MICHIGAN STATE
UNIVERSITY

DEVELOPMENT OF A PAVEMENT MANAGEMENT SYSTEM

Final Report
For
Michigan Department of Transportation

By

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1.0 ABSTRACT

A summary of the progress of a 5-year research program between the Michigan Department of Transportation (MDOT) and Michigan State University (MSU) to review current pavement marking practices and develop new pavement marking management strategies is presented in this report. The initial goal of the program was to define the relationship between retroreflectivity and the degradation of glass bead content over time and due to winter maintenance activity. After unsatisfactory progress and a recommendation by the University, the focus of the research program has switched to developing alternative pavement marking systems resilient to winter maintenance activities. Two alternative pavement marking systems have been investigated: thicker pavement marking materials and profiled pavement markings. Based on initial research findings, the thicker pavement marking materials (HD-21 and Sahara WaterDry) have proved to be less than satisfactory in increasing the durability of the retroreflectivity of edge line markings. The profiled pavement marking system, developed by placing standard waterborne paint in milled rumble strips, has shown exceptional results. Based on the geometric configuration of the marking system, the reflective plane and glass beads of the edge line are protected from the high-pressure underbody and front mounted snow blades utilized by MDOT. An additional advantage of the geometry is faster rainwater runoff, thus exposing the glass beads. Final dry and wet retroreflectivity measurements indicate rumble strip markings are up to 6 and 20 times higher than standard edge line markings, respectively.

2.0 INTRODUCTION

This report provides a summary of the progress of a 5-year research program collaborated between MDOT's Traffic and Safety Division and Michigan State University (MSU). In particular, it reviews previous research topics for the program and ultimately addresses the latest research topic for FY 2002-2003. The purpose of the research program is to review current pavement marking practices and develop new pavement marking management strategies. This project successively follows a previous pavement marking material study collaborated between MDOT and MSU, which concluded that winter maintenance activity is the primary factor in pavement marking degradation (Lee, et al. 1999). Accordingly, this project attempts to discover alternative methods of increasing the durability of pavement markings subjected to winter maintenance activity, utilizing standard MDOT pavement marking materials.

On May 26, 2000 MDOT/MSU Contract # 2000-0232, Control Section 84900, Job Number 51324 was executed. The initial goal of the project was to define the relationship between retroreflectivity and the degradation of glass bead content over time and due to winter maintenance activity. It was proposed that this relationship could be quantified by utilizing two yield analysis techniques, pyrolysis and image analysis, to investigate the glass bead contents' of standard MDOT pavement marking materials placed on roadways subjected to varying ADT and winter maintenance activity. Results from the initial phase of the project include: A paper published in Transportation Research Record No. 1794 titled *Development of a Pavement Marking Management System* in 2002. Nonetheless, it was concluded that both yield analysis techniques were time consuming, labor intensive and uneconomical for quantifying the durability of pavement markings. A new approach for developing durable pavement markings resilient to winter maintenance activities was needed.

In 2002, after unsatisfactory progress with the yield analysis techniques and a recommendation by the University, the focus of the research program changed directions to investigating alternative strategies that could increase the durability of the pavement markings. The researchers hypothesized that either a thicker application of standard paint to the road surface or the application of standard paint to a profiled surface could increase pavement marking durability, therefore preserving retroreflectivity during winter maintenance activities. Concurrently, information was received at MDOT about a project in the state of Mississippi. The Mississippi study indicated wet-night retroreflectivity benefits of pavement markings being placed on a profiled surface. MDOT has employed recessed pavement markings in the past but the expense prohibits this strategy for wide use. The department does however, position milled rumble strips on freeway shoulders. Due to the winter weather conditions in the state of Michigan, as compared to Mississippi, it appeared there could be added benefits to expanding on the Mississippi profiled surface study. Additionally, interest in painted rumble strips increased in Michigan when a researcher documented a dramatic improvement in wet-night retroreflectivity during a heavy rain in the summer of 2002. Based on the above circumstances, the main focus of the MSU/MDOT research program has changed to investigating retroreflectivity, wet-night retroreflectivity, and paint durability by utilizing profiled pavement markings.

3.0 LITERATURE REVIEW OF PREVIOUS PAVEMENT MARKING RESEARCH

A summary of recent research on pavement markers is presented in this report. This research has addressed the following topics:

- Service life and cost-effectiveness of durable pavement marking materials

- Research conducted by Dale (1988), Lee et al. (1999), Cottrell and Hanson (2001), Davis and Campbell (1995), Thomas and Schloz (2001) and Migletz et al. (2001) among others.

- Influence of glass beads on the retroreflective properties of pavement markers

- Research conducted by Meydan (1994), Bowman and Kowshik (1994), Meydan and Senior (1990) and Wang et al. (2002) among others.

- Significance of ultraviolet light on curable marker coatings and increasing retroreflectivity

- Research conducted by Szczech and Chrysler (1994), Turner et al (1998) and Mahach et al. (1997) among others.

- Retroreflectivity of pavement markings and public perception

- Research conducted by Zwahlen and Schnell (2000), Loetterle et al. (2000) and Schnell and Zwahlen (2000) among others.

- Visibility of pavement markings based on width, color, lateral separation, headlights, age and preview distances

- Research conducted by Gates and Hawkins (2002), Zwahlen et al. (1995, 1997, 1999), Jacobs et al. (1995), Schnell and Zwahlen (1999), Khan et al. (1999), and Plant (1995) among others.

- Interactive pavement management systems

- Research conducted by Sarasua et al. (2001), Wang (1995), and Wang et al. (1995) among others.

3.1. PREVIOUS RESEARCH

A summary and review of recent pavement marking research is presented in this chapter. In general, recent pavement marking research has sought to improve on the understanding of the following objectives:

- Service-life and durability of pavement marking materials
- Influence of glass beads on the retroreflectivity of pavement markers
- UV light on curable marker coatings and increasing retroreflectivity
- Visibility of pavement markings based on width, color, lateral separation, headlights, age and preview distances
- Interactive pavement management systems

The above objectives have been addressed through research on the application, effects, and limitations of using specific pavement marking materials based on road type, ADT and environmental effects. To date, numerous experimental studies have been published addressing the above objectives. These studies are summarized and discussed within this chapter.

A brief summary of the background of pavement markings is presented in this section. In particular: the purpose, benefits, types, retroreflectivity and environmental effects of pavement marking materials are discussed. It is noted that the *Manual on Uniform Traffic Control Devices for Streets and Highways* (MUTCD) provides guidelines for pavement markings.

3.1.1. Purpose of Pavement Markings

Traffic pavement markings serve to regulate, guide, canalize traffic and supplement other traffic control devices. Under favorable conditions, traffic markings may provide information to the vehicle driver without diverting his attention from the roadway. This proves to be an important driving aid as well as an efficient delineation system on multilane roads. Even in daylight, pavement markings make it possible for vehicles to travel safely and quickly. Thus reducing congestion and raising roadway capacity.

Pavement markings are the only continuous means of guidance for motorists in their travels. They are visible at night because light from the vehicle headlights is reflected back to the driver from glass beads in the markings. The interaction of these three components (glass beads, paint and light) defines the effectiveness of the overall system.

The true quality of pavement markings is revealed under less favorable light and weather conditions, such as fog and precipitation. During which the optical phenomenon of retroreflection is critical in maintaining the guiding function of the pavement marking system.

3.1.2. Benefits of Pavement Markings

Research has already shown that existing longitudinal pavement markings reduce crashes by 21% and edge lines on rural two-lane highways reduce crashes by 8%. This analysis establishes that pavement markings improve traffic flow and roadway capacity during the typical travel hours (6:00am - 7:00pm) on arterials, freeways, and interstate highways (Miller, 1992). In general, pavement markings increase average speed by 2 mph on these roadways during typical travel time. From an economical point of view, on average, each dollar currently spent on pavement markings yields sixty dollars in benefits. These benefits result mainly from reductions in automobile accidents. For example, one study showed that installing transverse markings at a sharp horizontal curve resulted in a cost-benefit ratio of 45.9 (Agent, 1980). Additionally, in areas of high congestion, travel timesaving alone yields a surplus in the benefit-cost ratio. At the most basic level, studies in California, showed that when a centerline was added to roads, which were totally unmarked, the number of accidents was reduced by 64% (Carnaby). Further studies in the United States on roads previously with a centerline only show that the addition of edge lines reduced accidents between 16 and 60%.

3.1.3. Types and Characteristics of Pavement Marking Materials

It is intuitive to understand that the binder's durability and ability to retain the retroreflective material (glass beads) influences the effective service life of pavement markings. Some binders are more durable and provide greater retention. These binders come at a greater economical cost and therefore must be justified. Davis and Campbell (1995) have developed a multi-criteria pavement marking selection model. Their model is based on 8 goals hierarchy and 12 measures. Dale (1988) determined that the most appropriate marking material can be selected based on consideration of the following parameters:

- Type of application, centerline, edge line, etc.
- Glass bead retention

- Traffic volumes, ADT
- Pavement surface type, PCC or AC
- Total cost over its service life

Presented in Table 1 (see Appendix) is a tabular representation of the pavement marking types, costs, durability and relative dry times. This table is intended to provide the reader with a quick comparison between the available pavement markings current in use. In general, the most popular pavement marking materials can be classified under four main categories:

- Paint (solvent-borne and water-borne)
- Thermosets (polyester and epoxy)
- Thermoplastics
- Tapes

Presented below are additional notes on the above marking materials:

- Water borne paints are environmentally friendly
- Epoxy provides better nighttime visibility than paint but is difficult to apply
- Thermoplastics provide good wet visibility but are subject to damage from snowplowing
- Performance of these marking materials is usually evaluated by appearance, durability and retro reflectivity.

The longevity of pavement marking material has a direct effect on the cost of pavement marking maintenance and user safety. The estimated cost of marking streets and highways in the United States each year is approximately $475 million (Miller, 1992). This cost consists of about $380 million for materials and the remaining $95 million for their application. Dale (1988) estimated that the quantity of marking materials used annually in the United States consists of the following:

- 37 million gallons of traffic paints
- 130,000 tons of glass traffic beads
- 55,000 tons of thermoplastic marking materials
- $55 million for: preformed tapes, raised pavement markers, polyesters, epoxies and adhesives

Paints

Traffic paint has been the most widely used pavement marking material since being introduced in the early 1920's. Drying time is determined by the quantity and ingredients used in the paint mixture. The relatively low initial cost, well-established technology, ease of installation, and readily available application equipment ensure the continued widespread use of traffic paints. They provide good dry night visibility, variety of drying times and are relatively safe to handle. The reduced drying time reduces labor cost and decreases traffic delays and potential accidents related to installation.

Listed below are paint descriptions:

- They are typically classified by drying time:
  - Instant dry (less than 30 seconds)
  - Quick dry (30 to 120 seconds)
  - Fast dry (2 to 7 min)
  - Conventional (more than 7 min)
- Traffic paints are composed of:
  - Paint vehicle (alkyd, modified alkyd, chlorinated rubber, or water base)
  - Solvent
  - Pigment
  - Glass beads
- Durability depends on:
  - Material composition
  - Weather
  - Application purpose
  - Traffic density
  - Type and condition of the application surface
- Difficulties with traffic paints relate to:
  - Bonding (Surface contamination and/or moisture content)
  - Reapplication over existing markings
  - Softening of the pavement surface resulting in "bleeding" or discoloration of the paint

Paints have the shortest service-life of the entire pavement marking materials available while providing poor wet night visibility. Year round delineation with one annual application is difficult to achieve in regions with severe winter climates, particularly on high volume roadways. Paints with accelerated drying times also require more expensive stripping equipment and cleaner pavement surfaces for successful adhesion and durability than those required for their longer-drying counterparts.

Epoxy. Epoxy is a solid, two-component, chemically reacted system. It is safe to handle and to apply since it has no solvents that can evaporate and requires low heat. Epoxy offers an abrasion resistant surface and is durable. It also adheres well to both asphalt and concrete. Under low to medium AADT conditions epoxy retroreflectivity is excellent when new and is still acceptable after 3 years. Epoxy can also be applied to damp pavement and requires a similar application procedure as paint.

Polyester. Polyester is a two-component thermosetting material consisting of a resin and a catalyst. The resin resembles standard traffic paint, and the catalyst is usually organic peroxide, methyl ethyl ketone peroxide (MEKP). MEKP must be handled with care because it can cause burns and its fumes are dangerous. Polyester has a long drying time however; it can be applied over old paint. The biggest problem with polyester markings is their abrasion resistance. Additionally, bond failure can occur if polyester is applied over an emulsion seal because of tracking, poor weather, oily asphalt, and/or poor equipment.

Thermoplastics. Proportioned and mixed in a factory, thermoplastics can be transported to job sites as solid slabs or as granular powder. Application procedures include either extrusion or expulsion. Most commercial thermoplastics today use a blend of synthetic hydrocarbon resins, although the use of alkyd based resin may become more widespread as its price decreases. Thermoplastic durability has been reported to be considerably better on asphalt compared to concrete pavements. Southern states have reported an average thermoplastic service life of 10 years.

Thermoplastics are thick pavement marking materials consisting of:

- Resin binder
- Coloring agents
- Inorganic filler
- Reflective glass beads

Common problems encountered in northern climates are:

- Abrasion (snow removal)
- Shaving (snow removal)
- Bond failure

Thermoplastics form a relatively durable retroreflective road marking system. The initial appearance is generally excellent, and retroreflectivity is sustained throughout its service life. Thermoplastics have an advantage over paint when year round painting is not possible and when nighttime visibility is important. However, it is a poor choice for transverse lines in areas with high traffic volumes and for longitudinal lines when turning traffic is common. Because of their thickness, thermoplastic markings are not suitable for use in regions with severe winter conditions because of their susceptibilities to snowplow damage.

Tapes

Two types of tapes are currently available: regular for permanent installations or temporary/removable for construction zones. Tapes are non-hazardous and typically come with a factory-installed pre-applied adhesive for simple installation. When properly installed they provide the highest ratings in appearance. However, if the tape moves and becomes distorted during its service life then the appearance rating drops significantly. Temporary tapes offer the convenience of easy removal. This is often the case in construction zones as the project progresses. Tapes are well suited for installations where conditions are severe and frequent application or replacement is necessary. They do require longer installation times and are the most expensive form of pavement marking. Additionally, they are more susceptible to damage when used in crosswalk or transverse applications due to accelerating and decelerating vehicles.

3.1.4. Retroreflectivity of Pavement Markings

Glass beads have been used in pavement markings for approximately 50 years (Bowman, 1994). Painted pavement markings are visible at night because the light from the headlight is reflected back to the driver from glass beads in the paint. As the light enters the bead, it is refracted downward by the rounded surface of the bead to a point below where the bead is embedded in the paint. The light that strikes the back of the paint-coated bead surface is reflected back toward the path of entry. The interaction of these three components glass beads, paint and light defines how effective the overall system will be at guiding drivers at night

Glass beads should be coated with an adhesion that promotes maximum bonding with the binder of the pavement marking material. This coating also aids in providing proper embedment depth of the spheres into the binder. Glass spheres have the following general requirements for use in pavement markings:

- Transparent
- Clean
- Colorless
- Smooth
- Spherical geometry
- Free of pits or excessive air bubbles

The National Manual on Uniform Traffic Control and the Michigan Manual on Uniform Traffic Control Devices require longitudinal pavement markings to be reflectorized unless ambient illumination assures adequate visibility (Painatic and Schwab, 1987) however, they do not specify minimum reflectivity levels. In general, a minimum retroreflectivity of 100 millicandelas/square meter/lux (mdc/m^2/lx) is typically accepted as the lower boundary.

3.1.5. Environmental Effects on Pavement Markings

Snow removal activities resulted in substantial damage to pavement markings. It was estimated that about half of the pavement markings in state of Virginia were damaged during the 1993-94 winter and that replacement costs were $8 million. The estimated retroreflectivity loss of 10 to 15% for pavement markings represented the majority of the costs. The estimated statewide cost of damage caused by snow plows was between $1.58 and $2.26 million for waffle tape and between $1.06 and $1.59 million for paint, for a total of between $2.64 and $3.85 million (Cottrell, 1995).

Urethane blades provide a suitable alternative to rubber blades for use on snowplows. Limited data has indicated that the life-cycle cost of urethane blades was 6.5 times greater than that of rubber blades. Many airports extend the blade life of urethane blades on their plows by removing the weight of the plow from the blade through the installation of wheels on the plow.

3.2. RESEARCH STUDIES

Research studies on the following topics have been reviewed and are presented in this section:

- Durability and cost-effective pavement marking materials
- Delineation & retroreflectivity of pavement markings
- Effect of glass beads on retroreflectivity
- Influence of UV light on application and visibility
- Pavement management systems

3.2.1. Durability and Cost-Effective Pavement Marking Materials

Recent papers primarily addressing the durability and cost-effectiveness of pavement marking materials are presented below. A brief introduction to the scope of the research is provided with research results and conclusions in bullet format.

Service Life of Durable Pavement Markings
By Migletz J et al.

This report discusses the results of a 4-year study on the durability of pavement marking materials.

- Study included 85 sites in 19 states for a total of 362 longitudinal marking lines.
- The following marking materials were studied:
    - Epoxy
    - Flat and profiled polyester
    - Flat and profiled poly (methyl methacrylate)
    - Flat and profiled thermoplastic
    - Profiles preformed tape
    - Glass beads
    - Standard and snow-plowable raised retroreflective pavement markers
- One site with conventional markings and three with water-borne paint were included.
- Variations in service life were found to be correlated to:
    - Roadway type
    - Region of the country (e.g. environment, manufacturers and DOT's)
    - Marking specifications
    - Contractors

- Quality control
- Winter maintenance/snow removal policies

Durable, Cost-Effectiveness Pavement Markings Phase I: Synthesis of Current Research
By Thomas, GB and Scholz, C

This report is the first phase of a research program that will monitor and update the Iowa Highway Research Board of various products used in the pavement marking industry.

- The paper consists of the following subsections:
  - Evaluation criteria
  - Review of the pavement marking process
  - Review of various materials used for pavement markings
  - Summary of recent research performed on pavement markings

Determining the Effectiveness of Pavement Marking Materials
By Cottrell, BH and Hanson, RA

This report presents findings from research aimed to determine the safety, public opinion and cost-effectiveness of pavement marking materials used by the Virginia DOT.

- A motorist survey indicated that drivers preferred higher reflectivity road markings and older drivers were dissatisfied with the brightness of road markings.
- Large paint contracts appear to be most economical for two-lane roads under any volume condition and four and six-lane roads under low-volume traffic.
- Polyurea used in conjunction with a large paint contract proved most economical for high-volume two and four-lane roads.
- Polyurea and waffle tape were most economical for high-volume six-lane roads.
- Conclusions include the consideration of the following:
  - Increasing the use of large paint contracts
  - A performance-based specification for durable marking materials
  - A holistic approach for pavement management and markings
  - Re-evaluate its pavement marking policy with the influence of this report

Evaluation of Long-Life Pavement Markings
By Bryden, JE and Gurney, GF

This paper describes the application and performance of several large installations of durable pavement markings.

- Heavy snowplow damage reduced the ultimate service life of 125-mil extruded thermoplastic markings in some cases.
- Some premature failure resulted on the first New York State installation of two-component epoxy, and on one brand of preformed tape installed on tine-textured concrete pavement.
- Most installations of the two-component epoxy provided good reflectivity.
- Preformed tape and thermoplastic provided satisfactory initial reflectivity, however night visibility declined as surface beads were lost.
- Insufficient matrix beads were included to provide good reflectivity throughout the service life of the preformed-tape and thermoplastic markings.
- The experiment concluded that thermoplastic, epoxy, and preformed-tape marking materials provided 4 or more years of service in longitudinal applications.

The Efficient and Permanent Road Marking for Traffic Safety
By Luthi, E

This paper discusses issues related to thermoplastics and pavement marking thicknesses.

- Thick pavement markings prevent proper drainage of surface water and increase the aquaplaning effect.
- Optimal requirements for road markings are:
  - Durability
  - Visibility by day or night
  - Degree of whiteness
  - Coefficient of friction and skid-resistance
  - Adhesive power
  - Ease of maintenance
- Reflectivity can be restored quickly and efficiently by application of a very thin layer of material and glass beads.

- PLASTIROUTE provides a maintainable and durable initial marking for several years without further material buildup. Its permanent elasticity and plasticity provides resistance to temperature gradients and cracking.

Pavement Markings
By Lara, EM

This paper treats a variety of topics related to pavement markings and contains standards relevant to their functions and limitations.

- Legal authority to install pavement markings
- Standardization of pavement markings in order to be recognized and understood by the users
- Types of pavement markings
- Colors (the specific use of yellow and white) pavement markings
- Retroreflectivity and its applications
- Maintenance of pavement markings
- Centerlines, lane lines, 'no over taking lines" markings etc.

Thermosetting Synthetic-Resin paints for Concrete Pavement Markings
By Slate, FO

This paper discusses specialized pavement markings used to prevent scaling for use on concrete.

- Concrete paints fail principally by scaling due to loss of adhesion between the point film and the concrete in the presence of water.
- Water transports soluble salts vertically from the moist soil beneath the pavement due to capillary action, which are deposited upon evaporation of the water at the concrete surface.
- The paint film offers resistance to the passage of the water vapor and to the growth of the salt crystals.
- Resulting forces may break the bond between and concrete, even causing surface damage to the concrete.
- Thermosets and thermoplastic synthetic resin paints have proven to provide higher water, alkali and abrasion resistance than standard paints.

Reflectivity and Durability of Epoxy Pavement Markings
By Bryden, JE et al.

This paper discusses reflectivity and durability of epoxy pavement markings.

- Epoxy pavement markings on 16 projects were surveyed to determine durability and reflectivity.
- Markings were up to 6-years old and were installed on both Portland cement and asphalt concrete pavements.
- Most projects were in good condition and providing acceptable daytime delineation.
- Majority of markings had fair/good reflectivity; some were not providing acceptable reflectivity and most of the poor reflectivity occurred on a few recent projects.
- Relational differences in condition or reflectivity to roadway characteristics, traffic, striping contractor, or material supplier could not be inferred.

Paint-Line Retroreflectivity over Time
Scheuer, M; Maleck TL; and Lighthizer DR

This paper discusses a research project between the Michigan Department of Transportation and Michigan State University. The objective of the project was to evaluate the performance of several types of pavement marking materials under various conditions.

- Performance was based on periodic evaluation of retroreflectivity levels using a Mirolux 12 meter.
- Pavement materials studied include:
    - Polyester
    - Water-based
    - Thermoplastic
- Three areas were studied providing the following conditions:
    - High volume of traffic and moderate snowfall
    - Low volume of traffic and heavy snowfall
    - Moderate volume of traffic and moderate snowfall
- Conclusion indicate that the durability of pavement markings are dependent on snowfall (plowing) as average daily traffic (ADT)

Benefit Cost Analysis of Pavement Markings

By Miller, RT

In this study a cost/benefit analysis of edge lines, centerlines, and lane lines is presented. The analysis considers markings applied with fast drying paint or thermoplastic.

Thermo-plastic lines have a higher initial cost but can have lower life cycle costs compared to paint. They yield lower life cycle costs in regions where snowplowing is absent.

The study establishes that pavement markings improve peak traffic flow (6:00am to 7:00pm) on arterials, freeways, and inter-state highways by increasing average speed by 2 mph.

Currently, each dollar spent on pavement striping yields an average sixty dollars in benefits.

The benefit-cost ratio is directly proportional with traffic volume. In areas of congestion, striping produces positive benefit-cost ratio in travel timesaving alone.

Rural two-lane highway edge lines are cost-effective if, on average one non-intersection crash occurs annually every 15.5 miles of road way.

Evaluation of Urethane Snow Plow Blades as an Alternative to Rubber Blades

By Roosevelt, DS

The purpose of this study was to determine if urethane blades are a suitable alternative to rubber blades for use on snow plows. The importance of finding a suitable alternative is due to the anticipated increased need to protect the new, longer lasting, and expensive preformed tape now being introduced as pavement markings in Virginia.

Two sites were selected to test urethane blades, and six sites were selected to test rubber blades. Researchers reviewed the cost and quality of snow removal for each type of blade.

The study found that urethane blades cleaned the roadway surface better than rubber blades but were also subject to low durability.

The Virginia Department of Transportation (VDOT) uses a plowing method that places the full weight of the plow on the blade. Resulting in high friction between the blade and the road surface and causing the blades to wear quickly.

Rapid disintegration of the blades within a single snow event creates a high life cycle. Based on limited data, the life-cycle cost of urethane blades was approximately 6.5 times greater than that of rubber blades.

This study recommends that VDOT plows be modified to take the plow's weight off the blade and that urethane blades be substituted for rubber blades.

It was indeterminable if the use of wheel-supported plows equipped with urethane blades would sharply reduce damage to pavement markings.

Investigation of the Impact of Snow Removal Activities on Pavement Markings in Virginia

By Cottrell, BH Jr

The objective of this study was to obtain accurate data on the pavement marking damage caused exclusively by carbide-tipped blades.

Data were collected from interstate highways and principal arterials (22 sites) due to the prevalence of a variety of pavement marking types and their high-priority routes for snow removal.

Three types of pavement markings - latex paint, thermoplastic, and waffle tape - were assessed for damage.

Based on the study sites, snow plow damage during the 1994-95 winters were estimated to be between $100,100 and $137,700 for waffle tape and $400 to $600 for paint.

Estimated retroreflectivity loss of 10 to 15% for both markings represented the majority of the costs.

It is reasoned that thermoplastic marking damage is greatest when ice is bonded over it.

Based on the new data the estimated statewide cost of damage caused by snow plows was between $1.58 and $2.26 million for waffle tape and between $1.06 and $1.59 million for paint.

3.2.2 Delineation & Retroreflection of Pavement Markings

Recent papers primarily addressing delineation and retroreflection of pavement marking materials are presented below. A brief introduction to the scope of the research is provided with research results and conclusions in bullet format.

Pavement Markings and Incident Reduction
By Storm, R

This paper discusses the role of pavement marking systems in reducing incidents.

- Pavement marking limitations in relevance to the following topics are discussed:
  - Horizontal curvature
  - Turning movements
  - Pedestrian Crosswalks
- The report concludes with recommendations for increasing motorist and pedestrian safety.

Development of Improved Procedures for the Removal of Pavement Markings During FDOT Construction Projects
By Ellis, R; Ruth, B and Carola, P

This study reviews the current removal technology and suggests best management practices for pavement marking removal in highway construction work zones.

- Incomplete removal may leave suggestions of marking which can be confusing to the motorist passing through the work zone.
- Aggressive removal may result in pavement scars, which under wet nighttime conditions may also be mistaken by the motorist as pavement markings and be misguiding.
- Field testing of different removal options was performed and the results are documented.
- The use of light reflectance as a measure of marking removal was investigated.
- Ultra-High Pressure Low Volume Water Blasting was demonstrated as a superior removal methodology.
- A management implementation plan for a State Highway Agency is suggested.

Field Studies of Temporary Pavement Markings at Overlay Project Work Zones on Two-Lane, Two-Way Rural Highways

By Dudek, CL et al.

This paper documents research consisting of field studies used to compare the safety and operational effectiveness of 1-ft, 2-ft, and 4-ft temporary broken line pavement markings in work zones.

- The following scope and test conditions were specified by NCHRP:
    - Surfacing operations on two-lane, two-way facilities
    - Field sites involving pavement overlays (not seal coats)
    - Data collection during hours of darkness
    - Dry roadway conditions
    - Sites with both tangent and curve sections
    - Centerline stripe only (no edge lines)
    - Use of a 40-ft pavement marking cycle
    - Field tests in real or staged work zones those are open to traffic.
- Field studies were conducted at night at seven pavement overlay project sites on two-lane, two-way rural highways in Arkansas, Colorado, Oklahoma, and Texas.
- Traffic stream measures of effectiveness included:
    - Vehicle speeds
    - Lateral distance from the centerline
    - Lane straddling
    - Erratic maneuvers
- In-vehicle studies with paid driver subjects were conducted to supplement the traffic stream evaluation.
- The 1-ft and 2-ft striping patterns on 40-ft centers performed as well as the 4-ft pattern for centerline striping at night for the following conditions studied:
    - Pavement overlay projects on rural two-lane two-way highways with 2.0 degree horizontal curvature
    - Level to rolling terrain
    - Average speeds between 50 and 62 mph
- Driver subjects at six sites rated the 1-ft pattern to be the least effective on average.

- Statistical differences in mean ratings or rankings among the three patterns were not evident.

Evaluation of Pavement Marking to Designate Direction of Travel and Degree of Safety

By Taylor, WC and Hubbell, JS

This study was designed to investigate the effectiveness of pavement markings as related to driver perception, driver understanding and driver performance.

- Three marking systems were studied using: white and yellow broken and solid lines, both singly and in combination.
- No single measure appears to fully describe the effectiveness of pavement markings.
- Five phases of the study were developed and directed toward a different measure of effectiveness:
    - Phase 1: Targeted toward driver perception and understanding
    - Phase 2: Lateral placement was a direct measure of driver performance
    - Phase 3: Passing study to measure the drivers understanding and acceptability
    - Phase 4: Lane usage study to study the drivers understanding and performance
    - Phase 5: Driver interview was designed primarily to measure driver perception
- Conclusions infer that drivers would require some period of education and adjustment to understand the pavement marking system.
- Colors appear to have greater potential in the long run than use of line shape.

Visibility of New Dashed Yellow and White Center Stripes as Function of Material Retroreflectivity

By Zwahlen, HT and Schnell, T

This paper addresses economic and environmental concerns about the continued use of yellow centerlines on two-lane highways and yellow left-edge lines on divided highways or freeway entrance and exit ramps.

The effects of color (white and yellow) and material retroreflectivity (low, medium, and high) on the end detection distance of finite-length centerlines at night under automobile low-beam illumination were determined.

Ten subjects were used in a field experiment (rural, automobile low-beam conditions) to obtain the end detection distances of finite-length center stripes of 0.1-m width. Results show the end detection distances of new yellow dashed center stripes and new white dashed center stripes are about the same.

The average end detection distance was 30 to 35 m for the low-retroreflectivity material and about 62 m for the high-retroreflectivity material (4-5 times retroreflectivity increase).

A tentative conclusion is that white center stripes most likely will not result in a significant increase in the end detection distance when compared with the use of similar yellow center stripes.

An increase in the retroreflectivity of the pavement marking materials will result in a significant and desirable increase of the visibility distance.

A minimum preview time of 3.6 sec (at a vehicle speed of 90 km/hr), requires higher-retroreflectivity materials than the ones used in this study.

Nighttime Visibility of Retroreflective Pavement Markings from Trucks Versus Cars

By Rumar, K et al.

This nighttime field study addresses the relative visibility of retroreflective pavement markings from trucks and cars. Both low-beam headlamp mounting height and observer eye height were varied and researched.

- The task involved detecting the presence of a strip of retroreflective pavement marking that was moved towards a stationary observer.
- A main finding is that headlamp mounting height had a statistically significant effect on detection distance.
- Increasing the mounting height from 0.6 to 1.2 m resulted in a 19% increase in detection distance.
- No effect of eye height from 1.2 to 2.4 m was observed.
- Present findings imply that retroreflective pavement markings are more visible and effective for truck than car drivers.

- These findings are in support of higher headlamp mounting height for all types of vehicles.
- Higher headlamp mounting heights lead to increased glare for both oncoming drivers and preceding drivers via rearview mirrors.
- Determining an optimal headlamp mounting height will require a complex weighing of both visibility and glare considerations.

Pavement marking Retroreflectivity Requirements for Older Drivers
By Graham, JR; Harrold, JK; and King, LE

This paper discusses both subjective evaluations and quantitative measures of in-place roadway markings made to determine minimum marking retroreflectivity levels required for older drivers.

More than 85% of subjects aged 60 years or older field rated a marking retroreflectivity of 100 mcd/sqm/lx as adequate or more than adequate for night conditions.

This value was based on a clean windshield and non-variability of individual vehicle headlight performance.

A comparison between these results and that of a similar 1989 study of younger drivers was performed. The comparison revealed that whereas the average subjective ratings were similarly distributed relative to the retroreflectivity of pavement markings, there was a significant difference in the subjective ratings made by older and younger drivers.

Older drivers consistently rated the retroreflectivity of markings lower as compared to younger drivers.

Correlation of the Nighttime Visibility of Pavement Marking Tapes with Photometric Measurement
By Hedblom, TP et al.

This paper attempts to correlate nighttime visibility of pavement marking tapes with a photometric field measurement test.

Retroreflective measurements in the laboratory and field generally lack correlation with the marking visibility performance of drivers. This is due to modern pavement markings and optical systems.

Nighttime visibility of new, dry centerline pavement markings viewed from a stationary automobile and semi truck is compared with laboratory and field photometric measurements.

The current industry test photometric geometry is found to have poor correlation with driver visual perception at most distances.

A laboratory test method has been developed with the hope of better characterizing actual pavement marking retroreflective performance.

The test method measures products at the same photometric geometry at which a driver actually observes pavement markings.

This study produced excellent agreement between driver visual observations while performed at multiple test distances.

Effects of Roadway Markings on Vehicles Stopping in Pedestrian Crosswalks
By Mortimer, RG and Nagamachi, M

A study was conducted to determine the effect of roadway markings with regard to vehicle encroachment on cross walks at signal-controlled intersections.

- The seven intersections selected provided evaluation of the following variables:
    - Number of lanes
    - One way versus two way traffic
    - Pavement markings (crosswalk, crosswalk and stop line, end of centerline).
    - Sex of driver
    - Type of vehicle
    - Vehicle direction after stopping
- A 16-mm movie camera was used to record the stopping point of each vehicle.
- Vehicles stopping close to the intersection had the following similarities:
    - Female drivers
    - Trucks rather than passenger cars
    - Turn after stopping.
- Vehicles were also likely to stop farther from the curb line on four lanes than on two lane roads.
- Stopping points on one way and two-way roads were not discernibly different.

- The percentage of vehicles stopping on crosswalks was found to be smallest at intersections marked with a crosswalk and a stop line.
- A tentative recommendation was made for a placement of stop lines likely to reduce vehicle encroachment on crosswalks to acceptable levels.

Measuring Wet-Night Delineation Reflectivity
By Dejaiffe, R

This paper focuses on the problems involved in effectively measuring wet performance and discusses an alternative measuring system.

- Pavement markings can lose their reflectivity and their visibility on dark rainy nights.
- Available methods of retroreflectivity measurement have been limited to panels of visual evaluators and telephotometers.
- Both methods are difficult to apply in field test programs.
- A new concept in retroreflectometers currently being researched uses a laser light source and a narrow band-pass filter to block ambient light.
- This mobile, day/night, wet/dry instrument should help accelerate development and demonstration of wet reflective delineation and provide insights and better understanding of the relationship between delineation performance and drivers' visual needs

Minimum Retroreflectance for Nighttime Visibility of Pavement Markings
By Ethen, JL and Woltman, HL

This paper discusses three studies that were found in the literature addressing minimum retroreflectivity levels for nighttime visibility. Additionally, subjective tests were performed to establish an acceptable minimum retroreflectivity level.

- Three studies addressing minimum retro reflectance agreed on the following factors:
    - Retroreflective quality of the painted line
    - Quality of headlamp luminance
    - Contrast between the line and the immediately adjacent road surface
    - Presence or absence of roadway lighting.
- Tests were conducted using markings with a broad range of retroreflectivity on a level tangent roadway of weathered asphalt concrete.
- Results from the subjective testing system for rating the lines correlated well with those of other studies.

- A Driving Task Experiment was conceived for the TFHRC's HYSIM Driving Simulator to test driving performance of subjects for various combinations and qualities of pavement markings and RRPMs.
- The experiment involves varying dark conditions on a simulated 2-lane rural road without other visual distractions.
- Drivers are tested at 2 speed levels. Efforts to develop a HYSIM capability to depict various RRPM configurations will allow future experiments to analyze additional applications, potentials for enhancements to RRPMs, and studies of delineation system effectiveness.

Visibility of Retroreflective Pavement Markings in Horizontal Curves Under Low-Beam Illumination

By Zwahlen, HT and Senthilnathan, V

This paper discusses three independent studies undertaken to investigate the nighttime detection distances of pavement markings of various widths under low-beam illumination.

Study 1 explored pavement marking visibility for detecting the beginning and end of a continuous pavement marking as a function of:

- Line width
- Material
- Color
- Lateral position

Study 2 explored the visibility distance of the onset of a curve along a tangent section marked with a continuous white taped edge line placed at approximately 1.83 m to the right of the car as a function of line width.

Study 3 explored the detection distances from the begin and end of yellow taped pavement marking configurations having different widths, placed on the left side of the vehicle representing a typical centerline on a two-lane rural highway.

Study 1 revealed no statistically significant differences for the average begin or end detection distances. Lane widths varied between 0.1 and 0.2m.

Study 2 revealed a statistically significant difference for 0.1 to 0.2m wide right edge line for a left curve.

- Two retroreflectivity values, expressed as specific luminance in units of millicandelas per square meter per lux (mcd/m2/1x) are suggested as acceptable and minimum. These values are approximately 300 and 100 mcd/m2/1x, respectively.
- The above minimum values may be useful in establishing acceptance and service criteria for pavement markings.
- Availability of portable instruments such as the Ecolux (used in this study) permits the assessment of pavement markings for conformance to such criteria.

Use of Road Markings to Narrow Lanes for Controlling Speed in Residential Areas
By Lum, HS

This article addresses road markings used to control speeding on residential streets.

- Speeding generally occurs on wide streets that have little or no horizontal or vertical curvature so drivers have a long sight distance.
- Study shows that longitudinal pavement markings combined with raised pavement markers to create an impression of a narrower street have no effect on the mean speeds or the speed distributions of drivers on residential streets.
- One conclusion is that the delineated lanes made the driver's task of tracking the roadway simpler.
- It is noted that few drivers straddled or crossed the edge lines, and when they did they quickly corrected their course to stay within their lane of travel.

Relative Luminance of Pavement Markings and Raised Reflective Pavement Markers on Simulated Rural Two-Lane Roads
By Opiela, KS et al.

The FHWA's Turner Fairbank Highway Research Center (TFHRC) is undertaking a multi-staged research program to study visibility issues associated with the use of retroreflective raised pavement markers (RRPMs).

- The limited past research on the human factor aspects of RRPMs and a need to develop a sound basis for minimum retroreflectivity requirements for pavement markings provided the impetus for this program.
- The initial effort of this project is determining the relative luminances for RRPMs and pavement markers.

Study 3 revealed a statistically significant difference for the double solid line configuration when compared to the other configurations.

Study 3 end distances were significantly longer than the beginning detection distances.

Evaluation of Pavement Marking Materials for Wet Night Conditions: Final Report
By King, LE and Graham, JR

This paper discusses the visibility of eight pavement-marking materials for wet/dry conditions.

- Three highways were test marked and their performance recorded for a period of eighteen months.
- Field measurements included periodic recording of retroreflectivity and percentage of missing pavement marking material.
- Field-tested materials were also subjected to controlled laboratory testing for dry and wet conditions.
- Subjective and quantitative evaluations of in-place roadway markings provided minimum marking luminance levels for reflective markings.
- Subjective and quantitative evaluations for controlled and repeatable laboratory conditions provided minimum luminance values for reflective markings.
- An equation expressing the relationship between the field and laboratory luminance subjective evaluations was formulated.

The Attitudes of Wisconsin Drivers About Pavement Markings: Final Report
By Palit, CD; Penaloza, LJ; Burrell, B; and Campbell, J

This paper documents a 1992 opinion and knowledge survey of licensed drivers.

- The opinion survey asked about the visibility of markings under different weather conditions, by type of line and driver reliance on the different lines.
- Different changes to the pavement-marking program were presented with and without cost information associated with the changes.
- Brighter materials were found to be the favorite option even after educating them of a substantial cost increase.
- The data were stratified by:
    - Driver age
    - Gender
    - Driving practices
    - Region of state.

- Younger drivers were generally the least satisfied with the current marking practices.
- Wider lines were not seen as important to respondents, although those who drive primarily at night were more supportive of wider lines than daytime drivers were.
- The knowledge portion of the survey revealed that up-to 20 percent of respondents misunderstood pavement markings.

Innovative Visibility – Based Measures of Effectiveness for Wider Longitudinal Pavement Markings

By Gates, TJ; Chrysler, ST and Hawkins, HG

A 2001 survey of international, U.S., and Canadian transportation agencies confirmed that many are using wider-than-standard longitudinal pavement markings.

- The survey data resulted in most agency personnel supporting wider pavement lines to improve highway safety.
- Further analysis suggests the basis for implementation of wider lines often lays in subjective and qualitative visibility comparisons.
- Measures involving long-range foveal detection of wider vs. standard markings are common in the literature and have shown positive results.
- Subjective opinions that wider lines are 'better' may be due in part to increased peripheral visibility and consequently, decreased driver workload.
- Investigations into line width and brightness could be improved by use of new measures of effectiveness related to changes in peripheral vision and driver comfort or workload.
- For example, such measures could be borrowed from other areas of cognitive science and human performance or based on traditional traffic-related performance measures.

The Use of Wider Longitudinal Pavement Markings

By Gates, TJ; Chrysler, ST and Hawkins, HG

This paper discusses a survey of DOT agencies addressing the issue of wider longitudinal pavement markings versus narrower for increasing visibility.

- Twenty-nine of the fifty state departments of transportation (DOT's) use wider markings to some degree for standard centerline, edge line, and/or lane line applications.
- The most widely cited reason for using wider markings is improved marking visibility (57 percent of respondents).

- The most common justification for implementing wider markings is pilot studies (32 percent of respondents), experience of other agencies (30 percent), and engineering judgment (27 percent).
- Most agencies (57 percent of respondents) have not measured the benefits of using wider markings.
- Most agencies using wider markings are satisfied with their use, and no agency indicated planned discontinuation of their use in the future.
- Some agencies that are not currently using wider markings are strongly considering their use.
- The survey findings indicate that the use of wider markings will continue to increase both in the total number of agencies using wider markings and the extent to which they are used in individual agencies.

3.2.2. Effect of Glass Beads on Retroreflectivity

Recent papers primarily addressing the effect of glass beads on retroreflectivity of pavement marking materials is presented below. A brief introduction to the scope of the research is provided with research results and conclusions in bullet format.

Effect of Glass Beads' Size on Their Wet Weather Retroreflectivity
By Meydan, A

This paper addresses the issue of glass bead diameters and their influence on wet weather retroreflectivity.

- A Laser Retroreflectometer was employed to measure the relationship between the diameter of the glass beads and wet weather retroreflectivity.
- Laboratory work investigated the micro-texture of a beaded paint layer.
- Results indicate the following:
  - Larger beads perform better in wet weather.
  - Glass beads of about 1 mm in diameter or larger should be used.
  - Wet weather retroreflectivity is also a function of the micro-texture of the beads surface.

Large Glass Beads for Improved Wet Weather Road Marking Visibility

By Meydan, A and Senior, DC

This paper discusses the development of large glass beads (Visibeads) for increased wet night retroreflectivity.

- Conventional beads are submerged during rainfalls at rates greater than 10 mm/hour.
- Visibeads remain reflective up to rainfall rates of 20 mm/hr.
- Dry film minimum pavement marking thickness is currently set at 0.700mm for using Visibeads.
- Field tests conclusively show the increased retroreflectivity values of using Visibeads.

Development of Improved Pavement Marking Materials

By Dale, JM

This paper addresses the development of a new pavement marking system and a systematic approach for selecting systems in general.

- Laboratory tests and field studies were conducted on the performance characteristics of conventional pavement marking materials.
- Shortcomings and the physical nature of conventional marking materials were discussed.
- Emphasis was placed on performance characteristics under various types of water films.
- A novel pavement marking was designed and tested with promising results.
- A systematic approach for the design of a pavement marking system has been developed based on the following approach:
    - The surface to be marked is first qualified
    - Determine water film thickness to be encountered
    - Select one of the qualifying marking systems
- Experiments were conducted to determine the effectiveness of silicone-treated glass beads to maintain maximum retroreflection.
- Researchers investigated the feasibility of applying a surface coating of small beads to a carrier (P_gravel) to obtain a large diameter reflecting material that would protrude through submerging water films.

- Conclusions indicate that this new pavement marking system has comparative performance to that of raised reflective markers. One-quarter inch diameter glass beads are imbedded in the pigmented epoxy binder in this system.
- Wet night visibility of the markers was excellent and the low-profile marker is not likely to be damaged by snowplows.

Retroreflectivity "The performance of Glass Beads In Road Markings"
By Bob Carnaby, Potters Industries Pty Ltd, Australia.

This paper summarizes the performance characteristics of standard and large diameter glass beads.

- Large beads (1mm) are used to add wet-weather retroreflectivity to conventional markings.
- The large beads allow the water to drain off more quickly than smaller beads thus more quickly recovering their dry weather retroreflectivity
- It has been established that 1 mm glass beads with dry marking retroreflective measurements of 250 mcd/lux/sqm, will provide a measurement of 100 mcd/lux/sqm when exposed to artificial rainfall rates of up to 125 mm/hr (5 inches per hour).
- When the rainfall stops the excess water will drain away, leaving the equilibrium film that adheres by surface tension. This film disappears reasonably quickly, and the measure of retroreflectivity will be seen to quickly climb towards the 'dry' measurement.
- Road markings with smaller standard size beads show readings near zero during rainfall and do not recover retroreflectivity for a considerable period of time after the rain stops.

3.2.3. Influence of UV Light on Application and Visibility

Recent papers primarily addressing the influence of UV light on the application and visibility of pavement marking materials is presented below. A brief introduction to the scope of the research is provided with research results and conclusions in bullet format.

A Preliminary Field Evaluation of Ultraviolet-Activated Fluorescent Roadway Delineation

By Mahach, KR et al.

This study investigates the potential of using fluorescent materials in roadway markings in combination with UV headlights on vehicles.

- Field trials
- UV headlights provide a noticeable increase in delineation visibility.
- Dynamic testing showed a roadway delineation increase of 19% over regular low-beams.
- Static testing using the UV lights and UV-activated pavement markings indicated:
    - 25 % increase in edge line sight distance.
    - 29 % more of the center skip lines were noticed.
    - Subjective rating of visibility increased by 47 %.

Ultraviolet Headlamp Technology for Nighttime Enhancement of Roadway Markings and Pedestrians

By Turner, D; Nitzburg, M; and Knoblauch, R

This paper discusses an extensive field study that was conducted to determine the conditions under which driver performance could be improved with fluorescent traffic control devices and auxiliary UV headlights.

Research conducted in Sweden has shown very promising results to the use of UV headlamps.

Preliminary field research recently completed in the United States found that the visibility of pavement markings increased 25% with UV.

Several static tests were performed to evaluate fluorescent pavement markings, post-mounted delineators, and various pedestrian scenes under two headlight conditions (low beam only and low beam with UV).

Dynamic tests included a subjective evaluation of two headlamp conditions and a performance test in which subjects drove an instrumented vehicle.

Results of the field study indicated that pavement markings could be observed 30% further, and pedestrians could be observed over 90% further with the addition of UV.

Subjects consistently evaluated the use of UV headlamps as beneficial.

3.2.4. Pavement Management Systems

This section presents a review of research that has been directed towards the role of pavement management systems.

An Interactive Graphical Pavement Management System: Windows ILLINET
Wang, L et al.

This paper researches the possibility of enhancing a pavement management system (PMS) to increase its usefulness in making pavement rehabilitation decisions.

- The research resulted in the development of an interactive, graphical multimedia PMS called Windows ILLINET
- The PMS is a Windows based and user friendly software system.
- It applies the following to assist with decision making:
    - Color graphics
    - Text
    - Digitalized video images of current and past pavement conditions
    - Rehabilitation information
    - Predicted pavement performance
    - Multiple decision-making options

Geographic Information Systems-Based Pavement Management System – A Case Study
Medina, A et al.

This paper describes a case study of a pavement management system (PMS) that was developed using a geographic information system (GIS) in Fountain Hills, Arizona.

- The first phase included data collection from the city.
- The research team selected the Road Surface Management System (RSMS) package with was developed at Arizona State University.
- MapInfo was selected as the GIS system for the project based on cost and ease of use.
- The two programs allowed a GIS-PMS program based on the existing digital data.

Multicriteria Dynamic Segmentation: Geographic Information System Application for Managing Retroreflectivity of Pavement Marking

By Sarasua, WA

This paper discusses the application of a geographic information system (GIS) for managing pavement markings.

- Dynamic segmentation reduces the problems associated with fixed or variable-length segmentation.
- It is used in conjunction with a mile point linear-referencing scheme.
- Dynamic segmentation can be slow and tedious when working with very small segments and constantly changing attributes.
- Binned data are assigned to each segment length by use of database manipulation and aggregation operations.

Pavement Marking Systems – How Users Rate Them

Better Roads

This article is based on a survey distributed to highway agencies by Better Roads. Table 2 (see Appendix) categories the response ratings from the survey. Additionally, information on how Ohio DOT utilizes its pavement marking materials is provided in the article.

Public Perception of Pavement-Marking Brightness

Loetterle, FE et al.

MnDOT performed a study comparing values from a LaserLux retroreflectometer and ratings provided by interviewed public citizens.

- Selected member of the general public participated in the research.
- Driving course consisted of pre-selected state and county roads.
- Interview was conducted after dark and consisted of questions regarding the brightness of pavement markings.
- Correlation was discovered between the interview ratings of visibility of pavement markings and retroreflectivity levels from the LaserLux.
- Threshold of acceptable retroreflectivity levels ranged from 80 to 120 $mdc/m^2/lx$.

Minimum In-Service Retroreflectivity of Pavement Markings
Zwahlen, TH and Schnell T

This paper discusses minimum in-service retroreflectivity values calculated by the CARVE computer model.

- CARVE provides retroreflectivity values of pavement markings for any selected single-point geometry (e.g. ASTM 30-m geometry).
- An initial set of in-service retroreflectivity values for fully marked, dark, straight and dry roads using painted and bead markings was developed.
- A constant minimum preview time of 3.65 sec for the markings without raised pavement markers (RPMs) was used.
- A separate set of in-service retroreflectivity values based on a constant preview time of 2.0 sec for roads fully marked with RPMs in good working condition were developed.
- Results indicate that the minimum retroreflectivity requirements for pavement markings could be set lower for roads with RPMs.
- Proposed minimum retroreflectivity levels are based on approximately the 85^{th} percentile of the licensed population and approximately the 95^{th} percentile of the nighttime driver population.

Computer-Based Modeling to Determine the Visibility and Minimum Retroreflectivity of Pavement Markings
By Schnell, T and Zwahlen, TH

This paper discusses the research efforts conducted at Ohio State University used to calibrate a pavement marking visibility model known as Computer Aided Road marking Visibility Evaluator (CARVE).

- The FHA, mandated by the US Congress, commissioned research on establishing in-service minimum levels of pavement marking retroreflectivity.
- CARVE was developed and refined to systematically investigate drivers visual needs at night.
- The components, methods, algorithms and equations used to develop CARVE are described in detail in this paper.
- Future expansions of CARVE will provide modeling of:
    - Wet-weather visibility of pavement markings

- Effects of combined pavement markings (pavement markings and raised markers)
- Visibility in fog and blowing snow

Development of a Pavement Marking Management System
Measurement of Glass Sphere Loading in Retroreflective Pavement Paints
By Rich, MJ; Maki, RE; and Morena, J

This paper discusses the evaluation of factors affecting the performance and durability of painted edge and center lines. The project was directed at developing a practical pavement marking management system.

- Project attempted to quantify relationship between glass sphere content of pavement marking and retroreflectivity over time.
- Two techniques were developed to quantify glass bead content. The first being high-temperature pyrolysis and the second being image analysis.
- Conclusions suggest that these two techniques will lead to a better understanding of the factors associated with retroflectivity degradation and improved products and maintenance practice.

3.3. STANDARDS FOR ROAD DELINEATION

ASTM has provided the latest standards and guidelines for properly measuring retroreflective properties of pavement markers:

- ASTM Designation E 1743 – 96: *Standard Practice for Selection and Use of Portable Retroreflectometers for the Measurement of Pavement Marking Materials*
- ASTM Designation E 1710 – 97: *Standard Test Method for Measurement of Retroreflective Pavement Marking Materials with CEN-Prescribed Geometry Using a Portable Retroreflectometer*
- ASTM Designation E 1696 – 95b: *Standard Test Method for Field Measurement of Raised Retroreflective Pavement Markers Using a Portable Retroreflectometer*

In addition, papers on pavement marking standards were found in the literature. Relevant papers have been reviewed and are presented below.

Recent Modifications to the Canadian Pavement Marking Standards

By Teply, S

The Manual on Uniform Traffic Control Devices for Canada has recently added important modifications to the chapter on pavement markings.

- The variety of the line forms has increased and new recommendations are made regarding their applications.
- This article, which describes the changes and the reasons for them, concentrates on the following points: how pavement markings influence driver behavior; what the new features of the markings section of the Manual on Uniform Traffic Control Devices are; and how they were evaluated.
- Legal implications, ease of application, and costs are also discussed.
- It is noted that the variety of the pavement marking features in the Canadian Manual makes it possible to consider pavement markings as an integrated part of the geometric design for new roadways. It also allows for improvements in areas with safety problems or capacity difficulties related to the disorientation of the drivers.
- Studies show that the new markings not only improve driver information processing, but also directly and positively affect driver behavior.

Retroreflective and Plastic Pavement Marking Standards Published Specification for White, Yellow, and Black Hot Applied Reflective Thermoplastic Striping Material

By Hefty, DE

This paper discusses a proposed equipment standard specification for thermoplastic marking materials.

- The specification covers the following categories:
  - Scope
  - Classification
  - Materials
  - Requirements of the thermoplastic mixture
  - Application properties
  - Packaging and markings
  - Methods of sampling and testing
  - Thermoplastic performance and application characteristics

3.4 CONCLUSION

To date, great strides have been made in improving pavement marking materials. Improvements have been made in the following categories:

- Durability
- Service-life
- Cost-effectiveness
- Retroreflective properties
- Wet night retroreflection

Based on the above literature review, the following research areas appear to be insufficient and should be further investigated:

- Durability of pavement marking subjected to winter maintenance activity
- Wet-night reflectivity of delineation systems
- Profiled pavement marking

3.5. APPENDIX

Table 1. Costs of pavement marking materials (Lee et al. 1999).

Pavement Marking Materials						
Type	Solvent-borne Paint	Water-borne Paint	Polyester	Epoxy	Thermoplastics	Tapes
Cost	\$0.03/ft	\$0.05/ft	\$0.09/ft	\$0.25 to \$0.35/ft	\$0.45/ft	\$1.50 to \$2.0/ft
Durability	< 1 year	< 1 year	2-3 years	3-5 years	3-5 years	4-8 years
Dry Time	Variable	Variable	Moderate	Long	Moderate	NA

Table 2. Survey of manufacturers marketing materials by highway agencies. (Better Roads).

Material and Manufacturer	Performance	Ease of Use	Lifetime Cost	Initial Cost	Mfr. Service	Overall Rating
Best Raised Reflective Markers: Stimsonite	8.4	9.1	7.3	5.7	8.0	7.70
Best Hot-Applied Thermoplastic, alkyd type: Pavemark	8.8	6.0	9.0	6.3	8.2	7.66
Best Water-Based Paint: Centerline Industries	5.7	8.3	5.0	7.1	7.0	6.6
Best Cold-Applied, Preformed Tape: 3M	7.1	8.2	5.7	4.1	7.8	6.58

4.0 PUBLICATIONS

The main results of this research work were reported in the following publications:

Lee, J., W. Taylor, and T. Maleck. Pavement Marking Material Evaluation Study in Michigan. *ITE Journal*, Vol. 69, No. 7, 1999, pp. 44-46, 48-51.

Rich, M. J., R. E. Maki, and J. G. Morena. Development of a Pavement Marking Management System. In *Transportation Research Record 1794*, TRB, National Research Council, Washington, D.C., 2002, pp. 49-54.

Filcek, M.J., Morena, J.G., Long D.C., and Maleck, T.L., (under review) "Investigation of the Dry/Wet-Night Retroreflectivity and Durability of Pavement Markings Placed in Milled Rumble Strips," ITE Journal.

Deviatov, M.M., Maleck, T.L., Rich, M., and Oulevski, V.V. (2002) "The Evaluation of Pavement Markings and Factors Affecting the Retro-reflectivity," *Science and Technology in Road Construction Industry* #3, Moscow (in Russian).

5.0 EXPERIMENTAL METHODS

This section discusses the experimental methods utilized for measuring the Rl (coefficient of retro reflected luminance) parameter of pavement markings for the research project. The Rl parameter is often referred to as the retroreflectivity level and represents the brightness of the pavement markings observed by drivers of motor vehicles by artificial illumination. Field tests of the Rl parameter for this project were measured through the employment of a handheld retroreflectometer. Listed below are the ASTM designations specified for portable retroreflectometers:

- ASTM Designation: E 1743 – 96. *Standard Practice for Selection and Use of Portable Retroreflectometers for the Measurement of Pavement Marking Materials.*
- ASTM Designation: E 1710 – 97. *Standard Test Method for Measurement of Retroreflective Pavement Marking Materials with CEN-Prescribed Geometry Using a Portable Retroreflectometer.*

The LTL2000 Retrometer, made by Delta Light and Optics – Denmark, was employed for this research project. It provides on site quality control of pavement markings in accordance with CEN specifications. An illumination angle of 1.24° with an observation angle of 2.29° simulates a driver's viewing distance of 30 meters at an eye height of 1.2 meters, while utilizing an observational area of approximately 45mm x 200mm. Presented below are additional features of the LTL2000 Retrometer:

- Portable self-contained instrument
- Measure in full daylight
- Automatic stray light compensation and error diagnostics
- Measure in dry and wet surfaces
- Plane, textured and profiled markings
- Measurement geometry and illumination corresponding to realistic viewing condition in night time traffic

Retroreflectivity measurements were performed at specified testing locations for the US-127 and I-75 study sites and were performed at randomly selected testing locations for all other study sites. Testing locations for US-127 and I-75 were specified at every other shoulder reflector, starting with the first reflector at the beginning of the painted rumble strips. The distance column in the retroreflectivity tables in the Appendix indicates these specified testing locations. Retroreflectivity measurements for each test location on US-127 and I-75 were performed for all four paint lines; white rumble, white solid, yellow rumble and yellow solid. Likewise, retroreflectivity measurements for each randomly selected test location along M-13 were performed for both yellow rumbled centerlines. Other study sites investigated during this research program focused on the application of standard and thicker pavement marking materials on edge lines. Retroreflectivity measurements for these study sites were performed for the edge markings only.

Further, six measurements for each paint line at each specified/random testing location for each study site were performed. Three of these measurements were performed with the retroreflectometer in the direction of traffic and three in the direction against traffic. The three measurements in each direction differed by the location of the observational area relative to the paint line; that is to the left, center and right of the paint line. The Rl parameter was calculated taking the average of all significant measurements based on the directionality of the roadway. For instance, significant measurements for a one-directional roadway (e.g.US-127) are in the direction of traffic. However, a two-directional roadway (e.g. M-13) utilizes the retroreflectivity from both directions and the Rl parameter would be obtained by averaging all six measurements.

For the Grand Rapids Region study sites the MDOT mobile retroreflectometer was used for the retroreflectivity surveys. The surveys were conducted during September – November of the year of 2003 (after completion of pavement marking) and during June – July of 2004 (after the winter maintenance).

Additionally, the mobile videotaping was performed by means of the MDOT mobile retroreflectometer. Still photos were also obtained.

6.0 RESEARCH RESULTS

6.1 YIELD ANALYSIS

This chapter provides information regarding the methods, study sites and results and discussion of the yield analysis techniques investigated at the beginning of this research program. In particular, characteristics of the study sites such as approximate site location, average daily traffic (ADT), and relative snowfall is provided. Information regarding the yield analysis research topic is completely self-contained within this chapter for simplicity purposes and to emphasize that the research program has changed its focus to investigating alternative strategies for increasing the durability of pavement markings.

6.1.1 Methods

The yield analysis techniques, pyrolysis and image analysis, were developed to quantify the glass bead content with the retroreflectivity of pavement markings. Pyrolysis requires the installation of 12 x 6 inch aluminum plates to the roadway over the existing white edge lines, thus allowing the paint truck to coat them while repainting the edge line. The plates are then removed and analyzed in the lab to calculate the mass fraction of glass beads in the painted marking. Image analysis utilizes low magnification photographs of paint markings and converts the picture to a binary image. Digital software is then employed to calculate the number of glass spheres per area, average sphere size, and aerial percentage. Presented below is information on the main study sites investigated during the yield analysis portion of the research project.

6.1.2 Study Sites

The first study site for the yield analysis research was located on M-100 in Eaton County between Potterville and Grand Ledge (Figure 1). Standard waterborne paint was applied to the white edge lines under favorable weather conditions at a rate of 5 mph. The study site features moderate snowfall and an approximate ADT of 4,500 vehicles/day. Field investigations were performed during specific times when traffic conditions were favorable. Retroreflectivity measurements for this study site started on May 8, 2001.

Two additional study sites were located on M-46 and M-37 near the Muskegon area (Figure 2). Standard waterborne paint was applied to the white edge lines of M-46 between Maple Island Road and Barnes Road and M-37 north of M-46. The study sites feature heavy lake effect snowfall and subsequent winter maintenance activities. The approximate ADT for M-46 and M-37 is 13,700, and 8,100 vehicles/day, respectively. Field investigations were performed during the weekend at specific times when traffic levels were low. Retroreflectivity measurements for M-37 and M-46 began at the end of December 2001.

6.1.3 Results and Discussion

Degradation curves were developed for each study site based on initial and periodical retroreflectivity measurements (Figure 53). Results indicate that the degradation of the retroreflectivity level differs for each study site. Analysis provides the following overall reductions in retroreflectivity for each study site for one winter season:

- 82.7% on M-46
- 55% on M-37
- 54% M-100

Comparing retroreflectivity measurements between the study sites reveal that pavement marking degradation is more rapid in the Muskegon area. The above study sites are listed in increasing distance from lake-effect snowfall from Lake Michigan. This illustrates a predominant trend that the level of degradation decreases with the distance from Lake Michigan. Additionally, it supports the conclusion that heavy snowplowing greatly affects the retroreflectivity of pavement marking materials. One reason for this pattern is the "lake effect" process. Cold winter air moving across Lake Michigan attracts moisture from the warmer lake water, resulting in significant snowfall amounts in the western side of the state.

Problems with fastening the aluminum plates to the roadway alerted researchers of difficulties with the pyrolysis yield method. Most of the aluminum plates at the study sites were dislodged and lost. Problems also surfaced with the image analysis yield method due to dimensionality issues and program capabilities. For instance, a 2-dimensional picture inaccurately defines the diameter of a glass bead. The bead may be large and sitting halfway in the binder or it could actually be a small glass bead sitting on top of the binder. The image analysis software also had trouble being able to perform the entire glass bead calculations mentioned above in the methods section of this chapter. Based on these problems and the fact that the yield analysis methods were time consuming, labor intensive, and uneconomical for the project, MSU researchers concluded a different approach was required.

6.2 THICKER PAVEMENT MARKINGS

This chapter provides information regarding the methods, study sites and results and discussion of the thicker pavement markings, HD-21 and Sahara WaterDry. These thicker pavement-marking materials were investigated during this research program based on a conclusion that the yield analysis methods were unsatisfactory. In particular, characteristics of the study sites such as approximate site location, average daily traffic (ADT), and relative snowfall is provided. The thicker pavement marking research topic is completely self-contained within this chapter for simplicity purposes and to emphasize that the research program has changed its focus to investigating alternative strategies for increasing the durability of pavement markings.

6.2.1 Methods

The main difference in HD-21 and standard waterborne paint is that the binder is thicker and the amount of glass beads is increased accordingly. HD-21 is applied using standard waterborne paint equipment with minor adjustments to the paint and glass bead guns. *Sahara WaterDry* is also a new thicker pavement marking material that was investigated during the research project. This material is a fast drying waterborne paint that uses a layer of WaterDry reagent between two layers of waterborne paint. This reagent creates a faster drying environment for the relatively thick pavement marking material. Sahara WaterDry has a thick consistency and is implemented using special technology. The painting truck (Figures 7 and 8) consists of the following guns:

- 15 mil waterborne paint gun
- WaterDry reagent gun
- 15 mil waterborne paint gun
- Large glass bead gun
- Small glass bead gun

6.2.2 Study Sites

A study site on US-31 just south of I-96 (Figure 2) in Muskegon was selected to investigate the durability of HD-21 for white edge lines. The study site features relatively heavy snowfall and winter maintenance activity and has an ADT of 37,300. Field investigations were performed during specific times when traffic conditions were favorable. Retroreflectivity measurements began at the end of December in 2002.

A second study site, consisting of two test areas (Farmlane and MSU Pavilion) on the campus of MSU, was selected to investigate the new experimental pavement marking material *Sahara WaterDry*. The white edge lines on Farm Lane Road across from the MSU Pavilion and a parking lot divider line in the MSU Pavilion parking lot were coated with the thicker marking material. The study site features moderate snowfall and ADT level. The manufacturer applied the experimental material during warm weather. Field investigations were performed during specific times when traffic conditions were favorable. Retroreflectivity measurements began September 4, 2002.

6.2.3 Results and Discussion

HD-21 provided excellent retroreflectivity on US-31 near Muskegon during the beginning of the monitoring period. Final retroreflectivity measurements indicate a 74 % degradation of retroreflectivity (Figure 53). *Sahara WaterDry* is a thicker marking material that supposes to provide high retroreflectivity over longer periods of time. However, field measurements indicate that degradation due to winter maintenance activities is similar to that of standard waterborne paint. Based on retroreflectivity measurements located in the Appendix, *Sahara WaterDry* provides insignificant improvement in the durability of the pavement markings subjected to winter maintenance activity.

6.3 PROFILED PAVEMENT MARKINGS

This section provides information regarding the methods, study sites and results and discussion of the milled rumble strip pavement markings investigated during this research program. These markings were investigated during this research program based on a conclusion that the yield analysis methods were unsatisfactory. In particular, characteristics of the study sites such as approximate site location, average daily traffic (ADT), and relative snowfall is provided. The milled rumble strip pavement marking research topic is completely self-contained within this chapter for the reader's simplicity and to emphasize that the researchers are currently exploring this topic for developing novel pavement marking management strategies.

6.3.1 Methods

In July of 2002 the experimental milled rumble strip pavement marking study commenced. Four one-mile length study sites in northern Michigan were chosen initially: US-127 SB, US-127 NB, I-75 SB, and I-75 NB (2002 Gaylord Rumble Strip Pavement Marking Project). Locations of study sites are shown in Figures 3 and 4. Each study site was painted with standard MDOT 4 inch white and yellow waterborne paint edge lines. The new edge lines were placed in the existing shoulder rumble strips 12" and 24" from the existing standard edge lines for US-127 and I-75 respectively (See Figures 9 and 19). This placement technique allows side-by-side comparison of the performance of the milled rumble strip pavement marking versus the standard edge line under varying weather conditions and over time.

At the same time, a pavement-marking contractor milled double rumble strips along the centerline on a two-way highway M-13 near Bay City (Figure 5). Standard waterborne paint was applied to the rumbled centerline (Figure 23).

In the summer of 2003 six new study sites were added in the MDOT Grand Rapids Region: I-96 EB, I-96 WB, US-131 NB, US-131 SB, US-31 NB, and US-31 SB (2003 Grand Rapids Region Pavement Marking Project). Locations of these study sites are depicted in Figure 6. The total length of these study sites is approximately 85 miles. The following two pavement marking strategies were investigated:

1. Application of 6-inch edge line placed with half the line on the milled rumble strip and half on the solid pavement.
2. Application of two 4-inch edge lines, with approximately 6" of spacing between the two lines, such that one of the lines is placed on the milled shoulder rumble strip and the other is placed on the driving lane to the left of the pavement/shoulder joint (traditional MDOT placement).

6.3.2 Study Sites

2002 Gaylord Pavement Marking Project

US-127 is a major expressway connecting the southern and northern regions of Michigan. This roadway is vital for traffic circulation between the U.S. and Canada with an approximate ADT of 7,900 vehicles/day. Snowfall and subsequent winter maintenance activity at the study site is relatively high. The study site consists of white and yellow edge lines on both north and southbound lanes between mile markers 227 and 228 in Crawford County directly south of Grayling (Figure 3). Testing conditions for this study site are favorable, primarily due to the open and flat terrain.

I-75 is also a major expressway connecting southern and northern Michigan. This roadway links Detroit to Canada and has an approximate ADT of 13,900 vehicles/day. Snowfall and subsequent winter maintenance activity at the study site is relatively higher than US-127, due primarily to its increased elevation. The study site consists of white and yellow standard edge lines on both north and southbound lanes between mile markers 283 to 284 in Otsego County directly north of Gaylord (Figure 4). Testing conditions for this study site are unfavorable due narrow expressway shoulders and hilly terrain.

M-13 is a two-lane highway near Bay City (Figure 5). The highway runs parallel to I-75 and is within a few miles of the Saginaw Bay. This roadway carries approximately 19,000 vehicles/day with a posted speed limit of 55 mph. Snowfall at the study site is moderate in comparison to the other two study sites, primarily due to its distance away from Lake Michigan and its relatively central location in the Lower Peninsula of Michigan.

2003 Grand Rapids Region Pavement Marking Project

I-96 is a major expressway connecting Eastern and Western coasts of Michigan (Figure 6). This highway connects major cities of Detroit, Lansing, and Grand Rapids, and has an approximate ADT of 40,000 vehicles/day. The study site on eastbound lane consists of consists of white and yellow 6-inch edge lines placed with half the line on the milled rumble strip and half on the solid pavement. The study site on westbound lane consists of white and yellow 4-inch rumbled edge lines placed on the milled rumble strips approximately 6 inches apart from the standard solid edge lines. Testing conditions for this study site are unfavorable due to heavy traffic conditions.

US-131 is a major expressway connecting the southern and northern regions of Michigan. US-131 is an important route in Michigan, connecting Kalamazoo and Grand Rapids with the North County. The ADT of this route to the north of Grand Rapids is 54,400 vehicles/day according to MDOT ADT map. The study site on northbound lane consists of white and yellow 6-inch edge lines placed with half the line on the milled rumble strip and half on the solid pavement. The study site on southbound lane consists of white and yellow 4-inch rumbled edge lines placed on the milled rumble strips approximately 6 inches apart from the standard solid edge lines. Testing conditions for this study site are unfavorable due to heavy traffic conditions.

US-31 is a major expressway leading up the western side of the Lower Peninsula, connecting the cities of South Bend, Ind., Benton Harbor/St Joseph, Holland, Muskegon, Ludington, Traverse City and Petoskey. US-31 is a major artery carrying tourist traffic to Michigan's North County. The ADT of this route to the north of Muskegon is 42,900 vehicles/day according to MDOT ADT map. The study site on northbound lane consists of white and yellow 6-inch edge lines placed with half the line on the milled rumble strip and half on the solid pavement. The study site on southbound lane consists of white and yellow 4-inch rumbled edge lines placed on the milled rumble strips approximately 6 inches apart from the standard solid edge lines. Testing conditions for this study site are unfavorable due to heavy traffic conditions.

6.3.4 Results and Discussion

2002 Gaylord Pavement Marking Project

Though research on pavement markings in rumble strips had been previously documented by Mississippi, interest increased in Michigan when a MDOT researcher documented a dramatic improvement in wet-night retroreflectivity during a heavy rainstorm in the summer of 2002. Video and still photos from the event show retroreflectivity, equivalent to dry conditions, maintained on the milled rumbled edge line even though water pooled in the bottom of the troughs. The profiled surface allows rainwater to run off, exposing enough glass beads to provide excellent delineation even during a heavy rainstorm. Retroreflectivity graphs comparing standard and milled rumble strip edge lines are located in the Appendix (Figures 54 – 77). These graphs compare initial dry, final dry and final wet retroreflectivity values. Based on the field data, milled rumble strip edge lines have higher retroreflectivity levels for both final dry and wet conditions as compared to standard edge lines. This indicates an increase in durability and wet-night retroreflectivity. These conclusions are supported by still digital photographs, which reveal a dramatic difference in the dry and wet-night visibility of the two pavement marking systems after winter maintenance (Figures 16, 20 and 21). Tables of retroreflectivity data representing initial dry, final (2003) dry and wet values for US-127, I-75 and M-13 are presented in the Appendix (Tables 1 – 19).

The only apparent physical difference between standard and milled rumble strip edge lines were a non-homogenous appearance of paint on the bottom of the grooves. Rumble strip grooves have very rough-cut surfaces, thus greatly increasing the variability in the retroreflectivity measurements. Often, the back slopes of the grooves were insufficiently painted due to the mounting angle of the paint and glass guns on the paint truck. This is an issue that must be addressed for undivided highways or other two-way roadways. However, the back slope is insignificant in providing the retroreflection effect for oncoming headlights for divided freeways. For divided highways, it is the front slopes that provide an increase in the retroreflection angle, thus increasing the efficiency of the glass beads and the amount of light returned to the drivers.

After studying these locations it is apparent that the milled rumble strips are very sensitive to the snowfalls and easily get filled up with snow, dirt, salt, and slush. However, high speed highway traffic actually cleans up approximately 0.5 to 1 foot from edge of metal. It was suggested that the pavement markings and rumble strips be placed closer to the edge of metal to take advantage of this self-cleansing system. Likewise, the milled rumble strip centerlines on M-13 in Bay County are also subjected to filling with dirt, road salt and slush. Wind velocity created by passing vehicles is apparently insufficient to keep the centerline grooves dry and clean. This is due to lower traffic speeds and opposite traffic flows creating a debris accumulation in the recessed areas of the center of the highway. Snowplows have caused minor damage to the paint on the tops of the milled rumble strips, but the slopes have been protected and possess sufficient paint and glass beads to provide adequate luminance and guidance to drivers' at night.

Investigation of the study sites from the 2002 Gaylord rumble strip pavement marking project was continued throughout the year of 2003 and the spring of 2004. Monthly visual inspections of the study sites were performed, still photographs acquired, and final measurements of the retained retroreflectivity of rumbled paintlines performed.

Monthly visual inspections have demonstrated that debris buildup for all study sites was negligible.

Environmental and mechanical degradation of the painted rumble strip pavement marking appears to be minimal, and rumbled paintlines show better performance compared to the standard solid paintlines. This observation is supported by still close-up photographs (Figures 10 – 12) as well as still photographs of side-by-side comparison of night-time performance of rumbled and solid paintlines (Figures 13, 14, 17, 18, 20, and 22). One exception is the yellow rumbled centerline on M – 13 that was significantly damaged by snowplowing in the winter of 2003/2004 (Figure 24) but still performs reasonably well (Figures 25 and 26).

Based on the data collected during the years 2002 – 2004 the graphs of retroreflectivity vs. time were constructed for study sites on US-127 and I-75 (Figures 78 – 85). The graphs show a significant drop of retroreflectivity during the winter time for both rumbled and solid paintlines that can be explained by the effect of low temperature, ice, and snow. However, rumbled paintlines regain higher retroreflectivity after the winter. Table 24 shows the retained retroreflectivity of rumbled paintlines on US-127, I-75 and M-13 after 2 years of service.

2003 Grand Rapids Region Pavement Marking Project

The objective of this project was to study the visual and reflective performance of two painted rumble strip configurations. The data obtained by mobile reflectometer is presented in Table 25. It should be noticed that the initial values of retroreflectivity vary significantly depending on test location. Retained retroreflectivity after the winter maintenance also varies significantly and does not allow for any definite conclusion.

Visual inspection showed that at certain locations the slopes and bottoms of the grooves were insufficiently painted that caused further deterioration of the paint during the winter (Figure 35).

Figures 37 – 52 show the night-time photographs of the pavement marking at different study sites.

Performance of the pavement marking under different light and weather conditions was also documented using mobile camcorder.

6.4 INCREASED BEAD LOADING

This section provides information regarding research on the increased bead loading in the Brighton and Lansing TSC areas.

6.4.1 Methods

Increased bead loadings were used for pavement marking material that had been applied during the 2003-striping season for the pavement marking systems in University Brighton TSC (10 lbs/gal) and University Lansing TSC (12 lbs/gal) areas. Control loading of 8 lbs/gal was used in University Jackson TSC area.

Initial pavement marking surveys in these areas were conducted by B.C. Traffic Engineering, inc. in October 2003. The locations of the survey sites were randomly chosen on roadways in the above mentioned areas and consisted of individual 2-mile long files. Surveys consisted of retroreflectivity measurements of the markings using the 30-meter mobile retroreflectometers.

Pavement marking surveys after the winter maintenance were performed in May – July of 2004 using the MDOT mobile retroreflectometer. The test sites were taken at approximately the same locations as the initial survey sites. Control data was taken from the surveys performed at different locations with the pavement marking performed by the same contractor with the same bead loading as University Jackson TSC pavement marking.

6.4.2 Results and Discussion

The data obtained is summarized in the Table 26 and diagrams shown in Figures 86 and 87. The diagrams demonstrate that the average retroreflectivity for freshly painted lines of all types at all study sites is above the minimum retroreflectivity requirement.

After the winter maintenance the lines with increased bead loading are still performing above the minimum level. Table 26 shows that the retained retroreflectivity for these lines varies from 90% to 100%.

Control lines with the regular bead loading show a significant decrease of retroreflectivity. All line types after winter maintenance are performing below the minimum retroreflectivity requirement.

The lack of data from the University Jackson TSC area does not yet allow for conclusion. It is recommended to continue the surveys.

7.0 CONCLUSIONS AND FUTURE WORK

The early studies in the development of alternative methods of increasing the durability of pavement markings subjected to winter maintenance activity, utilizing standard MDOT pavement marking materials concluded the following:

- Yield analysis techniques proved to be less than satisfactory
- Thicker markings materials (HD-21 and Sahara WaterDry) were insignificant in increasing the durability of the pavement markings

Surveys performed in the University Lansing and University Brighton TSC areas with the increased bead loading in pavement marking material yielded the following result:

- Increased bead loading in the pavement marking material increases the initial retroreflectivity and improves the performance of the paintlines after winter maintenance. Further investigation is recommended

Investigations performed for the Gaylord Rumble Strip Pavement Marking Project throughout the years of 2002 - 2004 yield the following conclusions:

- The profiled pavement markings increased paint line durability

- The initial dry retroreflectivity levels for the profiled pavement markings are approximately the same as those for standard marking
- The initial wet retroreflectivity levels for the profiled pavement markings are higher than those for standard marking
- The main advantage of the profiled pavement marking is the dramatic increase in retroreflectivity under wet-night condition
- The retroreflectivity of the profiled pavement marking varies significantly depending upon the following factors:
    - Precipitation
    - Temperature
    - Snow and ice
- On the other hand, the monthly inspections showed that debris accumulation in the grooves is negligible and do not have a noticeable effect on the paintline performance

Investigations performed for the Grand Rapids Region Rumble Strip Pavement Marking Project throughout the years of 2003 - 2004 yield the following results:

- The previous conclusions on profiled pavement marking performance were confirmed
- The winter inspections proved that placement of the rumbled marking close to the traffic lane does not significantly affect the accumulation of snow
- The quality of the paintline application significantly affects its initial and long-term performance
- Placement of the traditional rumble strip on the edge of the shoulder close to the traffic lane increases the noise level

Based on the above conclusions the following recommendations are proposed for the future work:

- Revised pavement design to remove joint line from the edge of metal
- Geometry of rumble strip for optimizing retroreflectivity
- Improved technique for the paint application to the rumble strip
- Cleaning mechanism for removing trapped dirt and snow in grooves

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9.0 APPENDICES

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Table 23. Average retroreflectivity for solid and rumble strip edge lines on southbound I – 75.

Table 24. Retained retroreflectivity for rumble strip edge lines on US – 127, I – 75, and M – 13 after 2 years of service life.

Table 25. Retained retroreflectivity for solid and rumble strip edge lines on I – 96, US – 131, and US – 31 after 1 year of service life.

Table 26. Retroreflectivity of paintlines with different bead loading

SITE MAPS

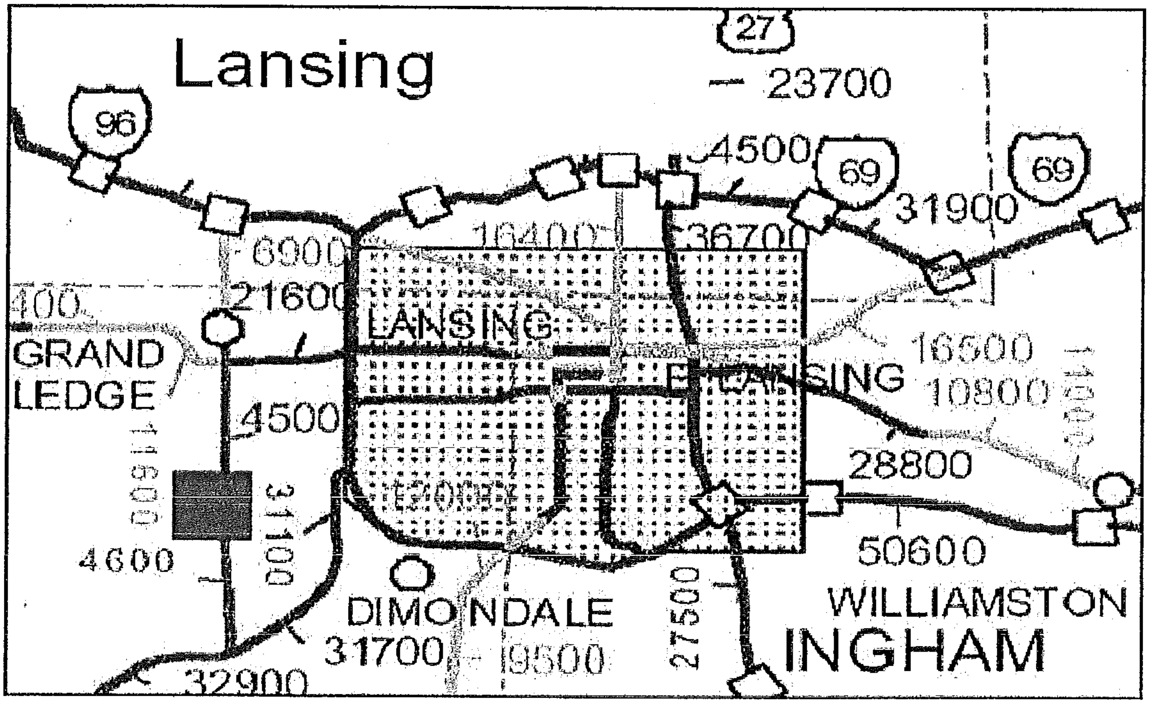

Figure 1. Map depicting M-100 study site (solid red square) located directly south of Grand Ledge.

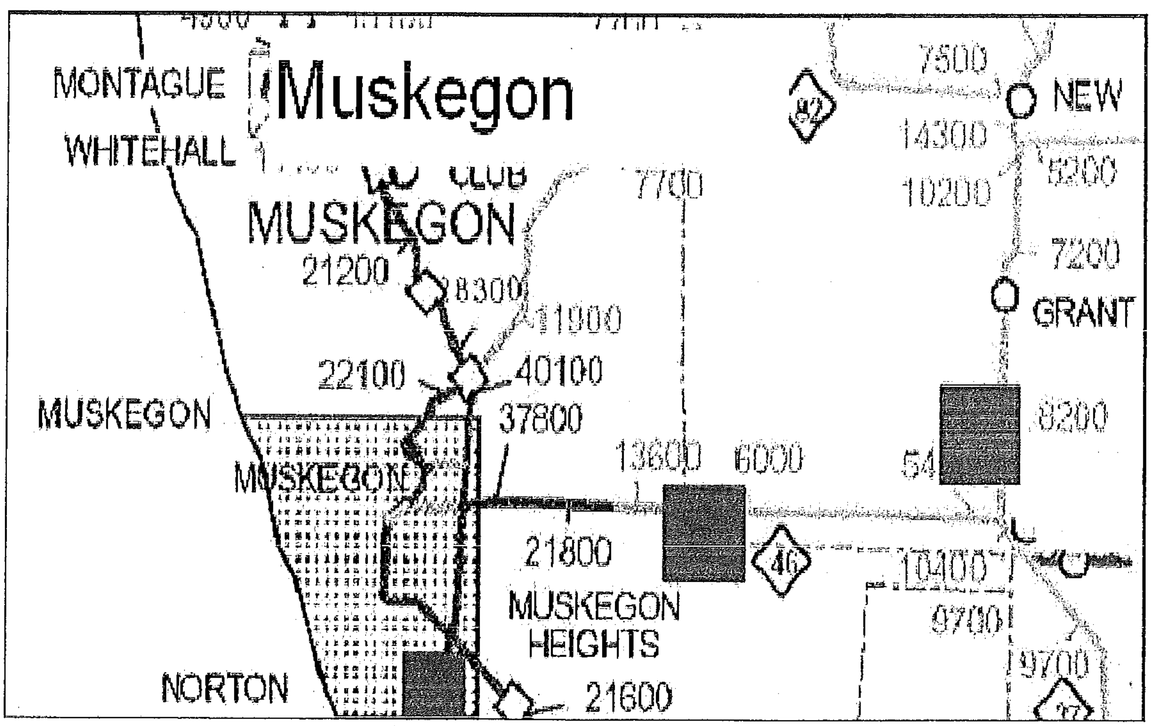

Figure 2. Map depicting US-31, M-46 and M-37 study sites (solid red squares) located in Muskegon region.

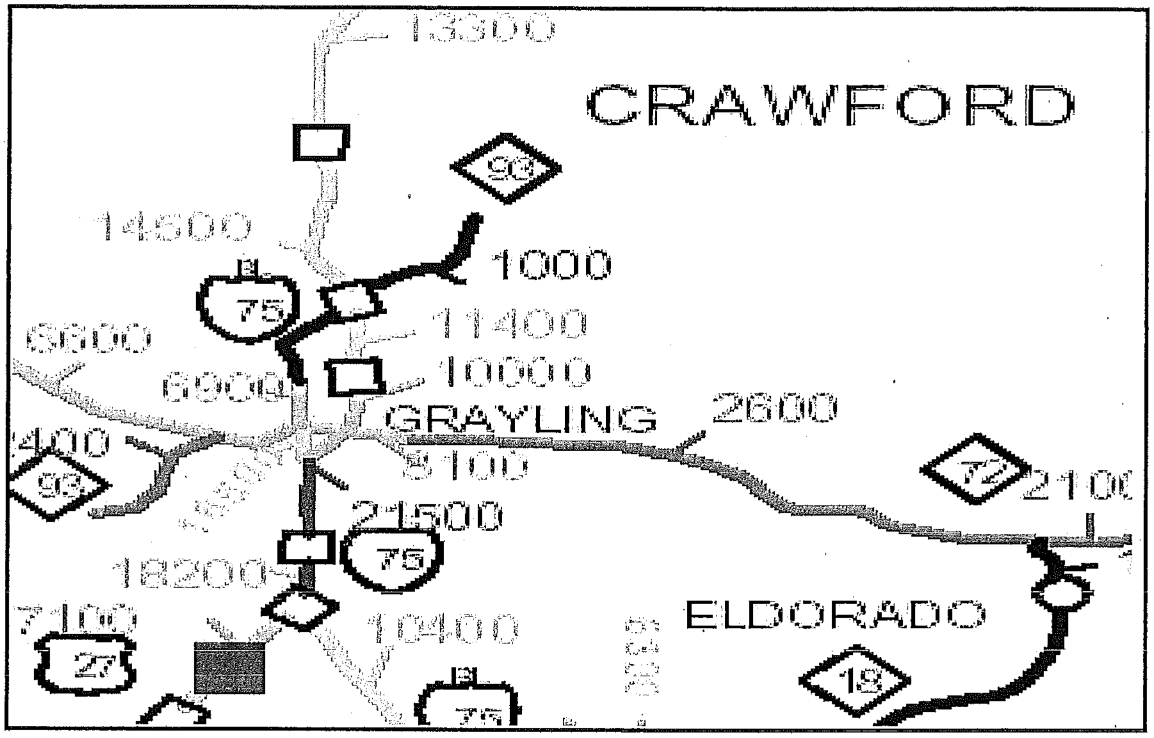

Figure 3. Map depicting US-127 study site (solid red square) located directly south of Grayling between mile markers 227 and 228.

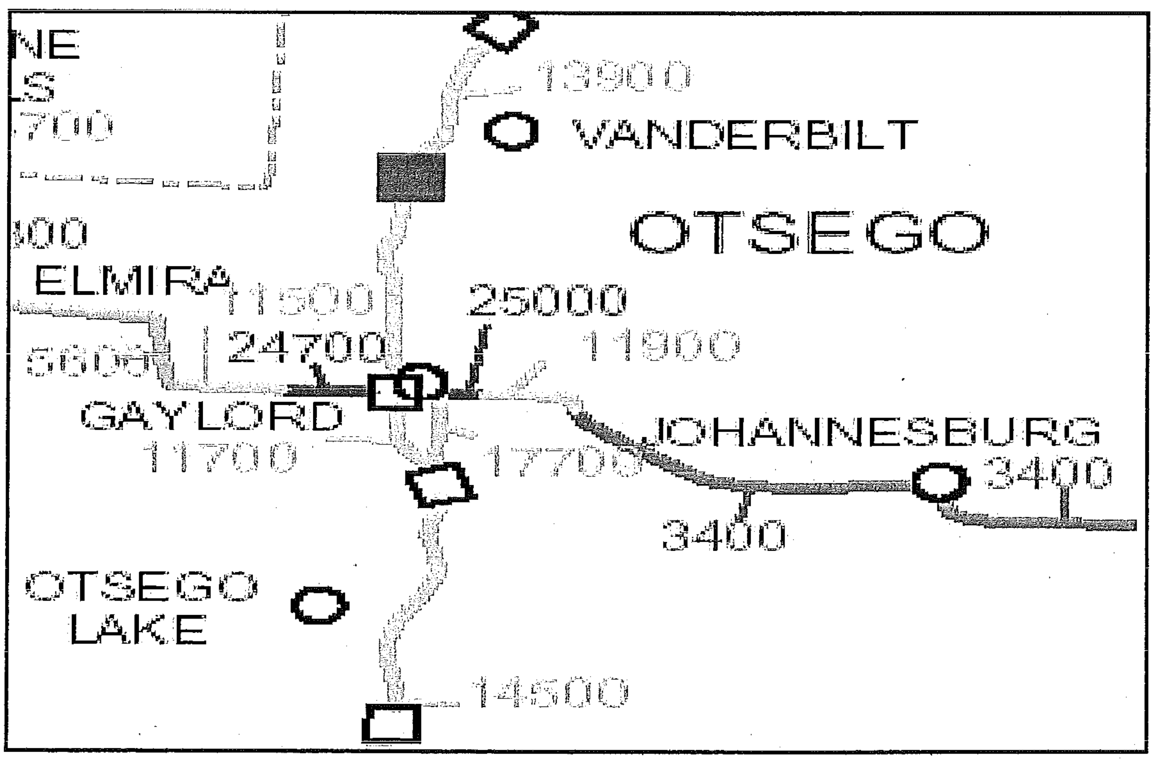

Figure 4. Map depicting I-75 study site (red square) located directly north of Gaylord between mile markers 283 and 284.

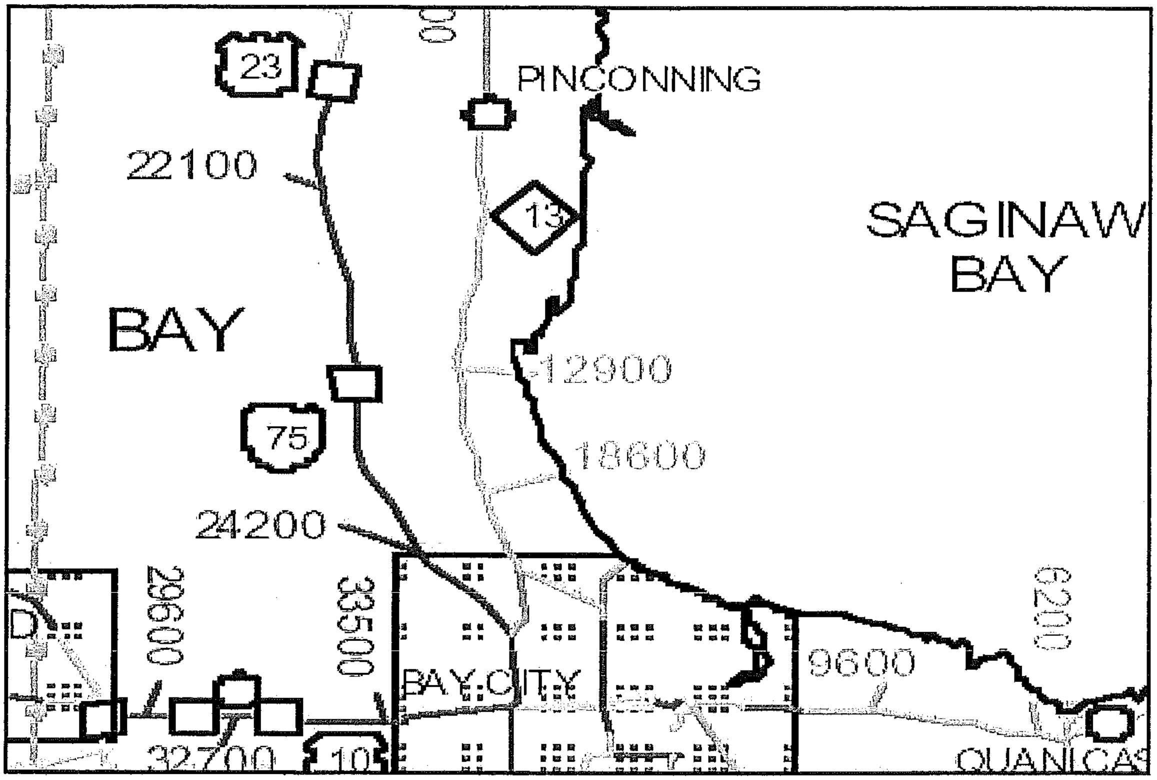

Figure 5. Map depicting M-13 study site (between 12900 and 18600) located directly north of Bay City.

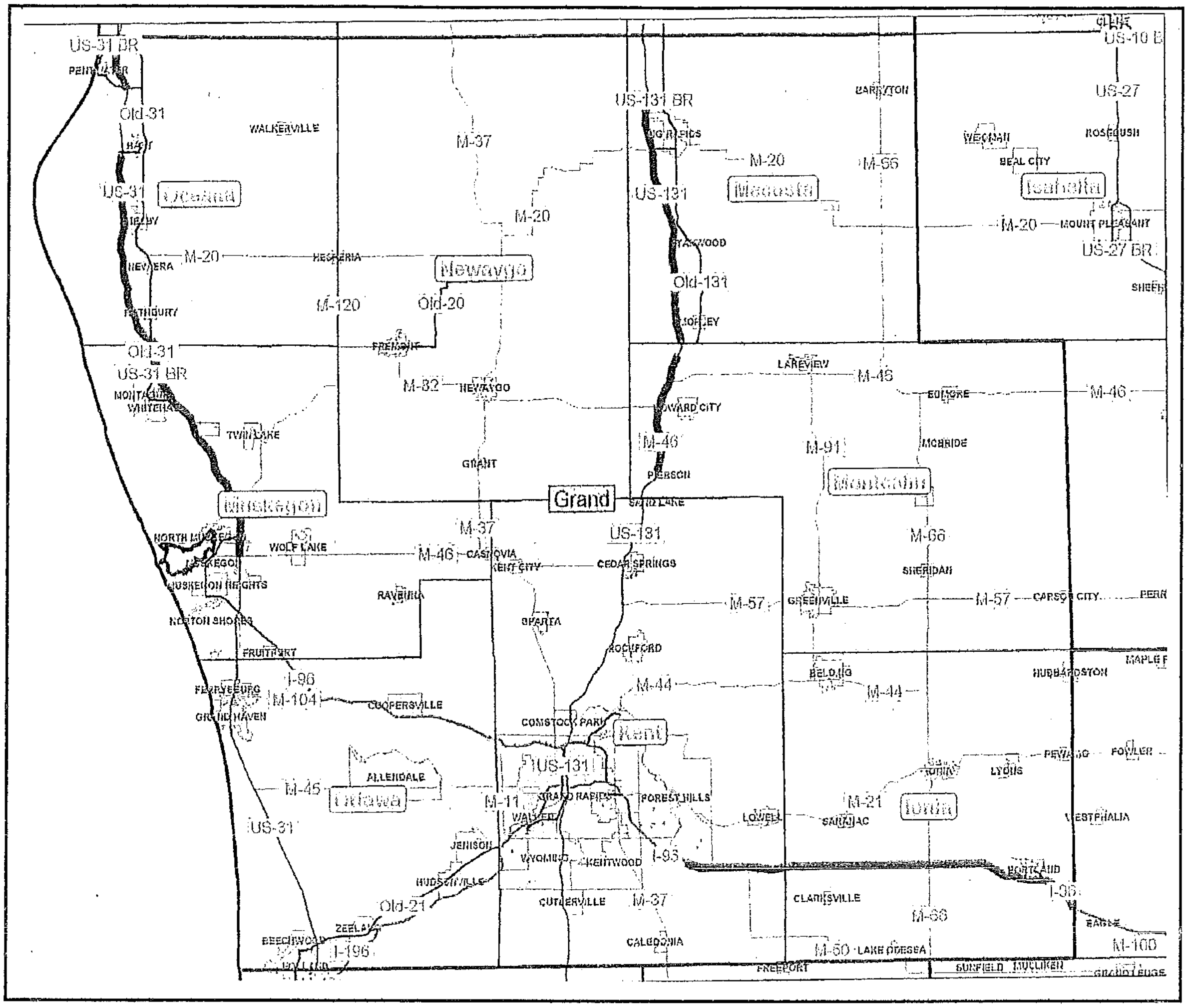

Figure 6. Map depicting I-96, US-131, and US-31 study sites.

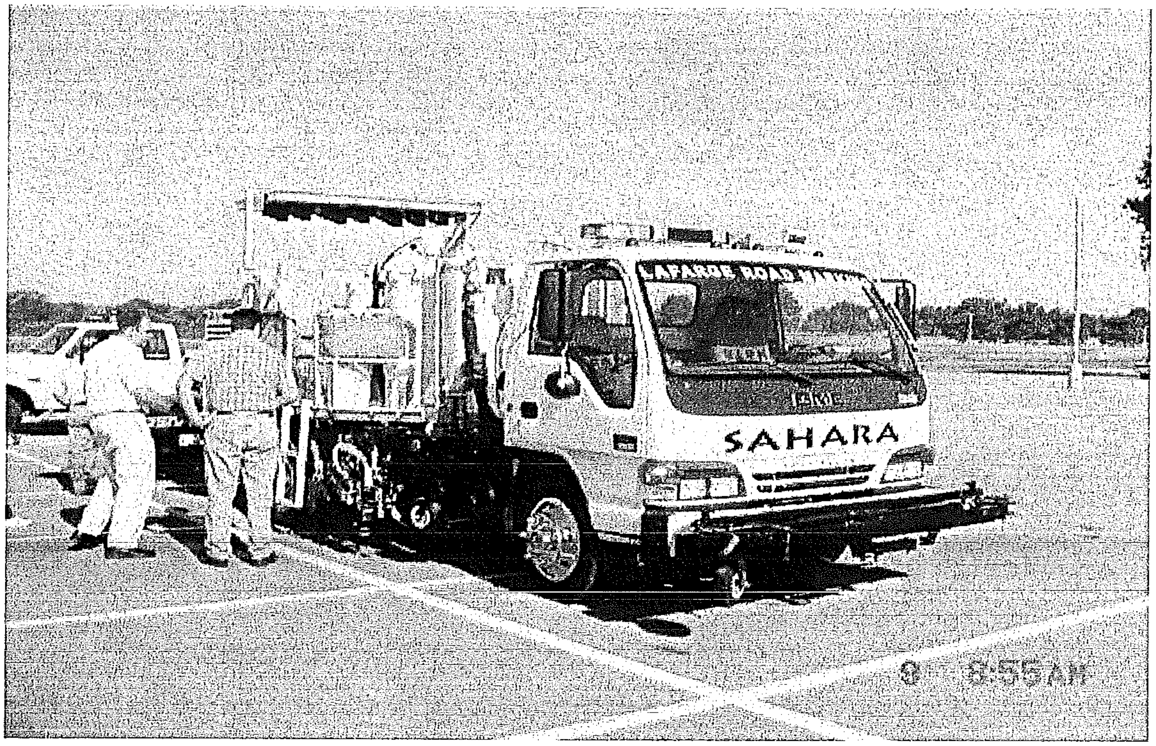

Figure 7. Paint truck applying *Sahara WaterDry* to MSU Pavilion parking lot.

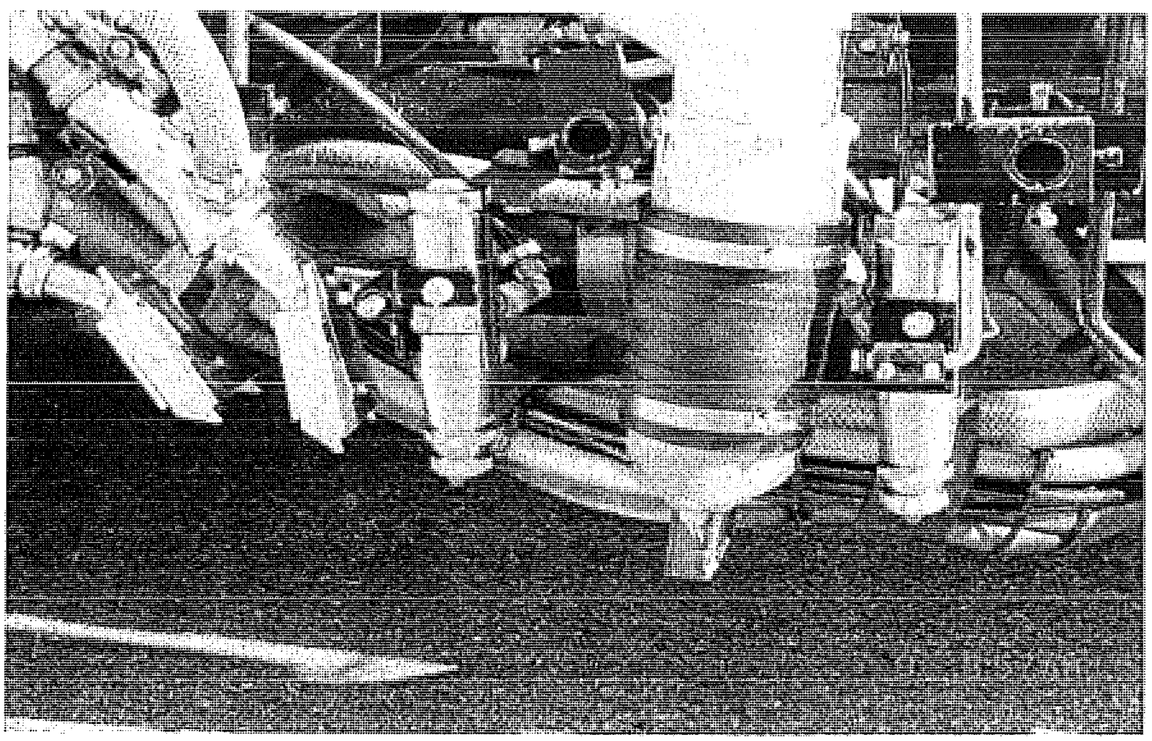

Figure 8. Paint, WaterDry reagent, and glass bead guns on Lafarge paint truck (right to left).

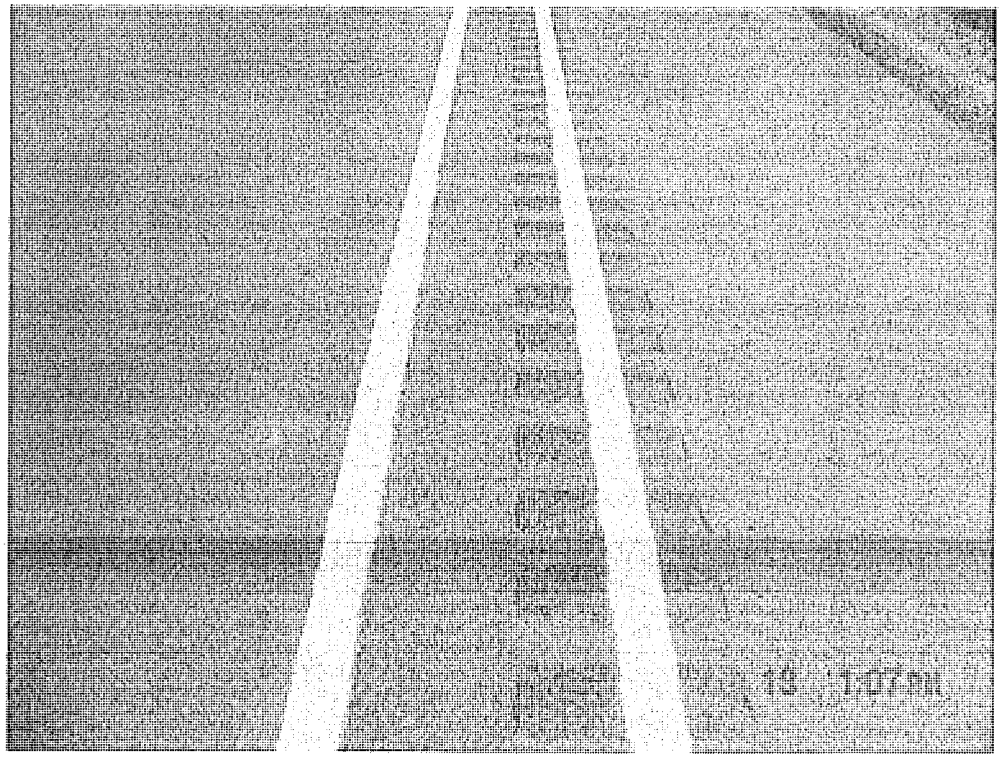

Figure 9. Initial side-by-side comparison of white solid and rumbled edge lines on northbound US-127, July 18, 2002.

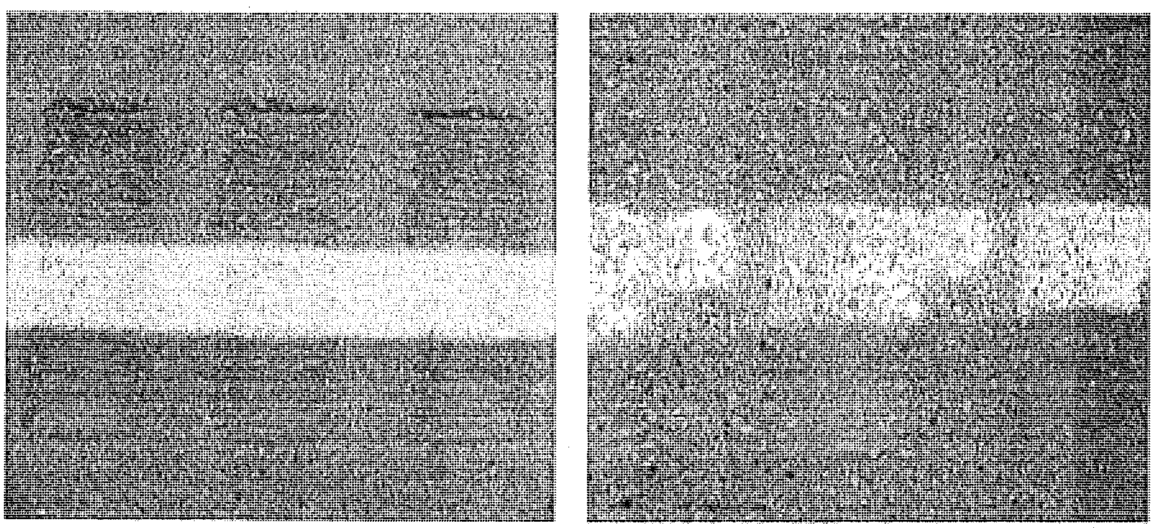

Figure 10. Close-up photo of white rumbled edge line on northbound US-127 after application (left) and after one-winter maintenance (right).

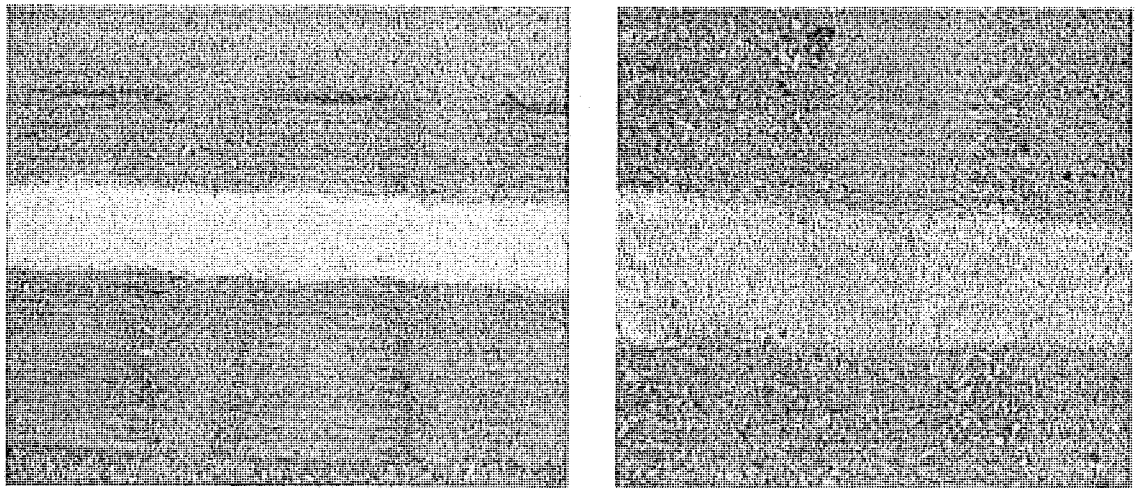

Figure 11. Close-up photo of yellow rumbled edge line on northbound US-127 after application (left) and after one-winter maintenance (right).

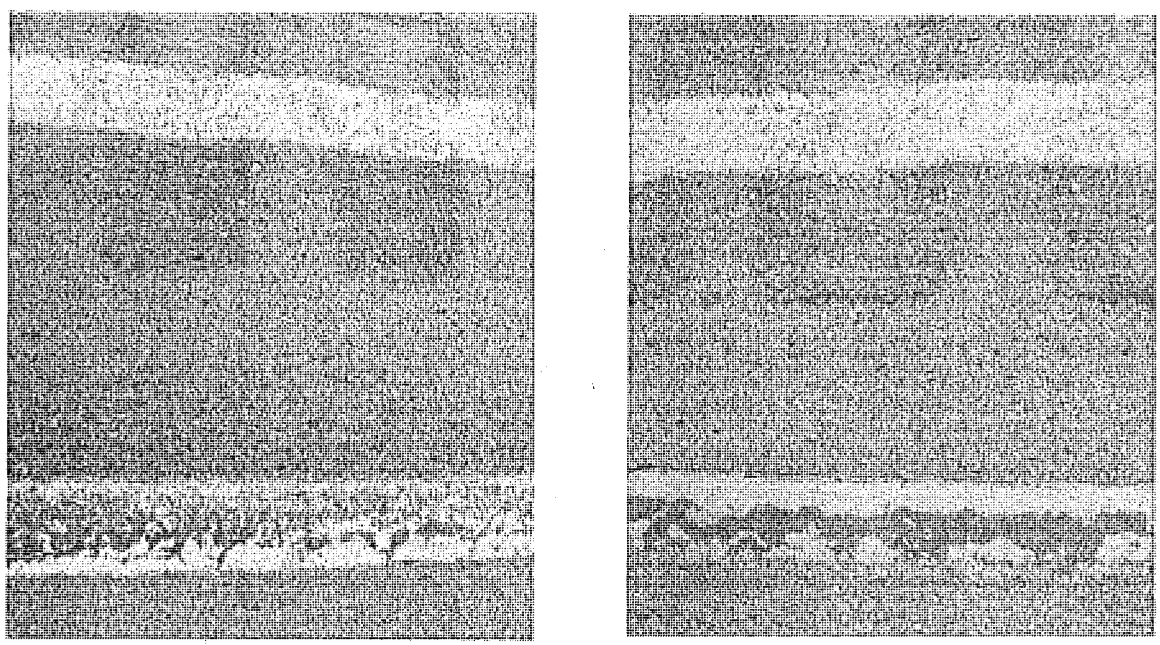

Figure 12. Close-up photo of white solid and white rumble (left) and yellow solid and yellow rumble (right) edge lines on northbound US-127 after two-year service.

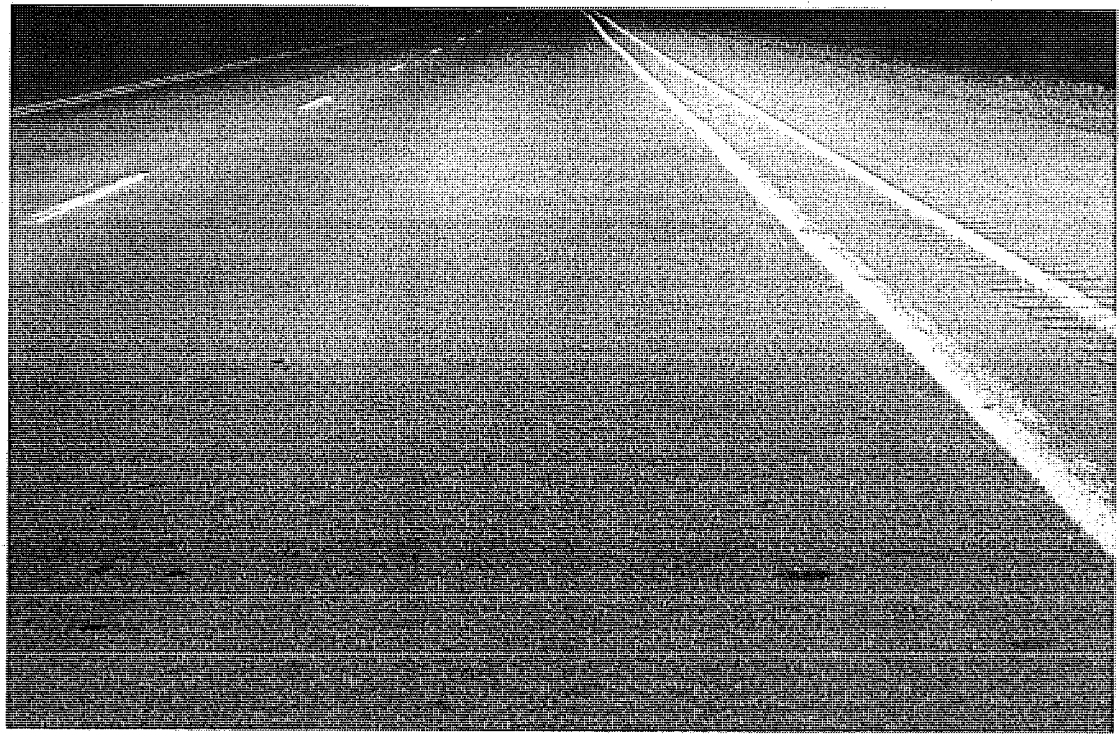

Figure 13. Photograph of dry night side-by-side comparison of white solid and rumbled edge lines northbound US-127 after one-year service, May 17, 2003.

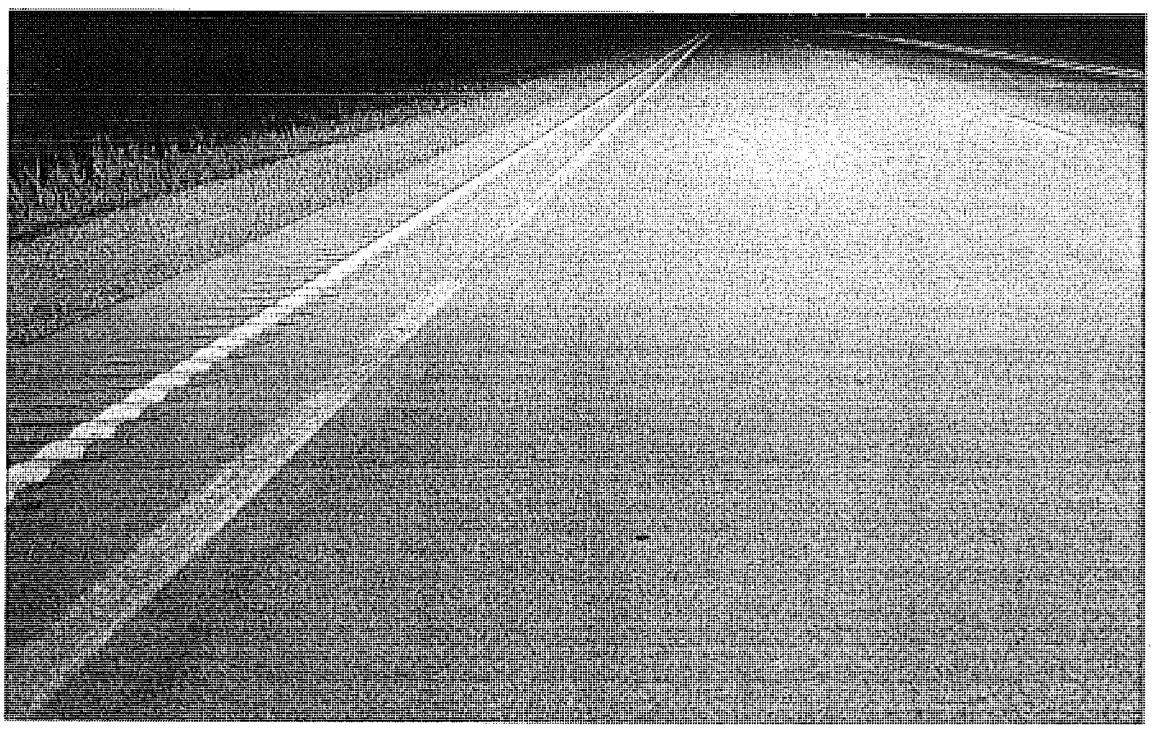

Figure 14. Photograph of dry night side-by-side comparison of yellow solid and rumbled edge lines northbound US-127 after one-year service, May 17, 2003.

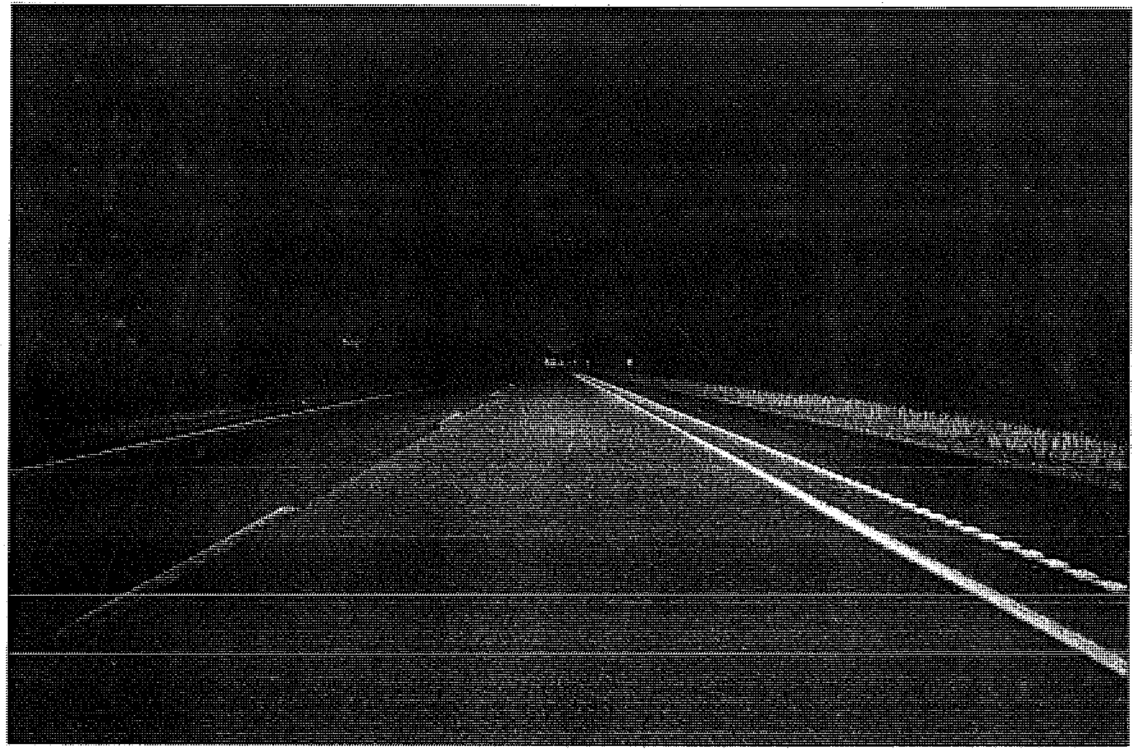

Figure 15. Photograph of wet night side-by-side comparison of white solid and rumbled edge lines northbound US-127 after one-year service, May 30, 2003.

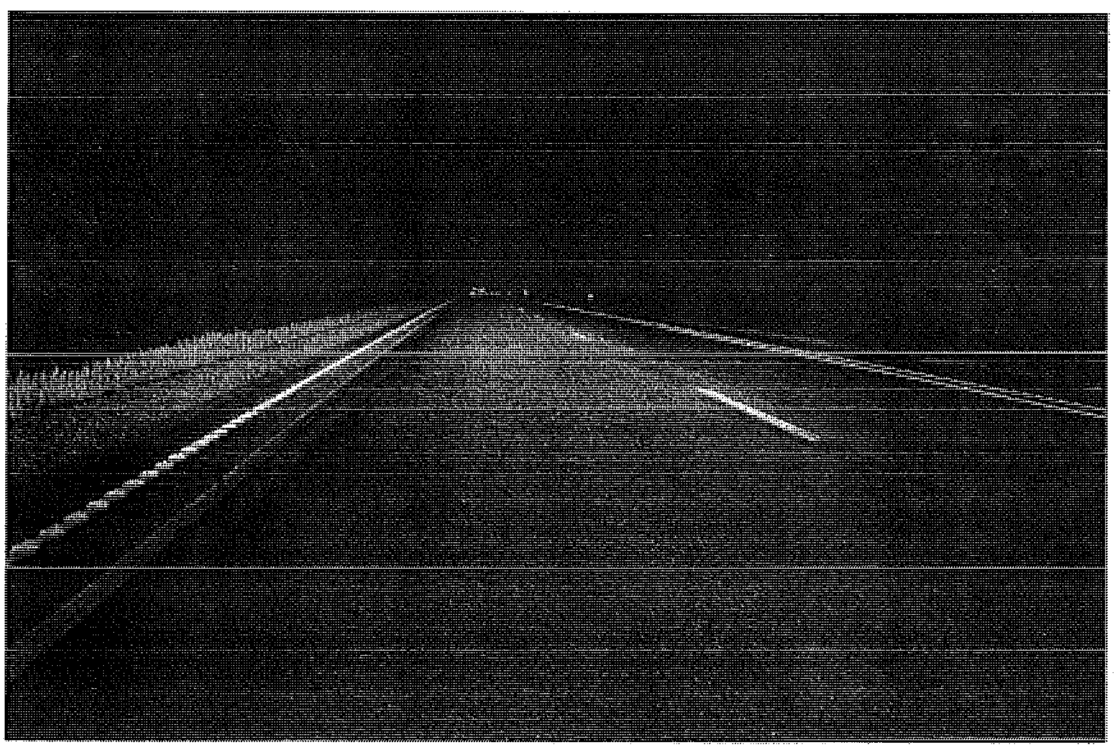

Figure 16. Photograph of wet night side-by-side comparison of yellow solid and rumbled edge lines northbound US-127 after one-year service, May 30, 2003.

Figure 17. Photograph of dry night side-by-side comparison of white solid and rumbled edge lines northbound US-127 after two-year service, April 8, 2004. *Note: The solid line has been repainted

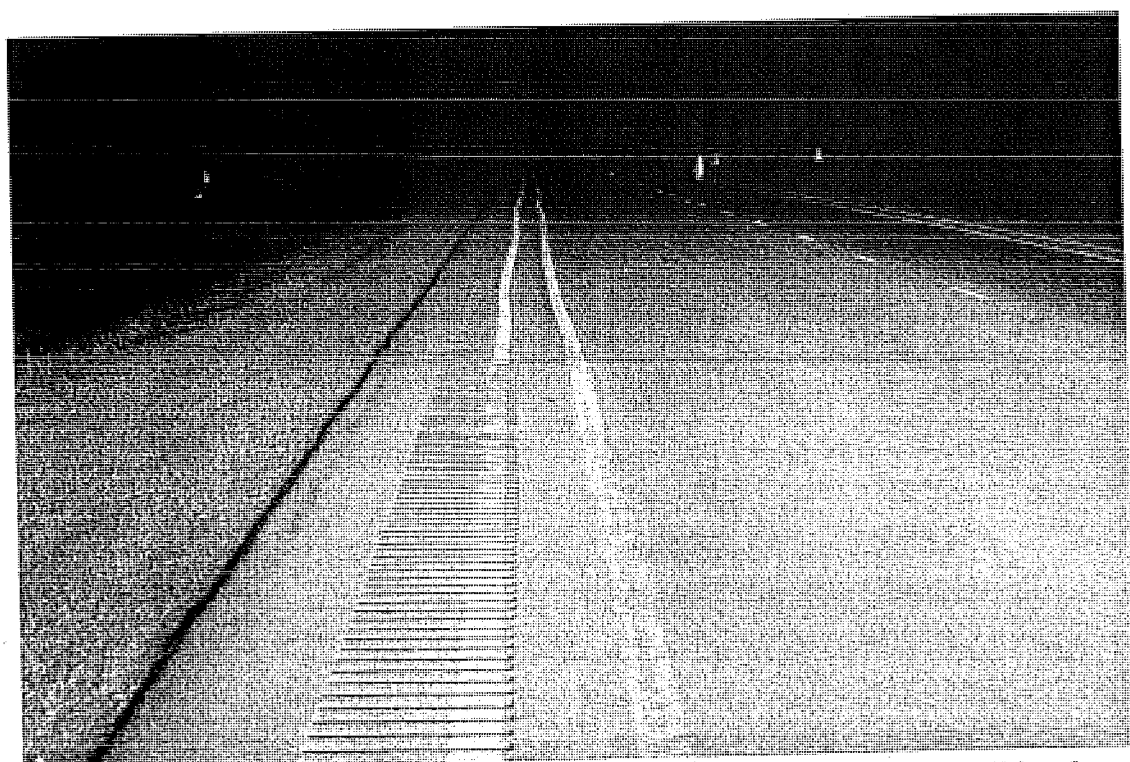

Figure 18. Photograph of dry night side-by-side comparison of yellow solid and rumbled edge lines northbound US-127 after two-year service, April 8, 2004.

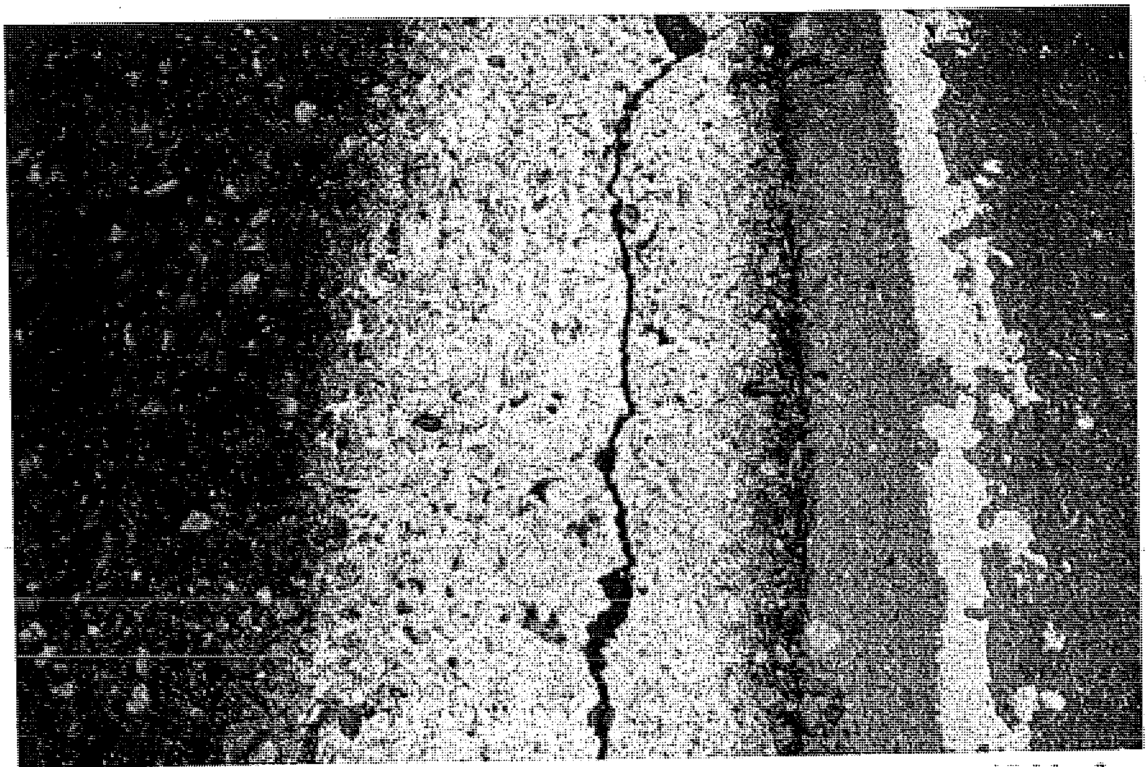

Figure 29. Close-up photo of 6-in white rumbled edge line on Eastbound I-96, after winter maintenance, April 25, 2004.

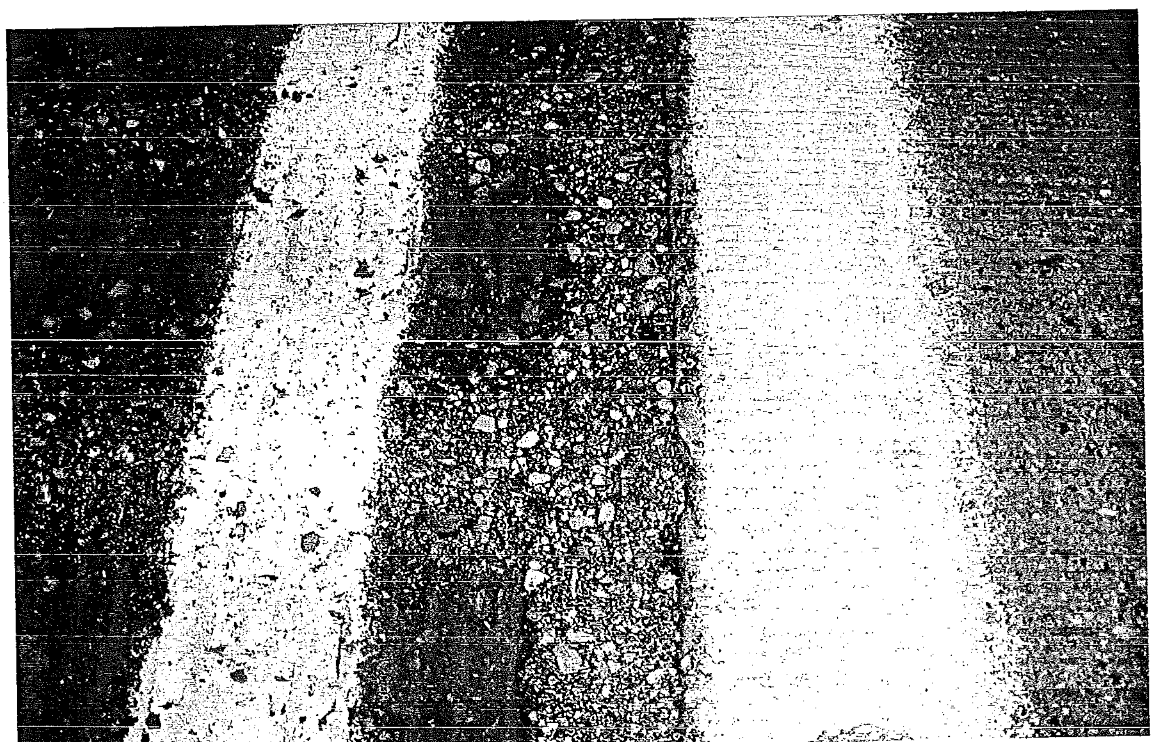

Figure 30. Close-up photo of 4-in white rumbled and white solid edge lines on Westbound I-96 after winter maintenance, April 25, 2004.

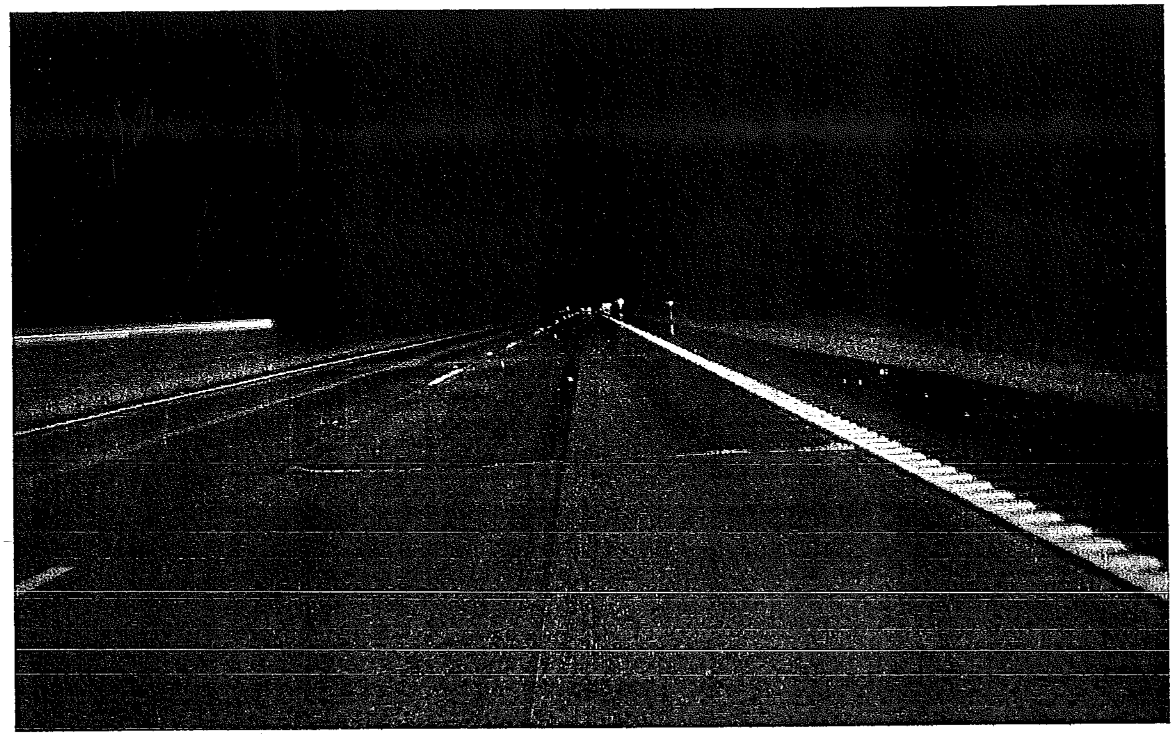

Figure 31. Initial wet-night photograph of white rumbled 6-in edge line on Northbound US-131, November 12, 2003.

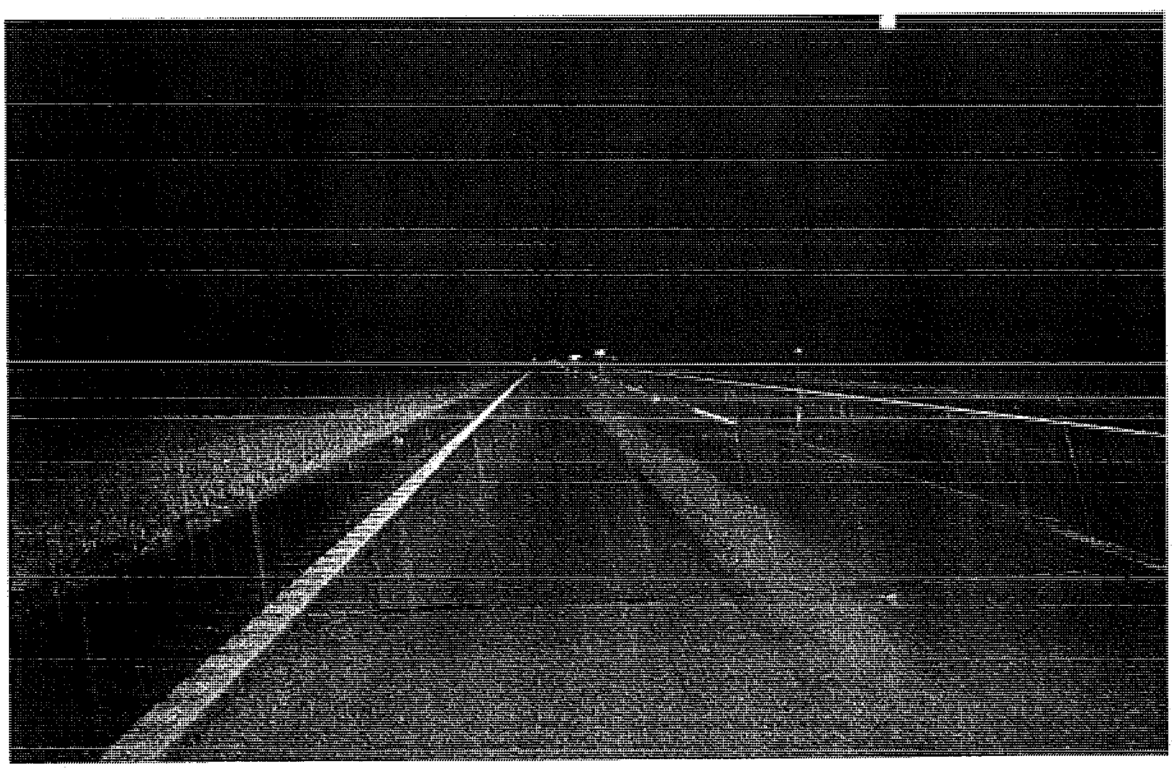

Figure 32. Initial wet-night photograph of yellow rumbled 6-in edge line on Northbound US-131, November 12, 2003.

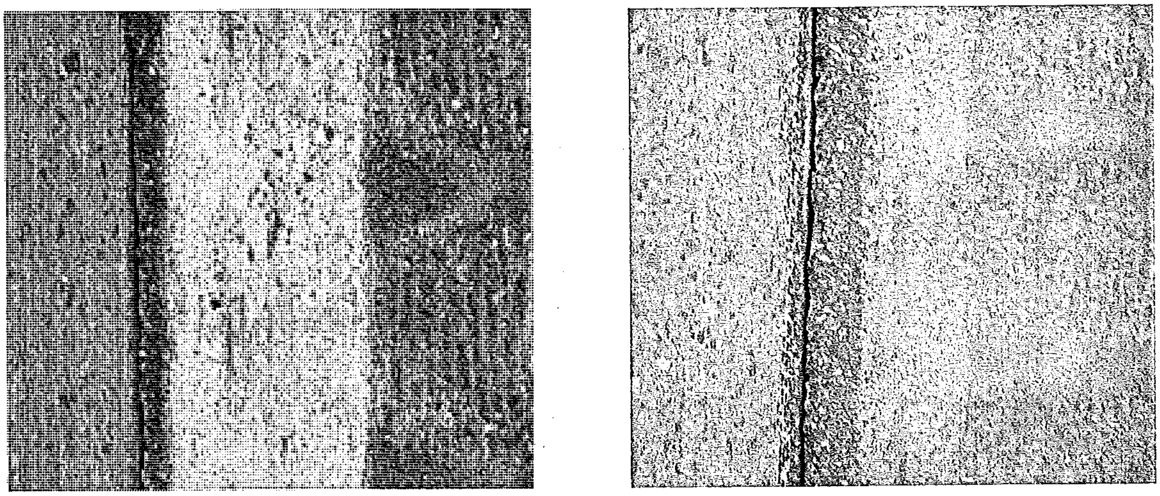

Figure 35. Close-up photo of 6-in white (left) and yellow (right) rumbled edge lines on Northbound US-131 after winter maintenance, February 15, 2004.

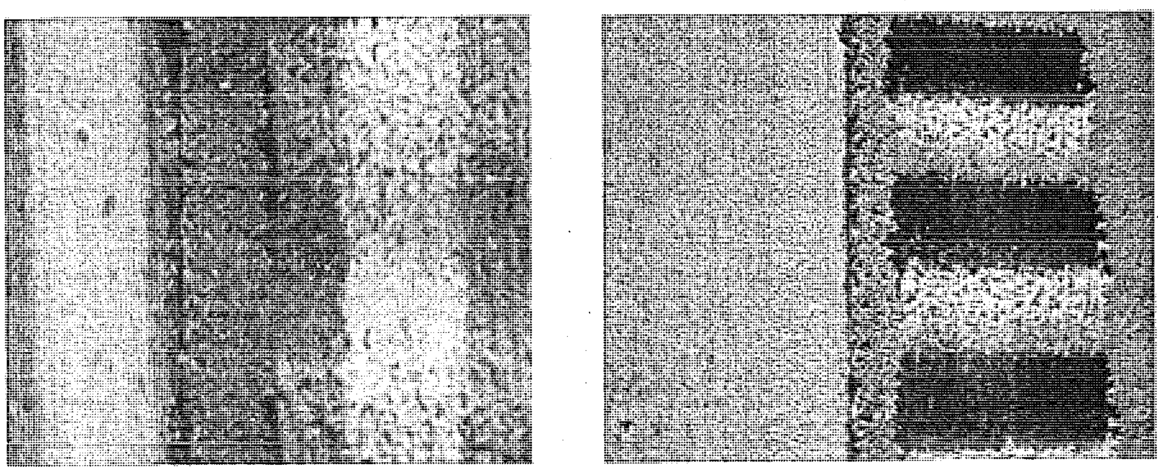

Figure 36. Close-up photo of white (left) and yellow (right) rumbled and solid edge lines on Southbound US-131 after winter maintenance, February 15, 2004.

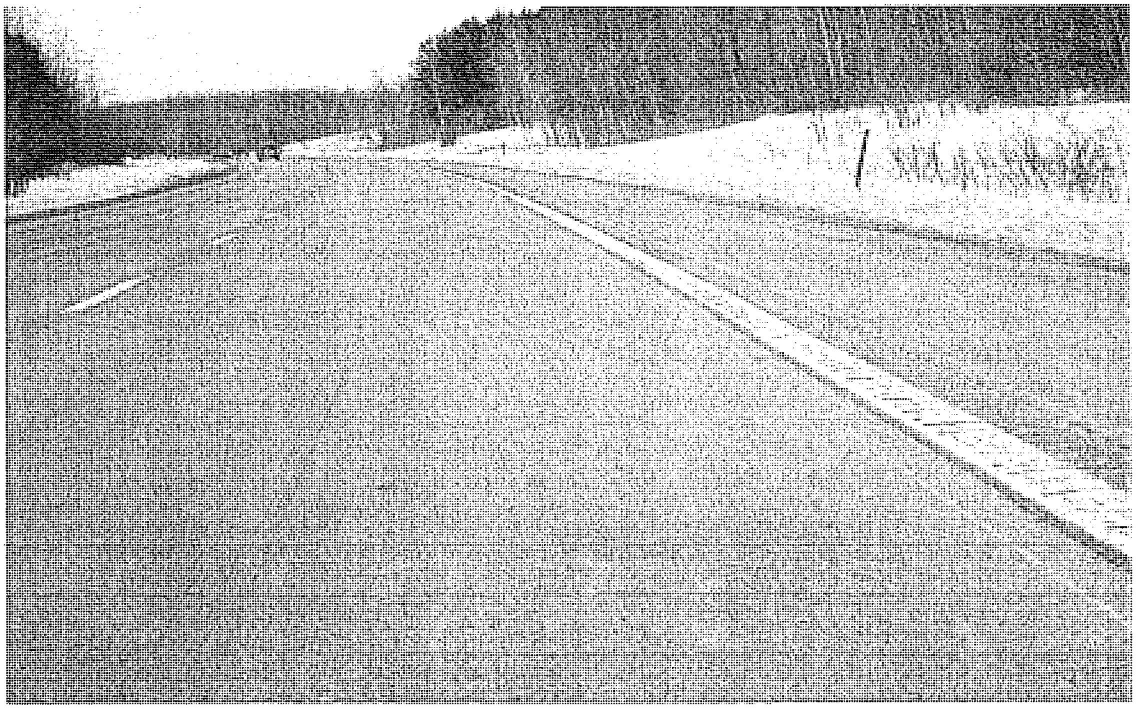

Figure 37. Performance of white 6-in rumbled edge line on Northbound US-131 after winter maintenance, February 15, 2004.

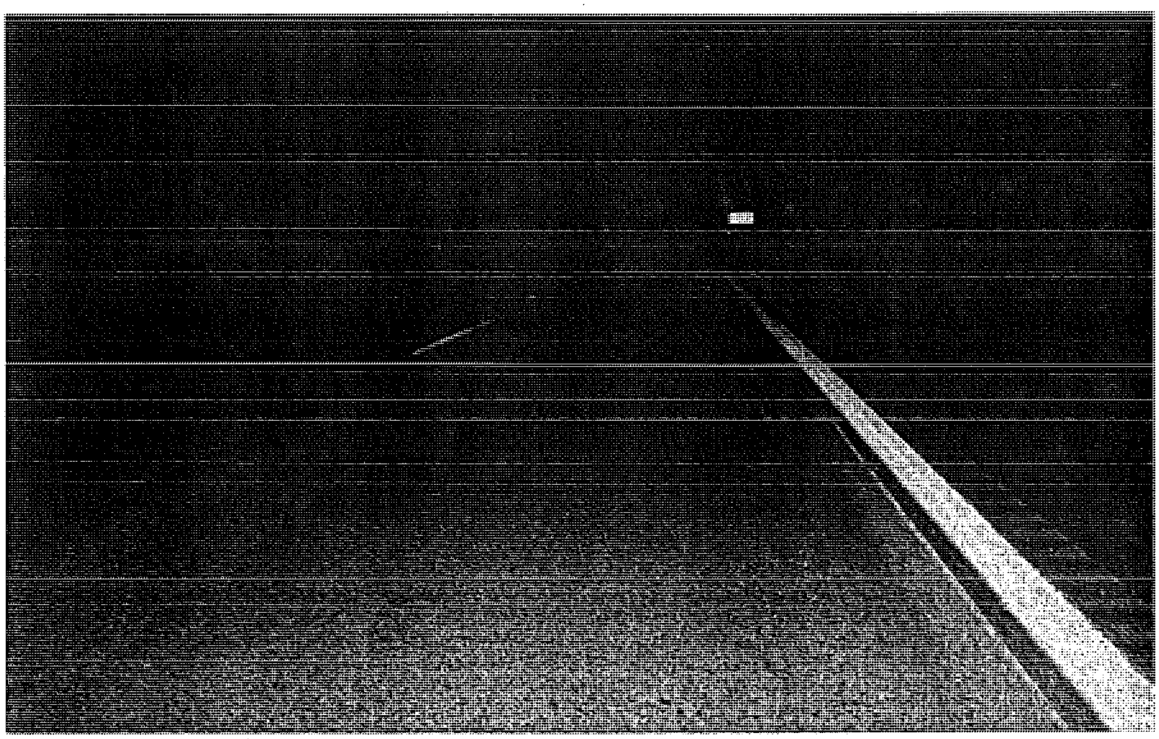

Figure 38. Night-time performance of white 6-in rumbled edge line on Northbound US-131 after winter maintenance, April 22, 2004.

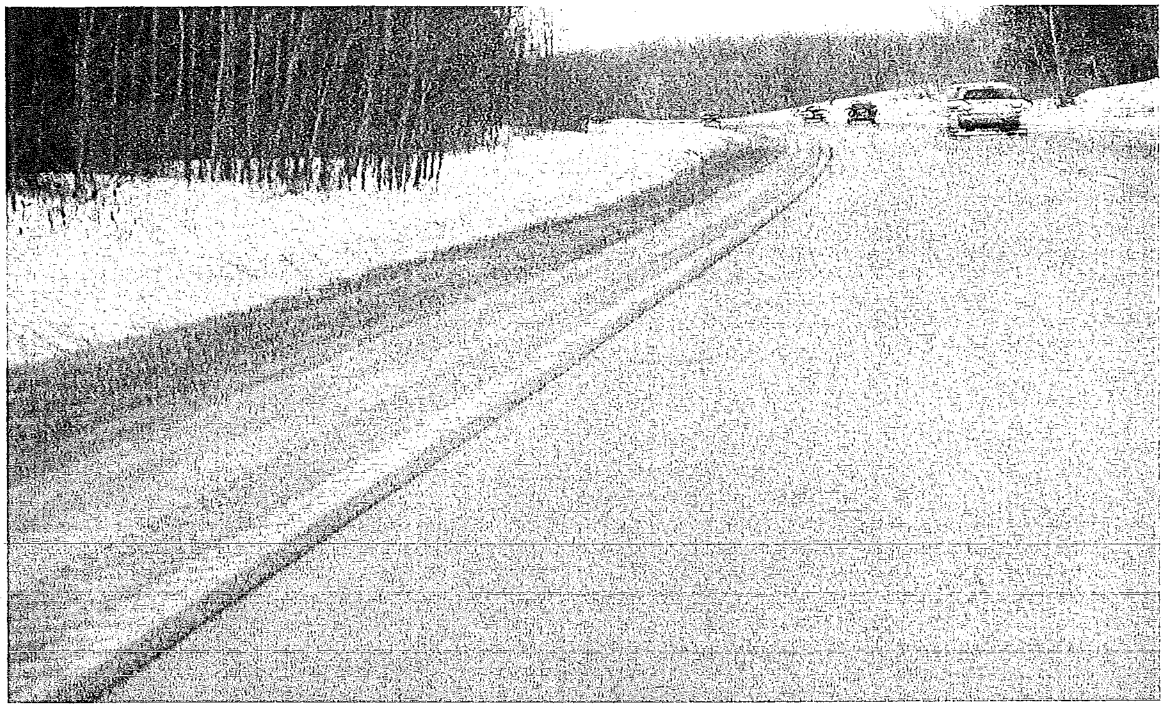

Figure 39. Performance of yellow 6-in rumbled edge line on Northbound US-131 after winter maintenance, February 15, 2004.

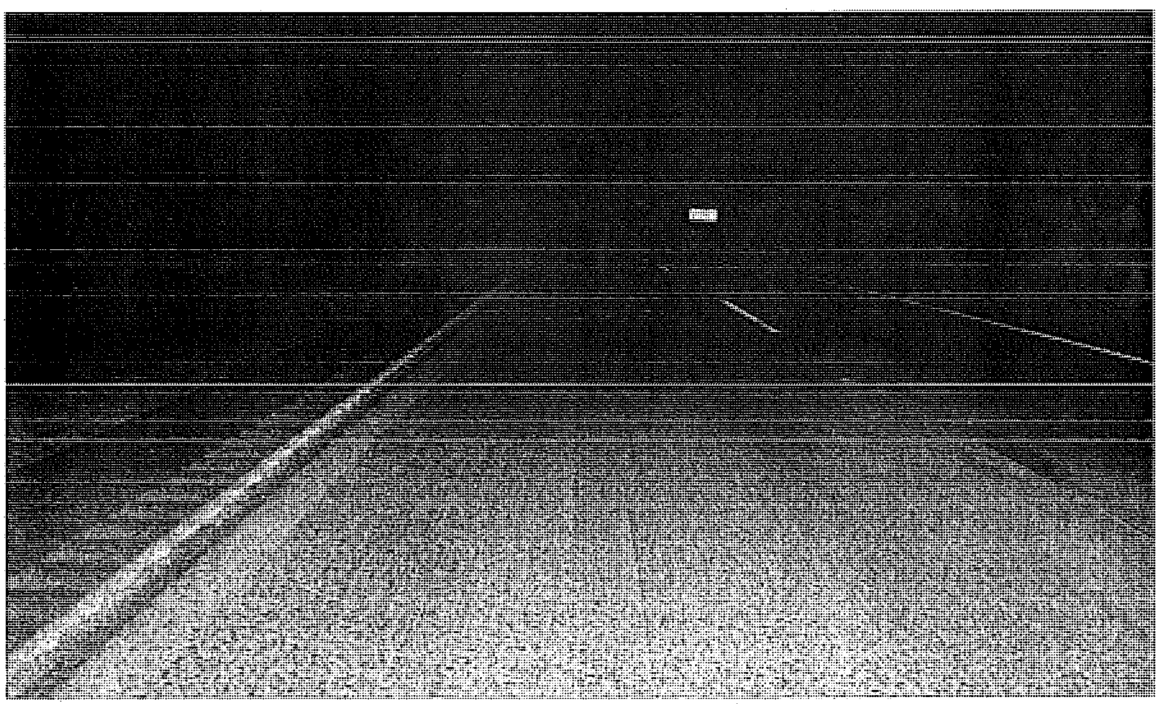

Figure 40. Night-time performance of yellow 6-in rumbled edge line on Northbound US-131 after winter maintenance, April 22, 2004.

Figure 41. Performance of white 4-in rumbled and solid edge lines on Southbound US-131 after winter maintenance, February 15, 2004.

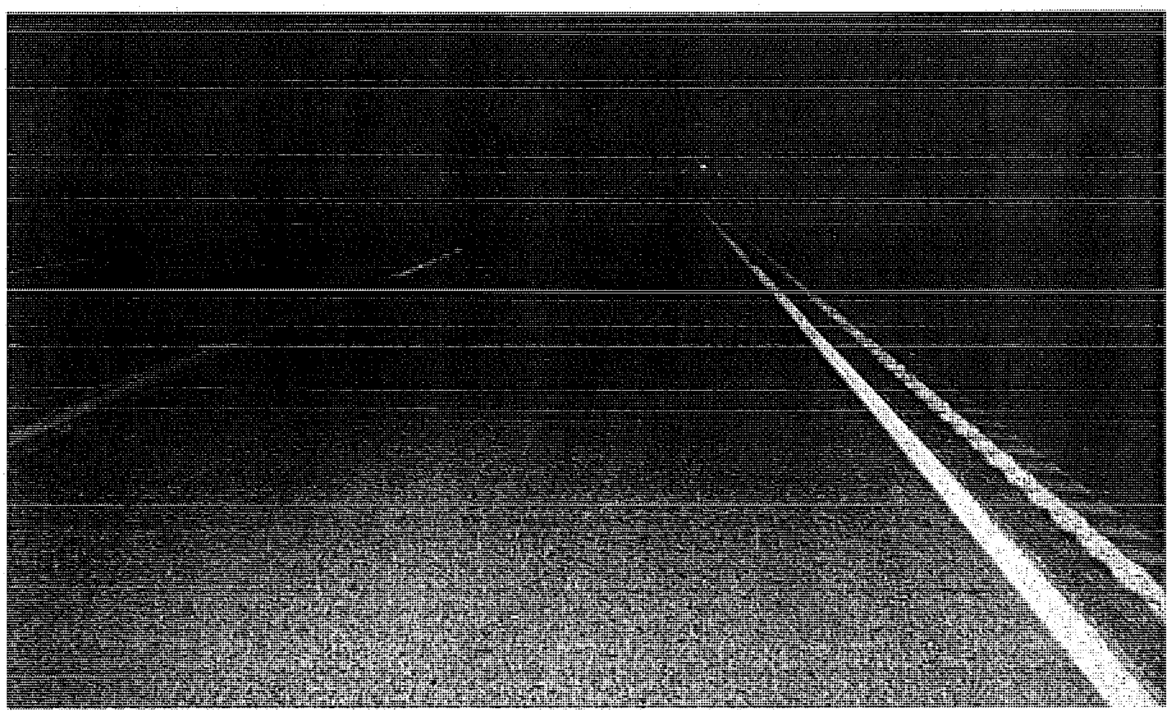

Figure 42. Night-time performance of white 4-in rumbled and solid edge lines on Southbound US-131 after winter maintenance, April 22, 2004.

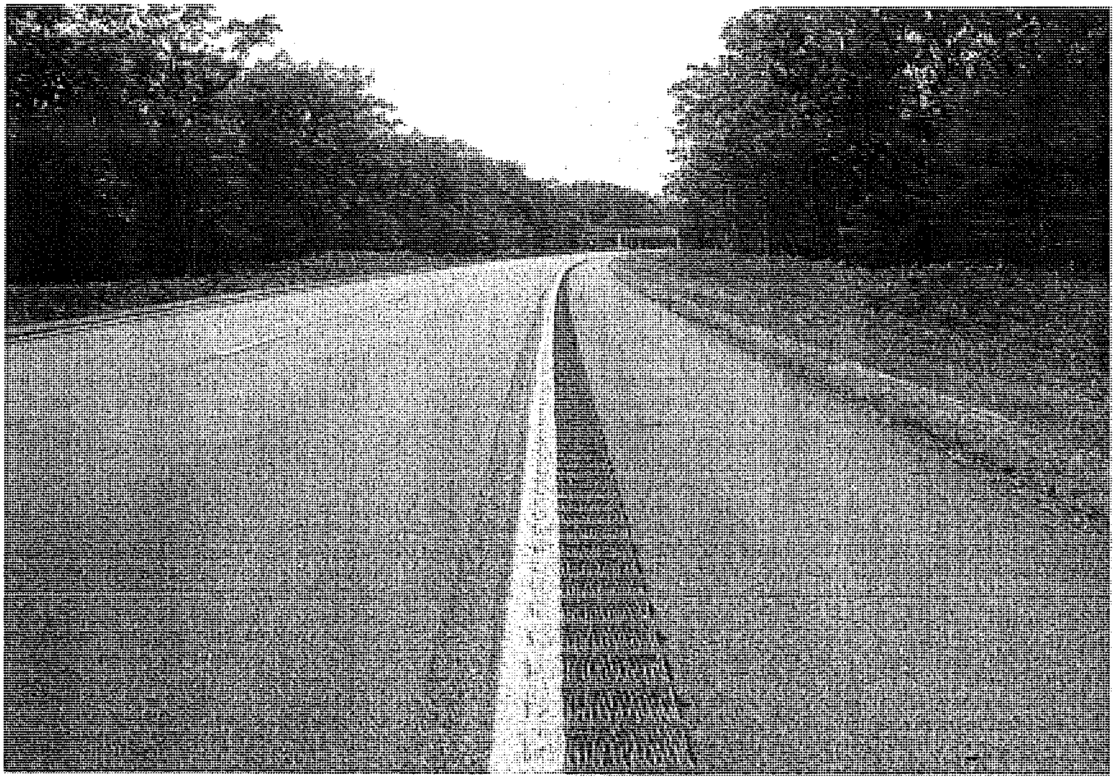

Figure 45. Initial photograph of white 6-in rumbled edge line on Northbound US-31, August 21, 2003.

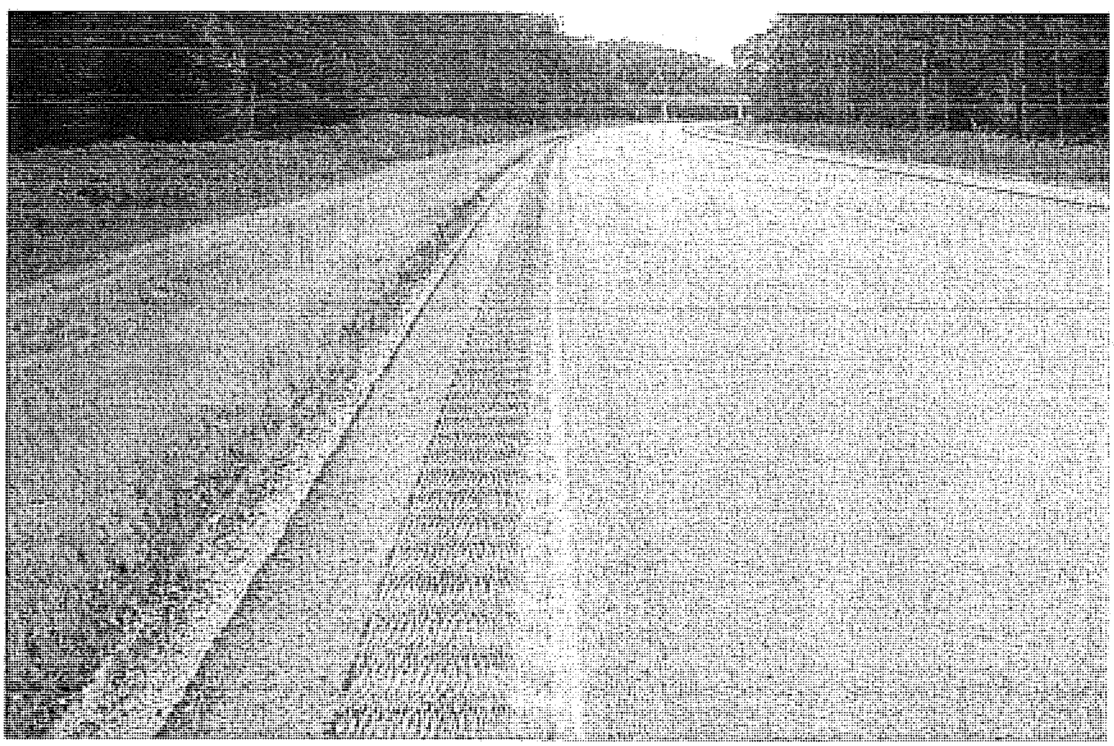

Figure 46. Initial photograph of yellow 6-in rumbled edge line on Northbound US-31, August 21, 2003.

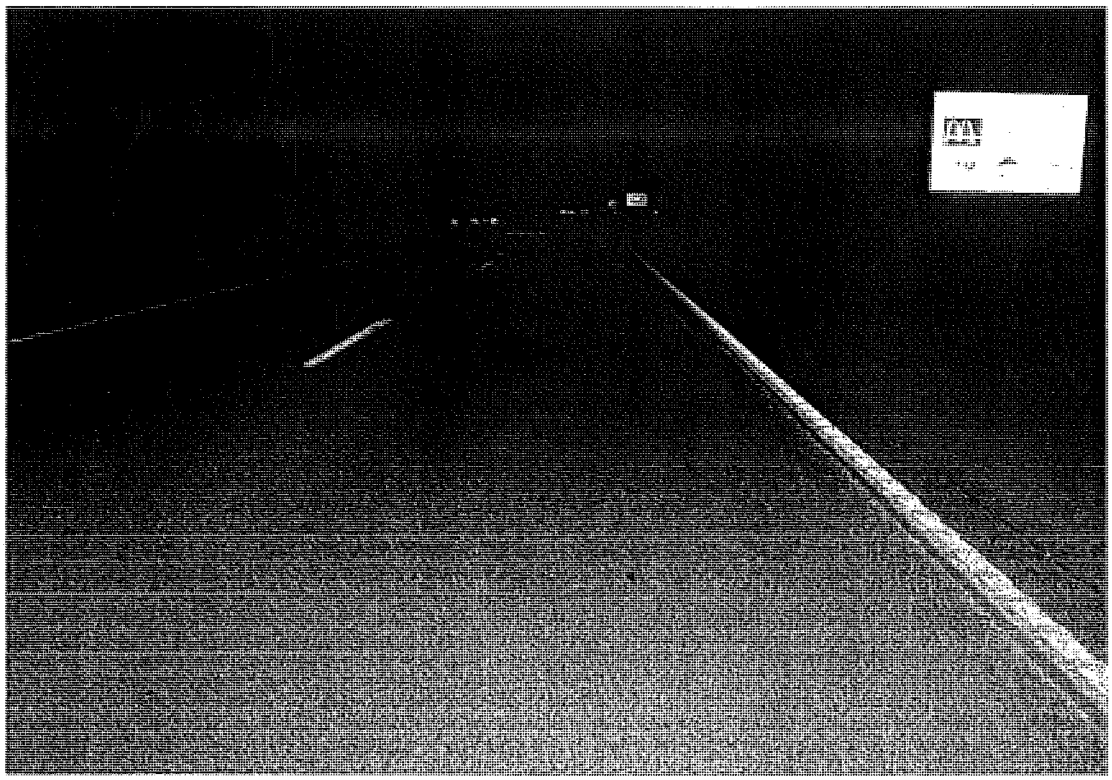

Figure 47. Night-time performance of white 6-in rumbled edge line on Northbound US-31 after winter maintenance, April 22, 2004.

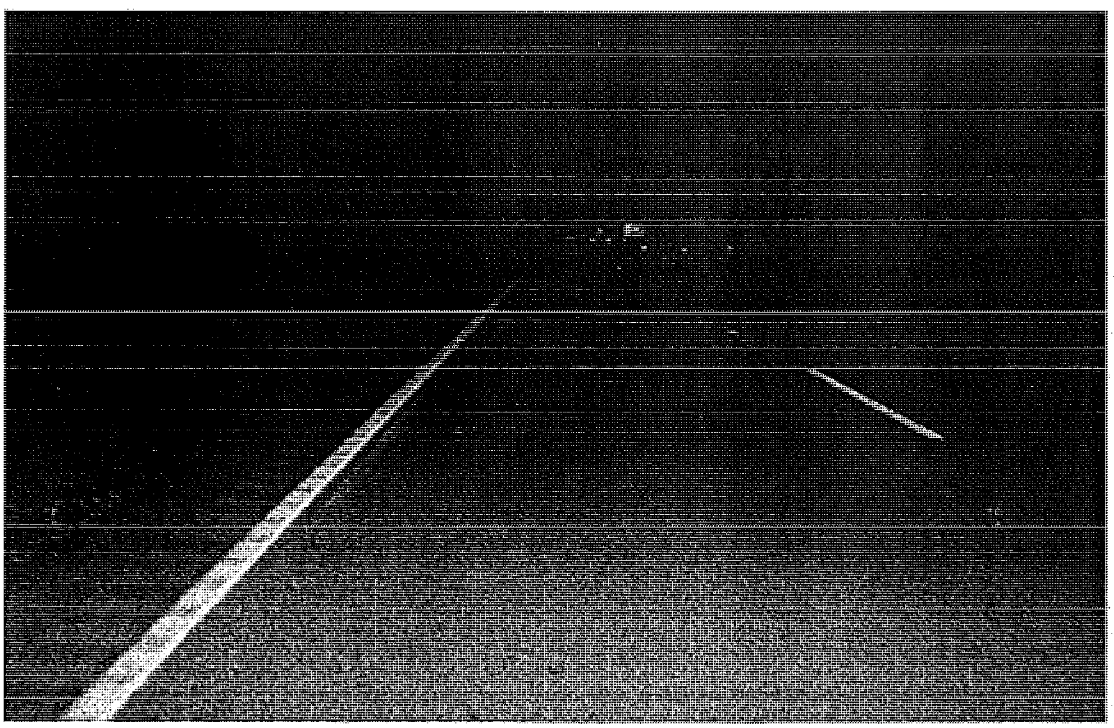

Figure 48. Night-time performance of yellow 6-in rumbled edge line on Northbound US-31 after winter maintenance, April 22, 2004.

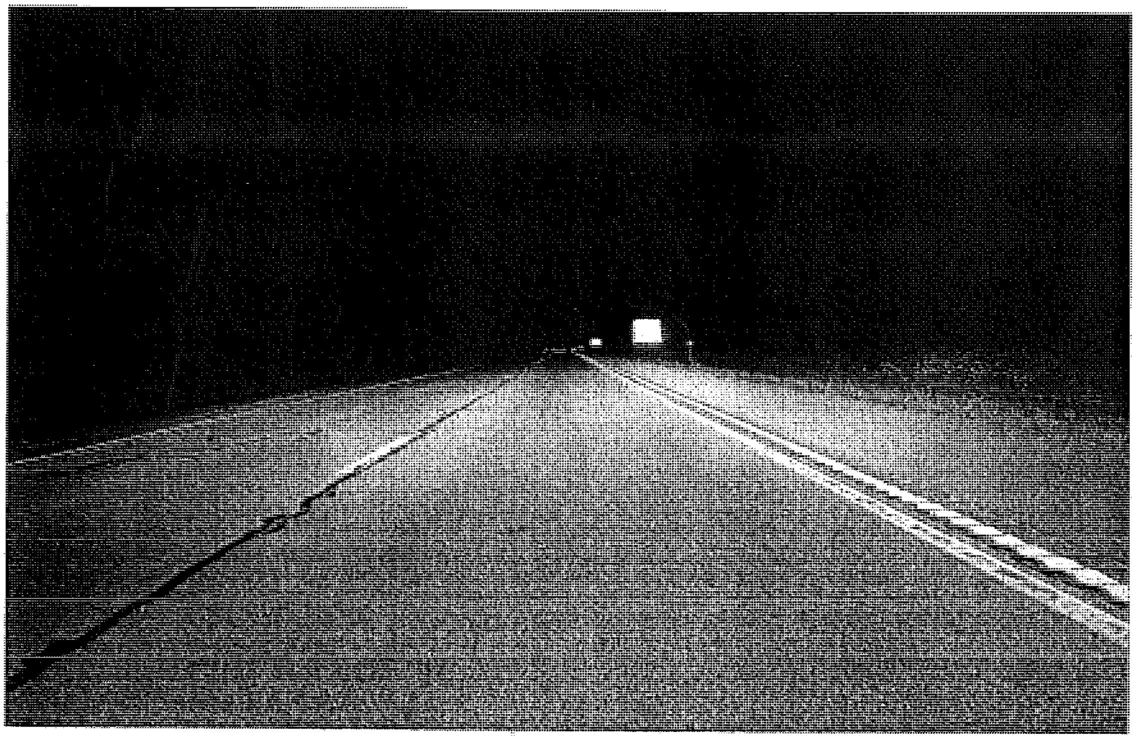

Figure 49. Initial night-time photograph of white 4-in rumbled and white solid edge lines on Southbound US-31, April 22, 2004.

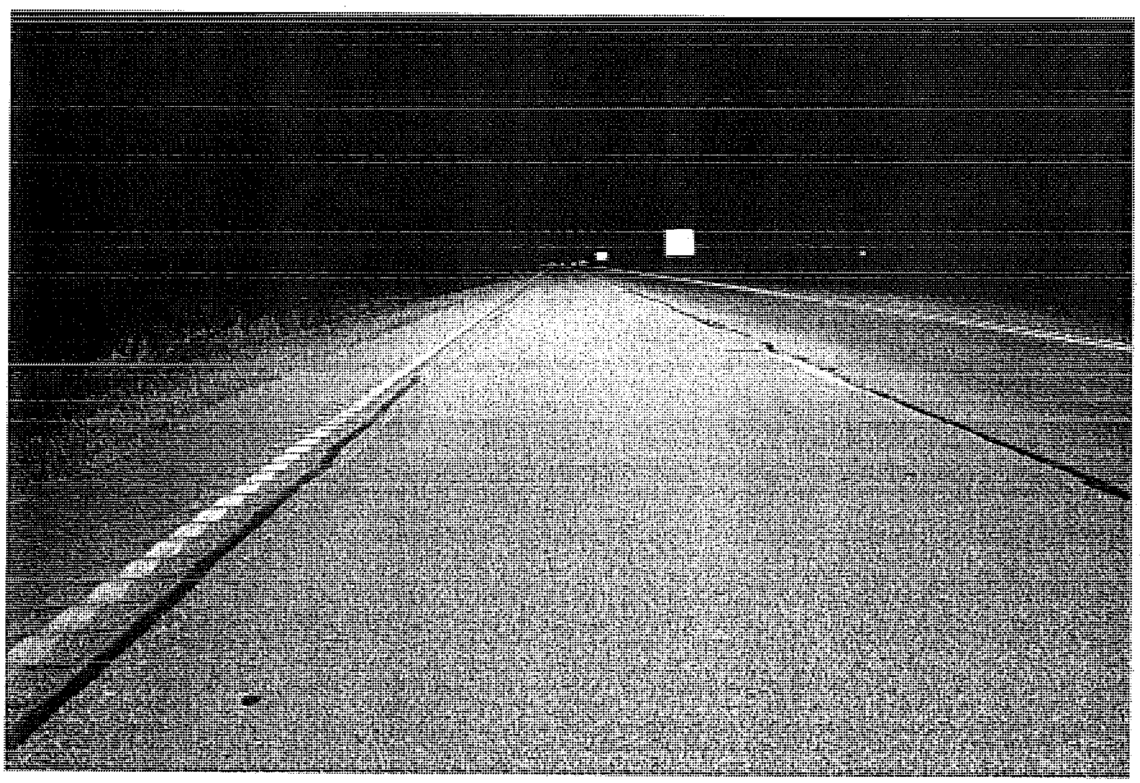

Figure 50. Initial night-time photograph of yellow rumbled edge line on Southbound US-31, April 22, 2004.

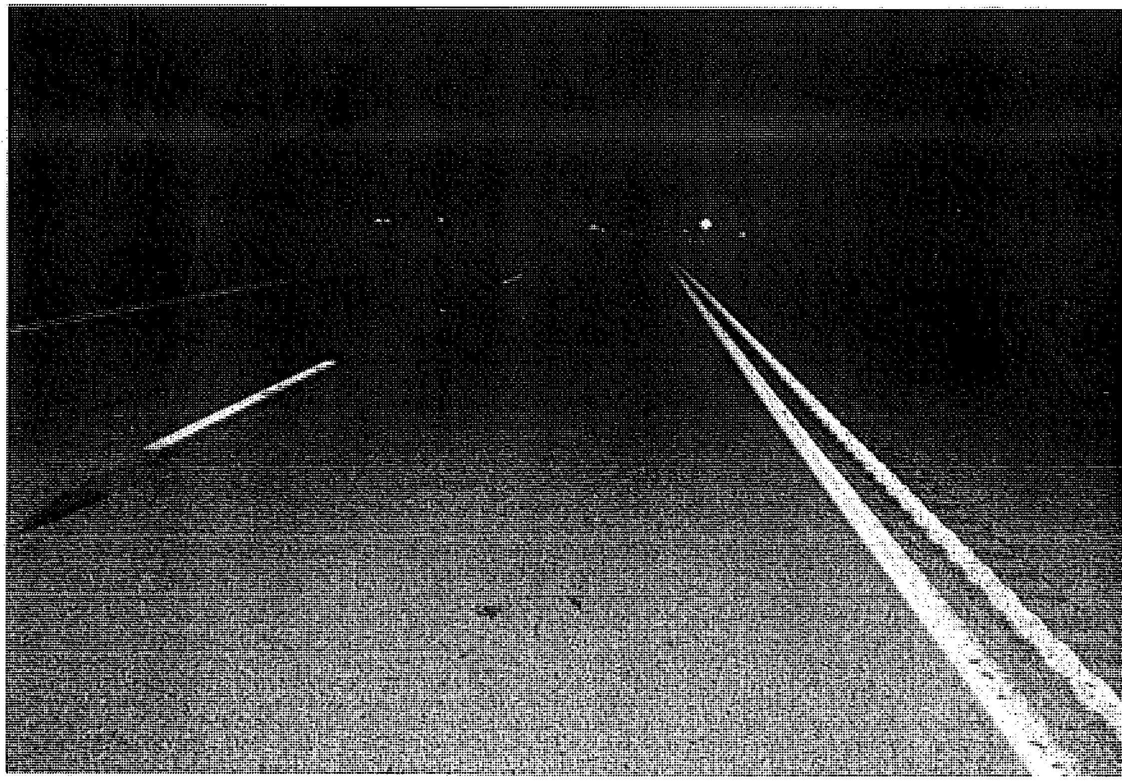

Figure 51. Night-time performance of white 4-in rumbled and solid edge lines on Southbound US-31 after winter maintenance, April 22, 2004.

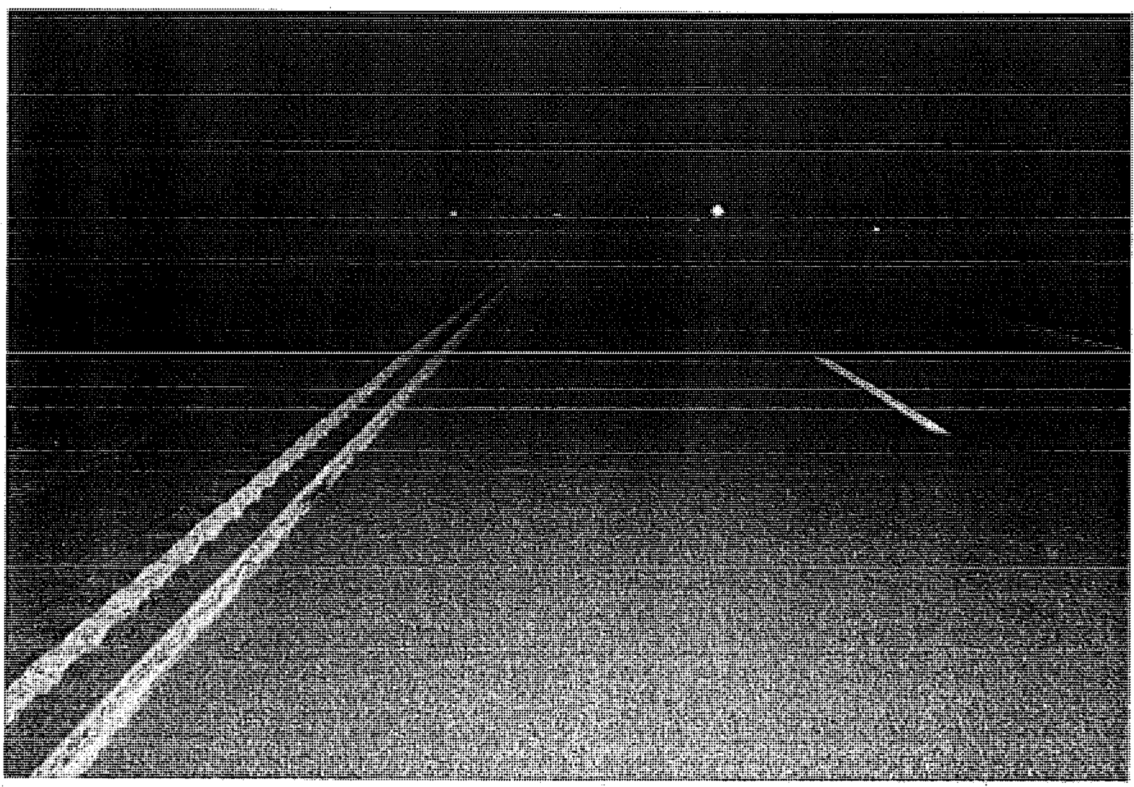

Figure 52. Night-time performance of yellow rumbled and solid edge lines on Southbound US-31 after winter maintenance, April 22, 2004.

9.3 RETROREFLECTIVITY GRAPHS

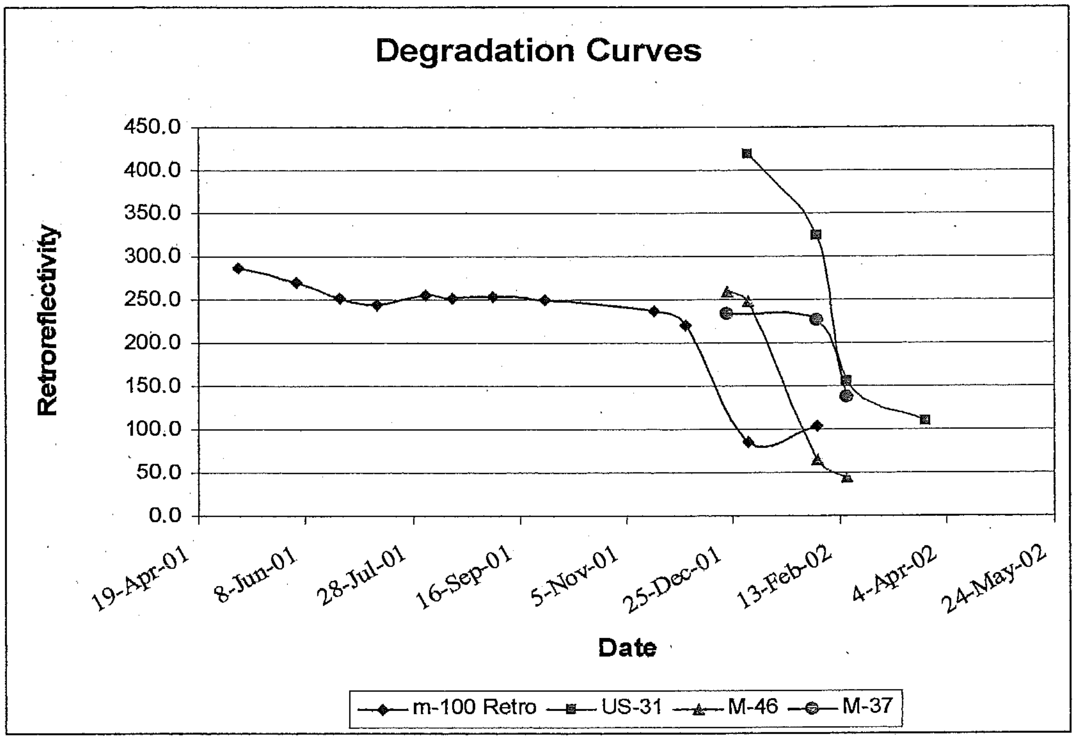

Figure 53. Graph of degradation curves depicting durability trend for standard pavement markings applied to white edge lines for roadways located in differing snowfall regions.

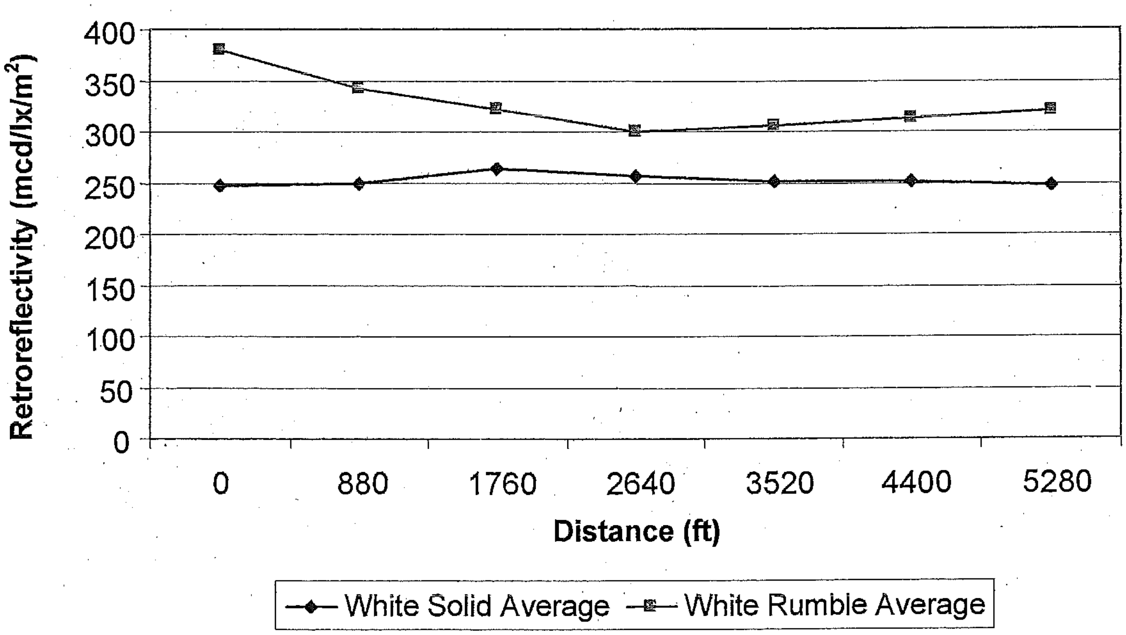

Figure 54. Average initial dry retroreflectivity measurements for white solid and rumble strip edge lines on northbound US-127 July 18, 2002.

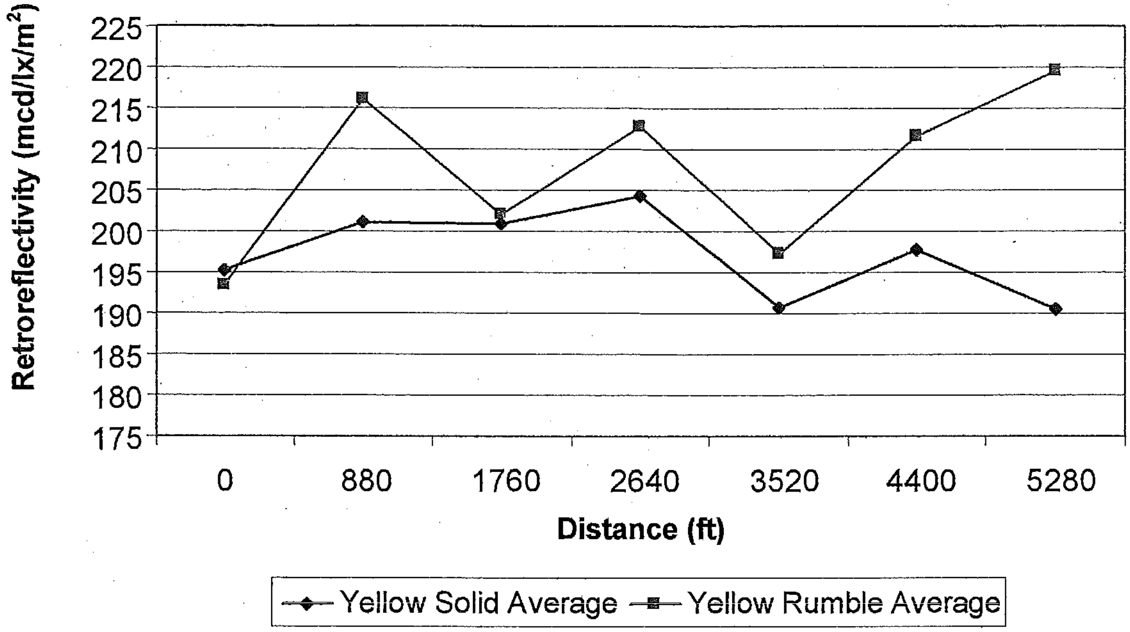

Figure 55. Average initial dry retroreflectivity measurements for yellow solid and rumble strip edge lines on northbound US-127 July 18, 2002.

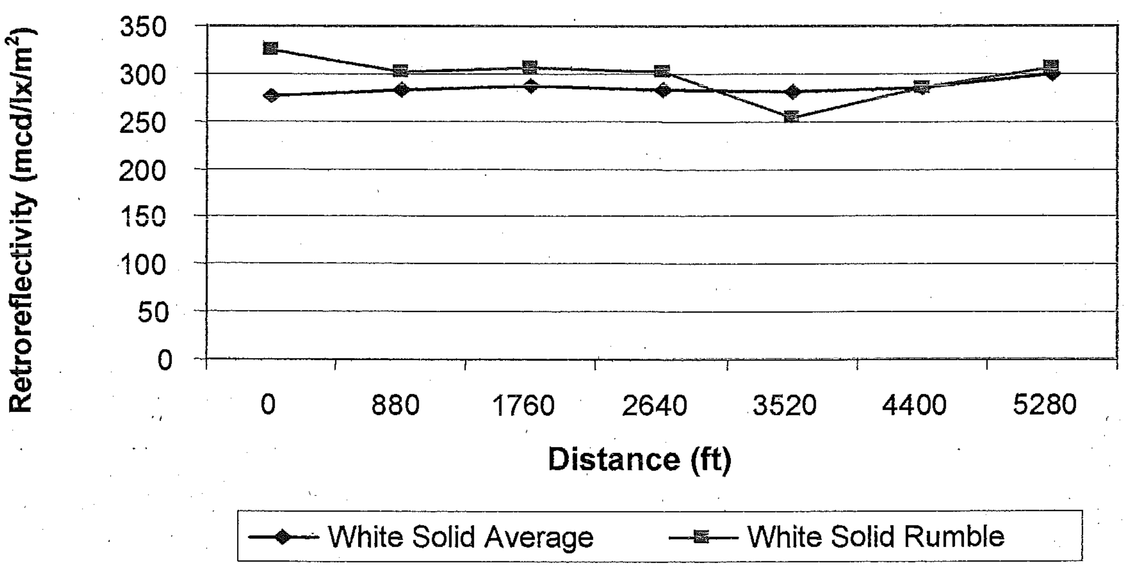

Figure 56. Average initial dry retroreflectivity measurements for white solid and rumble strip edge lines on southbound US-127 July 18, 2002.

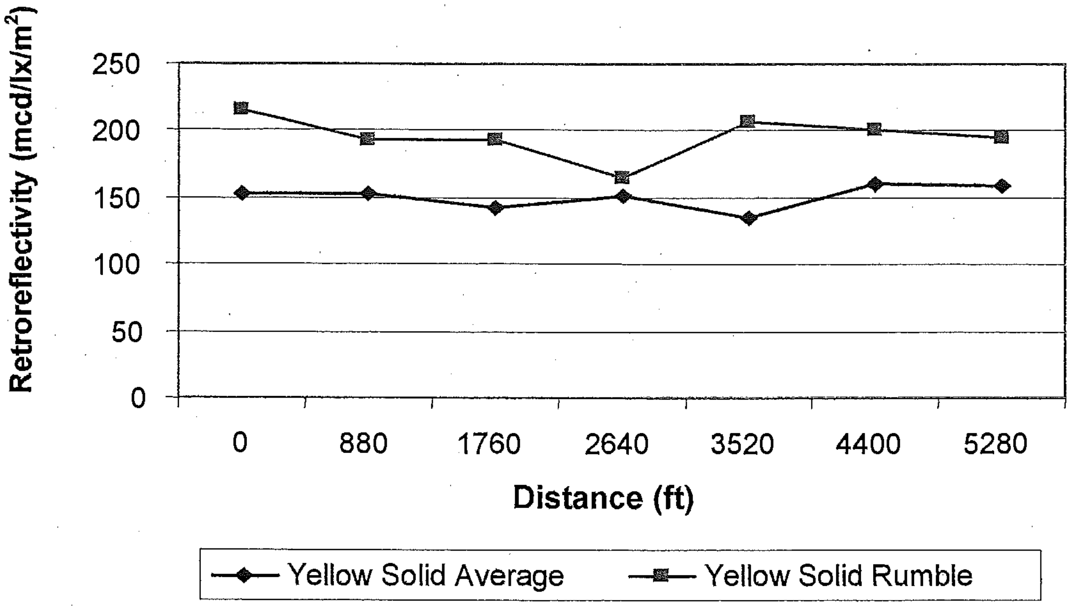

Figure 57. Average initial dry retroreflectivity measurements for yellow solid and rumble strip edge lines on southbound US-127 July 18, 2002.

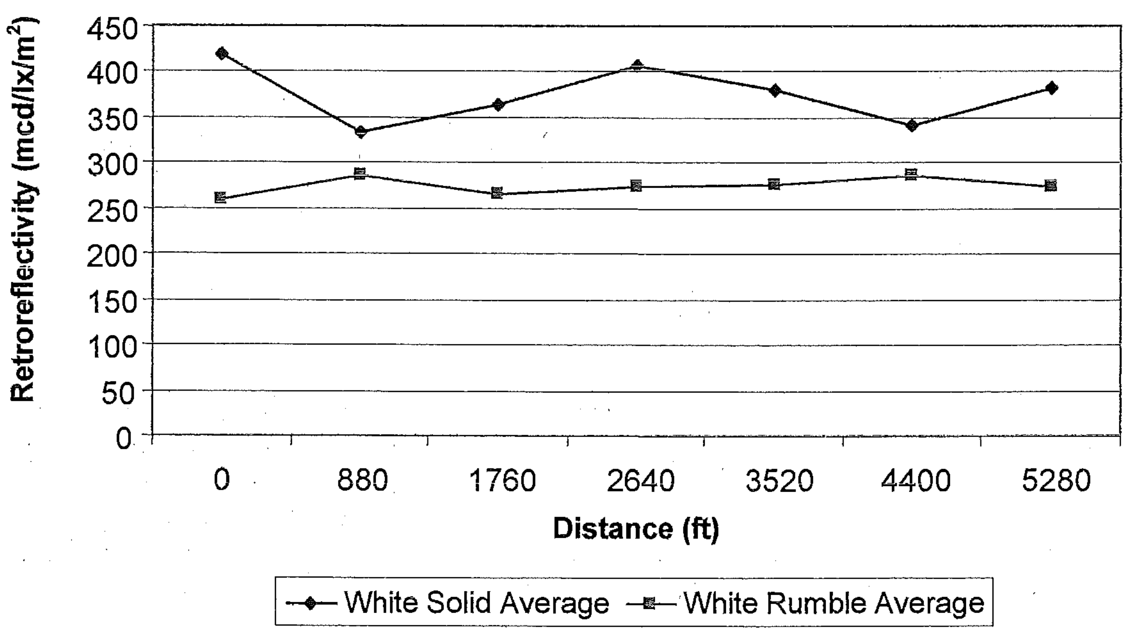

Figure 58. Average initial dry retroreflectivity measurements for white solid and rumble strip edge lines on northbound I-75 July 18, 2002.

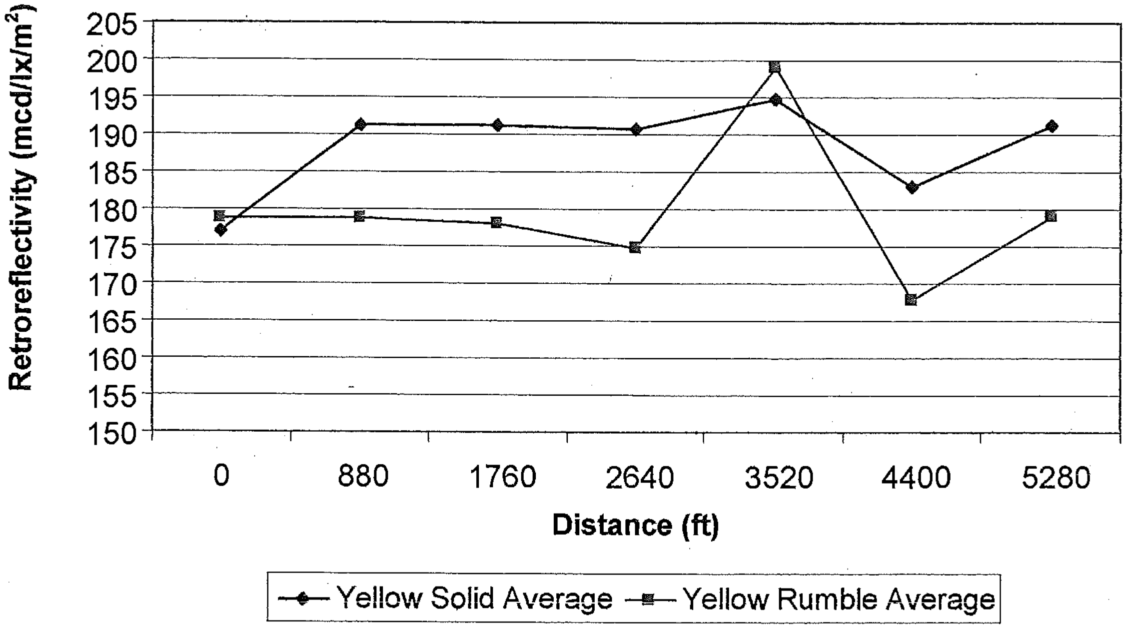

Figure 59. Average initial dry retroreflectivity measurements for yellow solid and rumble strip edge lines on northbound I-75 July 18, 2002.

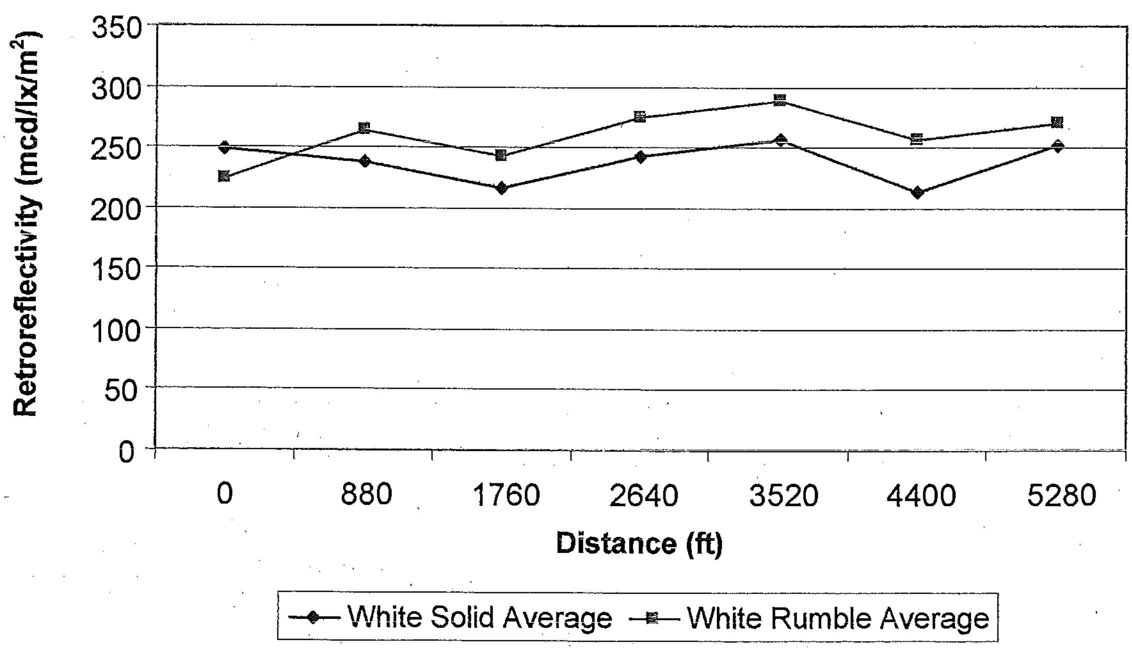

Figure 60. Average initial dry retroreflectivity measurements for white solid and rumble strip edge lines on southbound I-75 July 18, 2002.

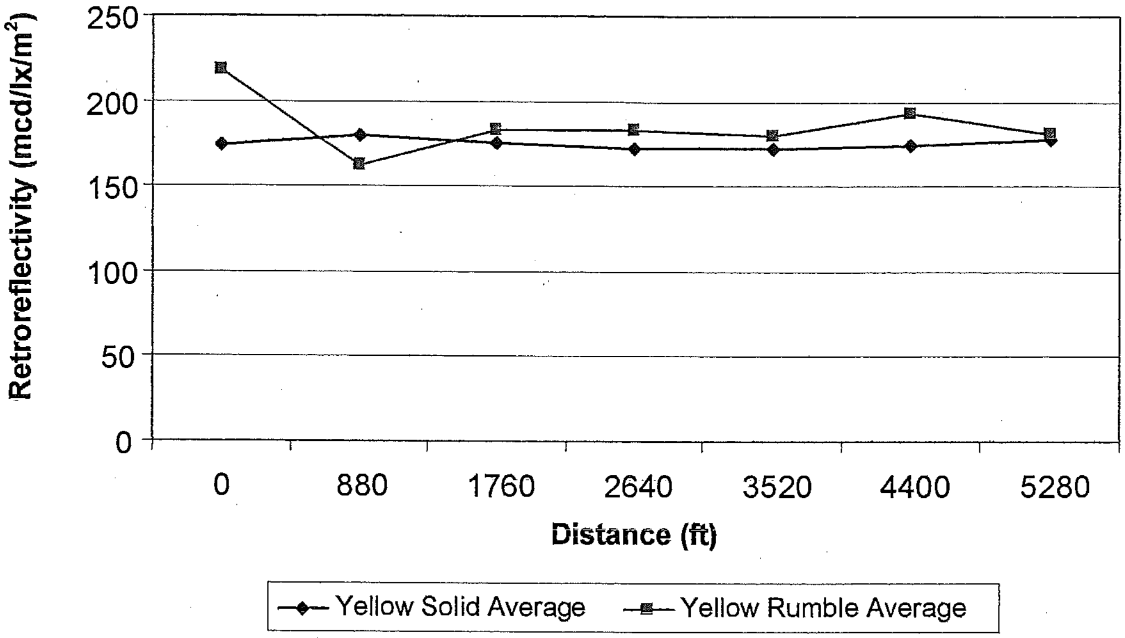

Figure 61. Average initial dry retroreflectivity measurements for yellow solid and rumble strip edge lines on southbound I-75 July 18, 2002.

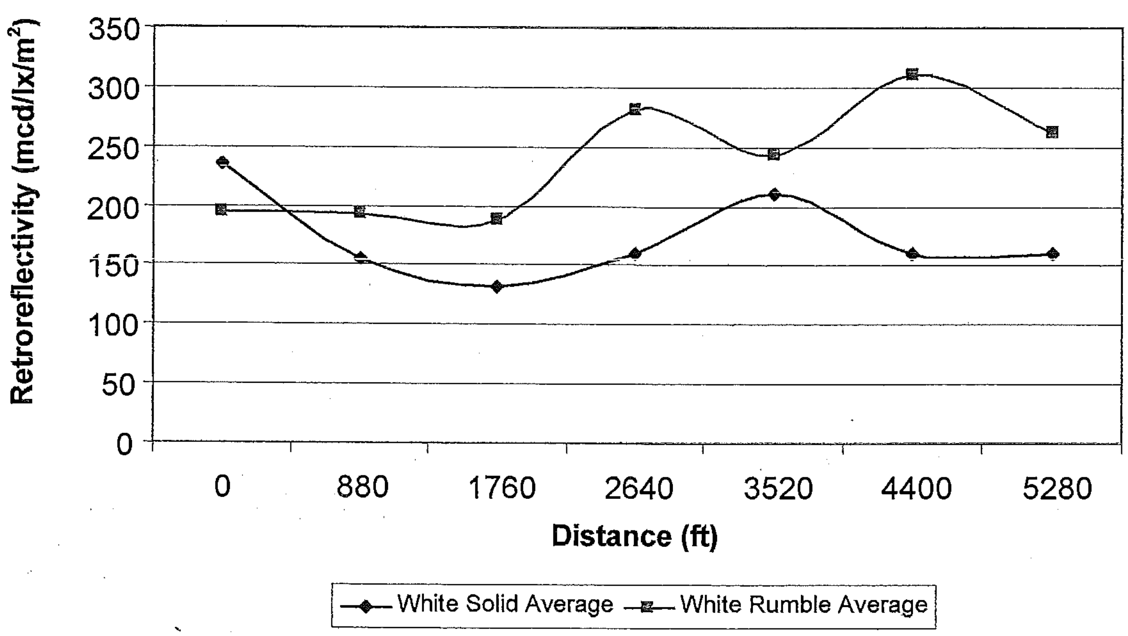

Figure 62. Average final dry retroreflectivity measurements for white solid and rumble strip edge lines on northbound US-127 May 17, 2003.

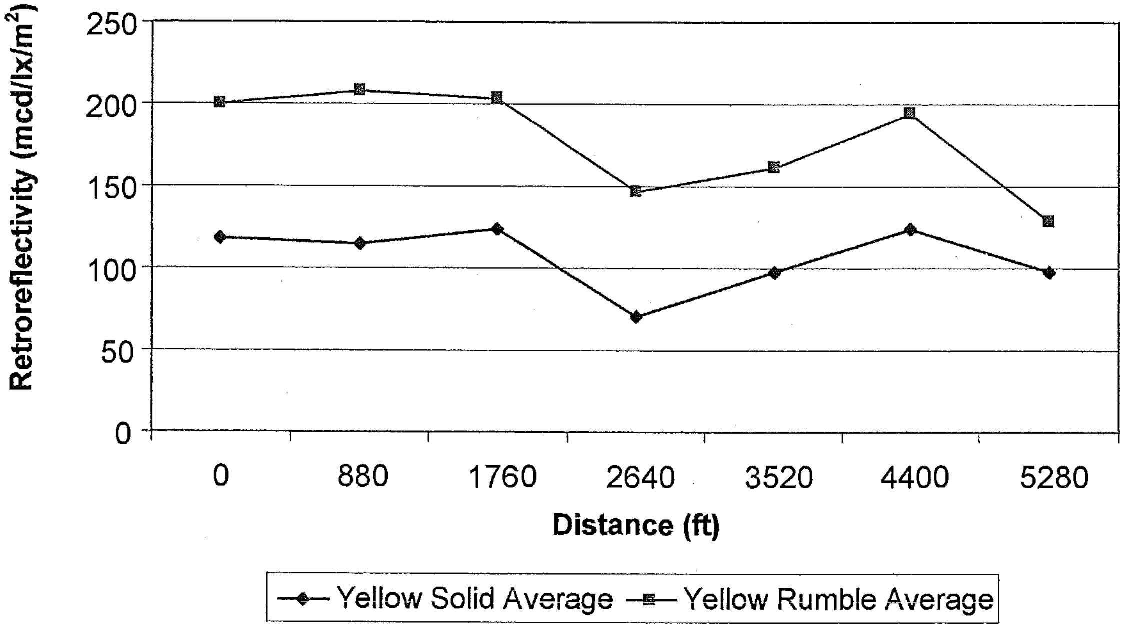

Figure 63. Average final dry retroreflectivity measurements for yellow solid and rumble strip edge lines on northbound US-127 May 17, 2003.

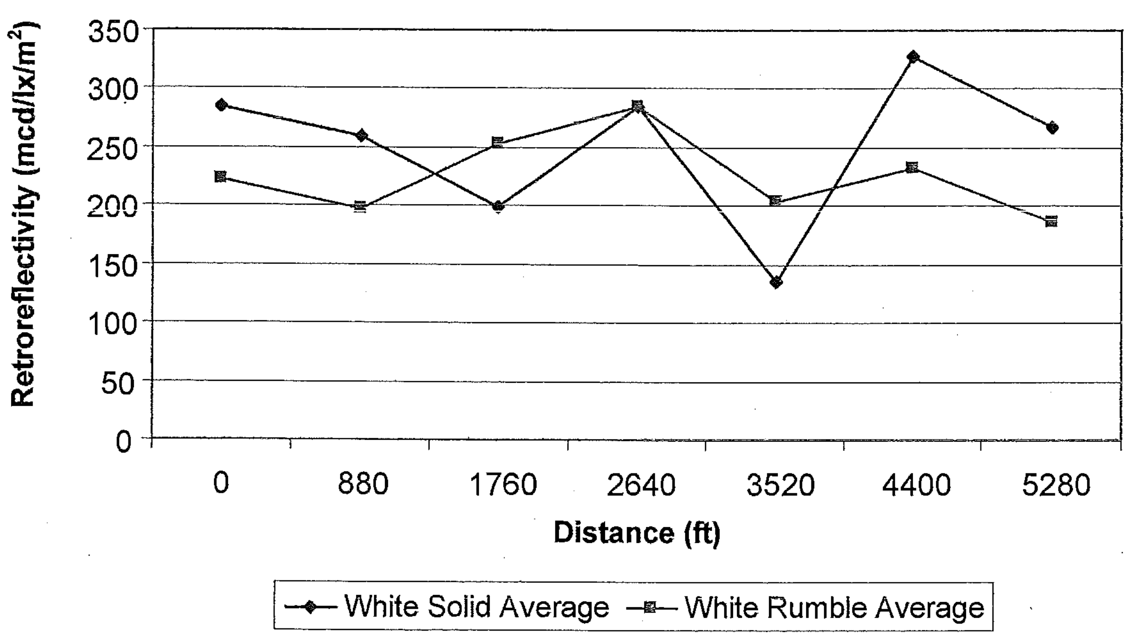

Figure 64. Average final dry retroreflectivity measurements for white solid and rumble strip edge lines on southbound US-127 May 17, 2003.

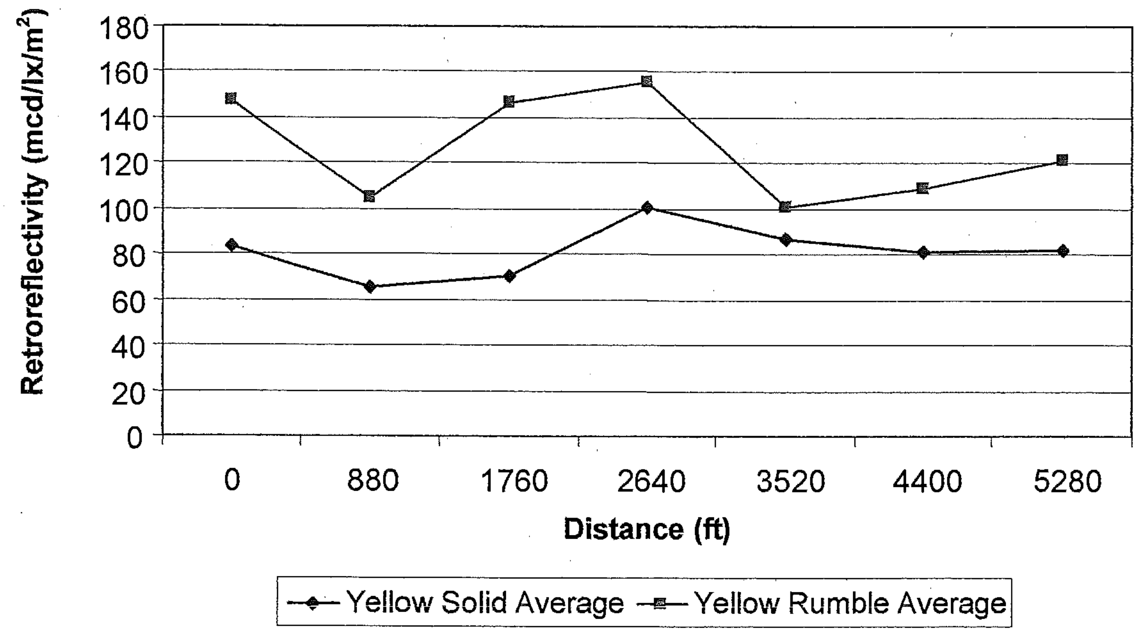

Figure 65. Average final dry retroreflectivity measurements for yellow solid and rumble strip edge lines on southbound US-127 May 17, 2003.

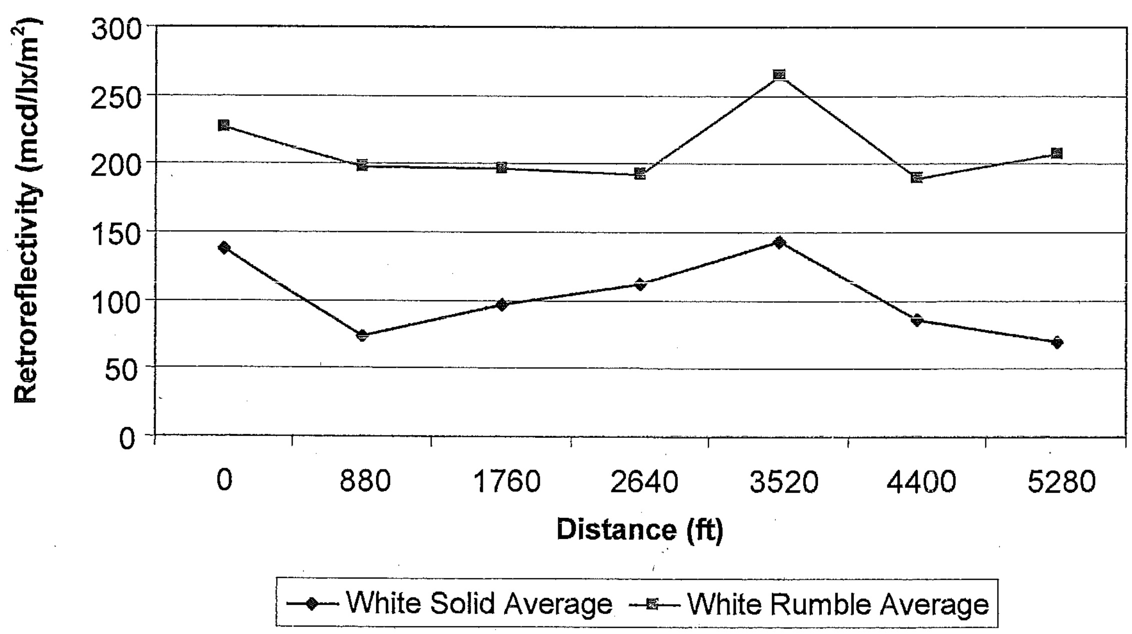

Figure 66. Average final dry retroreflectivity measurements for white solid and rumble strip edge lines on northbound I-75 May 17, 2003.

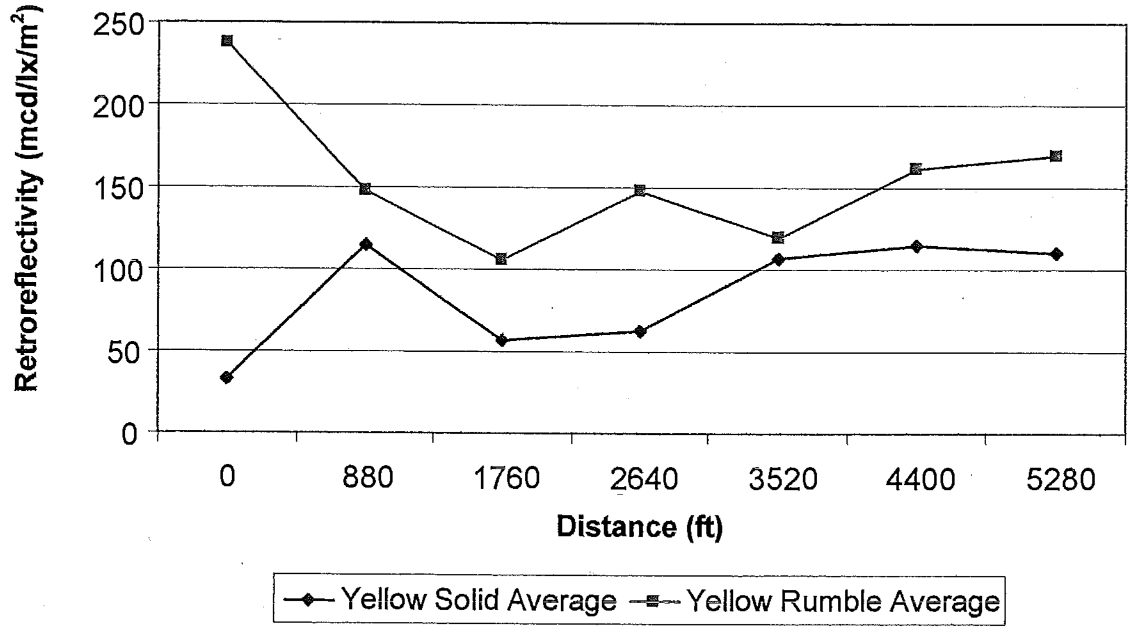

Figure 67. Average final dry retroreflectivity measurements for yellow solid and rumble strip edge lines on northbound I-75 May 17, 2003.

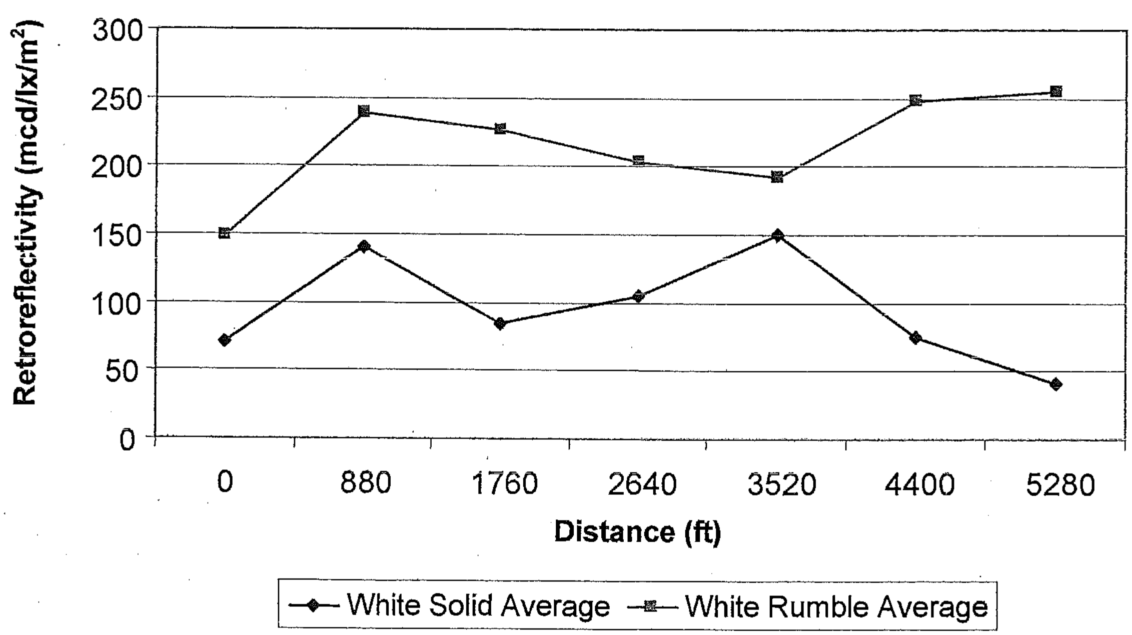

Figure 68. Average final dry retroreflectivity measurements for white solid and rumble strip edge lines on southbound I-75 May 17, 2003.

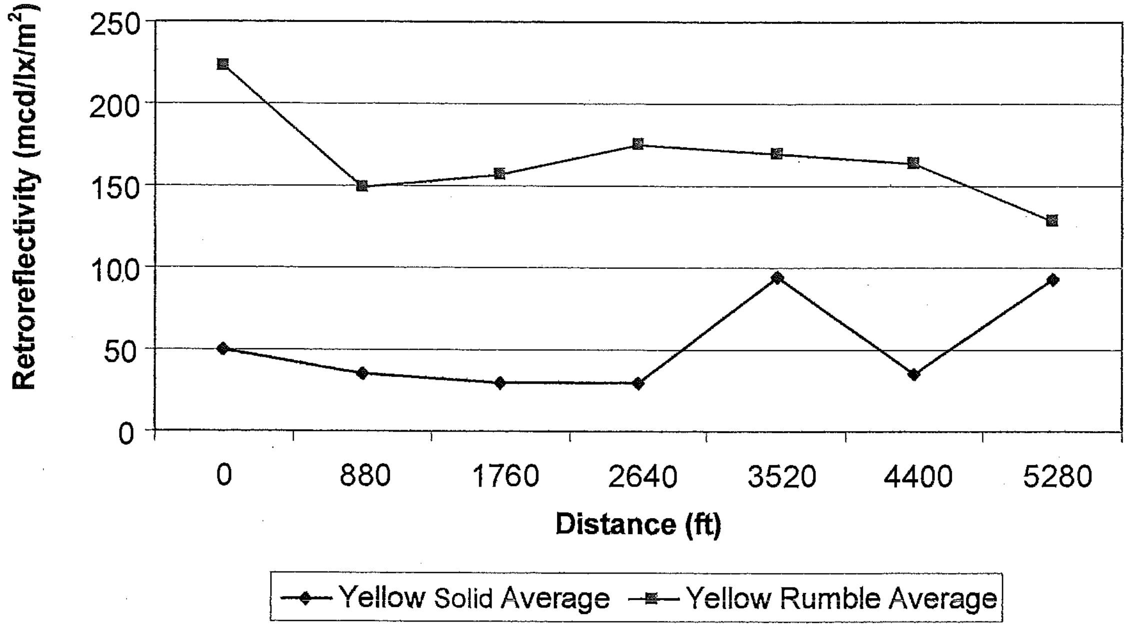

Figure 69. Average final dry retroreflectivity measurements for yellow solid and rumble strip edge lines on southbound I-75 May 17, 2003.

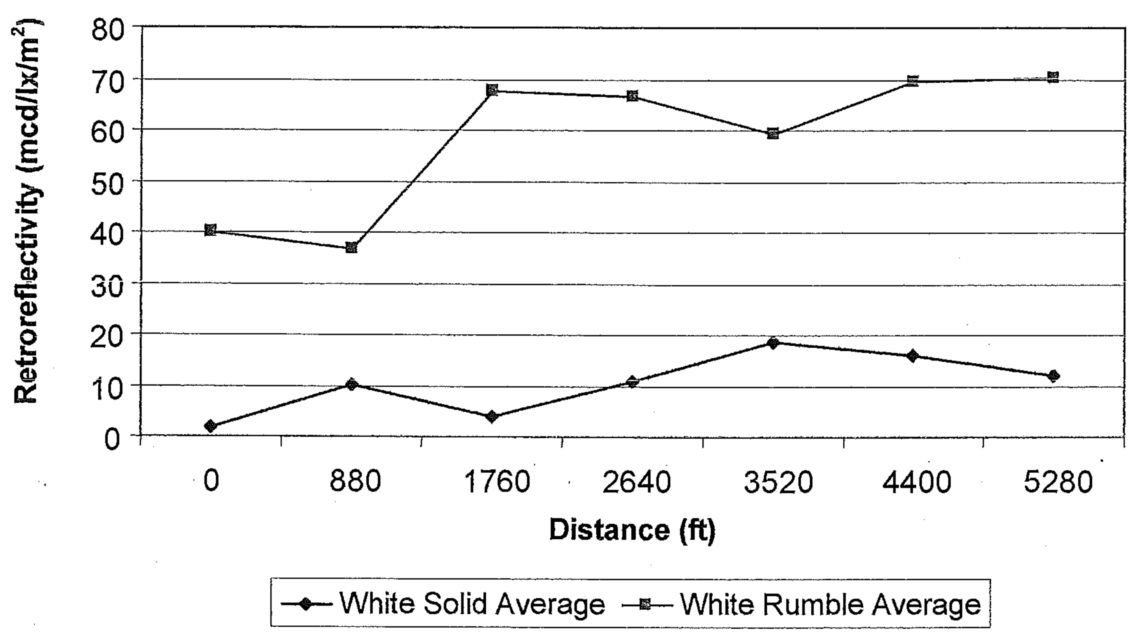

Figure 70. Average final wet retroreflectivity measurements for white solid and rumble strip edge lines on northbound US-127, May 30, 2003.

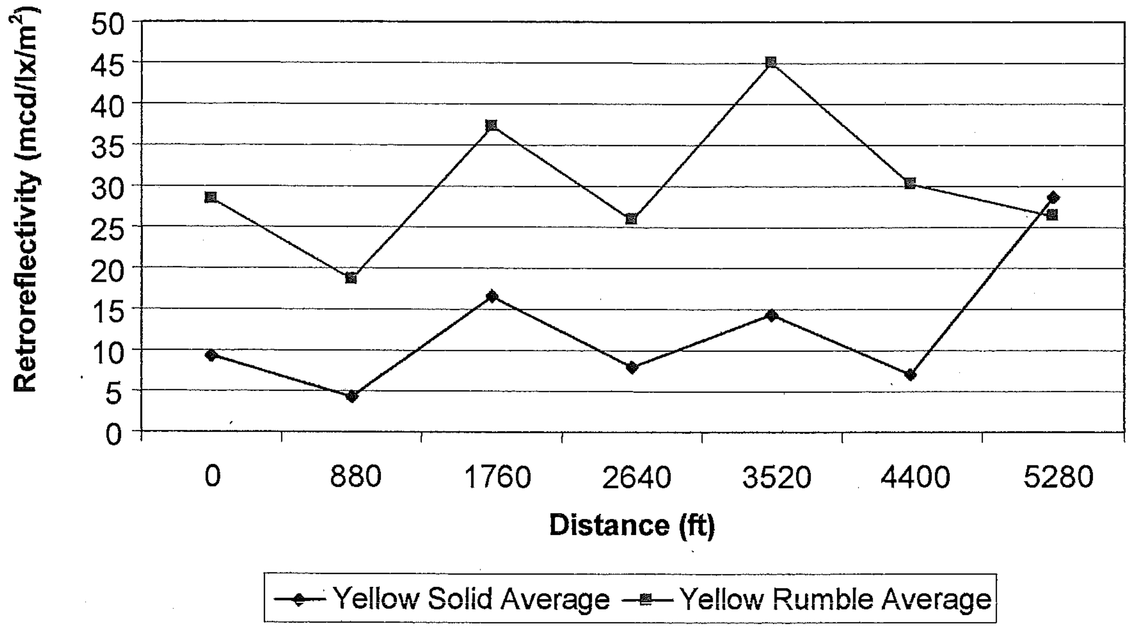

Figure 71. Average final wet retroreflectivity measurements for yellow solid and rumble strip edge lines on northbound US-127, May 30, 2003.

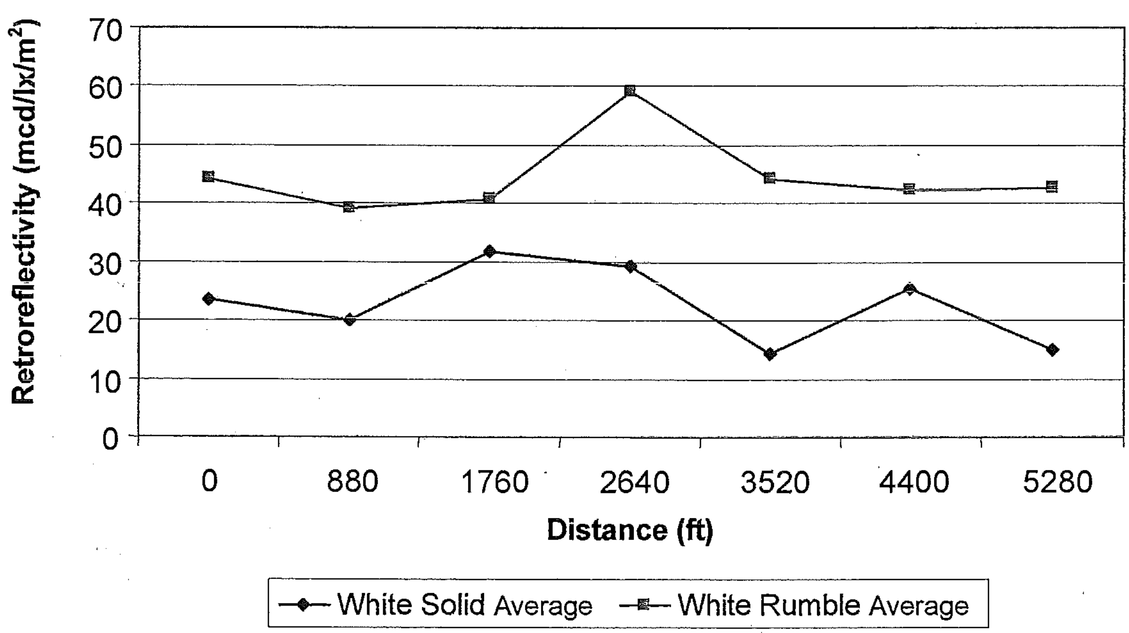

Figure 72. Average final wet retroreflectivity measurements for white solid and rumble strip edge lines on southbound US-127, May 30, 2003.

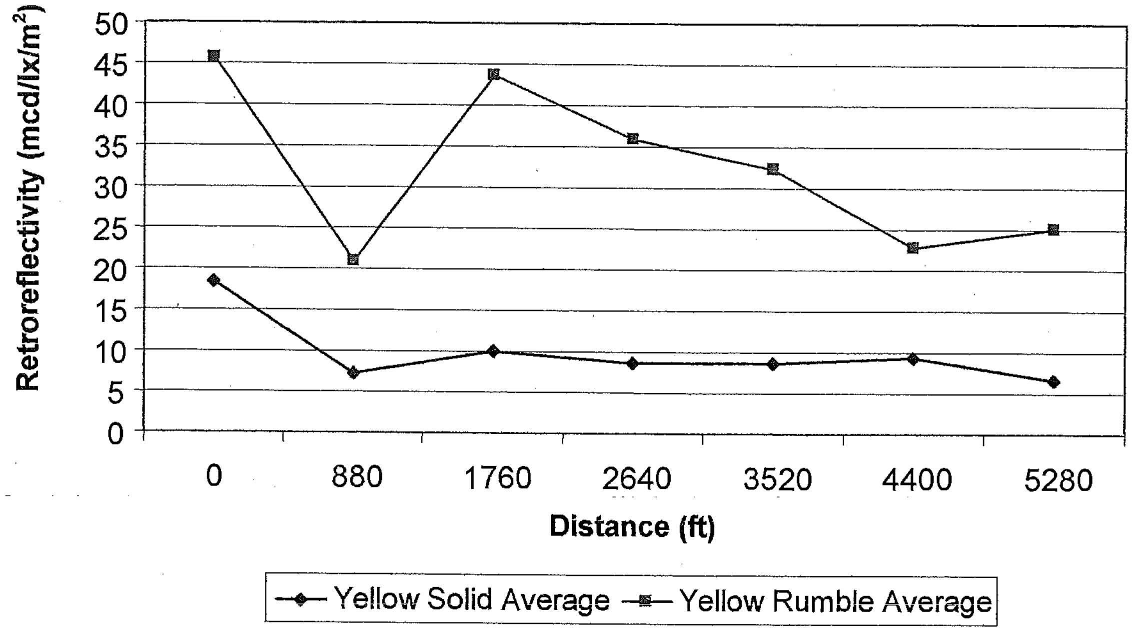

Figure 73. Average final wet retroreflectivity measurements for yellow solid and rumble strip edge lines on southbound US-127, May 30, 2003.

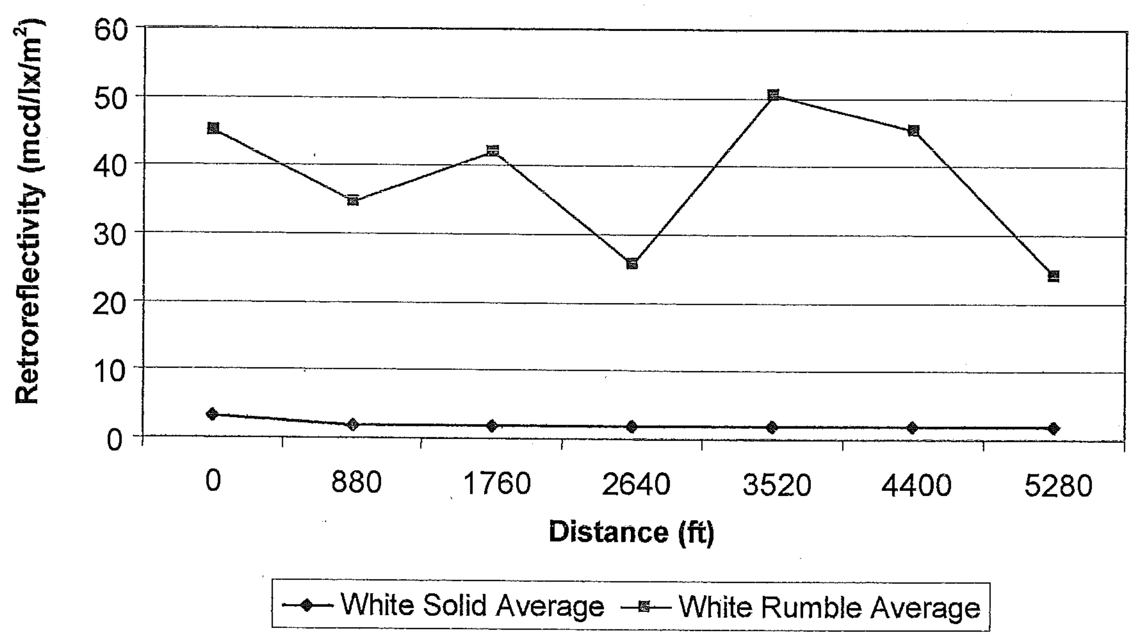

Figure 74. Average final wet retroreflectivity measurements for white solid and rumble strip edge lines on northbound I-75, May 30, 2003.

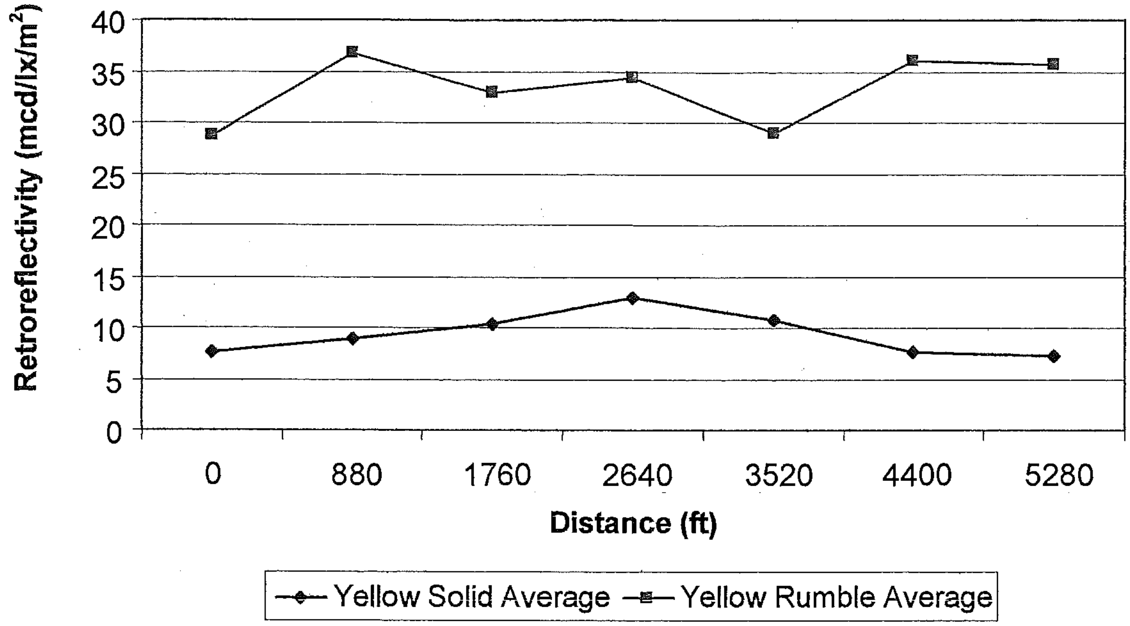

Figure 75. Average final wet retroreflectivity measurements for yellow solid and rumble strip edge lines on northbound I-75, May 30, 2003.

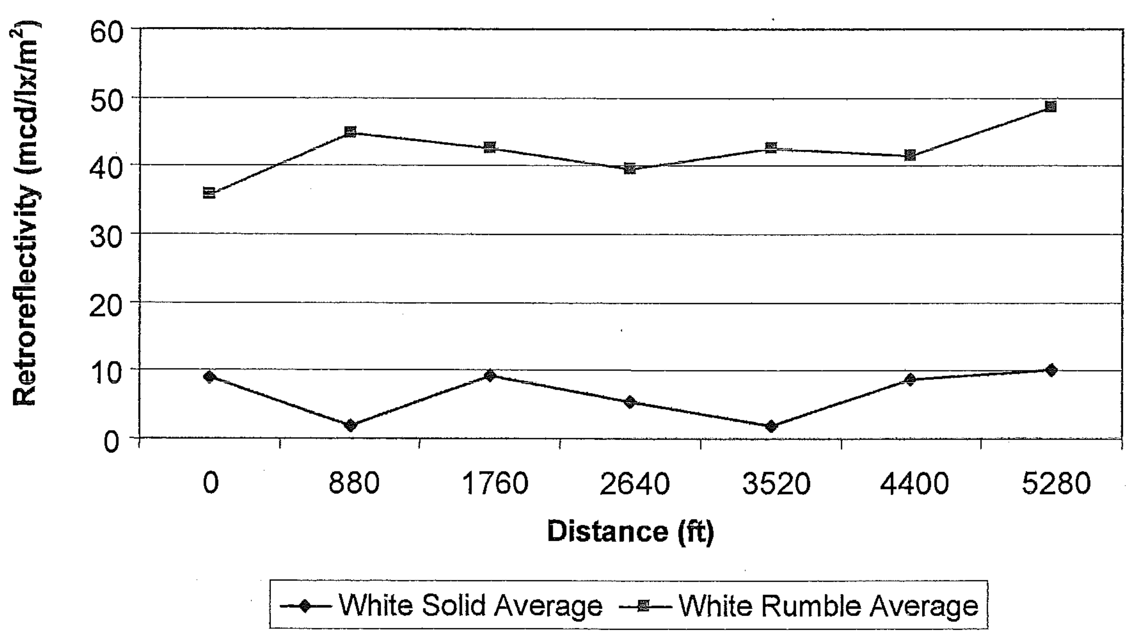

Figure 76. Average final wet retroreflectivity measurements for white solid and rumble strip edge lines on southbound I-75, May 30, 2003.

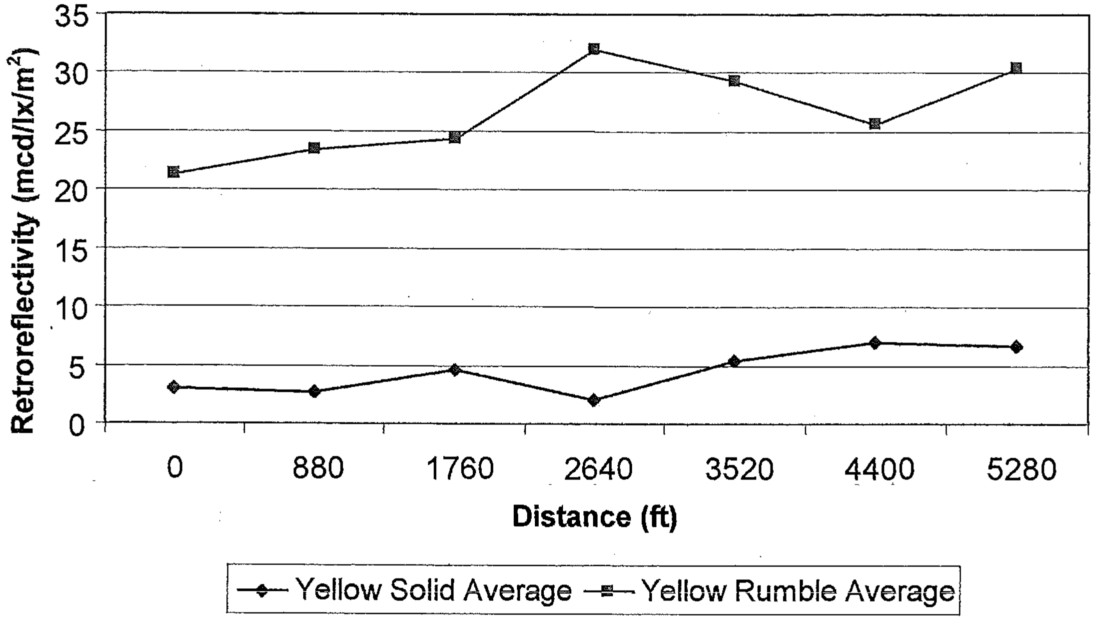

Figure 77. Average final wet retroreflectivity measurements for yellow solid and rumble strip edge lines on southbound I-75, May 30, 2003.

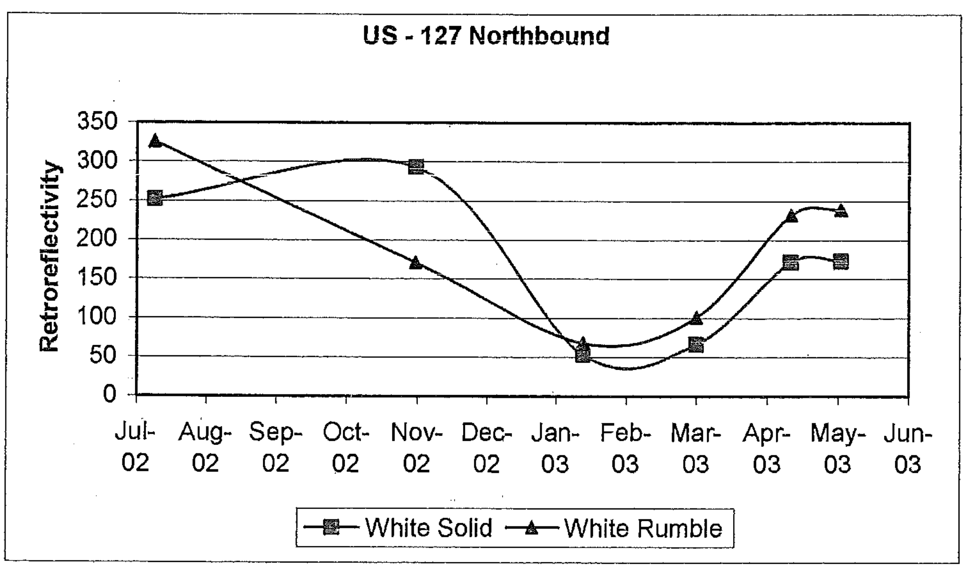

Figure 78. Average retroreflectivity vs. time function for white solid and rumble strip edge lines on northbound US-127.

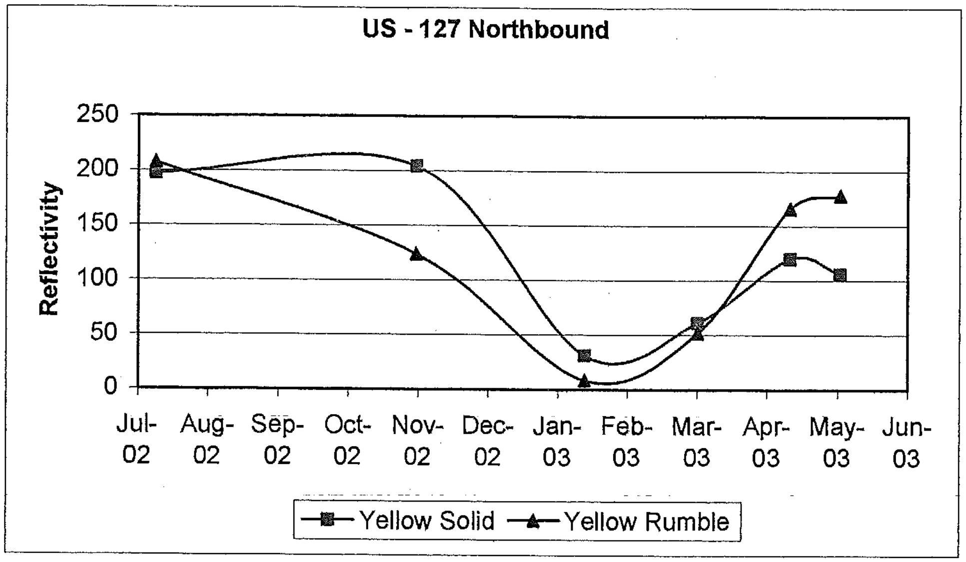

Figure 79. Average retroreflectivity vs. time function for yellow solid and rumble strip edge lines on northbound US-127.

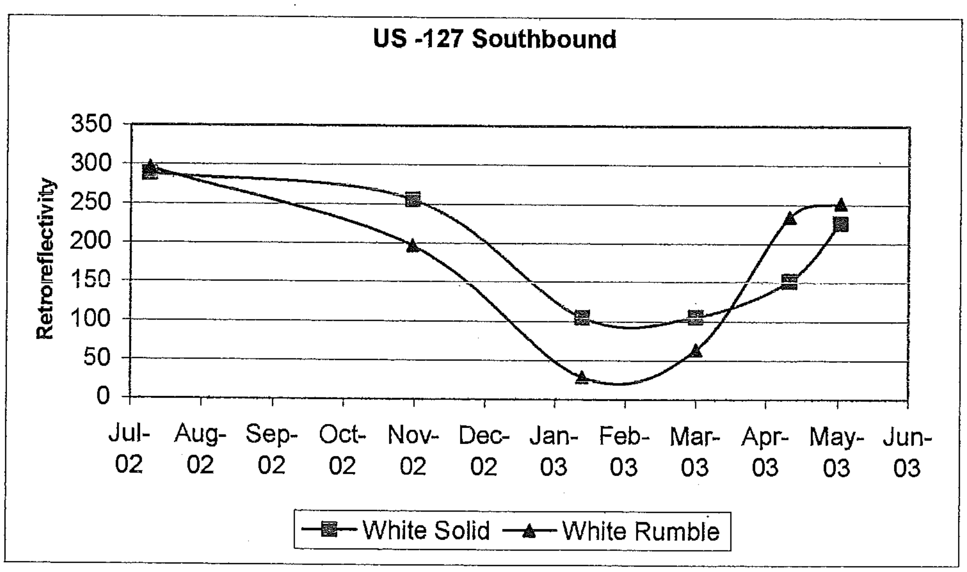

Figure 80. Average retroreflectivity vs. time function for white solid and rumble strip edge lines on southbound US-127.

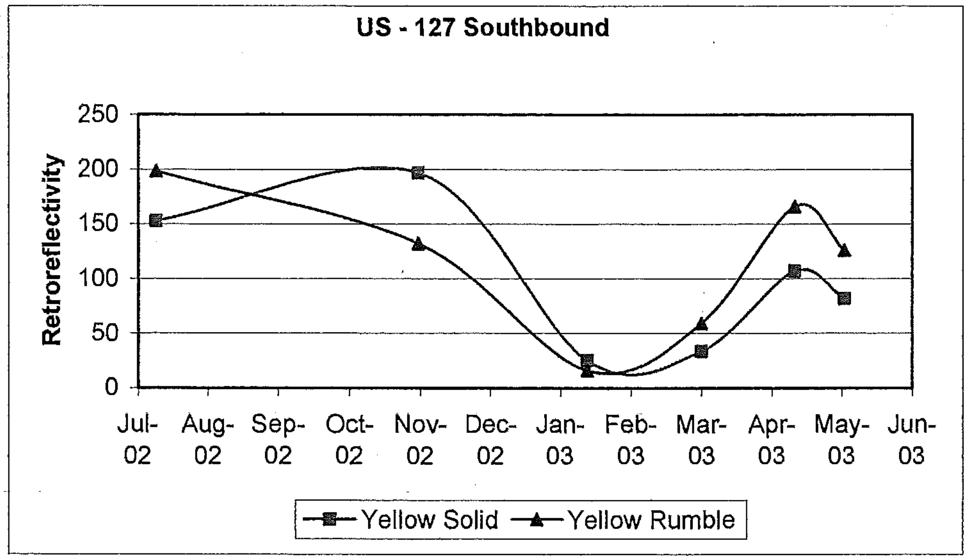

Figure 81. Average retroreflectivity vs. time function for yellow solid and rumble strip edge lines on southbound US-127.

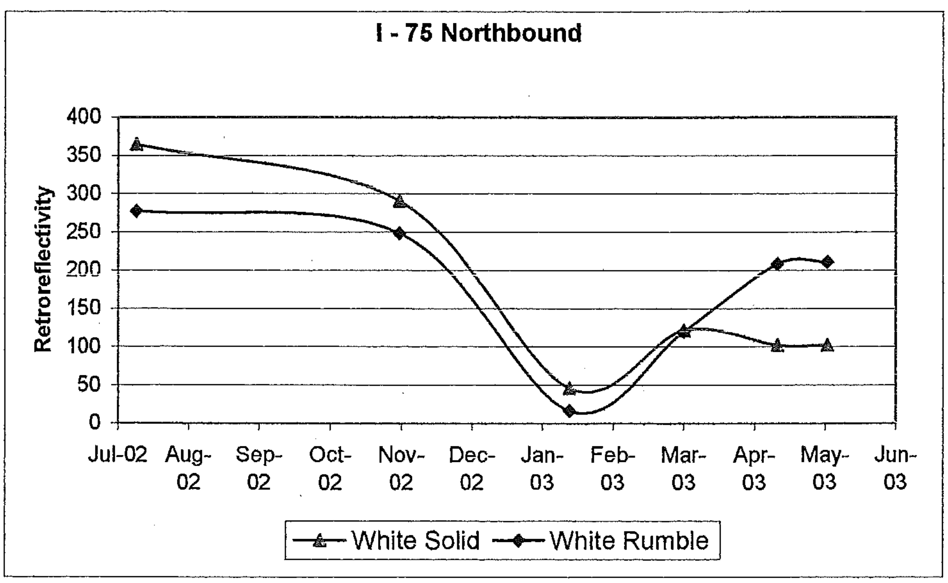

Figure 82. Average retroreflectivity vs. time function for white solid and rumble strip edge lines on northbound I – 75.

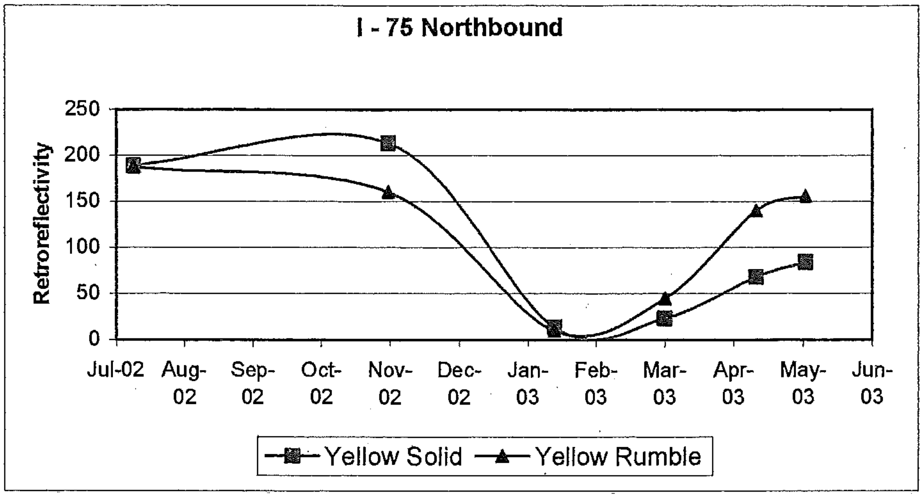

Figure 83. Average retroreflectivity vs. time function for yellow solid and rumble strip edge lines on northbound I – 75.

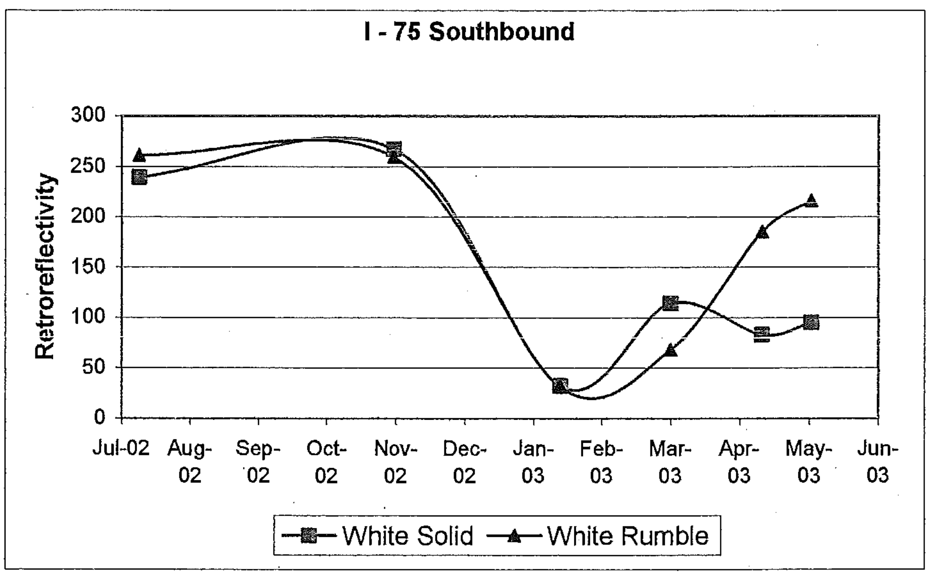

Figure 84. Average retroreflectivity vs. time function for white solid and rumble strip edge lines on southbound I – 75.

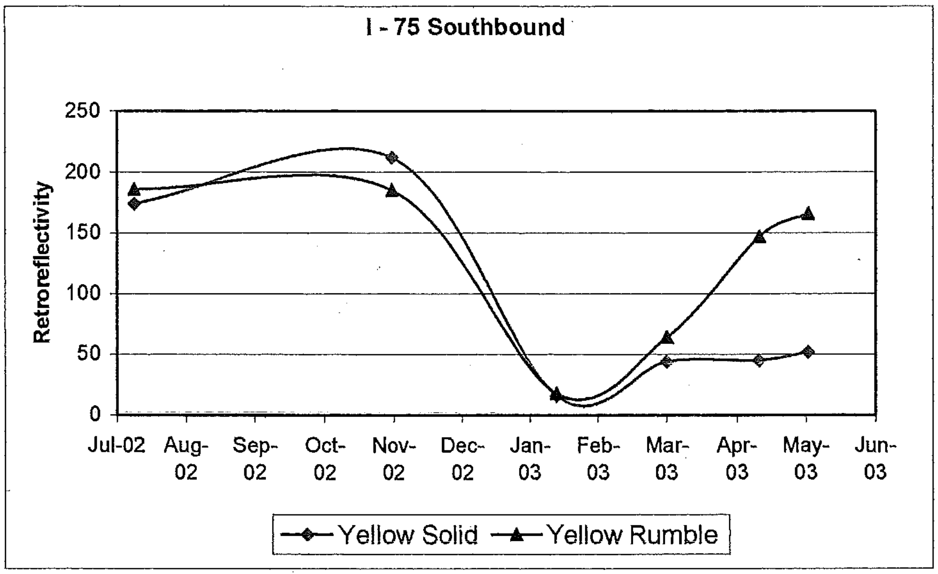

Figure 85. Average retroreflectivity vs. time function for yellow solid and rumble strip edge lines on southbound I – 75.

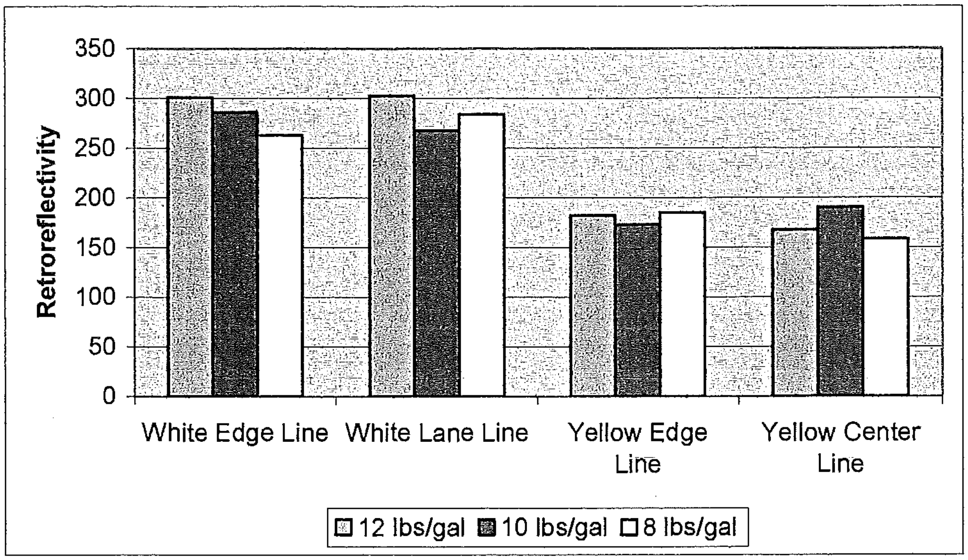

Figure 86. Average initial retroreflectivity of paintlines with different bead loading

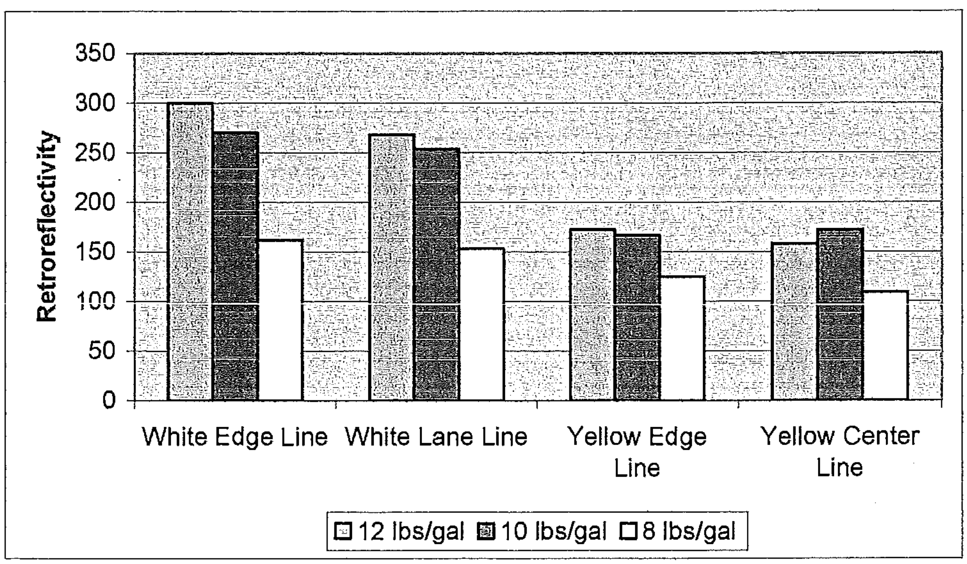

Figure 87. Average retroreflectivity of paintlines with different bead loading after winter maintenance.

9.4 RETROREFLECTIVITY TABLES

Table 1. Average initial dry retroreflectivity measurements of edge lines from northbound US-127 July 18, 2002.

US-127 Northbound				
Mile point between 227 & 228				
	White Solid	White Rumble	Yellow Solid	Yellow Rumble
Distance	***Average***	***Average***	***Average***	***Average***
0	235	392	195	196
880	246	352	198	222
1760	258	334	204	189
2640	258	299	209	215
3520	245	302	192	210
4400	246	314	193	196
5280	241	306	193	211

Table 2. Average initial dry retroreflectivity measurements of edge lines from southbound US-127 July 18, 2002.

US-127 Southbound				
Mile point between 227 & 228				
	White Solid	White Rumble	Yellow Solid	Yellow Rumble
Distance	***Average***	***Average***	***Average***	***Average***
0	277	324	153	216
880	282	302	152	193
1760	288	306	142	193
2640	282	302	151	165
3520	280	253	134	206
4400	285	284	160	200
5280	300	305	159	194

Table 3. Average initial dry retroreflectivity measurements of edge lines from northbound I-75 July 18, 2002.

I-75 Northbound				
Mile point between 283 & 284				
	White Solid	White Rumble	Yellow Solid	Yellow Rumble
Distance	*Average*	*Average*	*Average*	*Average*
0	419	260	177	179
880	334	287	191	179
1760	365	265	191	178
2640	407	275	191	175
3520	381	276	195	199
4400	341	286	183	168
5280	383	275	191	179

Table 4. Average initial dry retroreflectivity measurements of edge lines from southbound I-75 July 18, 2002.

I-75 Southbound				
Mile point between 283 & 284				
	White Solid	White Rumble	Yellow Solid	Yellow Rumble
Distance	*Average*	*Average*	*Average*	*Average*
0	249	225	174	218
880	237	263	180	162
1760	216	243	175	183
2640	243	275	173	183
3520	256	289	172	180
4400	213	256	174	193
5280	252	270	178	181

Table 5. Average initial dry retroreflectivity measurements for profiled centerlines from M-13 July 18, 2002.

M-13		
	Yellow Rumble	
Test No.	***Southbound Line Average***	***Northbound Line Average***
1	103	113
2	119	95
3	134	127

Table 6. Average initial dry retroreflectivity measurements for Sahara WaterDry white edge lines from Farmlane Road on September 4, 2002.

Farmlane Road		
	White Edge Line	
Test No.	***Northbound Average***	***Southbound Average***
1	246	231

Table 7. Average initial dry retroreflectivity measurements for Sahara WaterDry white paint line from MSU Pavilion parking lot on September 4, 2002.

MSU Pavilion Parking Lot	
	White Paint Line
Test No.	***Average***
1	287

Table 8. Average final dry retroreflectivity measurements of edge lines from northbound US-127 May 17, 2003.

US-127 Northbound				
Mile point between 227 & 228				
	White Solid	White Rumble	Yellow Solid	Yellow Rumble
Distance	*Average*	*Average*	*Average*	*Average*
0	236	195	118	200
880	156	192	115	208
1760	131	189	123	204
2640	160	281	70	147
3520	211	244	97	161
4400	161	311	124	195
5280	159	262	97	128

Table 9. Average final dry retroreflectivity measurements of edge lines from southbound US-127 May 17, 2003.

US-127 Southbound				
Mile point between 227 & 228				
	White Solid	White Rumble	Yellow Solid	Yellow Rumble
Distance	*Average*	*Average*	*Average*	*Average*
0	284	223	84	147
880	259	198	66	105
1760	199	254	70	146
2640	284	284	101	156
3520	135	204	87	101
4400	327	233	81	109
5280	267	187	82	121

Table 10. Average final dry retroreflectivity measurements of edge lines from northbound I-75 May 17, 2003.

I-75 Northbound				
Mile point between 283 & 284				
	White Solid	White Rumble	Yellow Solid	Yellow Rumble
Distance	*Average*	*Average*	*Average*	*Average*
0	137	227	33	238
880	74	198	115	148
1760	96	196	57	106
2640	112	193	63	148
3520	143	265	106	119
4400	86	190	115	161
5280	70	208	110	169

Table 11. Average final dry retroreflectivity measurements of edge lines from southbound I-75 May 17, 2003.

I-75 Southbound				
Mile point between 283 & 284				
	White Solid	White Rumble	Yellow Solid	Yellow Rumble
Distance	*Average*	*Average*	*Average*	*Average*
0	71	148	50	222
880	141	239	36	149
1760	84	226	30	157
2640	105	204	30	175
3520	151	193	94	169
4400	75	248	35	164
5280	41	255	93	129

Table 12. Average final dry retroreflectivity measurements for profiled centerlines from M-13 May 17, 2003.

M-13		
	Yellow Rumble	
Test No.	*Southbound Line Average*	*Northbound Line Average*
1	103	113
2	119	95
3	134	127

Table 13. Average final dry retroreflectivity measurements for white edge lines from Farmlane Road on May 17, 2003.

Farmlane Road		
	White Edge Line	
Test No.	*Northbound Average*	*Southbound Average*
1	195	151
2	203	177
3	278	158

Table 14. Average final dry retroreflectivity measurements for white paint line from MSU Pavilion parking lot on May 17, 2003.

MSU Pavilion Parking Lot	
	White Paint Line
Test No.	*Average*
1	284
2	250
3	305

Table 15. Average final wet retroreflectivity measurements of edge lines from northbound US-127, May 30, 2003.

US-127 Northbound				
Mile point between 227 & 228				
	White Solid	White Rumble	Yellow Solid	Yellow Rumble
Distance	*Average*	*Average*	*Average*	*Average*
0	2	40	9	28
880	10	37	4	19
1760	4	68	17	37
2640	11	67	8	26
3520	19	59	14	45
4400	16	69	7	30
5280	12	70	29	26

Table 16. Average final wet retroreflectivity measurements of edge lines from southbound US-127, May 30, 2003.

US-127 Southbound				
Mile point between 227 & 228				
	White Solid	White Rumble	Yellow Solid	Yellow Rumble
Distance	*Average*	*Average*	*Average*	*Average*
0	24	44	18	46
880	20	39	7	21
1760	32	41	10	44
2640	29	59	9	36
3520	14	44	9	32
4400	25	42	9	23
5280	15	43	7	25

Table 17. Average final wet retroreflectivity measurements of edge lines from northbound I-75, May 30, 2003.

I-75 Northbound				
Mile point between 283 & 284				
	White Solid	White Rumble	Yellow Solid	Yellow Rumble
Distance	*Average*	*Average*	*Average*	*Average*
0	3	45	8	29
880	2	35	9	37
1760	2	42	10	33
2640	2	26	13	34
3520	2	50	11	29
4400	2	45	8	36
5280	2	24	7	36

Table 18. Average final wet retroreflectivity measurements of edge lines from southbound I-75, May 30, 2003.

I-75 Southbound				
Mile point between 283 & 284				
	White Solid	White Rumble	Yellow Solid	Yellow Rumble
Distance	*Average*	*Average*	*Average*	*Average*
0	9	36	3	21
880	2	45	3	23
1760	9	43	5	24
2640	5	40	2	32
3520	2	43	5	29
4400	9	41	7	26
5280	10	49	7	30

Table 19. Average final wet retroreflectivity measurements for profiled centerlines from M-13, May 30, 2003.

M-13		
	Yellow Rumble	
Test No.	***Southbound Line Average***	***Northbound Line Average***
1	33	24
2	30	33
3	25	23

Table 20. Average retroreflectivity for solid and rumble strip edge lines on northbound US-127.

US-127 Northbound between miles 227 & 228				
Date of Measurements	Average Retroreflectivity (mcd/lx/m^2)			
	White Solid	White Rumble	Yellow Solid	Yellow Rumble
18.07.02	252	326	197	208
10.11.02	293	171	204	124
24.01.03	53	68	31	9
15.03.03	67	101	61	52
25.04.03	172	232	120	166
17.05.03	173	239	106	178

Table 21. Average retroreflectivity for solid and rumble strip edge lines on southbound US-127.

US-127 Southbound between miles 227 & 228				
Date of Measurements	Average Retroreflectivity (mcd/lx/m^2)			
	White Solid	White Rumble	Yellow Solid	Yellow Rumble
18.07.02	288	296	153	198
10.11.02	255	196	197	132
24.01.03	105	29	25	16
15.03.03	106	63	34	59
25.04.03	152	234	107	166
17.05.03	226	251	82	126

Table 22. Average retroreflectivity for solid and rumble strip edge lines on northbound I – 75.

I – 75 Northbound between miles 283 & 284				
Date of Measurements	Average Retroreflectivity (mcd/lx/m²)			
	White Solid	White Rumble	Yellow Solid	Yellow Rumble
18.07.02	365	277	189	187
10.11.02	291	249	213	160
24.01.03	46	16	14	10
15.03.03	121	120	23	45
25.04.03	102	208	68	140
17.05.03	102	211	84	156

Table 23. Average retroreflectivity for solid and rumble strip edge lines on southbound I – 75.

I – 75 Southbound between miles 283 & 284				
Date of Measurements	Average Retroreflectivity (mcd/lx/m²)			
	White Solid	White Rumble	Yellow Solid	Yellow Rumble
18.07.02	239	261	174	186
10.11.02	267	259	212	185
24.01.03	32	31	16	18
15.03.03	114	68	44	64
25.04.03	83	185	45	147
17.05.03	95	216	52	166

Table 24. Retained retroreflectivity for rumble strip edge lines on US – 127, I – 75, and M – 13 after 2 years of service life.

	Average Retroreflectivity (mcd/lx/m²)				
	2002 Initial	2003 1 year	Retained Reflectivity	2004 2 years	Retained Reflectivity
US – 127					
White Rumble	311	245	79%	242	78%
Yellow Rumble	203	152	75%	143	70%
I - 75					
White Rumble	286	231	81%	147	51%
Yellow Rumble	192	156	81%	126	66%
M - 13					
Yellow Rumble	115	115	100%	87	76%

Table 25. Retained retroreflectivity for solid and rumble strip edge lines on I – 96, US – 131, and US – 31 after 1 year of service life.

Line Type	Average Retroreflectivity (mcd/lx/m^2)					
	2003 Initial	2004 1 year	% Retained	2003 Initial	2004 1 year	% Retained
	I – 96					
	Ionia County			Kent County		
White Solid	200	179	90%	258	198	77%
White Rumble 4"	240	170	71%	248	164	66%
White Rumble 6"	217	135	62%	218	171	78%
Yellow Solid	130	146	112%	150	110	73%
Yellow Rumble 4"	142	124	87%	115	113	98%
Yellow Rumble 6"	137	114	83%	145	96	66%
	US - 131			US – 31		
White Solid	200	134	67%	142	202	-
White Rumble 4"	160	105	66%	120	179	-
White Rumble 6"	250	138	55%	132	177	-
Yellow Solid	150	119	79%	-	132	-
Yellow Rumble 4"	150	90	60%	-	142	-
Yellow Rumble 6"	130	91	70%	-	133	-

Table 26. Retroreflectivity of paintlines with different bead loading

Line Type	Average Retroreflectivity (mcd/lx/m²)		
	October 2003 Initial	May - July 2004	% Retained
	University Lansing TSC Bead Loading: 12 lbs/gal		
White Edge Line	301.2	300.1	100%
White Lane Line	302.7	268.5	88%
Yellow Edge Line	182.4	172.6	94%
Yellow Center Line	167.7	158.1	94%
	University Brighton TSC Bead Loading: 10 lbs/gal		
White Edge Line	286.0	270.4	94%
White Lane Line	267.6	254.0	95%
Yellow Edge Line	173.0	166.6	96%
Yellow Center Line	190.4	172.2	90%
	University Jackson TSC Bead Loading: 8 lbs/gal		
White Edge Line	262.8	-	-
White Lane Line	284.0	-	-
Yellow Edge Line	185.2	-	-
Yellow Center Line	158.5	-	-