management program will be provided in the form of a report as well.

2 National Committee on Uniform Traffic Control Devices' Recommendations

The NCUTCD provides suggestions to the Federal Highway Administration (FHWA) regarding amendments to the MUTCD. As of June 2019, the following recommendations (National Committee on Uniform Traffic Control Devices, 2020), which are those that would facilitate machine vision systems in recognizing pavement markings, are discussed. The first is that longitudinal pavement markings would be six inches wide for expressways, freeways and their connecting ramps. For non-freeways with speed limits of fifty-five miles per hour or higher and average daily traffic volumes of six thousand vehicles per day or higher, edge lines ought to be six inches wide. If such conditions are not satisfied, longitudinal lines are required to be four to six inches wide. In the current MUTCD (Federal Highway Administration, 2009), longitudinal lines may be four to six inches wide regardless of the road's functional classification and traffic volume. Also, wide lines, of which widths are double those of typical longitudinal lines, are suggested to be eight inches or wider when striped in conjunction with four-inch lines and ten inches or wider when striped in conjunction with six-inch lines. Furthermore, NCUTCD recommended a guidance note stating that, for expressways and freeways, broken longitudinal lines be fifteen feet long. The spacing between the lines is suggested to be twenty-five feet. Hence, the combined length of a broken line segment and spacing would be forty feet. Another suggestion is that interchange ramps ought to have dotted line extensions similar to the ones shown in Figures 1 and 2. As shown inFigure 2, the dotted line ought to be extended from the gore point to the upstream beginning point of the taper. This suggestion is also applicable to freeway on-ramp acceleration lanes, auxiliary lanes within weaving freeway segments and intersections with auxiliary lanes. In the current MUTCD, dotted lines of freeway ramps without auxiliary lanes are optional. For freeway ramps having auxiliary lanes, the current MUTCD specifies that dotted lines within the lanes' transition taper areas are optional. Deploying optional dotted line extensions is also suggested by NUTCD for two-lane highway passing lane and climbing lane sections.

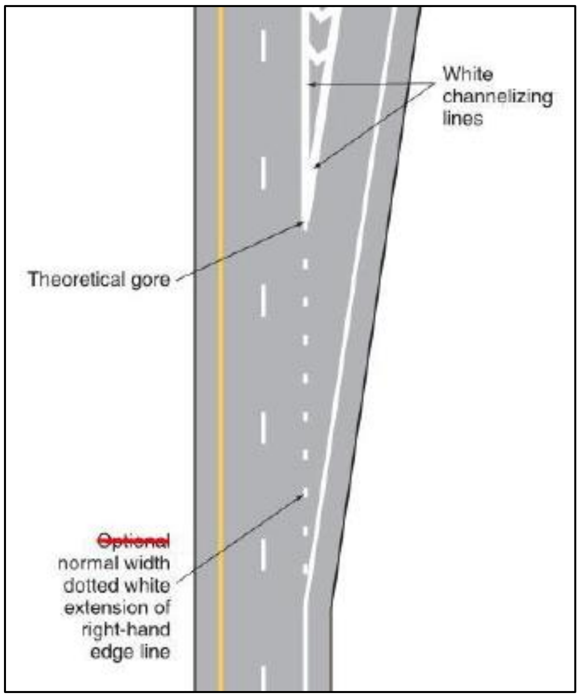


Figure 1: Dotted line extension at freeway ramp.
Source: National Committee on Uniform Traffic Control Devices (2020).

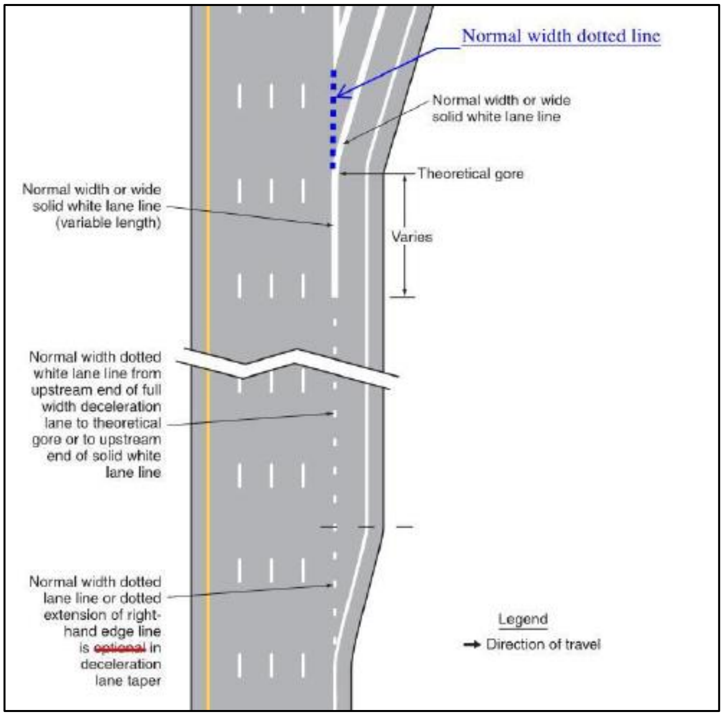


Figure 2: Dotted line extension at freeway ramp with deceleration lane.
Source: National Committee on Uniform Traffic Control Devices (2020).

3 Pavement Management Practices in Multiple States

With the recommended changes to the MUTCD made to accommodate machine vision systems discussed, it is worth exploring pavement marking practices of a variety of states, especially those which implemented the suggested pavement marking specifications. For instance, Missouri’s longitudinal lines, belonging to main roads, are six inches wide. However, because the centerline of two-lane highways consists of two lines, each’s width is four inches. That is also applicable to conditions in which a line is composed of dual lines such as those of multilane undivided highways (Missouri Department of Transportation, 2019). California is also implementing six-inch longitudinal lines as suggested by the California Department of Transportation (Caltrans), Google and Tesla (American Traffic Safety Services Association, 2019; Falsetti, 2017). Remarkably, ceramic buttons, also known as Botts’ dots, are being removed (Richards, 2017) since they may be displaced or even completely knocked off the road surface. This confuses machine vision systems when it comes to pinpointing the vehicle’s location within the traveled way. Instead, Caltrans are replacing Botts’ dots with thermoplastic marking material (Richards, 2017). Colorado is not only widening its longitudinal markings to six inches on 3,000 lane miles of its roadways but also striping black lines succeeding the white broken lines on their concrete pavement segments as shown in Figure 3 to enhance contrast (Principe, 2019). The following subsections summarize a pavement marking management optimization study in South Dakota, pavement marking management practices in Florida and marking management practices in Michigan.

Figure 3: Black markings succeeding white markings.
Source: (Principe, 2019).

4 Pavement Marking Management Optimization Study in South Dakota

An extensive pavement marking study was conducted by Wehbe et al. (2017) for the South Dakota Department of Transportation (SDDOT). The study was aimed at assessing the conspicuity, service life, feasibility and ease of applying different types of pavement marking paints. Multiple roadway segment locations were designated for data collection. The variables of which data were collected were the marking paint, weather condition, marking thickness in mils, marking color, marking line type, type of retroreflective material blended with the marking paint and type of pavement. When it comes to retroreflective materials mixed with the marking paint, such materials comprised glass beads having specific grain size distributions and glossy compounds. The retroreflective material types were the AASHTO M247, Iowa Department of Transportation (DOT) specification, Megablend and P40. Specifically, the thicknesses of the marking materials were measured, the marking retroreflectivities were measured and visual inspections of the markings were conducted. The results of the visual inspections were scores gauging pavement marking conditions. Furthermore, post-processing of the data involved analyzing the deterioration of retroreflectivity as a function of time and evaluating the association between the visual inspection scores and measured retroreflectivities. Another effort involved investigating the influences of the variables, of which data were collected, on the durability of the pavement markings specifically when it comes to retaining acceptable levels of retroreflectivity. Evaluating the feasibility of the different types of marking materials was conducted as well. Inferences drawn from the study results were as follows:

- Scores of visual inspections conducted during nighttime conditions would be considered inconclusive.
- Regarding paint markings designed to be visible during rainy conditions, the marking thicknesses were lower than their respective specified thicknesses.
- Water-based paints, designated as Types II and III as per federal specifications (Safety Coatings Inc., 2014a, 2014b) exhibited comparable deterioration rates. Note that Type II paint is used for severe conditions characterized by low temperatures while Type III paint is used for clear ambient weather conditions. It is also desirable since it is known for its long service life and tendency to bond with retroreflective glass beads (Wehbe et al., 2017).

- Yellow paint was less retroreflective (< 200 millicandelas per square meter per lux [mcd/m^2/lux]) than white paint.
- The thicknesses, fifteen, seventeen and twenty mils, of water-based paints, applied, did not considerably influence retroreflectivity degradation rates differently.
- The AASHTO M247 Type I retroreflective material exhibited greater retroreflectivity than the P40 material when blended with water-based paint but exhibited a shorter service life.
- There was an insubstantial difference in the performances of the M247 material blended with water-based paint and the Iowa DOT specification material blended with water-based paint in terms of retroreflectivity. The service lives of both materials were not considerably different as well.
- The Megablend material demonstrated the highest retroreflectivity when mixed with epoxy-based markings. However, the service lives of all retroreflective materials, blended with epoxy markings, were similar.
- The M247 retroreflective material exhibited similar performance levels when blended with water-based paint irrespective of pavement surface type.
- The retroreflectivities of water-based paint markings on surfaces, encountering frequent precipitation during the winter, deteriorated quicker than those of water-based paint markings on surfaces not subjected to frequent precipitation during the winter.
- Inlaid epoxy paint markings outperformed surface epoxy paint markings when it comes to retaining acceptable levels of retroreflectivity for prolonged periods.
- The retroreflectivities of the glossy compounds used with the M247, P40, Iowa DOT specification and Megablend materials wore off in under a year.

Wehbe et al. (2017) suggested that SDDOT implement stringent protocols for assessing marking thicknesses and retroreflective material (M247, P40, Iowa DOT specification and Megablend) concentrations. Another suggestion was that pavement marking inspections be conducted on a regular basis to gauge the degradations of the markings by region. That would aid in the evaluation of the feasibilities of the different types of markings to be implemented. With that, another recommendation was made. It was that the days during which roadway maintenance may be conducted and availability of pavement marking materials be considered as criteria when optimizing the marking material selection process. Note that road maintenance schedules may be interrupted due to adverse weather conditions.

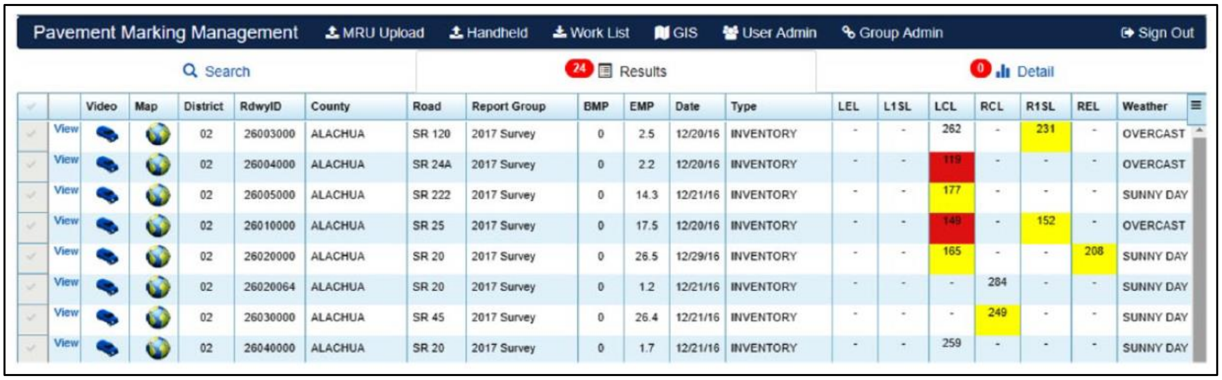
4.1 Florida's Pavement Marking Management System

The Florida Department of Transportation (FDOT) rigorously maintains its pavement markings (Choubane et al., 2018). It employs mobile retroreflectivity units (MRUs) to measure the retroreflectivity of road pavement markings. Adequate retroreflectivity is required for nighttime conditions. A typical MRU is installed in a testing vehicle, similar to the one shown in Figure 4, traveling at the speed of the traffic stream. This was deemed safer and more convenient than measuring the retroreflectivity manually using the appropriate equipment.

Figure 4: Typical mobile retroreflectivity unit installed in test vehicle.
Source: Choubane et al. (2018).

Note that, in some cases, technicians might have subjectively evaluated pavement marking retroreflectivity by means of visual inspections when conducting manual examinations. The need to cordon off lanes and hence interrupt traffic was eliminated when MRUs were used. Also, obtaining MRU measurements is now an objective rather than a subjective means of evaluating pavement marking retroreflectivity. FDOT developed and adopted detailed protocols for calibrating the MRU equipment, applying it to collect the retroreflectivity measurements and processing the data. Data collection quality assurance protocols are being followed as well. Handheld devices are occasionally used for measuring pavement marking retroreflectivity for purposes of constructing new roads and re-striping markings as well. Detailed pavement marking retroreflectivity data are collected every 0.1 mile. They are uploaded to FDOT's web-based Pavement Marking Management System (PMMS) database, which also includes roadway characteristics data and traffic data. Weather data, at the time during which the retroreflectivity data are collected, are included as well. The data may be visualized via video files showing the marking conditions as shown in Figure 5. Also, as shown in Figure 6, records of directional roadway segments with marking retroreflectivities of 150 mcd/m^2/lux or lower are marked as red while those of segments with retroreflectivities ranging from 150 to 250 mcd/m^2/lux are marked as yellow indicating that such markings require maintenance. Marking statistics are presented for not only the road level but also the county and district levels in the form of geographic information system (GIS) maps as shown in Figure 7.

Figure 5: Pavement Marking Management System's video log data.
Source: Choubane et al. (2018).



		Video	Map	District	RdwyID	County	Road	Report Group	BMP	EMP	Date	Type	LEL	L1SL	LCL	RCL	R1SL	REL	Weather
	View			02	26003000	ALACHUA	SR 120	2017 Survey	0	2.5	12/20/16	INVENTORY	-	-	262	-	231	-	OVERCAST
	View			02	26004000	ALACHUA	SR 24A	2017 Survey	0	2.2	12/20/16	INVENTORY	-	-	119	-	-	-	OVERCAST
	View			02	26005000	ALACHUA	SR 222	2017 Survey	0	14.3	12/21/16	INVENTORY	-	-	177	-	-	-	SUNNY DAY
	View			02	26010000	ALACHUA	SR 25	2017 Survey	0	17.5	12/20/16	INVENTORY	-	-	149	-	152	-	OVERCAST
	View			02	26020000	ALACHUA	SR 20	2017 Survey	0	26.5	12/29/16	INVENTORY	-	-	165	-	-	208	SUNNY DAY
	View			02	26020064	ALACHUA	SR 20	2017 Survey	0	1.2	12/21/16	INVENTORY	-	-	-	284	-	-	SUNNY DAY
	View			02	26030000	ALACHUA	SR 45	2017 Survey	0	26.4	12/21/16	INVENTORY	-	-	-	249	-	-	SUNNY DAY
	View			02	26040000	ALACHUA	SR 20	2017 Survey	0	1.7	12/21/16	INVENTORY	-	-	259	-	-	-	SUNNY DAY

Figure 6: Pavement Marking Management System's segment level data presentation.
Source: Choubane et al. (2018).

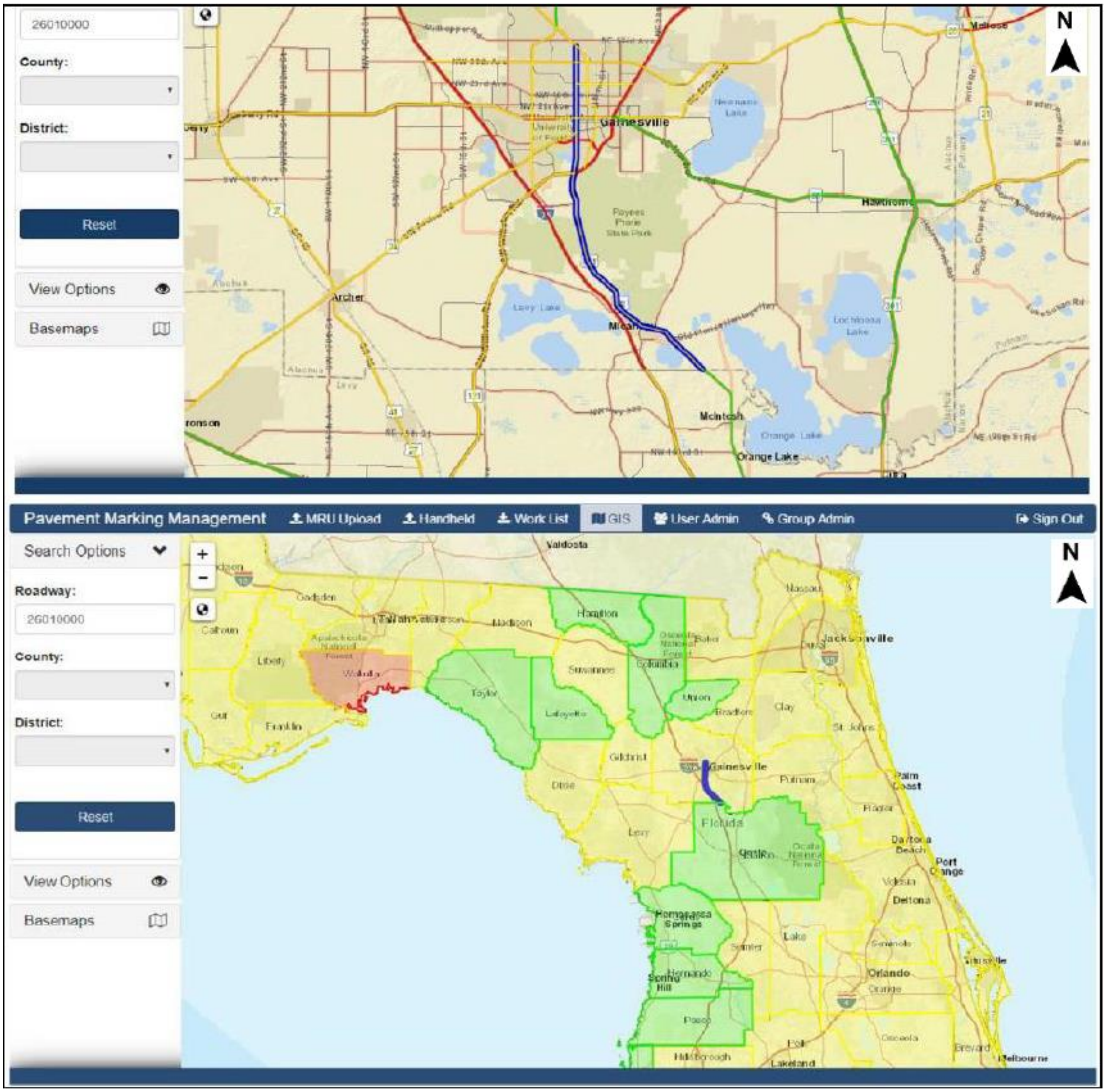


Figure 7: Pavement Marking Management System's geographic information system data presentation.
Source: Choubane et al. (2018).

Notices are sent to county offices stating that the pavement marking retroreflectivity data are collected as part of the PMMS. The county and district offices validate the collected data. Also, FDOT issues an annual report documenting the PMMS data for local jurisdictions in Florida to devise effective strategies to maintain their pavement markings. Maintenance constraints are those of budgets and time.

4.2 Pavement Marking Management Practices in Michigan

In Michigan, challenges pertaining to pavement marking maintenance include cost constraints, weather conditions and few contractors (Dwyer et al., 2018). During the winter, adverse weather damages the pavement markings and disrupts maintenance schedules. The application of de-icing salts disfigures the markings and snow covers the markings rendering them invisible. Furthermore, there are only two contractors with a limited number of trucks to conduct maintenance.

Michigan's longitudinal pavement marking maintenance strategy is to apply specific types of marking materials for particular regions and road segments. The types of materials considered and their life cycle costs per year are listed in Table 1. Note that the method of applying the material and maintenance practices influence its service life and yearly cost. For instance, the recessed water-based markings may have a service life of a year and cost $1,234.67 per mile. They may also have a service life of two years and cost $917.96 per mile. The state's strategy is to stripe its major routes as depicted in Figure 8 to take into account the pavement marking material service lives and costs.

Table 1: Pavement Marking Materials' Service Lives and Costs

Material	Service Life (years)	Equivalent Uniform Annual Cost ($/mi)
Recessed Water-Based	1	1,234.67
	2	917.96
Non-Recessed Water-Based	1	792.00
Recessed Thermoplastic	2	1,076.39
	5	664.00
Non-Recessed Thermoplastic	1	1,056.00
Recessed Modified Urethane or Polyurea	5	1,383.34
Non-Recessed Modified Urethane or Polyurea	5	940.67

Source: Dwyer et al. (2018).

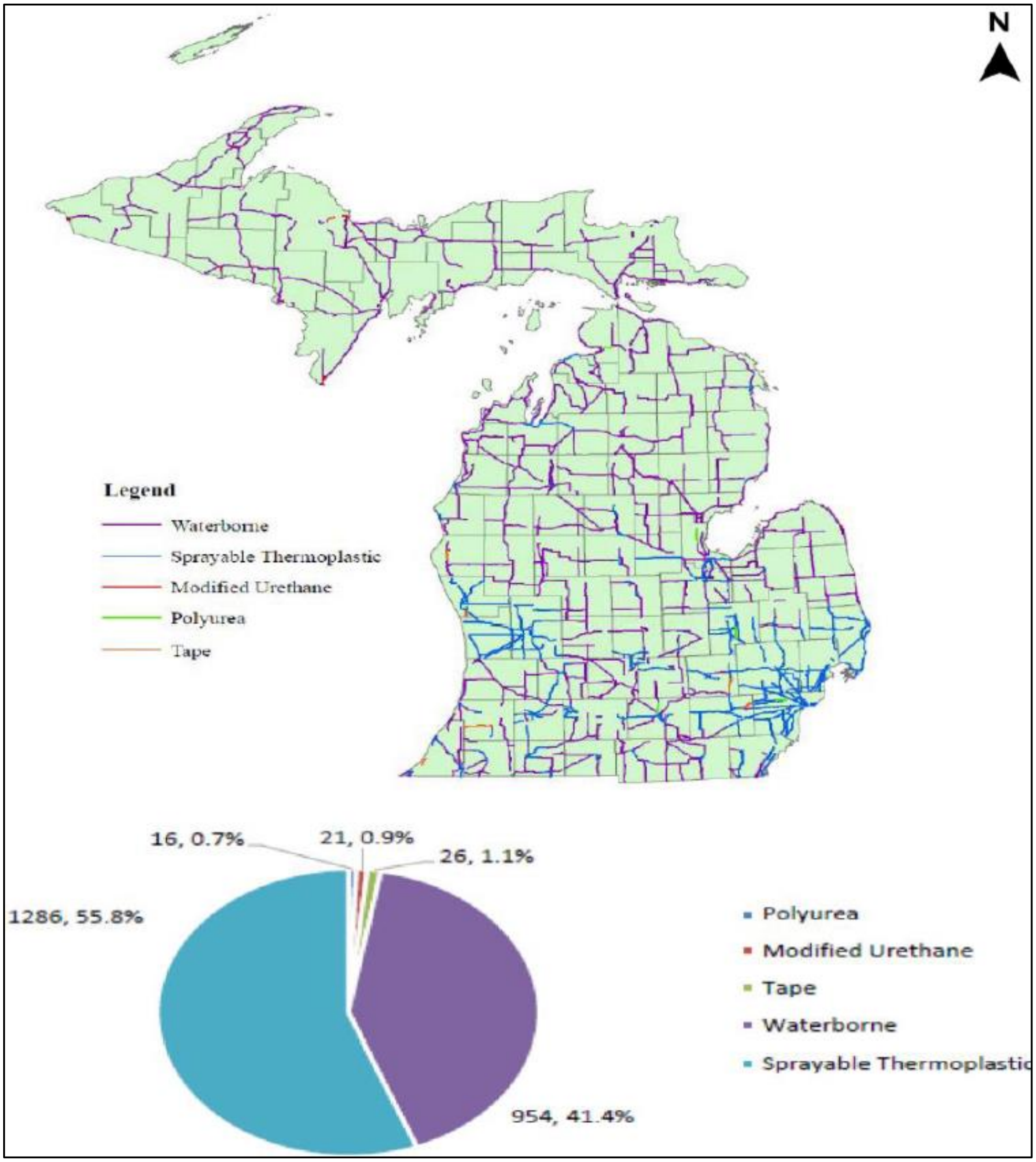


Figure 8: Proportions of longitudinal pavement marking material types applied.
Source: Dwyer et al. (2018).

Water-based paint and thermoplastic materials are applied to the majority of the roads as shown in the figure. For locations requiring special markings such as pedestrian crossings, a quarter of them are maintained yearly using cold plastic tape and polyurea. Polyurea offers safety benefits particularly regarding nighttime conditions. In addition, methyl methacrylate (MMA) is used for striping special markings in areas of which road surface conditions deteriorate rapidly (Dwyer et al., 2018). Also, 3M and the Michigan Department of Transportation (DOT) developed a wet reflective marking tape for striping pavement lane markings with black edges to enhance contrast and hence visibility. The tape, with its variants, shown in Figure 9, is known as one with wet reflectivity. That is, it is designed to be visible during rainy and nighttime conditions unlike conventional markings shown in the figure.

Figure 9: 3M's wet reflective tapes versus conventional markings.
Source: Hallmark et al. (2019).

When it comes to assessing pavement marking retroreflectivity, retroreflectivity data are collected by a retroreflectometer van for 20% of the roadways in both fall and spring seasons. Data collection efforts may also be conducted via requests. The data provide insights on not only the markings' quality but also the effects of winter on the markings.

5 Study Tasks

The previous sections served as the background information required for this study. This study's tasks involve developing viable pavement marking management plans, taking into consideration NCUTCD's recommended pavement marking specifications that accommodate machine vision systems, for WYDOT. Essential preliminary steps will be carried out as well. The tasks are listed as follows:

1) Establish an advisory group for this study comprising the state traffic engineer in addition to two other WYDOT traffic engineers. This group will be consulted throughout the course of the study.
2) Conduct an extensive detailed literature review of the pavement marking management practices and studies.
   a) Summarize pavement marking management practices of multiple state DOTs. Research questions to be addressed pertain to the pavement marking maintenance strategies implemented, maintenance schedules, types of marking materials used, whether the DOTs stripe the markings according to NCUTCD's suggested specifications, budgets expended, labor resource allocations and any other relevant information.
   b) Summarize scientific peer-reviewed articles related to pavement marking materials, marking specifications and marking management practices.
3) Develop and disseminate a survey to DOTs of states having weather trends similar to those of Wyoming. The states are North Dakota, South Dakota, Nebraska, Michigan, Colorado, Utah, Idaho, Minnesota, Montana and Missouri. The survey is intended to ask about the state DOTs' strategic pavement marking management plans, how the plans were developed, marking maintenance schedules, marking materials used, challenges faced, whether NCUTCD's recommended marking specifications were adhered to and any other critical information.

4) Communicate with WYDOT to evaluate their pavement marking management practices and specifically ask about their current pavement marking management plans. Essential inquires include those of the resources dedicated to urban facilities by road functional classification and resources dedicated to rural facilities by road functional classification. The resources include funds and labor resources. Information about labor policies are required since such policies influence pavement marking maintenance activities including schedules. Information regarding the types of materials used to stripe the markings by road functional classification, material quantities and labors' experiences with the materials are required as well. Currently, Wyoming's pavement markings are not striped as per NCUTCD's suggested specifications. Note that since markings striped as per the suggested specifications are wider than those striped as per the current MUTCD, their enhanced visibility renders them to be in need of fewer maintenance resources. Road pavement marking inventory data, traffic data and snowplow operations data will be requested. This is to identify the road segments of which markings deteriorate rapidly due to inclement weather conditions, snowplow operations and traffic patterns. Any other crucial information will be inferred from the data. WYDOT will be purchasing a retroreflectometer by October 2020 to measure the pavement marking retroreflectivity in order to improve their marking management system. This task's efforts culminate in the documentation of WYDOT's detailed current pavement marking management program.
5) Aid WYDOT in implementing the newly purchased pavement marking retroreflectometer and analyze its data. This task is composed of the following subtasks.
   a) Document procedures for setting up, calibrating, using and maintaining the retroreflectometer. This is to ensure that the retroreflectometer does not experience any issues such as lapses. The data logs ought to be complete without any missing or miscoded data.
   b) Develop data collection protocols. It is crucial to note that pavement marking retroreflectivity ought to be measured not only during daytime conditions but also during nighttime conditions to ensure that the markings are visible throughout the day. Furthermore, as previously mentioned, data collection schedules may be interrupted by adverse weather conditions. Hence, data collection schedules ought to be planned accordingly.

c) Provide guidelines regarding acceptable and unacceptable pavement marking retroreflectivity levels. Note that acceptable retroreflectivity levels vary by marking dimensions, color, whether white or yellow, and time of day conditions, whether daytime or nighttime. The guidelines will be developed based on the suggestions of NCUTD in order to accommodate vehicles with machine vision technologies.

d) Develop a structured database, similar to the web-based PMMS of FDOT for logging the retroreflectivity data. The retroreflectivity summary statistics will be depicted by road, milepost information, county and district in interactive GIS maps. The road sections will be color coded to indicate whether their marking retroreflectivity levels need urgent maintenance, impending maintenance or no impending maintenance. Similarly, the counties and districts shall be color coded in the maps. Video logs of the collected data will also be stored in the database for the operators to visually inspect the marking retroreflectivities in addition to recording the retroreflectivity readings.

e) Analyze the pavement marking retroreflectivity data and provide suggestions to WYDOT. Statistical regression models will be developed to predict the service lives of the pavement markings. It should be noted that the marking serviceability is heavily dependent on the retroreflectivity which degrade due to traffic loads and weathering effects. The degradation rate also varies by marking material and line type. Shoulder edge lines of highways are infrequently used unlike lane lanes. Hence, they are expected to have longer service life spans. In addition, an optimization analysis will be conducted to formulate a maintenance schedule to not only retain acceptable pavement marking retroreflectivity levels but also minimize budgets. Based on the analysis results, recommendations will be provided to WYDOT regarding the maintenance schedule.

6) Develop a five-year pavement marking management plan accounting for the suggested marking specifications of NCUTD for the following scenarios:

   a) In the baseline scenario, it is assumed that no additional funding will be provided to account for the excess material quantities needed for striping the roads according to the suggested specifications. Hence, an analysis will be conducted to determine the road segments that require the most frequent maintenance activities to allocate budget and labor resources. With the analyses conducted, road segments with markings that would not be adequately maintained due to resource limitations would be identified. A typical plan would include the following:

      i) The criteria for choosing the pavement marking materials is essential. The criteria encompass pavement marking striping cost, marking life cycle cost, marking retroreflectivity and service life (Hawkins et al., 2006). Note that with the aid of the retroreflectometer, retroreflectivity data will enhance the pavement marking management program. Hawkins and Smadi (2010) recommended durable marking materials when less frequent pavement marking maintenance is required, high traffic volumes are encountered and the road is expected to be serviceable for five or more years. Otherwise, conventional markings would be used (Hawkins et al., 2006).

      ii) The plan would also factor the latest pavement marking standards intended to accommodate machine vision systems including those of contrast markings, pavement surface types, traffic loads, road functional classifications, land uses, minimum required marking retroreflectivity levels, which are gauged using the retroreflectometer, interruption of traffic at the time of striping, quality control at the time of striping, method of inspecting the markings, deployment of deicing salts, snowplow operations and other relevant information. Note that both deicing salts and snowplow operations degrade the marking material (Hawkins et al., 2006; Migletz et al., 2001). Hawkins and Smadi (2010) also noted the challenges faced concerning the contracting agencies performing the striping and maintenance work. Both government agencies and their contractors may agree on the marking materials to implement and striping costs. The contractor may offer discounts as well. Resolving conflicts between both parties is another critical issue. Hawkins and Smadi (2010) also noted that the line type plays a role in the marking's service life.

iii) A database containing all the pavement marking management data is crucial since it is needed to establish the inspection and maintenance schedules. Previous striping cost, inspection and maintenance data shall be logged into the database as well. The database would be similar to that of FDOT (Choubane, 2018) discussed previously. It will include the pavement marking retroreflectivity data collected using the retroreflectometer to be purchased by WYDOT. Hawkins and Smadi (2010) also suggested that GIS maps belonging to the database be updated to reflect future maintenance and inspection dates. They also recommended that maintenance quality control inspections be made and recorded in the database. The motive is to have cost efficient striping, inspection and maintenance schedules (Hawkins et al., 2006).

iv) Accurate performance curves by marking material type, road functional classification, traffic load and district at which the material is applied are required for establishing maintenance schedules. This involves requesting information from pavement marking material suppliers, requesting marking material performance curves from other state DOTs and retrieving historical data regarding pervious pavement marking surveys conducted in Wyoming. The data collected are to be processed to develop pavement marking material performance curves for Wyoming's conditions by district, road functional classification and traffic load.

b) In the other scenarios, it is assumed that additional funding will be provided for the pavement marking maintenance program. The budget amount varies by scenario.

7) Develop a ten-year pavement marking management plan following the same procedure conducted for developing the five-year plan.

8) Document the five- and ten-year plans (tasks 6 and 7) in a draft report to be presented to the advisory group, described in the first task, and the group will provide feedback.

9) Revise the report to incorporate the advisory group's concerns and re-submit it.
10) Present the final strategic five- and ten-year pavement marking management plans to the district traffic engineers to secure their feedback and approval.
11) Suggest recommendations regarding the comprehensive pavement marking management program to WYDOT. The recommendations may include the following:
    a) Implement pavement markings with enhanced contrast such as the ones with black edges.
    b) Conduct an analysis regarding the feasibilities and service lives of the different types of viable pavement marking materials.
    c) Develop and implement detailed pavement marking evaluation criteria. An essential component of the criteria, other than pavement marking scouring is the marking retroreflectivity. Hence, the mobile retroreflectometer, similar to the ones implemented by FDOT, shall be implemented.
    d) Set data collection scheduling protocols. The data will be used for developing mathematical regression models that predict the marking's future performance levels. With the knowledge of the estimated performance levels, WYDOT shall be able to arrive at better informed decisions regarding pavement marking maintenance. This approach is more economical than carrying out blanket replacements.

6 Summary

Pavement marking management is essential and, with the advent of advanced automobile technologies having machine vision systems, marking specifications are currently being updated. Even though WYDOT maintains its road markings on a regular basis, there is a need to develop a fully-fledged pavement marking management system that takes into account budget, labor resources and the newly suggested marking specifications. The marking specification suggestions were made by NCUTCD while input was provided by other entities such as ATSSA and the Auto Alliance. WYDOT is planning to implement NCUTCD's recommendations as did state DOTs such as the Caltrans, the Missouri DOT and the Colorado DOT. This study's tasks involve evaluating pavement marking management practices on the local level, evaluating marking management practices on the national level, providing guidance regarding pavement marking retroreflectivity data collection, analyzing marking retroreflectivity data, developing a strategic five-year pavement marking management plan and developing a ten-year marking management plan for WYDOT. The plans take into consideration NCUTCD's suggested pavement marking specifications that accommodate machine vision systems. Multiple scenarios, each of which is characterized by a specific pavement marking management budget, are to be evaluated. Throughout the course of the study, an advisory group consisting of the state traffic engineer and two WYDOT engineers will be consulted. Once, the five- and ten-year strategic plans are finalized, they will be presented to the advisory group for feedback. Afterwards, the plans will be revised to address the group's concerns, resubmitted and presented to the district traffic engineers. Also, documented recommendations, regarding the comprehensive pavement marking management program, will be provided to WYDOT.

7 Study Timeline

This study is expected to commence on January 2nd, 2021 and be completed in 26 months.

8 Study Budget

The tasks of this study require the contributions of one postdoctoral research fellow, one faculty member, and one graduate student funded for two years. The overall project budget is estimated as $115,582. Table 2 shows the budget's breakdown.

Table 2: Budget for County Paved Road Monitoring Program

Categories	Cost	Explanatory Notes
Engineer/ Post Doc Salaries	$15,900	
Faculty Salaries	$15,300	
Administrative Staff Salaries		
Staff Fringe Benefits	13,510	
Student Salaries	$34,754	
Student Fringe Benefits	$1,355	
Total Personnel Salaries	$65,954	
Total Fringe Benefits	$14,865	
TOTAL Salaries & Fringe Benefits	**$80,819**	
Travel	$3,000	
Equipment	$0	
Supplies	$2,500	Reports and etc.
Contractual	$0	
Construction	$0	
Other Direct Costs (Specify)*	$12,000	
TOTAL Direct Costs	$98,319	
F&A (Indirect) Costs[$]	$17,264	
TOTAL COSTS	**$115,582**	

9 References

American Traffic Safety Services Association, 2019. American Traffic Safety Services Association Policy on Road Markings for Machine Vision Systems. Fredericksburg, Virginia. https://www.reflective-systems.com/atssa-policy-on-road-markings-for-machine-vision-systems-for-operation-of-adas/ (accessed April 8, 2020).

Choubane, B., Sevearance, J., Holzschuher, C., Fletcher, J., Wang, C., 2018. Development and Implementation of a Pavement Marking Management System in Florida. *Transportation Research Record: Journal of the Transportation Research Board* 2672, 209– 219.

Dwyer, C., Satterfield, C., Holzschuher, C., 2018. Pavement Marking Maintenance: Proposed Standards and Practices. http://onlinepubs.trb.org/onlinepubs/webinars/180329.pdf (accessed February 7, 2020).

Falsetti, R., 2017. Implementation of 6-Inch Traffic Lines and Discontinued Use of Nonreflective Pavement Markers. https://dot.ca.gov/-/media/dot-media/programs/construction/documents/policies-procedures-publications/cpd/cpd17-3.pdf (accessed January 30, 2020).

Federal Highway Administration, 2009. *Manual on Uniform Traffic Control Devices for Streets and Highways*. Washington, D.C.

Hallmark, S., Veneziano, D., Litteral, T., 2019. *Preparing Local Agencies for the Future of Connected and Autonomous Vehicles*. MN/RC 2019-18. Saint Paul, Minnesota. http://www.dot.state.mn.us/research/reports/2019/201918.pdf (accessed February 7, 2020).

Hawkins, N., Smadi, O., Hans, Z., 2006. *Planning, Developing, and Implementing the Iowa Pavement Marking Management System (IPMMS): Phases I and II*. Report Number MTC Project 2004-02. Iowa Department of Transportation, Ames, Iowa.

Hawkins, N., Smadi, O., 2010. *Local Agency Pavement Marking Plan*. Report Number IHRB Project TR-551. Iowa Department of Transportation, Ames, Iowa.

Migletz, J., Graham, J., Harwood, D., Bauer, K., 2001. Service Life of Durable Pavement Markings. *Transportation Research Record: Journal of the Transportation Research Board* 1749 (1), 13-21.

Missouri Department of Transportation, 2019. Construction Inspection for Section 620. In: Missouri Department of Transportation Policy Guide. https://epg.modot.org/index.php/620.12_Construction_Inspection_for_Sec_620 (accessed March 1, 2020).

National Committee on Uniform Traffic Control Devices, 2020. National Committee on Uniform Traffic Control Devices Proposal for Changes to the Manual on Uniform Traffic Control Devices. 19B-MKG-02. National Committee on Uniform Traffic Control Devices, Sun City West, Arizona. https://ncutcd.org/wp-content/uploads/meetings/2020A/04.19B-MKG-02.LineWidthforCAV.pdf (accessed April 1, 2020).

Principe, S., 2019. Denver-Metro Area Drivers Benefit from Wider More Visible Pavement Markings. CISION PRWeb. https://www.prweb.com/releases/denver_metro_area_drivers_benefit_from_wider_more_visible_pavement_markings/prweb16654613.htm (accessed March 1, 2020).

Richards, G., 2017. Caltrans Says Bye-Bye to Botts' Dots. *Mercury News*. https://www.mercurynews.com/2017/08/23/caltrans-says-bye-bye-to-botts-dots/ (accessed February 7, 2020).

Road Readiness Criteria for Automated Vehicle Technologies (Society of Automotive Engineers Levels 1 through 3), 2020. https://mndot-lrrb.ideascale.com/a/idea/550963/10862/download (accessed February 4, 2020).

Safety Coatings Inc., 2014a. TTP-1952E Type II. https://safetycoatings.com/fed-ttp-1952e-2.html (accessed February 4, 2020).

Safety Coatings Inc., 2014b. TTP-1952E Type III. https://safetycoatings.com/fed-ttp-1952e-3.html (accessed February 4, 2020).

Wehbe, N., Jones, A., Druyvestein, T., 2017. *Mountain Plains Consortium 17-341: Optimization of Pavement Marking Performance*. Mountain Plains Consortium, Fargo, North Dakota.